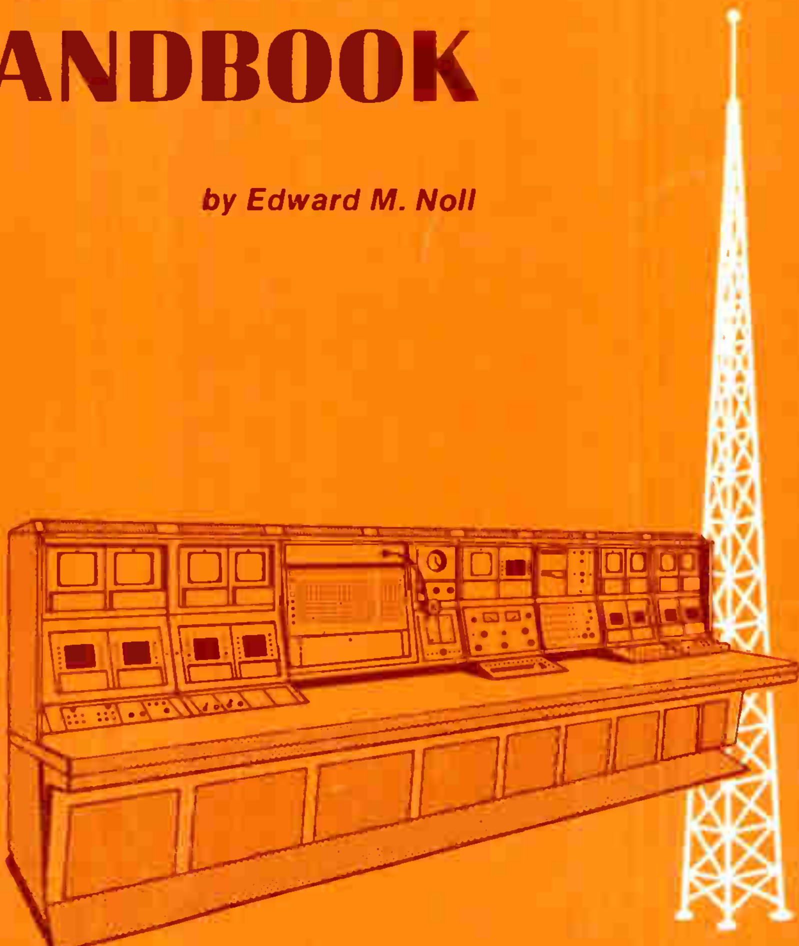
PUBLICATION 20804

FIRST-CLASS RADIOTELEPHONE LICENSE HANDBOOK

by Edward M. Noll



First-Class Radiotelephone License Handbook

by Edward M. Noll

HOWARD W. SAMS & CO., INC.
THE BOBBS-MERRILL CO., INC.
INDIANAPOLIS · KANSAS CITY · NEW YORK

THIRD EDITION

SECOND PRINTING—1971

International Standard Book Number: 0-672-20804-0
Library of Congress Catalog Card Number: 77-135994

Preface

In the half century since station KDKA in Pittsburgh first took to the air, commercial broadcasting has mushroomed at a phenomenal rate. Today that one lonely voice has been joined by almost 7000 a-m, fm, and television stations.

The maintenance and operation of all such stations, by law, must be done under the supervision of a first-class radiotelephone licensee. In the larger stations, he must be on duty whenever the transmitter is on the air.

First-Class Radiotelephone License Handbook has two major objectives: (1) to help you acquire your license and (2) to prepare you for the responsibility of operating and maintaining broadcast equipment on the job. Transmitter equipment is stressed because it will be your prime responsibility to supervise, maintain, and perhaps operate the transmitter. Studio, master control, and remote equipment are also covered, even though a license is not needed to operate them. However, you will be required to supervise their operation and, in a pinch, may even be called on to operate them.

This third edition has been completely revised to contain all the new material included in the recently revised FCC Study Guide. The first thirteen chapters contain study material related to all the various phases of broadcasting and are arranged according to subject matter. The next five chapters contain all the questions—and the answers—included in the newly revised FCC Study Guide. The questions and answers are also arranged in a logical manner according to subject.

Three simulated examinations are included in Chapter 19. They are in the multiple-choice form of the FCC tests. Answers are included along with an evaluation of your grade that will help you find your weak subjects.

Important broadcast extracts, taken from the *FCC Rules and Regulations*, are included in the Appendices. Study this material carefully; in fact, read it over several times to fix it in your memory. This will also take care of additional questions that might be inserted into the FCC examination at a later date.

Since you will be responsible for making sure your station operates within the law, it is suggested you buy a copy of the complete broadcasting rules and regulations. Write the U.S. Government Printing Office, Washington, D.C. 20402, and ask for Volume III of the *FCC Rules and Regulations*, currently $4.50.

EDWARD M. NOLL

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CHAPTER 1

Introduction

Anyone wishing to progress in the technical phase of broadcasting should have a first-class radiotelephone operator license. In fact, some stations do not employ technical personnel unless they have such a license. Other stations will hire licensees of a lower grade, but usually with the understanding that he or she will obtain a first-class license in the near future. In short, if you do not have a first-class license, you will be hampered with respect to the responsibilities which the chief engineer of the station can assign you.

This text will serve as a study guide for the material covered in the FCC examination for Element IV. The study material in this book is arranged according to subject matter. Fundamentals, audio, a-m, fm, and television broadcasting are covered separately. The questions and answers in the later chapters are also broken down into similar categories.

Throughout this book, it is assumed that the reader is the holder of a second-class radiotelephone license. Holders of second-class licenses are required to pass only Element IV of the examination in order to obtain their first-class license. However, holding a second-class license is not a requirement for obtaining a first-class license. You may obtain this license by passing Elements I through IV of the license exam. For readers desiring to try this approach, a companion volume, *Second-Class Radiotelephone License Handbook*, also published by Howard W. Sams & Co., Inc., is recommended. This book contains coverage similar to that in this volume, but for Elements I, II, and III.

Element IV of the FCC exam is titled, "Advanced Radiotelephone." It covers technical, legal, and other matters applicable to the operation of the various broadcast stations. In addition to the study material in the first chapters, this book contains all the questions listed under Element IV of the FCC Supplement to *Study Guide and Reference Material for Commercial Operator Examinations*, dated November 1965, and the answers to these questions.

The test for Element IV consists of fifty multiple-choice questions based on broadcast equipment and broadcast rules and regulations. Some simple mathematical problems, completion of incomplete diagrams, and correction of incorrect ones are included. Two percent credit is allowed for each correct answer and 75% is passing.

Study the material in this book very carefully. In fact, read and re-read it several times to fix it in your memory and to prepare you for any additional questions that may be added to the examination at a later date. When you are satisfied that you are ready to take the license exam, send FCC Form 756 and the current examination fee to the Engineer in Charge, at the FCC field office serving your area. (A list of FCC field offices is included in Table 1-1.)

Table 1-1. Mailing Address for License Applications

Dist. No.	Office Location	Dist. No.	Office Location
1	BOSTON, MASSACHUSETTS 02109 1600 Custom House India & State Streets Phone: Area Code 617 223-6608	8M	MOBILE, ALABAMA 36602 439 U.S. Court House 113 St. Joseph Street Phone: Area Code 205 433-3581
2	NEW YORK, NEW YORK 10014 748 Federal Building 641 Washington Street Phone: Area Code 212 620-5745	9	HOUSTON, TEXAS 77002 5636 Federal Building 515 Rusk Avenue Phone: Area Code 713 226-0611
3	PHILADELPHIA, PENNSYLVANIA 19106 1005 U. S. Customhouse Second & Chestnut Streets Phone: Area Code 215 597-4412	9B	BEAUMONT, TEXAS 77701 239 Federal Building 300 Willow Street Phone: Area Code 713 835-3911
4	BALTIMORE, MARYLAND 21201 819 Federal Building 31 Hopkins Plaza Phone: Area Code 301 962-2727	10	DALLAS, TEXAS 75202 707 Thomas Building 1314 Wood Street Phone: Area Code 214 749-3243
5	NORFOLK, VIRGINIA 23510 Granby & York Streets 400 Federal Building Phone: Area Code 703 627-7471	11	LOS ANGELES, CALIFORNIA 90012 U. S. Courthouse, Room 1758 312 N. Spring Street Phone: Area Code 213 688-3276
6	ATLANTA, GEORGIA 30303 1602 Gas light Tower 235 Peachtree Street N. E. Phone: Area Code 404 562-6381	11SD	SAN DIEGO, CALIFORNIA 92101 Fox Theatre Building 1245 Seventh Avenue Phone: Area Code 714 234-6211
6S	SAVANNAH, GEORGIA 31402 238 Post Office Building York & Bull Streets Phone: Area Code 912 232-7602	11SP	SAN PEDRO, CALIFORNIA 90731 300 South Ferry Street Terminal Island Phone: Area Code 213 831-9281
7	MIAMI, FLORIDA 33130 919 Federal Building 51 S. W. First Avenue Phone: Area Code 305 350-5541	12	SAN FRANCISCO, CALIFORNIA 94111 323A Custom House 555 Battery Street Phone: Area Code 415 556-7700
7T	TAMPA, FLORIDA 33602 738 Federal Building 500 Zack Street Phone: Area Code 813 228-7711	13	PORTLAND, OREGON 97204 314 Multnomah Building 319 S.W. Pine Street Phone: Area Code 503 226-3361
8	NEW ORLEANS, LOUISIANA 70130 829 Federal Building South 600 South Street Phone: Area Code 504 527-2094	14	SEATTLE, WASHINGTON 98104 8012 Federal Office Building 909 First Avenue Phone: Area Code 206 583-7653

Table 1-1. Mailing Address for License Applications—Cont'd

Dist. No.	Office Location	Dist. No.	Office Location
15	DENVER, COLORADO 80202 504 New Customhouse 19th St. between California & Stout Streets Phone: Area Code 303 297-4054	21	HONOLULU, HAWAII 96808 502 Federal Building P.O. Box 1021 Phone: 546-5640
16	ST. PAUL, MINNESOTA 55101 691 Federal Building Fourth and Robert Streets Phone: Area Code 612 725-7819	22	SAN JUAN, PUERTO RICO 00903 322 Federal Building P.O. Box 2987 Phone: 722-4562
17	KANSAS CITY, MISSOURI 64106 1703 Federal Building 601 East 12th Street Phone: Area Code 816 374-5526	23	ANCHORAGE, ALASKA 99501 54 U.S. Post Office Building 4th Avenue between F & G Streets Phone: Area Code 907 272-1822
18	CHICAGO, ILLINOIS 60604 1872 U. S. Courthouse 219 South Dearborn Street Phone: Area Code 312 353-5386	24	WASHINGTON, D. C. 20554 Room 216 1919 M Street, N.W. Phone: Area Code 202 632-7000
19	DETROIT, MICHIGAN 48226 1029 Federal Building Washington Blvd. & LaFayette Street Phone: Area Code 313 226-6077	—	GETTYSBURG, PENNSYLVANIA 17325 P. O. Box 441 Phone: Area Code 717 334-3109
20	BUFFALO, NEW YORK 14203 328 Federal Office Building 121 Ellicott Street Phone: Area Code 716 842-3216		

CHAPTER 2

Station Frequency Assignments and Power-Output Ratings

There are a variety of broadcast stations including a-m, fm, television, auxiliary, and international broadcast services. Each of these stations is assigned a specific carrier frequency on specific broadcast bands by the FCC. The stations so licensed are legally obligated to operate on their assigned frequency (within a rather close tolerance) and in accordance with the FCC technical standards for the particular type of broadcast service.

Frequency assignments are made in a manner that precludes as much as possible interference among stations operating on the same channel. In general, the same channel or an adjacent channel is not allocated to more than one broadcast station within the same general listening area. However, even careful allocation does not preclude interference; it is not unusual, at times, for two or even more stations to be received at certain settings on the receiver dial.

2-1. A-M BROADCAST

The a-m broadcast band lies between 535 and 1605 kilohertz. Each a-m channel is 10 kHz wide. (Refer to the carrier-frequency assignments in Table 2-1.) There are 107 a-m channels available, and a-m stations are authorized for powers from 250 watts to 50 kilowatts. The three classes of standard broadcast channels are clear (C), regional (R) and local (L) as indicated by Table 2-1.

A *clear channel* is one on which the dominant station, or stations, renders service over wide areas and cleared of objectionable interference within its primary service area and overall for a substantial portion of its secondary service area. As will be detailed later, Class I and II, A, B, and D stations operate on clear channels and have a maximum power of 50 kilowatts. A *regional channel* is one on which several Class III-A or III-B stations may operate with power not in excess of 5 kilowatts. The primary service area of a station operating in any such channel is protected from interference out to a given

Table 2-1. A-M Channels and Assigned Carrier Frequencies

Freq (kHz)	Class	Channel
540	C	1
550	R	2
560	R	3
570	R	4
580	R	5
590	R	6
600	R	7
610	R	8
620	R	9
630	R	10
640	C	11
650	C	12
660	C	13
670	C	14
680	C	15
690	C	16
700	C	17
710	C	18
720	C	19
730	C	20
740	C	21
750	C	22
760	C	23
770	C	24
780	C	25
790	R	26
800	C	27
810	C	28
820	C	29
830	C	30
840	C	31
850	C	32
860	C	33
870	C	34
880	C	35
890	C	36
900	C	37
910	R	38
920	R	39
930	R	40
940	C	41
950	R	42
960	R	43
970	R	44
980	R	45
990	C	46
1000	C	47
1010	C	48
1020	C	49
1030	C	50
1040	C	51
1050	C	52
1060	C	53
1070	C	54

Freq (kHz)	Class	Channel
1080	C	55
1090	C	56
1100	C	57
1110	C	58
1120	C	59
1130	C	60
1140	C	61
1150	R	62
1160	C	63
1170	C	64
1180	C	65
1190	C	66
1200	C	67
1210	C	68
1220	C	69
1230	L	70
1240	L	71
1250	R	72
1260	R	73
1270	R	74
1280	R	75
1290	R	76
1300	R	77
1310	R	78
1320	R	79
1330	R	80
1340	L	81
1350	R	82
1360	R	83
1370	R	84
1380	R	85
1390	R	86
1400	L	87
1410	R	88
1420	R	89
1430	R	90
1440	R	91
1450	L	92
1460	R	93
1470	R	94
1480	R	95
1490	L	96
1500	C	97
1510	C	98
1520	C	99
1530	C	100
1540	C	101
1550	C	102
1560	C	103
1570	C	104
1580	C	105
1590	R	106
1600	R	107

field-intensity contour. A *local channel* is one on which several Class IV stations operate. The primary service area of a station operating on any such channel may be limited to a given field-intensity contour to reduce interference among stations. Daytime power may be no greater than 1 kilowatt while the nighttime power is limited to no greater than 250 watts.

A Class I station is a dominant station operating on a clear channel and rendering primary and secondary service over an extended area and at relatively long distance. Its primary service area is free from objectionable interference from the other stations on the same and adjacent channels. Its secondary area is free from interference except from stations on adjacent channels and from stations on the same channel in accordance with the engineering standards of allocation. The operating power of a Class I station cannot be less than 10 kilowatts nor can it be more than 50 kilowatts. The term *dominant station* is applied to any Class I station that is operating on a clear channel.

A Class II station also operates on a clear channel. It renders service over a primary service area which is limited by and subject to interference from Class I stations. It is known as a *secondary station*, which is any station except Class I operating on a clear channel. A Class II-A (an unlimited time) station must operate with a power no less than 10 kilowatts nighttime nor more than 50 kilowatts at anytime. Class II-B (unlimited time) and Class II-D (daytime or limited time) must operate with a power no less than 250 watts or more than 50 kilowatts. Whenever necessary, a Class II station must employ a directional antenna to prevent intereference between it and Class I and other Class II stations.

A Class III station operates on a regional channel and renders service primarily to a metropolitan district and to the surrounding rural area. There are two types of Class III stations: A Class III-A station must operate with a power of not less than 1 kilowatt nor more than 5 kilowatts. A Class III-B station must have a power of not less than 500 watts nor more than 5 kilowatts, and not more than 1 kilowatt during nighttime operation.

A Class IV station operates on a local channel and renders service primarily to a city or town and the neighboring rural area. Power must not be less than 250 watts and not more than 1 kilowatt (250 watts nighttime). Its service area is subject to interference in accordance with standards of allocation.

Standard broadcast stations are licensed to operate only within certain time schedules, unless licensed for unlimited time. If a station has a daytime assignment, it can operate only during the hours between the average monthly sunrise and sunset. Some stations are required to share their time with one or more stations using the same channel. Other stations can go on the air during certain hours only, as specified in the license. Some stations operate on a limited-time basis. This is applicable to a Class II secondary station operating on a clear channel. The time of operation assigned depends on the geographical location of the secondary station relative to the geographical location of the dominant station.

2-2. INTERNATIONAL A-M BROADCAST

The transmissions of an international a-m broadcast station are intended for reception by the general public in foreign countries. Such stations are assigned frequencies between 5.95 MHz and 26.1 MHz, within the following bands:

Band	*Frequency (MHz)*
A	5.95–6.2
B	9.5–9.775
C	11.7–11.975
D	15.1–15.450
E	17.7–17.9
F	21.450–21.750
G	25.6–26.1

International a-m broadcast stations will not be authorized for a power less than 50 kW. Carrier frequency must be held with 0.003 percent of the assigned value. Their frequencies and directional-antenna systems are determined by the countries to be covered, and also by the propagation characteristics of the ionosphere. In short-wave transmission the most effective frequency, in terms of coverage, depends on the time of day and year in addition to the ionospheric variables. For this reason, international a-m broadcast stations are assigned a number of frequencies on the various short-wave bands so they can use the frequency giving the desired coverage at the time.

2-3. FM BROADCAST

The fm broadcast band lies between 88 MHz and 108 MHz. Each fm channel is 200 kHz wide, making a total of 100 available channels. (See Table 2-2.) Fm power assignments are made on the basis of both the effective radiated power and the transmitter power output. The effective radiated power (ERP) is equal to the transmitter power delivered to the antenna, multiplied by the antenna power gain:

$$\text{ERP} = \text{Antenna Input Power} \times \text{Antenna Power Gain}$$

There are two general classifications of fm broadcast stations, commercial and noncommercial. In the commercial broadcast classification, there are Class A, B, and C stations. In the noncommercial there are Class A, B, C, and D stations. The first fm channels shown in Table 2-2 are the noncommercial education stations. The commercial and noncommercial Class A, B, and C stations are assigned to the remaining 80 channels. The same FCC regulations cover both the commercial and noncommercial Class A, B, and C stations.

A Class A fm station renders service primarily to a community and the surrounding rural area. It is limited to three kilowatts of effective radiated power, and its antenna height cannot exceed 300 feet above the average terrain.

A Class B station renders service primarily to a metropolitan district or urbanized area of a principal city and the surrounding rural area. Class B stations cover the heavily populated northeastern part of the United States (Zone 1) and Southern California below the 40th parallel, Puerto Rico and the Virgin Islands in Zone 1-A. A Class B station is

Table 2-2. FM Channels and Assigned Carrier Frequencies

Freq (MHz)	Class	Channel	Freq (MHz)	Class	Channel
88.1	A-B-C-D	201	98.1	B-C	251
88.3	A-B-C-D	202	98.3	A	252
88.5	A-B-C-D	203	98.5	B-C	253
88.7	A-B-C-D	204	98.7	B-C	254
88.9	A-B-C-D	205	98.9	B-C	255
89.1	A-B-C-D	206	99.1	B-C	256
89.3	A-B-C-D	207	99.3	A	257
89.5	A-B-C-D	208	99.5	B-C	258
89.7	A-B-C-D	209	99.7	B-C	259
89.9	A-B-C-D	210	99.9	B-C	260
90.1	A-B-C-D	211	100.1	A	261
90.3	A-B-C-D	212	100.3	B-C	262
90.5	A-B-C-D	213	100.5	B-C	263
90.7	A-B-C-D	214	100.7	B-C	264
90.9	A-B-C-D	215	100.9	A	265
91.1	A-B-C-D	216	101.1	B-C	266
91.3	A-B-C-D	217	101.3	B-C	267
91.5	A-B-C-D	218	101.5	B-C	268
91.7	A-B-C-D	219	101.7	A	269
91.9	A-B-C-D	220	101.9	B-C	270
92.1	A	221	102.1	B-C	271
92.3	B-C	222	102.3	A	272
92.5	B-C	223	102.5	B-C	273
92.7	A	224	102.7	B-C	274
92.9	B-C	225	102.9	B-C	275
93.1	B-C	226	103.1	A	276
93.3	B-C	227	103.3	B-C	277
93.5	A	228	103.5	B-C	278
93.7	B-C	229	103.7	B-C	279
93.9	B-C	230	103.9	A	280
94.1	B-C	231	104.1	B-C	281
94.3	A	232	104.3	B-C	282
94.5	B-C	233	104.5	B-C	283
94.7	B-C	234	104.7	B-C	284
94.9	B-C	235	104.9	A	285
95.1	B-C	236	105.1	B-C	286
95.3	A	237	105.3	B-C	287
95.5	B-C	238	105.5	A	288
95.7	B-C	239	105.7	B-C	289
95.9	A	240	105.9	B-C	290
96.1	B-C	241	106.1	B-C	291
96.3	B-C	242	106.3	A	292
96.5	B-C	243	106.5	B-C	293
96.7	A	244	106.7	B-C	294
96.7	B-C	245	106.9	B-C	295
97.1	B-C	246	107.1	A	296
97.3	B-C	247	107.3	B-C	297
97.5	B-C	248	107.5	B-C	298
97.7	A	249	107.7	B-C	299
97.9	B-C	250	107.9	B-C	300

restricted to 50 kilowatts of ERP and an antenna height of not more than 500 feet above the terrain. Minimum ERP is 5 kilowatts

A Class C station renders service to a community and a large surrounding Area in Zone II. Zone II covers the less populated areas consisting of Alaska, Hawaii and the area of the United States not included in Zone I. A Class C station is limited to a maximum ERP of 100 kW at an antenna height of 2000 feet above average terrain. Minimum ERP is 25 kW.

Class D stations are noncommercial educational fm stations. The maximum power output allowed is 10 watts. Class D stations may be assigned to any of the first 20 channels listed in Table 2-2 (Channels 201 through 220).

2-4. TELEVISION BROADCAST

Television broadcast assignments are made on three bands—54-88 MHz (low-band vhf), 174-216 MHz (high-band vhf), and 470-890 MHz (uhf). As shown in Table 2-3, there are 82 television channels, 12 for vhf and 70 for uhf. Each channel is 6 MHz wide. To provide a more uniform signal level for all channels in a given area, their maximum power output is restricted as follows:

Channels	*Effective Radiated Power*
2-6	100 kW (20 dBk)
7-13	316 kW (25 kBk)
14-83	5000 kW (37dBk)

The abbreviation *dBk* refers to the power output related to an output of 1000 watts. For example, an output of 100 kW is 20-dBk greater (power-ratio gain of 100) than an output of 1 kW (0 dBk).

Any one of the twelve vhf channels (2-13 inclusive) may be assigned to vhf translator use in the condition that no interference is caused to the direct reception of any television broadcast station. Vhf translator stations for any one of the twelve channels can be allocated for transmitting signal into an area where direct reception of the television-broadcast station is unsatisfactory due to distance or terrain barriers. Vhf translator power is limited in general to a peak-visual power that shall not exceed one watt east of the Mississippi, and 10 watts west of the Mississippi. Power level is 10 watts when the transmission is on the same frequency as that of the primary station. There are various restrictions as to their use. For example, they can only be assigned if no interference is caused to the direct reception of any television broadcast station operating on the same or an adjacent channel. They will not be authorized to serve an area which is receiving satisfactory service from one or more uhf television stations or uhf translators.

The upper 14 uhf Channels, 70-83 inclusive, were formerly assigned to television translator stations. The FCC has now reallocated these channels to land mobile service. This move leaves dangling the fate of over 800 uhf television translators operating on Channels 70-83. At the present time, the license of these translators is to be renewed only on a "secondary" basis. On this basis the translators are required to accept any interference from land mobile operation and are not permitted to cause any interference to land mobile operation.

Television translator stations are operated solely for the purpose of retransmitting the signals from a television broadcast or another translator station into an isolated or remote area. This is done by direct frequency conversion and amplification of the incoming signal, without significantly altering any of its characteristics other than frequency and amplitude. Uhf translator stations are restricted to a peak visual power output of 100 watts.

Table 2-3. Television Channels and Frequency Bands

Freq (MHz)	Channel	Freq (MHz)	Channel
LOW-BAND VHF		**UHF BAND (Cont.)**	
54-60	2	638-644	42
60-66	3	644-650	43
66-72	4	650-656	44
76-82	5	656-662	45
82-88	6	662-668	46
HIGH-BAND VHF		668-674	47
174-180	7	674-680	48
180-186	8	680-686	49
186-192	9	686-692	50
192-198	10	692-698	51
198-204	11	698-704	52
204-210	12	704-710	53
210-216	13	710-716	54
UHF BAND		716-722	55
470-476	14	722-728	56
476-482	15	728-734	57
482-488	16	734-740	58
488-494	17	740-746	59
494-500	18	746-752	60
500-506	19	752-758	61
506-512	20	758-764	62
512-518	21	764-770	63
518-524	22	770-776	64
524-530	23	776-782	65
530-536	24	782-788	66
536-542	25	788-794	67
542-548	26	794-800	68
548-554	27	800-806	69
554-560	28	806-812	70
560-566	29	812-818	71
566-572	30	818-824	72
572-578	31	824-830	73
578-584	32	830-836	74
584-590	33	836-842	75
590-596	34	842-848	76
596-602	35	848-854	77
602-608	36	854-860	78
608-614	37	860-866	79
614-620	38	866-872	80
620-626	39	872-878	81
626-632	40	878-884	82
632-638	41	884-890	83

Uhf translator signal boosters can be used for retransmitting of uhf translator signals on any channel (70 thru 83) to provide reception to small-shadowed areas within the alloted primary-station service area. The maximum power output cannot exceed five watts.

Vhf and uhf translators and uhf translator boosters cannot be operated in a manner that will cause harmful interference to the reception of other primary commercial or noncommercial stations and the translators of these stations.

In the 6-MHz television channel it is necessary to allocate space for both the picture and the sound signal components. As shown in Fig. 2-1, the picture carrier is positioned 1.25 MHz from the low-frequency end of the assigned television channel, and the sound carrier is 0.25 MHz below the high-frequency end. Note that the upper sideband of the video channel is substantially broader than the lower sideband. This technique, called vestigial-sideband transmission, permits the sending of a high-definition picture in a 6-MHz channel. Thus, video-frequency components of up to 4 MHz and even higher can be transmitted in a channel only 6 MHz wide.

In the transmission of a color picture, a subcarrier is employed to convey the color hue and saturation information. Its position in the bandpass spectrum is also shown in Fig. 2-1. Brightness detail and

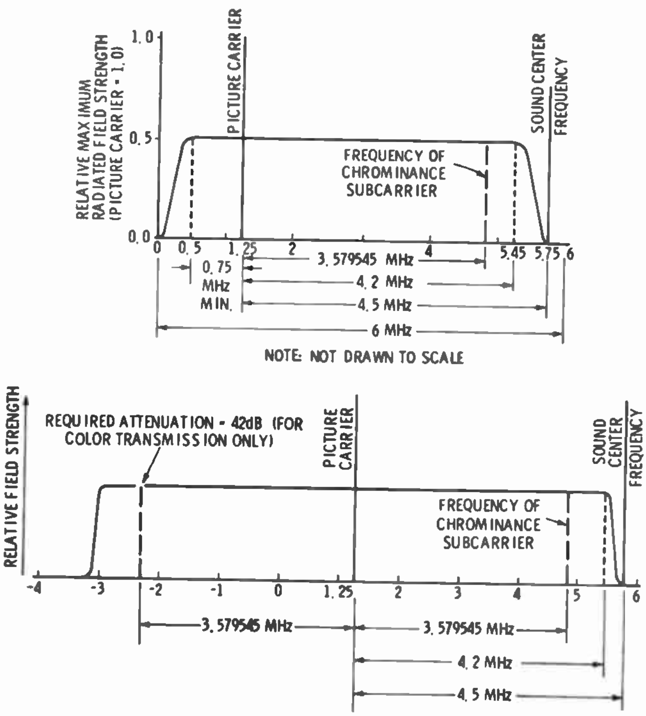


Fig. 2-1. FCC idealized picture transmission amplitude characteristic.

picture definition of the televised scene are conveyed by the picture carrier.

2-5. COMMUNITY ANTENNA RELAY STATIONS

A community antenna relay (CAR) station is a station used for the amplification and reradiation of television signals and related audio signals, and signals of a-m and fm broadcast stations on another frequency to a terminal point. Here the signals are converted for cable distribution to subscribers. There are three types of stations in operation: attended, unattended, and remote control. The power output cannot exceed five watts. Frequencies between 12,700 MHz and 12,950 MHz are assigned to this service.

2-6. COMMUNITY ANTENNA TELEVISION SYSTEM

The term "community antenna television system (CATV system) means any facility which, in whole or in part, receives directly or indirectly over the air and amplifies or otherwise modifies the signals broadcast by one or more television stations and distributes such signals by wire or cable to subscribing members of the public who pay for such service. Such term shall not include (1) any such facility which serves fewer than 50 subscribers, or (2) any such facility which serves only the residents of one or more apartment dwellings under common ownership, control, or management, and commercial establishments located on the premises of such an apartment house.

2-7. AUXILIARY BROADCAST SERVICES

There are several additional broadcast services useful in the pickup and relay of audio and visual programming signals.

Remote-pickup (a-m) broadcast stations are used for relaying remote program material. The station (fixed base or mobile) license will specify the maximum authorized power. The allotted power will be no more than required for satisfactory service in the specified frequency band. For the frequency allocations of this service see Table 2-4.

Aural (a-m) broadcast stl station (studio-to-transmitter link) is a fixed-base station for aural transmission between the studio and a remote primary transmitter (other than the transmitter of an international broadcast station). The power limitations are the same as for the remote-pickup (a-m) station. For frequency allocations, see Table 2-4.

Aural (a-m) broadcast intercity relay stations retransmit an aural program between two broadcast stations. The same limitations apply to this station as for the aural (a-m) stl station.

Television remote-pickup stations transmit program material and related communications from a remote to the primary television broadcast station. A *television stl station* transmit program and related communication from a fixed-base remote station to the primary television broadcast transmitter. A *television intercity relay station* retransmits

Table 2-4. Auxiliary Broadcast Allocations

Service	Group	Frequencies (MHz unless otherwise specified)
Remote Broadcast Pickup	A	1606kHz, 1622 kHz, 1646kHz
	D	25.87, 26.15, 26.25, 26.35
	E	25.91, 26.17, 26.27, 26.37
	F	25.95, 26.19, 26.29, 26.39
	G	25.99, 26.21, 26.31, 26.41
	H	26.03, 26.23, 26.33, 26.43
	I	26.07, 26.11, 26.45
	J	26.09, 26.13, 26.47
	K	152.87, 152.93, 152.99, 153.05, 153.11, 153.17, 153.23, 153.29, 153.35, 161.64, 161.67, 161.70, 161.73, 161.76
	L	166.25
	M	170.15
	N	450.05, 450.15, 450.25, 250.35, 450.45, 450.55, 450.65, 450.75, 450.85, 450.95, 455.05, 455.15, 455.25, 455.35, 455.45, 455.55, 455.65, 455.75, 455.85, 455.95
Aural Broadcast Studio Transmitter Link (stl)		942.5, 943.0, 943.5, 944.0, 944.5, 945.0 945.5, 946.0, 946.5, 947.0, 947.5, 948.0, 948.5 949.0, 949.5, 950.0, 950.5, 951.0, 951.5
Television Remote Pickup, Television stl, Television Intercity Relay	Band A	1990-2008, 2008-2025, 2025-2042, 2042-2059, 2059-2076, 2076-2093, 2093-2110, 2450-2467, 2467-2484, 2484-2500
	B	6875-6900, 6900-6925, 6925-6950, 6950-6975, 6975-7000, 7000-7025, 7025-7050, 7050-7075, 7075-7100, 7100-7125
	D	12700-12725, 12725-12750, 12750-12775, 12775-12800, 12800-12825, 12825-12850, 12850-12875, 12875-12900, 12900-12925, 12925-12950, 12950-12975, 12975-13000, 13000-13025, 13025-13050, 13050-13075, 13075-13100, 13100-13125, 13125-13150, 13150-13175, 13175-13200, 13200-13225, 13225-13250

the program and related communications between two television sta-ions. These three categories of stations use the frequencies tabulated in Table 2-4. The license for any one of three types will specify a maximum authorized power that is sufficient for satisfactory service in the alloted frequency band. Power cannot exceed 10 percent of the maximum power specified in the station license.

A *television broadcast translator station* is a fixed station that retransmits the initial television program on a different carrier frequency and has been described previously in this chapter under television broadcast stations. A *television broadcast booster station* retransmits the signal of a primary television broadcast station by amplifying and reradiating the incoming signal on the same carrier frequency.

CHAPTER 3

Broadcast Duties and Facilities

This handbook will stress the small a-m, fm, or am/fm stations because they outnumber the large ones, and your chances initially of being employed in a small station are therefore much greater. However, the difference between a large and a small station is a matter of degree; in terms of employment, the technical responsibilities initially are not likely to differ to any great extent. So, a thorough knowledge of small-station operation will be of benefit, whether you are employed by a small or a large station.

3-1. LICENSE REQUIREMENTS

At any a-m, fm commercial, or television broadcast station one or more operators having a first-class radiotelephone operators license shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter or a remote control point. Exceptions to these regulations are the following: a commercial and noncommercial fm station with a power of 25 kW or less, and an a-m station that is authorized for nondirectional operation with a power of 10 kW or less. The routine operation of such a transmitter may be performed by an operator holding a valid first-class or second-class radiotelephone or radiotelegraph operator license or a third-class radiotelephone operator permit that has been endorsed for broadcast station operation. Except at times when the operation of the station is under the immediate supervision of a first-class radiotelephone operator, adjustments of the transmitting equipment shall be limited to the following:

1. Those necessary to turn the transmitter on and off.
2. Adjustments of external controls as may be required to compensate for voltage fluctuations in the power supply.
3. Adjustments of external controls to maintain modulation of the transmitter within the prescribed limits.
4. Adjustments of external controls necessary to affect routine changes in operating power as required by the station instrument of authorization.

5. Adjustments of external controls necessary to effect operation in accordance with a National Defense Emergency Authorization during an emergency action condition.

The licensee of a station which is operated by one or more operators holding other than a first-class operator license shall have one or more operators having a first-class radiotelephone operator license in regular full-time employment at the station, or contract for services on a "part-time" and "on-call" basis with one or more such operators. The primary duty of the first-class operator shall be to ensure the proper functioning of the transmitting equipment.

If the transmitter power in noncommercial fm stations is not more than 1 kW, a radiotelephone second-class operator can perform the functions required of a first-class operator, but he must be a full-time employee of the station. The radiotelephone second-class operator may be under contract on a part-time basis.

In a noncommercial fm broadcast station of 10 watts or less, proper functioning of the transmitter can be the responsibility of either a full-time or part-time employed station employee who has a first- or second-class radiotelephone or radiotelegraph license.

An international broadcast station must have at least one first-class radiotelephone licensee on duty at each transmitter, and he is in charge whenever it is being operated. The same applies to all television broadcast stations.

A remote-pickup mobile or portable station, or a remote base station, can be operated by persons holding any class of commercial radio-operator license or permit. This is true of studio-transmitter link (stl) or intercity relay stations.

Auxiliary broadcast services can be operated by other than a first-class operator, although maintenance must be done by, or under the supervision of, a first-class radiotelephone operator.

Television broadcast translator stations can be operated by anyone holding any class of commercial radio-operator license, although any repairs and adjustments must be done by, or under the actual direct supervision of, a duly licensed first- or second-class radiotelephone operator.

3-2. STATION LOGS

Each broadcast station must maintain program, operating, and maintenance logs. Logs must be kept by persons competent to do so, having actual knowledge of the facts required. The person keeping them must sign the log when going on duty and again when going off duty. They must be kept in an orderly and legible manner in accordance with established procedure and must be made available on request of an authorized representative of the Federal Communications Commission. No portion of the log shall be erased or otherwise obliterated, nor shall the log be destroyed for a two-year period. When the log contains information concerning a disaster or a complaint, it is retained until notified by the FCC. Only the person making the original entry in the log can correct that entry; he does this by crossing out the error, initialing the correction, and indicating the date of the correction.

The operating log is almost always maintained by the operator on duty at the transmitter; sometimes the operator on duty also keeps the program log as well. In other stations the program log is kept by studio and program personnel. Operating log samples are shown in Fig. 3-1. The operating log must contain the following entries:

1. The starting and stopping times at which power was supplied to the antenna.
2. Each interruption of the carrier wave, including its cause and duration.
3. An entry at the beginning of an operation and at intervals not exceeding one-half hour of the operating constants of the final radio stage (total plate current and total plate voltage), antenna current, and frequency monitor readings.
4. Entries appropriate to the operation of remote antenna meters and directional antenna systems. (The latter requirement does not apply to fm and television stations.)
5. Any other entry required by the instrument of authorization.

The maintenance log is kept by the first-class radiotelephone operator who is in charge of the transmitter. A second-class operator is permitted to perform this function only in a 1-kW noncommercial fm station. A-m broadcast station maintenance logs must contain the following entries:

1. An entry each week of the following:
   (a) Tower base-antenna and remote-antenna current meter readings. Calibration of remote meter with tower meter.
   (b) Time and results of tests of the auxiliary transmitter.
   (c) A notation of all frequency checks and measurements made independently of the frequency monitor, and of the correlation of these measurements with frequency monitor indications.
   (d) A notation of the calibration checks of automatic recording devices.
2. An entry of the date and time of removal and restoration of any of the following equipment in the event it becomes defective:
   (a) Modulation monitor.
   (b) Frequency monitor.
   (c) Final-stage plate voltmeter.
   (d) Final-stage plate ammeter.
   (e) Base-current ammeter.
   (f) Common-point ammeter.
3. A record of tower light inspections where required.
4. Entries made so as to describe fully any experimental operation during the experimental period.

CALL LETTERS
A-M TRANSMITTER LOG

DATE ____________

POWER ____________ FREQUENCY ____________ LOCATION ____________

TIME	FINAL PLATE CURRENT	FINAL PLATE VOLTAGE	ANTENNA CURRENT	FREQUENCY DEVIATION	ADDITIONAL ANTENNA CURRENT COLUMNS FOR LEGS OF DIRECTIONAL ANTENNA			REMARKS
					CURRENT	CURRENT	PHASE	

CALL LETTERS
FM TRANSMITTER LOG

DATE ____________

POWER ____________ FREQUENCY ____________ LOCATION ____________

TIME	FINAL PLATE CURRENT	FINAL PLATE VOLTAGE	TRANSMISSION LINE CURRENT	FREQUENCY DEVIATION	REMARKS

Fig. 3-1. Small operating logs.

5. Complete daily inspection information by a qualified first-class radiotelephone operator as required by the FCC Rules and Regulations.
6. Any entries required by the instrument of authorization.

Some of the main parts of a program log are:

1. The time of each station-identification announcement (call-letters and location).
2. A brief description of each program broadcast—such as music, drama, speech, etc.; name or title; sponsor's name; the time the program began and ended. If a mechanical recording is played, the entry must show whether it was a record, transcription, etc., and the time it was announced as a mechanical recording. If a speech is made by a political candidate, his name and political affiliation must also be entered.
3. A notation that an announcement has been made for each sponsored program as "sponsored by," "paid for," or "furnished by" the sponsor.
4. For all programs originated by a network, the name of the network must be logged. Similar logs must be kept by standard a-m, fm, and television broadcast stations.

3-3. BROADCAST STATION LAYOUT

There are three small broadcast station arrangements. In one arrangement the studio and transmitter can share a common site. In another arrangement the transmitter is separated from the studio. An interconnecting telephone program line links the two. There is an operator on duty at the transmitter site. A third possible arrangement consists of a separate studio and transmitter, with the transmitter being controlled remotely from the studio. In this case the transmitter is unattended and is operated from a studio position.

Three small-station plans as suggested by RCA are given in Figs. 3-2, 3-3 and 3-4. In the plans of Figs. 3-2 and 3-3, the transmitter is part of the studio and control-room facilities. In Fig. 3-4 the transmitter has a different location.

The arrangement of Fig. 3-2 is very compact, with all essential operating equipment located in the control room. The control-room personnel operate the transmitter, make announcements, spin records, play tapes, etc. The equipment rack to the left of the consolette contains the transmitter monitoring equipment. The transmitter itself can be viewed from the control room and its meters are read through a glass pane.

If a directional antenna system is used and/or if the transmitter output exceeds 10 kilowatts, the control room operator must have a first-class radiotelephone license. Otherwise, an operator having a lower grade license can take over. However, the station must employ at least one first-class radiotelephone licensee, or must contract with such a license holder who is responsible for keeping the equipment in proper operating condition.

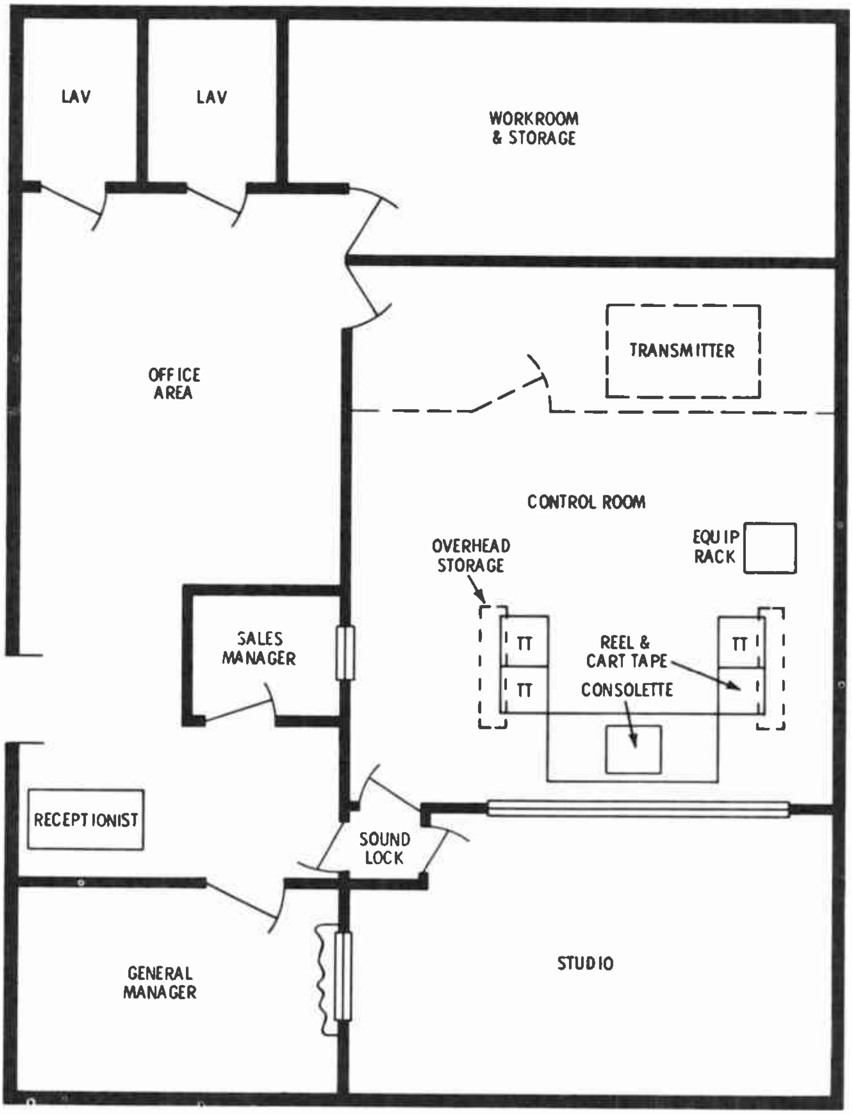


Fig. 3-2. Small broadcast station layout.

Most small radio broadcast stations do employ a chief engineer who has a first-class radiotelephone license. Except in a very limited operation, he is excused from spinning records, playing tapes and making announcements. Nevertheless he probably had to do so at one time, so it would not hurt your chances of breaking into broadcasting if you know how to operate various audio devices and do some limited announcing.

Larger stations have a more decided break between program and technical personnel. In such stations the license holder is assigned technical and operating assignments only, but this is no guarantee that he will not be called on, in an emergency, to sub for an ailing "disc jockey," "tape-jockey," or announcer.

In addition to the audio control console or consolette there are turntables and various reel and cartridge tape players and recorders. There is a single studio that can be viewed through a window from the consolette operating position. Some live programming is possible, such as interviews and small orchestras.

The control-room operator switches and otherwise controls the studio microphones, regulating the absolute and relative amplitudes of the various signals arriving at the console (called "riding the gain"). He is able to observe all studio activities through a soundproof monitoring window.

All station switching operations—changeovers from local announcements, network programs, taped or recorded material, local studio programs, etc.—are made from the console in accordance with the program schedule of the station. If the control-room operator is the only technical person on duty, he is also responsible for the program and operating logs.

One-man operation of this type, although not uncommon, especially in smaller stations, usually occurs during the late evening and other less active hours when more or less continuous records or tape programs are broadcast. Many modern stations are equipped with automatic record and tape players, and even spot announcements are pretaped or prerecorded and cut in automatically or by push-button operation.

A more elaborate studio plan is given in Fig. 3-3. The studio is larger, and there is a separate record room and library containing an audition turntable for previewing records and setting up the program continuity. There is also a separate announce studio.

There is a main control room and a production control room. The main control room contains the consolette, turntables, and tape equipment, plus an equipment rack which is used for the transmitter monitoring gear.

The production control room is used to preview recorded tapes, news, spot announcements, special promotions, commercials, etc., for future broadcast. Inasmuch as the audio equipment in the production control room is identical to that of the main control room, it can serve as an alternate on-the-air control room.

The station plan of Fig. 3-4 is appropriate for a small a-m/fm facility. There are separate control rooms for a-m and fm programming. The equipment lineup is similar, including racks for mounting separate transmitter monitoring equipment or other audio and studio test equipment. Transmitter monitoring equipment is necessary if the station employs unattended remote-control operation.

There are separate announce booths and production control rooms and other facilities that can be accommodated by a much larger floor area.

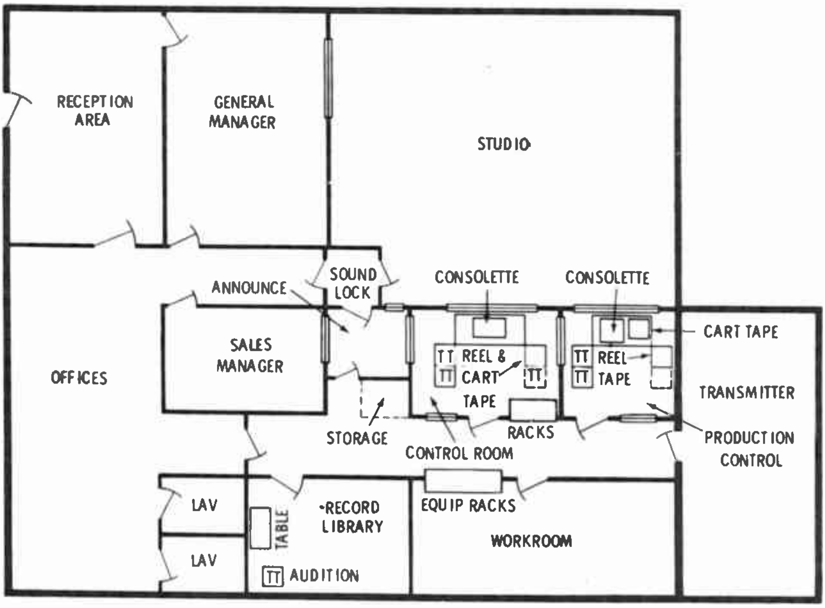


Fig. 3-3. Alternative small station plan.

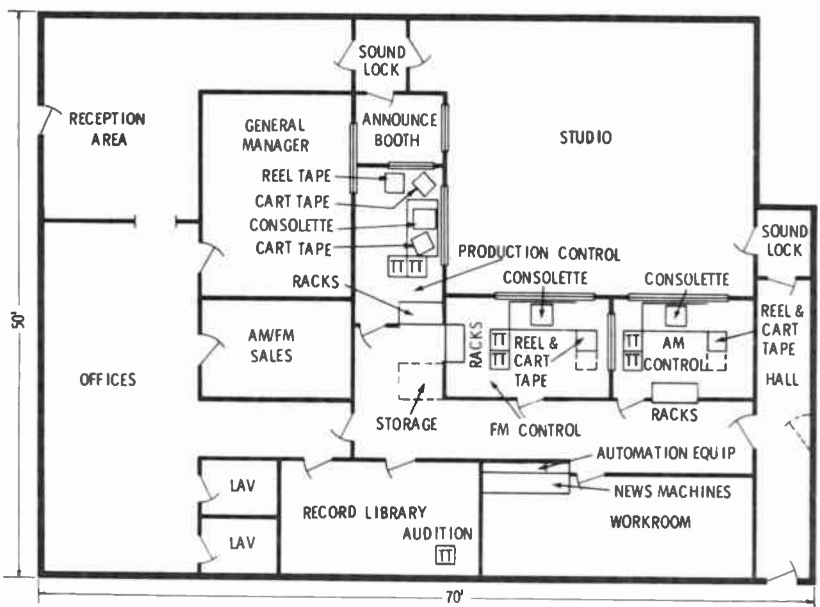


Fig. 3-4. An a-m/fm studio plan.

When the studio and transmitter plant are separated from each other and there is a licensed operator on duty at the transmitter, it is not compulsory for the technical personnel of the studio to be licensed. However, the maintenance of the studio equipment and other technical facilities is usually the responsibility of the licensed technical personnel of the station, and in many cases, the control room operator has a first-class license. Often the technical personnel are rotated between studio and transmitter to give each person an overall background of station operation and equipment.

The transmitter is located at the antenna site. If the antenna is mounted atop a tall building, the transmitter is often located on one of the upper floors. More often the transmitter is located near or outside the city limits. A high location is usually chosen to obtain the best coverage. Where feasible, fm antennas and the transmitter building are located on a mountain top, again from the standpoint of securing additional coverage. The audio signals are normally conveyed over common carrier wires between the studio and transmitter. In some installations, especially when the transmitter is on a mountain top or other remote location, a studio-transmitter radio-link operating in the uhf or microwave portion of the radio spectrum is employed.

A suggested transmitter floor plan appears in Fig. 3-5. The transmitter building need not be very large, since it houses only the transmitter and associated equipment, along with the operating personnel. In a separate transmitter building, a first-class operator is usually on duty during air time, and must always be on duty if the transmitter power exceeds 10 kilowatts and/or a directional-antenna system is used. Sometimes an operator with a lower-grade license is employed on an interim basis, with the understanding that he will acquire a first-class license within a reasonable length of time.

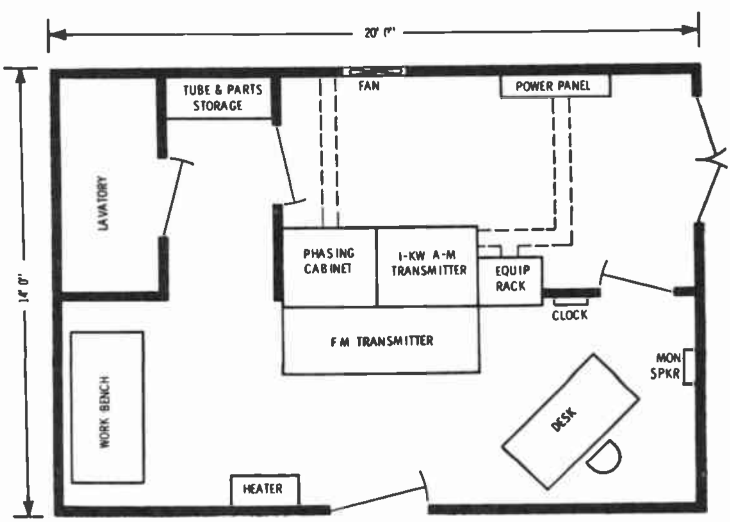


Fig. 3-5. Transmitter floor plan and equipment arrangement.

The phasing cabinet in the transmitter floor plan of Fig. 3-5 is not required when the antenna is not directional. The cabinet houses the circuitry that supplies current of the proper amplitude and phase to the various transmitting towers of a directional-antenna system.

The transmitter can be an a-m or fm type, or a combination of both as in Fig. 3-5. Only a single operator must be on duty.

3-4. REMOTE TRANSMITTER CONTROL

When the transmitter and studio are not under the same roof, it is permissible to operate the transmitter by remote control. However, the following FCC stipulations must be met when remote transmitter equipment is attended:

1. The equipment at the operating (studio) and transmitting locations must be so installed and confined that it is accessible only to authorized personnel.
2. The control circuits from the operating to the transmitting location must provide positive on-and-off control. That is, open or short circuits, grounds, or other line faults must not actuate the transmitter. Moreover, any defect causing such loss of control must automatically "kill" the transmitter.
3. If any part of the remote-control equipment or associated line circuits results in improper control or an inaccurate meter reading, the remote-control transmitter operation must cease.
4. All control and monitoring equipment must be so installed that the licensed operator at the remote-control point can perform his functions in an FCC-approved manner.
5. The indications at the remote-control point of the antenna current meter, or for directional antenna the common-point current meter and remote base current meters, shall be read and entered in the operating log each half-hour.
6. The indications at the transmitter, if a directional antenna station, of the common-point current, base currents, phase monitor sample loop currents and phase indications shall be read and entered in the operating log once each day for each pattern. These readings must be made within two hours after the commencement of operation for each station.

The broadcast transmitter carrier may be amplitude modulated with a tone for the purpose of transmitting to the remote control point essential meter indications and other data on the operational condition of the broadcast transmitter and associated devices, subject to the following conditions:

1. The tone shall have a frequency no higher than 30 hertz.
2. The amplitude of modulation of the carrier by the tone shall not be higher than necessary to effect reliable and accurate data transmission, and shall not, in any case, exceed 6 percent.

3. The tone shall be transmitted only at such times and during such intervals that the transmitted information is actually being observed or logged.
4. Measures shall be employed to insure that during the periods the tone is being transmitted the total modulation of the carrier does not exceed 100 percent on negative peaks.
5. Such tone transmissions shall not significantly degrade the quality of program transmission or produce audible effects resulting in public annoyance.
6. Such tone transmissions shall not result in emissions of such a nature as to result in greater interference to other stations than is produced by normal program modulation.

All stations, whether operating by remote control or direct control, shall be equipped so as to be able to follow the procedures of an emergency action notification (FCC Secs. 73.932 and 73.67).

A remote-control panel is shown in Fig. 3-6. This is the studio or control-room unit; a second unit is installed at the transmitter and makes the necessary interconnections that permit the transmitter to be controlled remotely and metered using two telephone lines that link the studio with the transmitter. The three meters permit a measurement of plate voltage, plate current, and antenna current. The transmitter remote-control facility gathers the information from the appropriate transmitter circuits and places a calibrated low voltage on the line to the studio. Proper calibration insures that an accurate reading of the three parameters can be obtained using the three meters of the studio remote-control unit.

The three meters do not record simultaneously but are switched into the circuit by the 11-position switch on the panel (Fig. 3-6). Positions

Courtesy Gates Radio Co.

Fig. 3-6. Remote control panel with meters.

2 (P.A. volts), 3 (P.A. amps), and 4 (Ant. amp) are used for making these important transmitter readings from the remote-control point. Another switch position gives an indication of tower light-circuit operation. Various other positions are available for use in a variety of remote-control, monitoring, and metering applications.

The OFF position of the selector switch also switches in a calibrating battery voltage. This position can be used to check calibration of the three meters and the proper functioning of the telephone lines that are used to interconnect the transmitter unit and the studio remote-control units.

Three control switches are located at the lower left of the remote-control panel. The first switch (Fil. on-off) is used to turn on the transmitter filaments, while the second one (Pl. on-off) controls the plate supply. The third toggle (Raise-off-lower) is an operational control that can be used to remotely turn on motors and associated controls at the transmitter which provide a means of correcting any fluctuations in certain key transmitter voltages or currents. Thus transmitter operation can be normalized as indicated by proper meter readings on the remote meters. A remote-control installation contains various fail-safe circuits that will shut down the transmitter when any defect results in a loss of control.

3-5. AUTOMATIC LOGGING

Automatic transmitter and program logging has become increasingly popular. Program logging can be handled with tapes and other means acceptable to the FCC. Some highly automated systems include automatic program switching and automatic control of program continuity along with automatic program logging.

An automatic operating-log recorder must record the transmitter meter readings specified by the license. Accurately calibrated automatic recorders with appropriate time, date, and circuit functions may be utilized to record the entries in the operating log, provided:

1. They do not affect the circuit operation or the indicating instrument accuracy of the equipment being recorded.
2. The recording devices have an accuracy equivalent to the accuracy of the indicating instruments.
3. The calibration is checked against the original indicators at least once a week, and the results obtained from these checks are noted in the maintenance log.
4. Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerance or other requirements specified in the rules or the instrument of authorization.
5. Unless the alarm circuit operates continuously, devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded.

6. The automatic logging equipment is located at the remote control point if the transmitter is remotely controlled, or at the transmitter location if the transmitter is directly controlled.
7. The automatic logging equipment is located in the near vicinity of the operator on duty and is inspected by him periodically during the broadcast day.
8. The indicating equipment conforms with the FCC specifications for indicating instruments, except that the scale need not exceed two inches in length and arbitrary scales may not be used. (Ref. FCC Sec. 73.39.)

A typical automatic operating log facility is shown in Fig. 3-7. Two identical units are used by television station WTTG, Washington, D.C., for automatic logging of their sound and picture transmitters. Transmitter readings of antenna current, plate current, and frequency deviation are recorded on graph paper as shown in Fig. 3-7.

The log-alarm unit also includes a frequency meter and a power meter. In the case of the frequency meter, two limit positions are set up on each side of the zero center. Whenever the carrier frequency drifts beyond these limits a warning light is turned on, and an alarm is sounded. The power alarm can also be set for prescribed power limits,

Courtesy WTTG Washington, D. C.

Fig. 3-7. Automatic logging installation.

say 90% and 105% of allocated power. If these limits are exceeded, the alarm circuits will also be energized.

Three switches are located at the lower left of the log-alarm unit. One turns the power on; the second switch (from left side of the panel) marked "auto" selects the automatic-switching process that samples and records the meter readings on the logging paper. The "Reset" switch is used to reset for normal operation of the unit after the log alarm has given an alarm of improper operation of the transmitter. Indicator lights at the bottom center show the particular parameter being monitored at that instant.

CHAPTER 4

Broadcast Microphones

Dynamic and ribbon microphones are the two types of microphones employed most often in modern broadcast stations, although a limited number of condenser microphones are also in use. In recent years the dynamic microphone has risen in popularity because of its improved design and performance, light weight, small size, ruggedness, and adaptability to modern broadcast techniques.

4-1. TYPES

The three basic microphone movements are shown in Fig. 4-1. The *dynamic microphone* (Fig. 4-1A) employs the moving-coil principle. A wire coil attached to a diaphragm is positioned in a strong magnetic field. Whenever sound waves strike the diaphragm and cause it to move, the coil also moves, and its turns cut the lines of force of the magnetic field. This motion induces a voltage in the coil, the ends of which are connected to a transformer in the microphone.

These coil movements can be made very rugged and can deliver a high output signal level. The output voltage varies with, and depends on, the sound pressure changes on the diaphragm. Microphones in which the output voltage varies with the sound intensity and pressure are referred to as *pressure types*.

The *condenser microphone* (Fig. 4-1B) is also a pressure type. It consists of an aluminum alloy diaphragm and a back plate, with a narrow air space in between. The aluminum diaphragm functions like the movable element of a variable capacitor. A polarizing voltage is applied between the diaphragm and back plate. Any movement of the diaphragm will cause a change in capacitance between the two plates. In turn, a proportional change will occur in the output voltage. Because a condenser microphone has a very low capacitance, the output impedance of its element is very high. In fact, the output voltage is so low and the output impedance so high that the element must be connected directly to the high-impedance input circuit of a vacuum-tube or transistor audio amplifier, which is often built into the microphone.

The *ribbon microphone* (Fig. 4-1C) movement consists of a thin corrugated aluminum ribbon in a strong magnetic field. Any vibration,

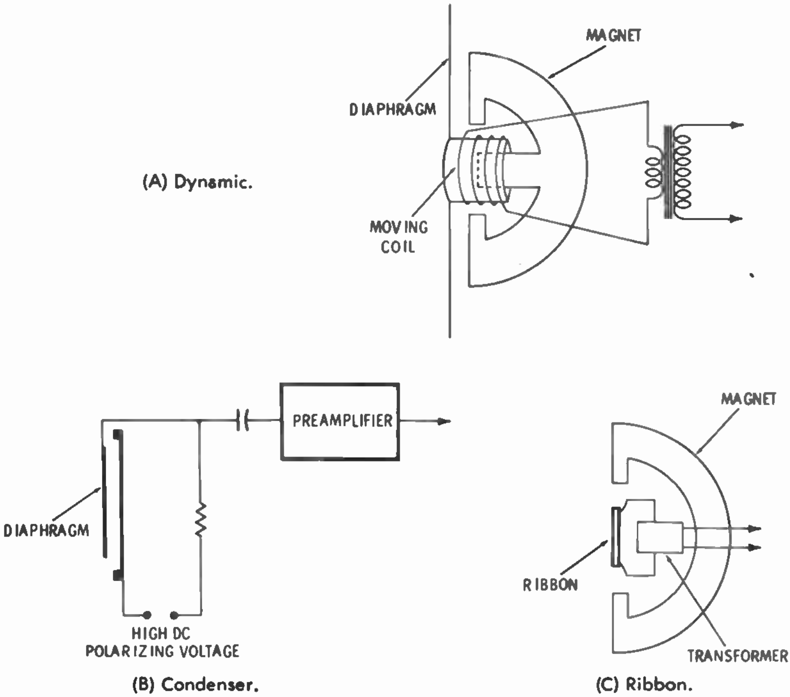


Fig. 4-1. The basic microphone movements.

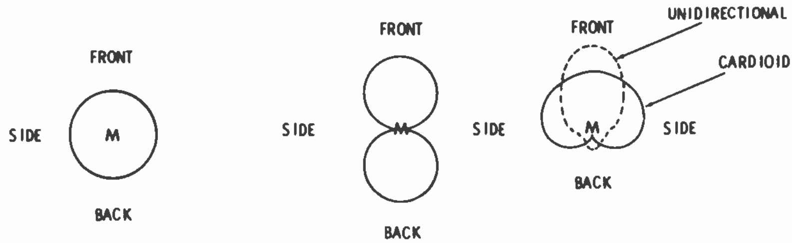
as a result of sound waves, causes the ribbon to cut the lines of magnetic force. A corresponding voltage is induced into the ribbon, and a current flows through it and into the primary of an associated transformer that raises the extremely low impedance of the ribbon to that of the audio lines and facilities of the broadcast audio equipment. The transformer also steps up the weak ribbon voltage in the primary to provide a usable output across the secondary.

The ribbon itself must be elastic, even though under tension. A ribbon microphone must never be jarred or subjected to intense sounds such as blasting and gunshots, or the ribbon may break. If stretched too tightly, the ribbon may loose its elasticity and shape. As a consequence, the microphone characteristics will be altered. Despite these disadvantages, ribbon microphones are used because of their excellent frequency response and hence quality of performance.

It is interesting to consider the motion of the ribbon when excited by a sound. The ribbon can move backward or forward from its resting position, its motion being a function of the differential sound pressure that exists between its back and front. It will always move in the direction of diminishing sound pressure. Thus, a ribbon microphone is referred to as a *pressure-gradient* type. Its movement responds to sound waves from the front or back—whereas dynamic and condenser movements are strictly pressure types because, regardless of the direction of sound arrival, the diaphragm moves in the same direction. Except for the ribbon types, all other microphones are pressure types.

4-2. MICROPHONE POLAR PATTERNS

Inasmuch as a pressure-type microphone responds to sounds arriving from any direction, it is basically nondirectional. However, it can be made directional through the use of specially constructed baffles and resonant chambers. The pressure-gradient ribbon microphone is basically a directional type. Recall that it responds to the difference in sound pressure between its front and back. However, sound waves arriving from the sides exert the same pressure on the front and back of the ribbon. Consequently, there is no ribbon motion and hence no output. It follows that the polar pattern of the pressure-gradient microphone is a figure-8 (bidirectional). By special construction it is possible to change this polar pattern, or to develop a variety of patterns by using more than one type of microphone movement.



(A) Nondirectional. (B) Bidirectional (C) Cardioid-unidirectional.

Courtesy RCA Corp.

Fig. 4-2. Basic microphone polar patterns.

There are three common polar patterns, as shown in Fig. 4-2. Some microphones have only one; others include facilities for changing the pattern to suit the broadcast needs. Although a microphone is a three-dimensional device, normally we are concerned only with its front, back, and side pickup (horizontal directivity).

It is apparent that a microphone with a nondirectional pattern (Fig. 4-2A) is preferred when the sound arrives from several directions. For best pickup, such a microphone should be placed at the approximate center of the sound. A microphone with a bidirectional pattern (Fig. 4-1B) is ideal where there are two opposite sound sources (for example, two people seated across from each other at an interview table). It has the added advantage of displaying minimum sensitivity to undesired sounds from the other two sides.

Microphones with unidirectional or cardioid patterns (Fig. 4-2C) are useful when the sound arrives from the same general direction. The cardioid pattern, for instance, can pick up sounds from the wide expanse of a large studio or stage. Its wide angle of pickup improves the balance of an orchestra or choir. At the same time, minimum noise is picked up from the rear (e.g., from the audience) because of the weak pressure from the rear. For more concentrated sources of sound, a microphone having a sharper unidirectional pattern can be used.

In summary, it is apparent that the choice of microphone and pattern hinges on the type of program material. However, the size of the room and the reverberations in it also influence the selection. A general rule is to use a directional microphone wherever there is high reverberation ("live" room) and/or high background noise, and to use a nondirectional microphone for all other programs. In fact, in a highly absorbent surrounding ("dead" room), a nondirectional microphone will provide greater program realism.

4-3. OUTPUT LEVEL AND FREQUENCY RESPONSE

The output level of broadcast microphones usually is rated in dBm, which corresponds to the output in decibels related to 1 milliwatt at a standard sound pressure of 10 dynes/cm^2. The latter figure is the approximate sound pressure impressed on the microphone by normal conversation when the speaker's mouth is one foot from the microphone. In other specifications the output is often given as so many microvolts/dyne/cm^2, or in output voltage in dB related to a standard of 1 volt/10 dynes/cm^2.

Of course, microphone outputs are much weaker than 1 milliwatt or 1 volt. In fact, they are so low that the output level is rated in minus dB—the higher the minus-dB figure, the lower the output level. For example, at a given sound level a microphone rated at −56 dBm has half the output voltage of a microphone rated at −50 dBm.

Frequency response is also an important characteristic. In modern broadcast microphones it extends from approximately 40 Hz to above 12 kHz. Very little program material extends below 40 Hz, and the high-frequency response depends largely on the broadcast service being rendered. High-fidelity fm programs are able to handle the higher-frequency components, whereas many of the highs (as a function of the audio facilities, network lines, and receiver response) are lost in standard a-m broadcasting. However, even in a-m broadcasting the high-frequency response may reach as high as 8 to 12 kHz.

The frequency response of a microphone is usually specified between the 6-dB-down points on the low- and high-frequency ends of the frequency curve. Some microphones and their preamplifiers include facilities for setting the frequency response according to the acoustical conditions and audio-line lengths.

Many microphones can also be switched to match one of the three standard impedances of 50, 150, or 250 ohms; lines and facilities are usually terminated in one or more of these three values.

4-4. HUM-PICKUP LEVEL

Another important microphone specification is its *hum-pickup level*, usually given as a minus-dB quantity. The 0-dB reference level is the hum output related to 1 milliwatt when a standard 60-hertz hum field of 0.001 gauss is used. In a microphone with a hum-pickup level of

−30 dBm, the amplitude of the hum voltage is twice that of a microphone with a −36-dBm hum level.

A high hum level can reduce the dynamic range of a broadcast. The lowest-amplitude passage (lowest level signal in dB) that can be conveyed satisfactorily depends on how well the signal resulting from this low passage is held above the hum (and noise) levels present in the system.

4-5. TYPICAL BROADCAST MICROPHONES

One widely used broadcast microphone is the RCA model shown in Fig. 4-3. It is a ribbon type and has an adjustable acoustical shutter which gives a choice of nondirectional, bidirectional, or unidirectional

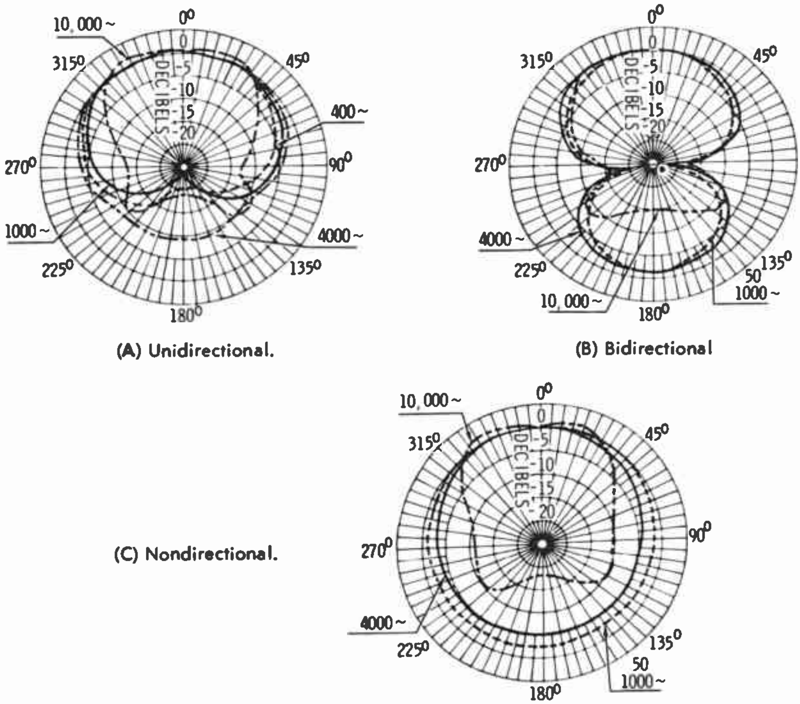
Fig. 4-3. RCA ribbon microphone.

pattern (Fig. 4-4). Such a microphone can be used for general programming and announcements, or it can be mounted on a television boom. Its characteristics are as follow:

Frequency Response: 50-15,000 Hz
Pattern: 3 choices
Output Level: Nondirectional, −56 dBm
Bidirectional, −50 dBm
Unidirectional, −53 dBm
Output Impedance: 250 ohms
Hum-Pickup Level: −128 dBm

Another popular microphone is the Electro-Voice dynamic type (Fig. 4-5). It can be mounted on a stand for general programming and television staging, or carried around during audience-participation shows and interviews. It has a nondirectional pattern and a choice of one of the three standard impedance outputs of 50, 150, and 250 ohms. The impedance can be changed by moving a lead inside the microphone, as shown by the transformer arrangement in Fig. 4-6. Its characteristics are as follows:

Frequency Response: 40-20,000 Hz
Pattern: Nondirectional
Output Level: −55 dBm
Output Impedance: 50, 150, or 250 ohms



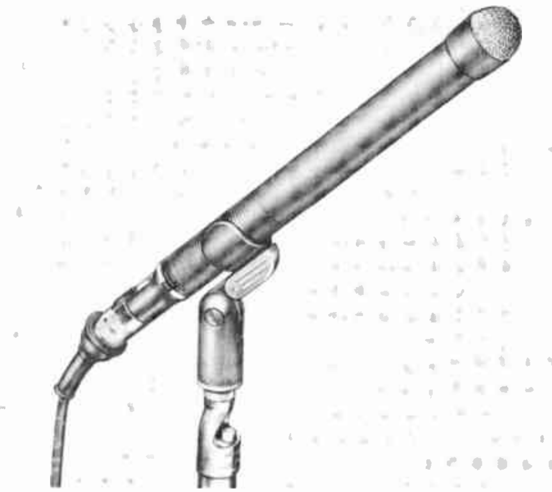
(A) Unidirectional.

(B) Bidirectional

(C) Nondirectional.

Fig. 4-4. Pattern characteristics of microphone shown in Fig. 4-3.

A good-quality broadcast microphone is a complex instrument. A dynamic microphone is more than a magnet and a moving coil attached to a diaphragm. Actually, a resonant circuit is formed by the mass of the diaphragm (which is equivalent to an inductance because it opposes a change in velocity), the compliance of the diaphragm (which can be compared to a capacitance because it opposes any change in the applied force), and the volume of air to the rear of the diaphragm



Courtesy Electro-Voice, Inc.

Fig. 4-5. An Electro-Voice dynamic microphone.

(also a capacitance for the same reason), as shown in Fig. 4-7A. This mechanical resonant effect peaks the response of the microphone at some low frequency. As in any electrical circuit, the Q of a resonant circuit can be lowered and the response flattened by insertion of a resistance (Fig. 4-7B). In a microphone a sound-absorbing felt is employed as a resistance to remove violent peaks in the frequency response.

Still another consideration in microphone design is proper low-frequency response. In a microphone it can be extended by admitting the outside air, through a tube, into the back case of the microphone.

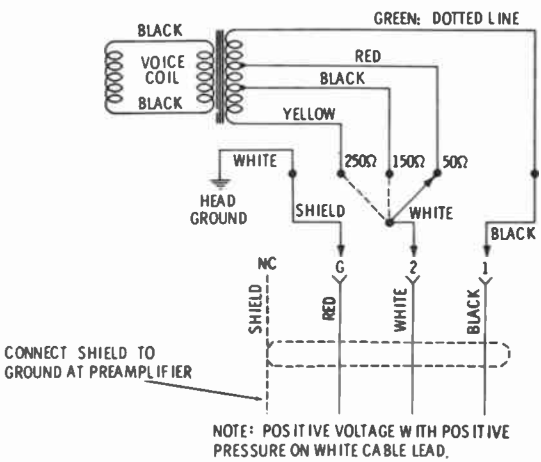


Fig. 4-6. Transformer arrangement for the Electro-Voice microphone.

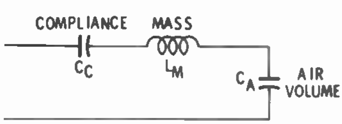
In effect, more inductance is added across the resonant circuit of the microphone, as shown in Fig. 4-7C. The combination of this bass-reflex principle and the acoustic resistance of the felt material provides the proper low-frequency response.

The high-frequency response of our hypothetical microphone can be made more desirable by keeping its diameter small and increasing its length (Fig. 4-7D). The long, slim case of the Electro-Voice microphone is a good example. The high-frequency response can be further extended by using a frontal resonant cavity between the diaphragm and grille. The cavity and its associated tube are concealed in the grille and form inductive and capacitive elements that extend the frequency response to 15 kHz and up.

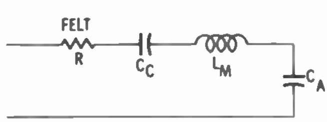
An RCA uniaxial ribbon microphone is shown in Figs. 4-8 and 4-9. The patterns of Fig. 4-8 are particularly helpful in showing its three-dimensional pickup characteristics (unlike most ribbon microphones, which are bidirectional). Around its vertical and horizontal axes the microphone has a cardioid pattern. Its longitudinal pattern is nondirectional and becomes compressed at the higher frequencies. The combined three-dimensional characteristics produce a good uniaxial pickup pattern.

The microphone is made to have directional characteristics and to operate as a pressure type by placing an acoustical labyrinth behind the ribbon. The labyrinth is a folded pipe approximately 31 inches long which is damped by acoustical material along its entire length to eliminate resonant conditions. An acoustical connector links the pipe to the air gap at the back of the ribbon. Two phase-shifting ports establish proper impedance relationships and maintain a uniform frequency response. (See Fig. 4-9.)

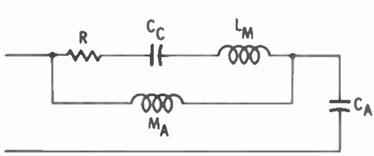
The remainder of the circuit consists of a line-matching transformer and an adjustable response compensator. The latter permits additional attenuation of the low frequencies in noisy locations or when the microphone is close-talked (which tends to emphasize the lows). Full-frequency pickup can be used for musical programs.



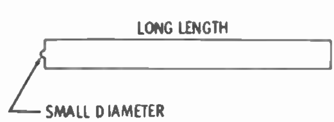
(A) Equivalent circuit.



(B) Introduction of acoustic resistance.

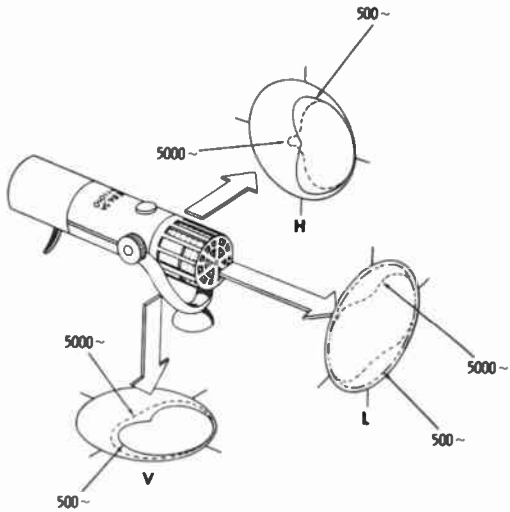


(C) Addition of air mass.



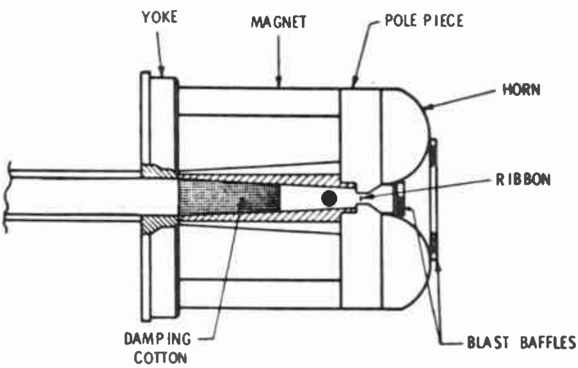
(D) Microphone shaping

Fig. 4-7. The factors which influence the overall response of the Electro-Voice dynamic microphone.

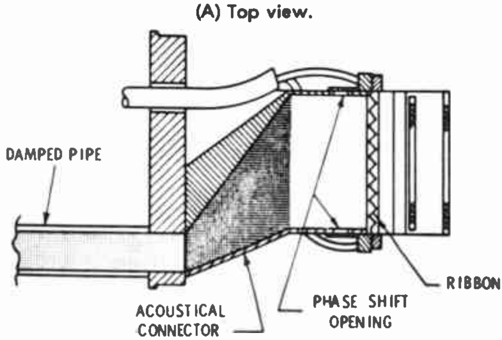


Courtesy RCA Corp.

Fig. 4-8. An RCA uniaxial microphone.



(A) Top view.



(B) Side view.

Courtesy RCA Corp.

Fig. 4-9. Basic construction of the RCA uniaxial microphone.

This style of microphone is particularly adaptable to boom and stand mounting, and for other applications where the microphone must be tilted in the direction of the sound without picking up noises from other directions.

Fig. 4-10 shows a very popular style of broadcast microphone whose characteristic pickup pattern is directional and uniaxial. This small dynamic type can be held in the hand or worn around the neck on a lanyard. When worn around the neck, such a microphone is often planned to emphasize the high frequencies because of the high-frequency shadow beneath the user's chin. Also, radiation from the user's chest tends to emphasize the lower frequencies.

Fig. 4-10. RCA miniature dynamic microphone.

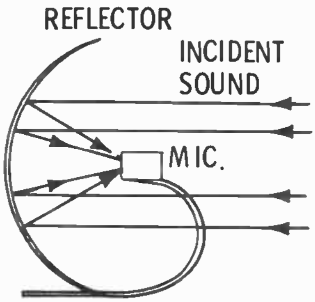
Courtesy RCA Corp.

The characteristics of the personal dynamic microphone are as follows:

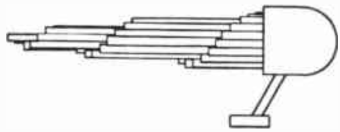
Frequency Response: 80-12,000 Hz
Pattern: Semidirectional
Output Level: −67 dBm
Output Impedance: 250 ohms
Hum-Pickup Level: −112 dBm.

Modern broadcasting trends emphasize remote pickups in the outdoors and in large amphitheaters. One example would be a small instrumental group riding on a float in a parade. In such applications the microphone must be able to reach out and pick up sounds from a rather concentrated area without picking up surrounding noises.

A parabolic reflector can be used to further concentrate the directivity of a microphone, as shown in Fig. 4-11A, but it of course has size limitations. The "machine-gun" or "line" type of microphone in Fig. 4-11B is composed of many small tubes varying in length from about two inches to five feet. The open ends act as pickup points, and their opposite ends terminate at the diaphragm of a microphone. All sounds coming directly toward the open ends will travel the same distance to the diaphragm—whether the sounds enter a tube and pass



(A) Parabolic reflector.

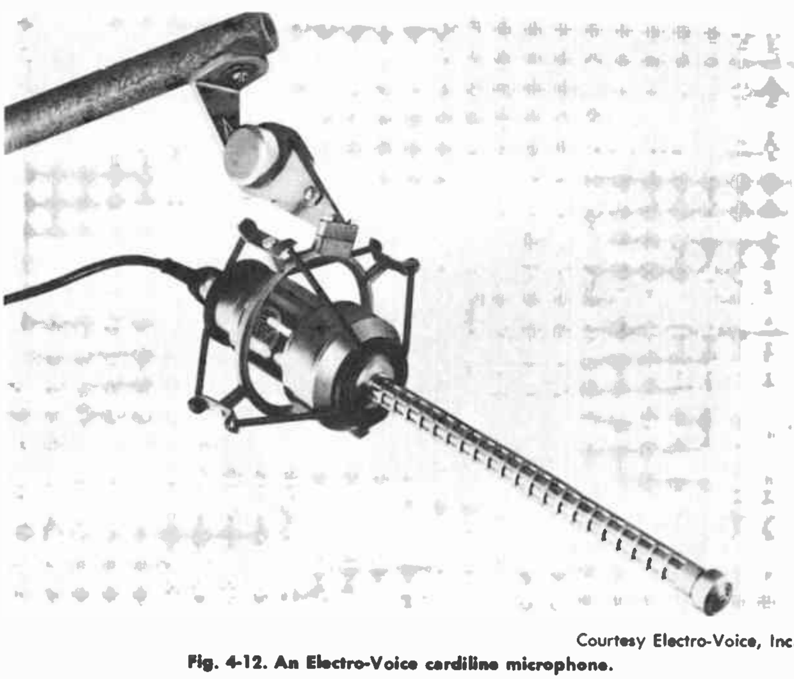


(B) Tube line.

Fig. 4-11. Methods of increasing microphone directivity.

through it, or continue through the air until entering a shorter tube. Since all sounds reaching the diaphragm have traveled the same distance from the source, they arrive at the same time and the diaphragm is actuated in phase.

Now let us see why background noises from the sides are not picked up. These side sounds will still enter all tubes at approximately the same time. But the sound entering the five-foot tube must travel almost five feet farther, to reach the diaphragm, than the same sound entering the two-inch tube. For example, a sound 10 feet to the right or left must travel anywhere from 10 feet 2 inches to 15 feet before



Courtesy Electro-Voice, Inc.

Fig. 4-12. An Electro-Voice cardiline microphone.

striking the diaphragm. The sounds arrive at the diaphragm at different times and, being out of phase, the sound waves have a canceling effect and do not cause the diaphragm to vibrate. An even greater phase difference will exist for sounds which originate at points behind the microphone.

The Electro-Voice microphone of Fig. 4-12 has high sensitivity, plus a sharp directivity obtained from the combination of line- and cardioid-microphone principles. A cardioid dynamic movement and a single-line tube approximately one foot long are used. A ⅛-inch covered slot in the tube, over its entire length from A to B in Fig. 4-13, displays a linear-taper acoustic resistance. All positions along the slot display equal sensitivity; therefore, equal sound pressures along the line will result in equal voltages being produced by the microphone element. Just as in the "machine-gun" arrangement, signals arriving from the sides and back will be canceled out at the cavity in front of the microphone.

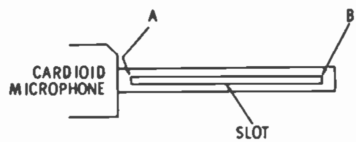


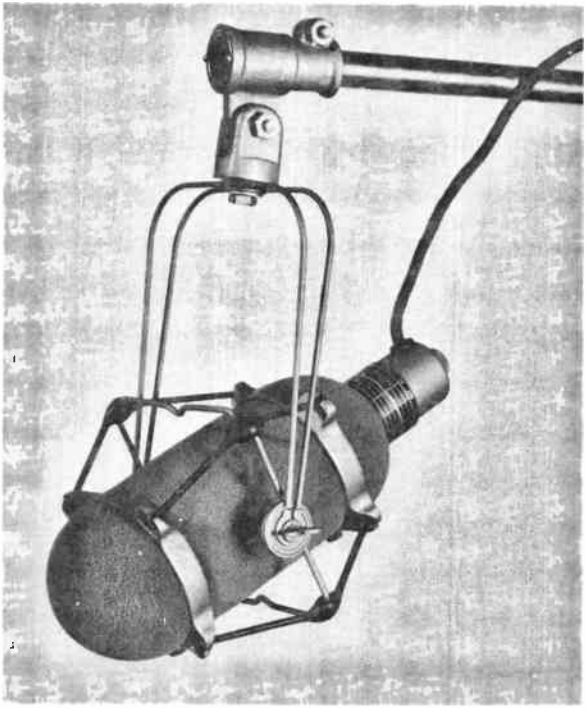
Fig. 4-13. Basic construction of an Electro-Voice cardiline microphone.

One of the most distracting disturbances in the audio signal in outdoor broadcasting is wind blast and noise. Also the operational-environmental conditions can cause microphone performance to deteriorate prematurely. For instance, in television broadcasting, boom microphones take a considerable beating; they are moved at fast speed from one position to another and are subject to wind-noise pickup. The simultaneous deterioration of the audio signal due to environmental conditions and the impaired quality of microphones has created a demand for an improved microphone.

Recently considerable effort has been directed to providing adequate shielding and protection for the boom microphone without disturbing its response. A foam jacket with good acoustical performance serves as an effective windscreen. It also protects the microphone from dust and magnetic particles and minimizes possible damage from being dropped or struck. Such protection is shown for the boom-mounted microphone of Fig 4-14.

The internal make-up of a North American Philips condenser microphone is shown in Fig. 4-15. The condenser element is mounted in the head at the extreme left. A transistor amplifier of high input impedance builds up the amplitude level of the audio signal. The amplifier is followed by an audio output transformer that permits a selection of output impedances.

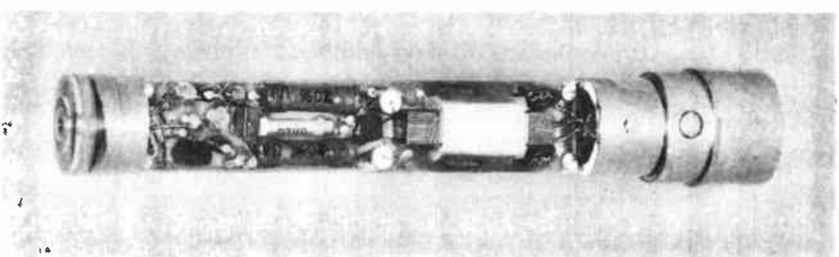
The high impedance input of the amplifier is established by the field-effect transistor which is connected in a source-follower configuration. This stage is followed by a bipolar emitter-follower circuit which drives the primary of the output transformer (Fig. 4-16).



Courtesy Electro-Voice, Inc.

Fig. 4-14. A boom-mounted microphone with a protective windscreen.

The supply voltage for the two-stage amplifier and the polarizing voltage for the condenser microphone element is developed by an oscillating high-frequency generator. Transistor Q3 oscillates at approximately 1 MHz. The high-frequency voltage across the primary is rectified and filtered to supply a dc operating voltage of about 7.5 volts for the amplifier. The higher voltage output across the secondary is rectified by diode CR1. The filtered output of about 60 volts is used as the polarizing voltage across the condenser microphone element.



Courtesy North American Philips Corporation

Fig. 4-15. Philips condenser microphone.

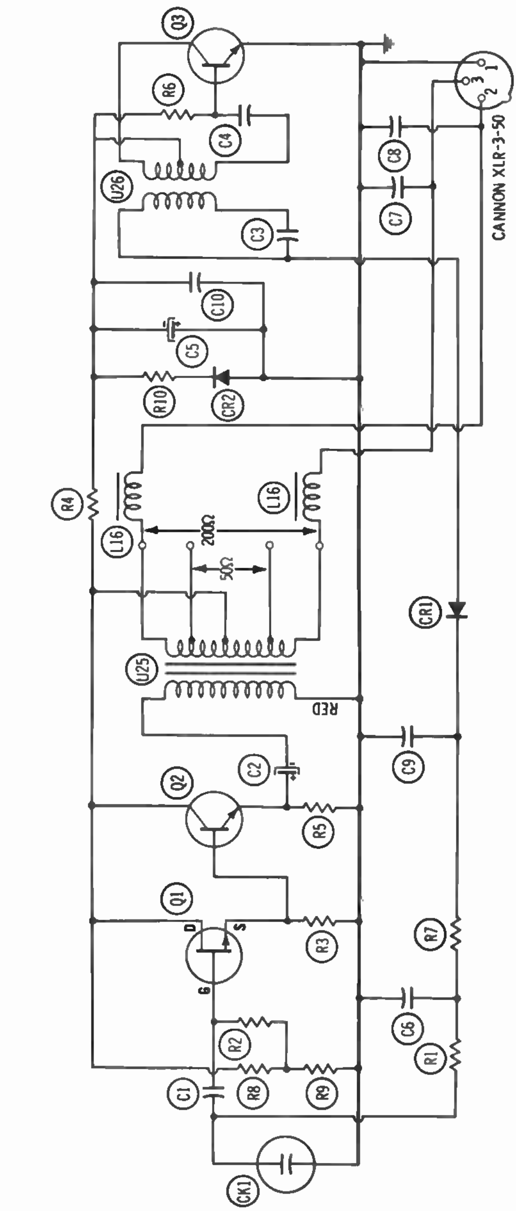


Fig. 4-16. Schematic of Philips condenser microphone.

4-6. MICROPHONE APPLICATION AND PLACEMENT

It is important that first-class radiotelephone license holders have an understanding of proper microphone placement and use. More often than not in a small broadcast station, the program originates from a small enclosure. This can be the control room itself, an announcing booth, or a mobile sound truck. For these applications the cardioid or unidirectional pattern is preferred. In such small enclosures, reverberations are numerous and strong; and acoustical treatment seldom supplies the most desirable correction.

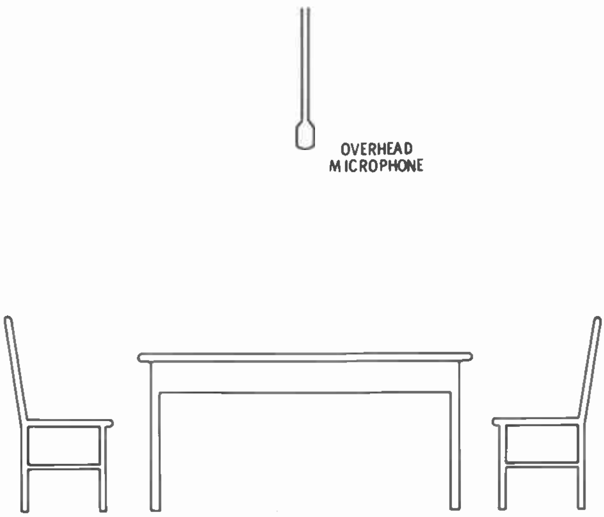


Fig. 4-17. Placement of an overhead microphone.

It is characteristic of most announcers to "mug" the microphone. If the announcer will keep at least two feet away from it, better voice quality will result. Television broadcasting, where the microphone must be out of the camera's range, has proved that close-talking is not necessary. This problem can often be avoided by mounting the microphone overhead, as in Fig. 4-17. The table can be sound-treated to minimize reflections.

In a small studio, meeting room, or hall that is highly reflective (high reverberation, or liveness), a directional microphone is usually mandatory—particularly if proper emphasis is to be obtained despite a noisy background.

The nondirectional microphone should be used in highly sound-absorbent broadcast locations, or where liveness and presence are to be added for the listener's benefit. Several factors contribute to this effect of "liveness" in broadcasting. The reverberation time, distance from sound to microphone, and total volume of the studio or broadcast location must be considered. The formula is

$$\text{Liveness} = \frac{1000\ T^2D^2}{G_P V}$$

where,

T is the reverberation time in seconds,
D is the distance from sound to microphone in feet,
G_P is the directivity of the pickup microphone,
V is the volume of the room in cubic feet.

Of course, the directivity of the microphone (G_P) influences the degree with which the three other factors (T, D, and V) affect the liveness. In general, a nondirectional microphone enhances the liveness, and a directional type reduces it. If the liveness and background noise of the area are so great that they interfere with the part of the program to be emphasized, a directional microphone should be used or a special accenting microphone in conjunction with a general microphone. In highly absorbent, "dead" locations where liveness must be added to better satisfy the radio listeners, the nondirectional microphone is more useful.

In recent years the small dynamic interview microphone has become increasingly popular. It adds versatility to the usual microphone setup because it can be carried around and thus taken directly to the source of sound. In conjunction with a general-purpose microphone the interview type can be used to sustain interest during many types of gatherings. For example, the general microphone can be placed on stage to pick up the music from an orchestra or band, and the interview microphone taken directly into the gathering—instead of the confusion of having people come up to the microphone on stage. A much more enjoyable program continuity can be maintained with this arrangement.

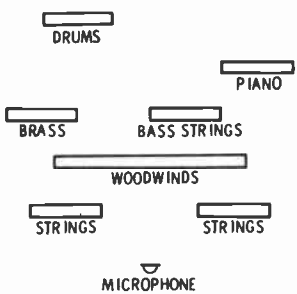
4-7. MUSICAL PICKUP

To obtain the most pleasurable brilliance and balance between audio-frequency ranges, it is important to avoid placing the microphone too close to the vocalist or solo instrument. In recent years the use of overhead microphones has become increasingly popular. Such a microphone can be positioned above the participant, out of reach, where it is safe from handling, jars, and direct pickup of vibrations.

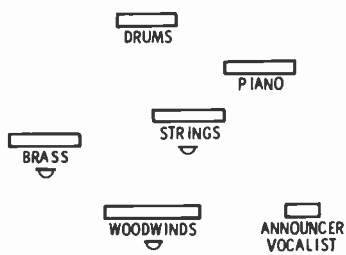
Successful musical programming is dependent to a great extent on experience gained at rehearsals and during previous pickups from the same location. Adequate rehearsal time permits you to experiment with the microphone positions until the most pleasing and balanced result is obtained. For example, the recommended spacing between microphone and piano is eight feet or more; less spacing upsets the tonal balance. Of course, if the pianist is also a soloist and only one microphone is available, it must be moved closer for the vocal part of the program. But if facilities are available, a separate microphone is preferred for the singing. For a program consisting of a vocalist and a pianist, the microphone should be correctly positioned relative to the piano. Then the vocalist can be placed in accordance with his or her volume and dynamic range. Optimum spacing between pianist and vocalist may be as much as ten feet.

To establish the proper level between a vocalist and a piano, it is sometimes necessary to use a unidirectional microphone to favor the vocalist, and have its minimum-pickup direction toward the piano. A vocalist accompanied by an orchestra must usually be positioned much closer to a single microphone. Rehearsal time is again important in learning beforehand the proper balance between vocalist and musical accompaniment.

A common technique, during musical programs consisting of an orchestra and soloists (instrumentals or vocals), involves the use of one general microphone plus one or several accent microphones which are used only during solo segments of the program. The general microphone is set up to obtain an overall balanced result from the orchestra. Often this microphone is placed overhead and with some sensitivity toward the audience to add liveness to the program. The amount of separation from the orchestra is a function of the liveness factors of reverberation time and volume. Again this is best determined by rehearsal and from experience. If the general microphone is a substantial distance from the orchestra, one must be certain the inherent noise levels around it are not so strong that they are distracting.



(A) Dance band.



(B) Small group.

Fig. 4-18. Basic microphone placement for dance band and small groups.

Accent microphones are then positioned in the orchestra to pick up the soloist or a small group. If the general microphone is not able to bring out a particular orchestra section adequately, an accent microphone may be employed, even during orchestral selections.

The use of a general microphone some distance away from an orchestra has become increasingly popular in high-fidelity broadcasting. Of course, accent microphones must be available for the solo, announce, and close-emphasis portions of the program.

Several typical microphone arrangements are shown in Figs. 4-18 and 4-19. With a single microphone, the various segments of the orchestra must be positioned in accordance with each one's amplitude and dynamic range. Usually the small strings are the closest, followed by the woodwinds, bass strings, brass (trombones, trumpets), piano,

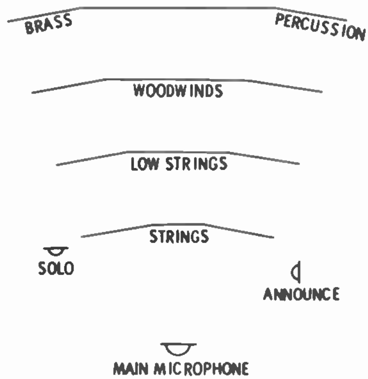


Fig. 4-19. Pickup of a large orchestra.

and drum in that order. If several microphones are available, they can be used to accent individual segments. It is also possible to use the mixer controls of the control amplifier to obtain the most desirable balance among the instrument groups.

In summary, effective placement and use of microphones require a knowledge of microphone characteristics, how the program site acts acoustically, how people respond to a microphone, plus a good listening ear and an understanding of what to emphasize and what is to be background.

CHAPTER 5

Record and Tape Machines

Recorded and taped shows occupy a large percentage of a radio station's total broadcast hours, especially if the station is small or does not have strong network ties. "Disc jockey" shows are at the peak of their popularity. In most stations the DJ is a combination announcer and control-console operator, but not a technical man. He spins records from the studio, a mobile broadcast truck, or remote location set up in department stores, shopping centers, and other locations. Sometimes he may have one of the lower-grade operator licenses, a necessity when the transmitter is part of the control-room facilities. The technical staff is responsible for maintaining the record and tape-playing equipment and for setting up remote facilities.

5-1. TRANSCRIPTION DESK AND CONTROL CONSOLE

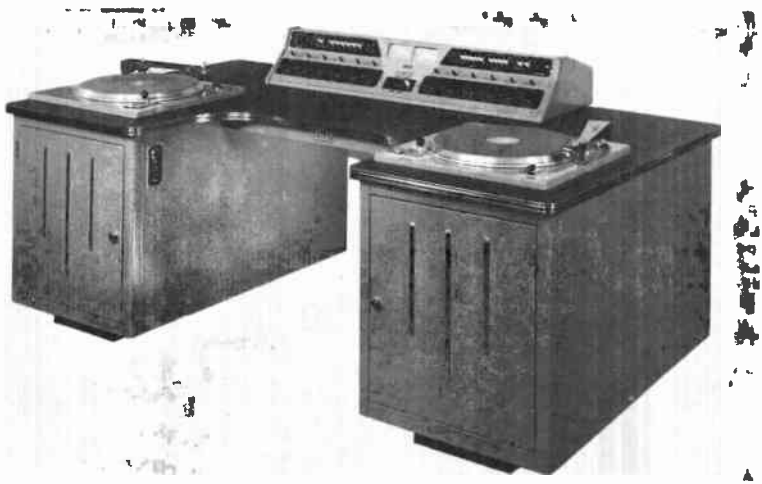
A Gates transcription desk and control-console combination is shown in Fig. 5-1. From this center the operator can spin records and at the same time control other signal sources such as studio, network, or remote sources. The switches permit the operator to establish program continuity by turning the various signal sources on and off at the proper times, and the knobs allow him to control the amplitudes of the various signals. By watching the needle of the sound-level (volume-unit) meter, the operator can make sure that the signal being supplied to the transmitter is of the proper magnitude.

When a record show is in progress, the operator can place a record on one of the turntables, ready for use, while the second turntable is in operation. In fact, with headphones or a monitoring speaker, he can even listen to the record that he is setting up and position the tone arm to provide a smooth continuity in changing over between turntables. This is referred to as "cuing" the record. A typical sequence follows:

1. While a selection is playing on the left turntable, the operator places another record on the right turntable.
2. Through the monitoring headphones or speaker he plays the record on the right turntable, listening until he finds the exact spot where the record is to begin, and at the same instant stops the rotation of the record.

3. With turntable motor still running, he then backs off the record a fraction of a turn and holds it stationary.
4. As soon as the selection is completed on the left turntable, he switches over to the right turntable and releases his hold on the record. With the right turntable now supplying signal to the transmitter, he is free to cue a different record, or to play another selection from the original record, on the left turntable.

In cuing a record, some operators permit the turntable to rotate and hold the record stationary with their fingers until ready to release it. Others, after finding the desired cue spot, turn off the turntable motor and back the record up a fraction of a turn. At the proper moment, they then switch on the turntable motor. This mode of operation is possible because turntables used in broadcasting are able to reach their normal operating speeds in a fraction of a revolution. If the turntable were slow in building up to maximum speed, the initial part of the selection would be distorted.



Courtesy Gates Radio Co.

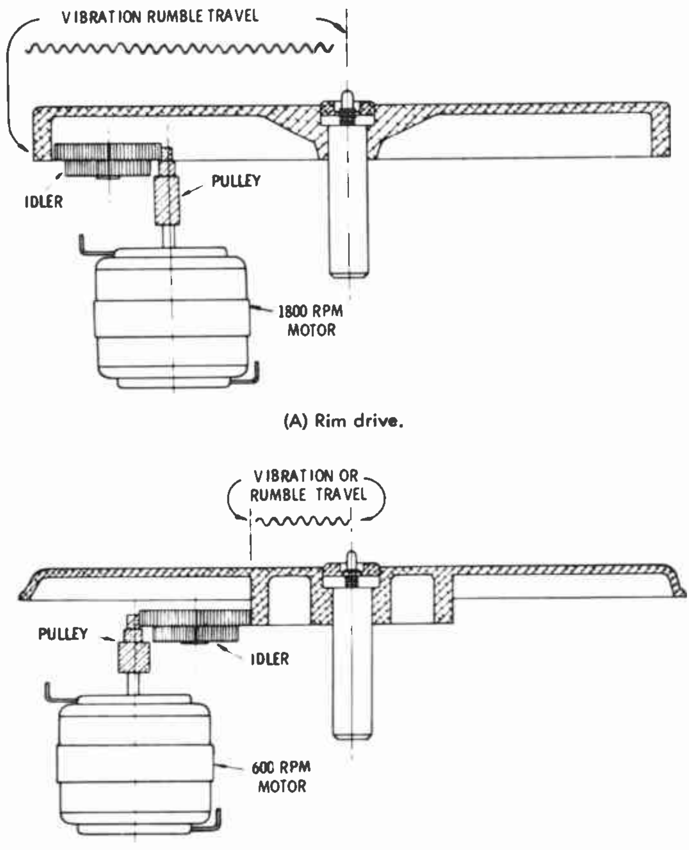
Fig. 5-1. Gates turntables and control room console.

The two most popular records are the 16-inch, 33⅓-rpm transcriptions and the smaller, 45-rpm records. Approximately fifteen minutes of program time, or a complete quarter-hour program, is available on a single transcription. Usually a number of selections, with suitable separations, are recorded on one transcription to permit spot announcements between selections. These transcriptions are sold to radio broadcast stations by numerous transcription services.

Most turntables have two, and sometimes three or four speeds, to handle the large variety of commercial records now available. Likewise, two sizes of stylii are incorporated to accommodate the different record grooves.

5-2. TURNTABLES AND PREAMPLIFIERS

The Gates turntable in Fig. 5-1 has three speeds. Unlike most rim-driven turntables used in the home (Fig. 5-2A), it is rotated by the power transferred from the idler to a solid inner hub, as shown in Fig. 5-2B. This lower and more centralized drive minimizes turntable rumble. At 33⅓ rpm the turntable will attain proper speed in one-eighth



(A) Rim drive.

(B) Inner rim drive.

Fig. 5-2. Types of turntable devices.

of a turn, and in one-sixth of a turn at 45 rpm. The turntable provides three methods of starting: (1) a rocker-arm switch; (2) the index lever, which must be depressed into the proper slot before the motor will start; and (3) "slip cuing" (holding the record while the turntable spins beneath it). For faster cuing, the rocker-arm switch is located close to the turntable so that the operator can flip it with his thumb while keeping one finger on the record.

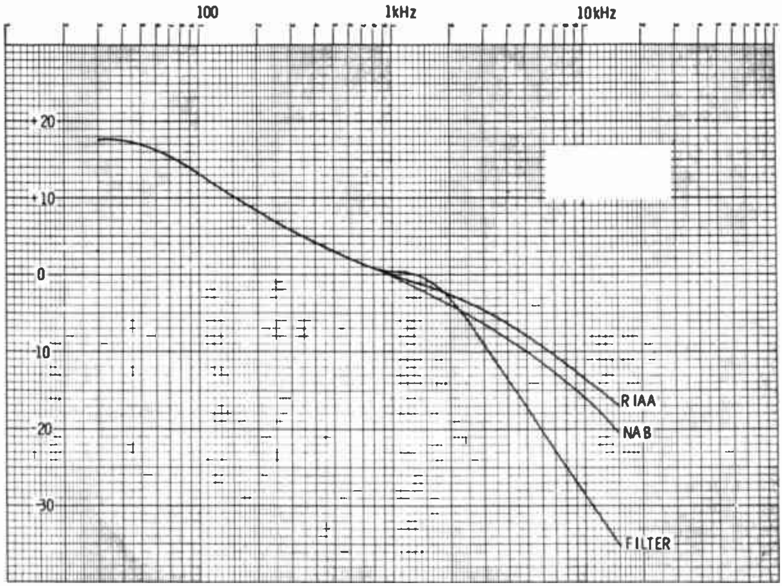


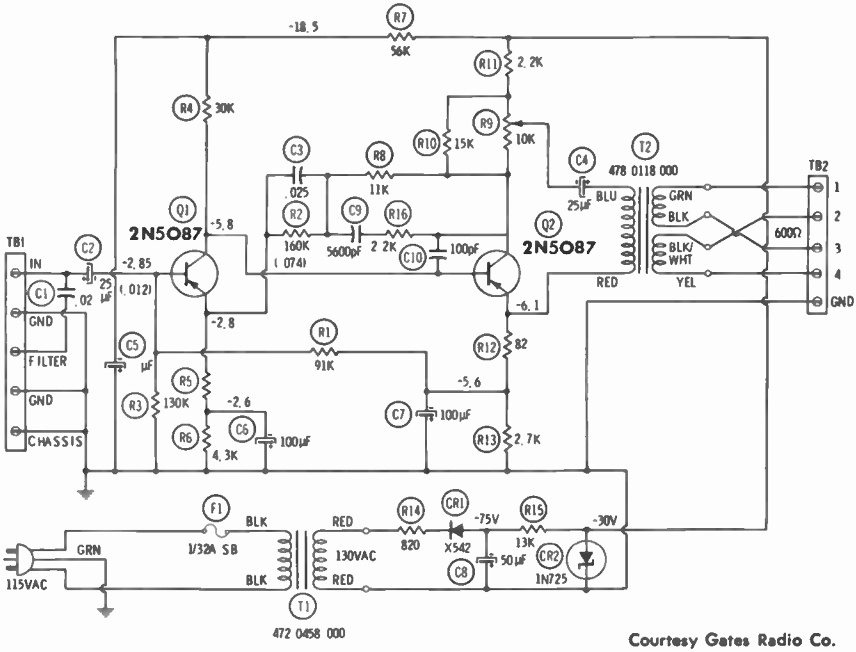
Fig. 5-3. Equalization curves for preamplifiers.

The tone-arm cartridge is equipped with a 0.001-inch stylus for microgroove recordings, and a 0.003- or 0.0025-inch stylus for transcriptions and 78-rpm records.

One function of a record preamplifier is to increase the level of the phonocartridge output before it is applied to the control-console input. A second function is to provide proper equalization according to the RIAA (Recording Industry Association of America) recording curve (Fig. 5-3). This is the recording industry's standard curve, and it provides a close match for the AES (Audio Engineering Society), RCA orthophonic, and NARTB (National Association of Radio and Television Broadcasters) curves.

A solid-state phono preamplifier is shown in Fig. 5-4. It is a two-stage amplifier consisting of an input voltage amplifier connected in a common-emitter configuration followed by a common-emitter power amplifier stage. Either a 150-ohm or 600-ohm output is made available. The input impedance is 47,000 ohms and the input connections are planned for operation with variable-reluctance cartridges. Additional high-frequency rolloff for noisy records or special effects can be obtained by jumping a connection between the filter terminal of the terminal strip TB1 and ground.

Normally the amplifier is designed for the standard RIAA/NAB equalization curve. Response shaping is handled by the compensated negative-feedback network connected between the collector of output transistor Q2 and the emitter of the input transistor Q1. For standard RIAA equalization there must be no shunt between the filter terminal and ground.

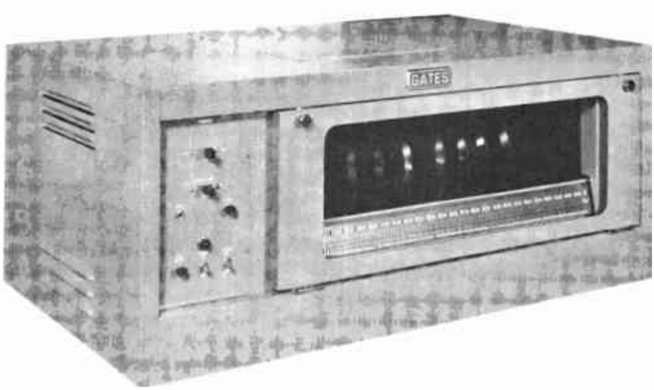


Courtesy Gates Radio Co.

Fig. 5-4. Gates solid-state phono preamplifier.

5-3. AUTOMATIC PLAYERS

The trend toward automation, coupled with the popularity of "disc jockey" programs resulted in the automatic record player for broadcast stations, especially smaller stations. The Gates record player in Fig. 5-5 consists of a Seeburg 200 mechanism, the necessary relay con-



Courtesy Gates Radio Co.

Fig. 5-5. Gates automatic record player.

trols, a preamplifier, and a remote-control unit. The automatic mechanism permits selective playing of either side of the 100 fine-groove, 45-rpm, 7-inch records that are stored vertically in magazines as shown. The operations occur in the following sequence: the "start" button is depressed, and the record turns instantly; the record plays; it returns to its magazine; a new record is withdrawn, set down on the pickup arm, and the mechanism is stopped.

When the control-room operator again depresses the "start" button, the second record will begin to play instantaneously. This split-second starting maintains the continuity required in broadcasting.

5-4. TAPED PROGRAM MATERIAL

Magnetic tape recording is an important phase of radio broadcasting. Because of their light weight, tape recorders can be carried around to record interviews, news events, and other programs originating away from the studio. This material can then be played back during a broadcast.

Tape recording systems can also be used to establish fast-moving and interesting program continuity, because it is a simple matter to edit-out the lengthy, uninteresting material. Many stations tape an incoming network program when, for example, a popular local show is on at the same time, and then broadcast the network program at a more convenient time. Complete shows, including music and spot announcements, can be recorded on tape and the entire program then broadcast at the most appropriate time or in accordance with the sponsor's wishes. Automatic spot-tape machines even make it possible to insert taped commercials or other announcements into the program continuity at the proper times.

5-5. BROADCAST TAPE RECORDER

A compact solid-state broadcast quality tape recorder is the Ampex model shown in Figs. 5-6 and 5-7. There are one- and two-channel models. A single channel model is shown in Fig. 5-6. In the two-channel version there is another section identical to the thin, light metal segment at the bottom. The case is slightly larger to accommodate this second module. The latter arrangement can be used for stereo recording and reproduction with appropriate record/reproduce heads.

The record section is shown at the top of the functional block diagram in Fig. 5-7. There is a dual input with separate gain controls. Tape equalization for both speeds is handled between the two emitter followers, Q9 and Q10. Additional amplification follows before the signal is applied to the record head. A 100-kHz bias signal for the erase and record heads is generated by the solid-state erase oscillator.

The reproduce section is shown at the bottom of Fig. 5-7 and consists of an input voltage amplifier and feedback equalization networks. Through an output-selector switching arrangement, the reproduced signal is passed on to a pair of amplifier stages and an emitter-follower

The output selector switch also permits the channeling of the incoming record signals to the input of the reproduce amplifier. The path is by way of resistor R51 ahead of the equalization network, and the record calibration potentiometer R50. From there the signal is passed to a group of amplifiers, and eventually to output transformer T2. The VU meter across the secondary can be used to check the level of the record signals. As a result the amplifier gain controls can be preset before the actual program material is taped. The same path is also open during the actual recording of the program and audio level can be monitored continuously on the VU meter.

In the reproduce mode the record section becomes inoperative. The signal taken off the reproduce head is increased in level by a two-stage common-emitter preamplifier, transistors Q1 and Q2. The audio signal output circuit. This output circuit and an appropriate transformer make a match into 600-ohm audio line.

A schematic diagram is given in Fig. 5-8. The two inputs are shown left center. The preamplifier is a direct-coupled common-emitter amplifier and emitter-follower output stage. Note that the second transistor serves as the collector load for the input transistor. The equalization and switching facility follow. After equalization the signal is passed to the input of the emitter-follower transistor Q10. It is followed by a high-gain, constant-current amplifier. The collector output is transferred through capacitor C15, inductor L1, and capacitor C16 to the record head by way of jack J8. The parallel combination of L1 and C15 blocks the bias oscillator 100-kHz component from the amplifier.

The 100-kHz bias component is generated by a multivibrator consisting of transistors Q13 and Q14. The bias signal is applied to the erase head, through the resonant output transformer, and to the record head through the bias-adjustment capacitor C27.

Courtesy Ampex Corp.

Fig. 5-6. Broadcast tape recorder.

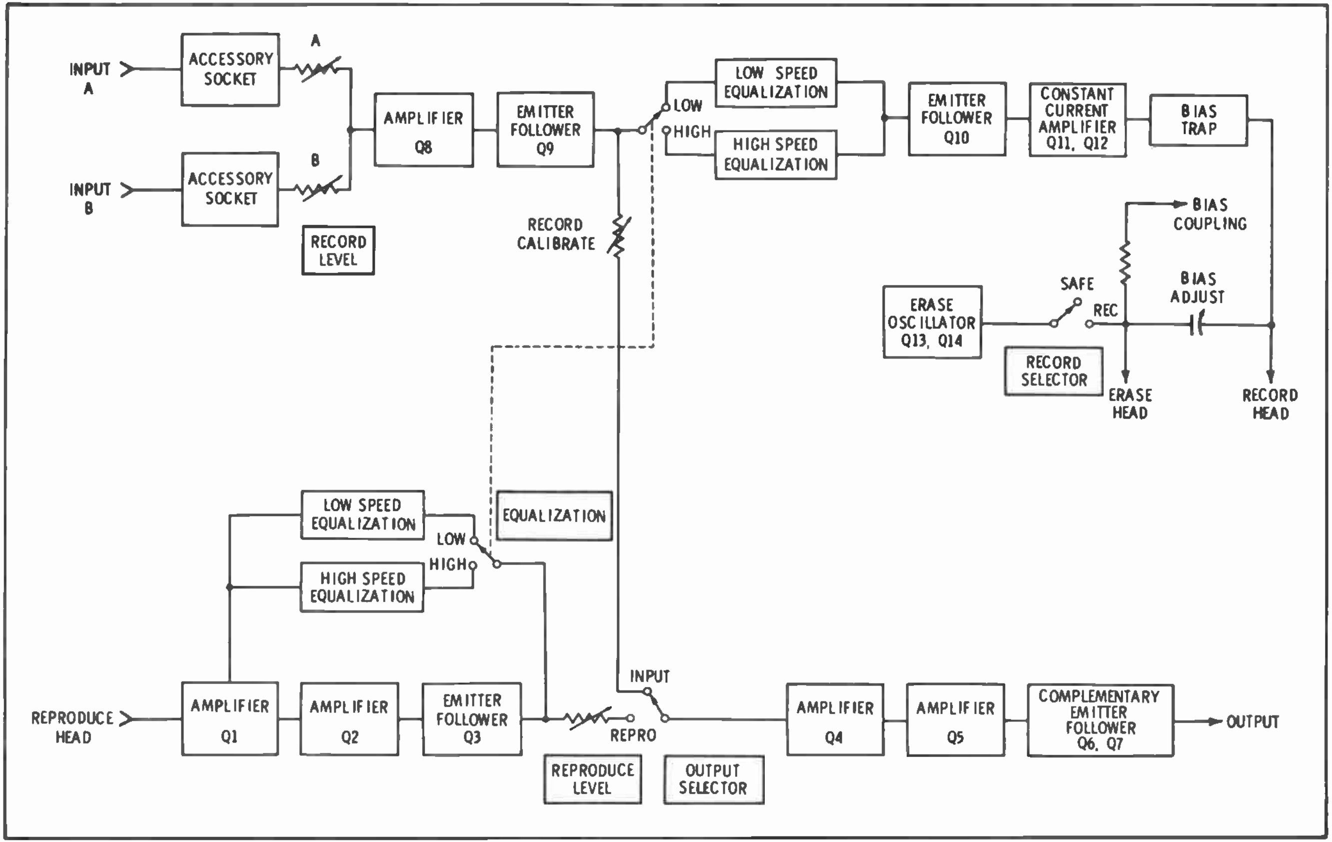


Fig. 5-7. Functional plan of broadcast tape recorder.

is transferred to the second amplifier group from the emitter-follower output transistor Q3 to the gain control and switching section at the input of emitter-follower Q14. The two equalization networks for both low-speed and high-speed operation are connected in the feedback path between the output of transistor Q3 and the emitter circuit of transistor Q1.

The actual record and reproduce responses are given in Fig. 5-9. They are based on the standard NAB (National Association of Broadcasters) responses. In the record mode high-frequency preemphasis is

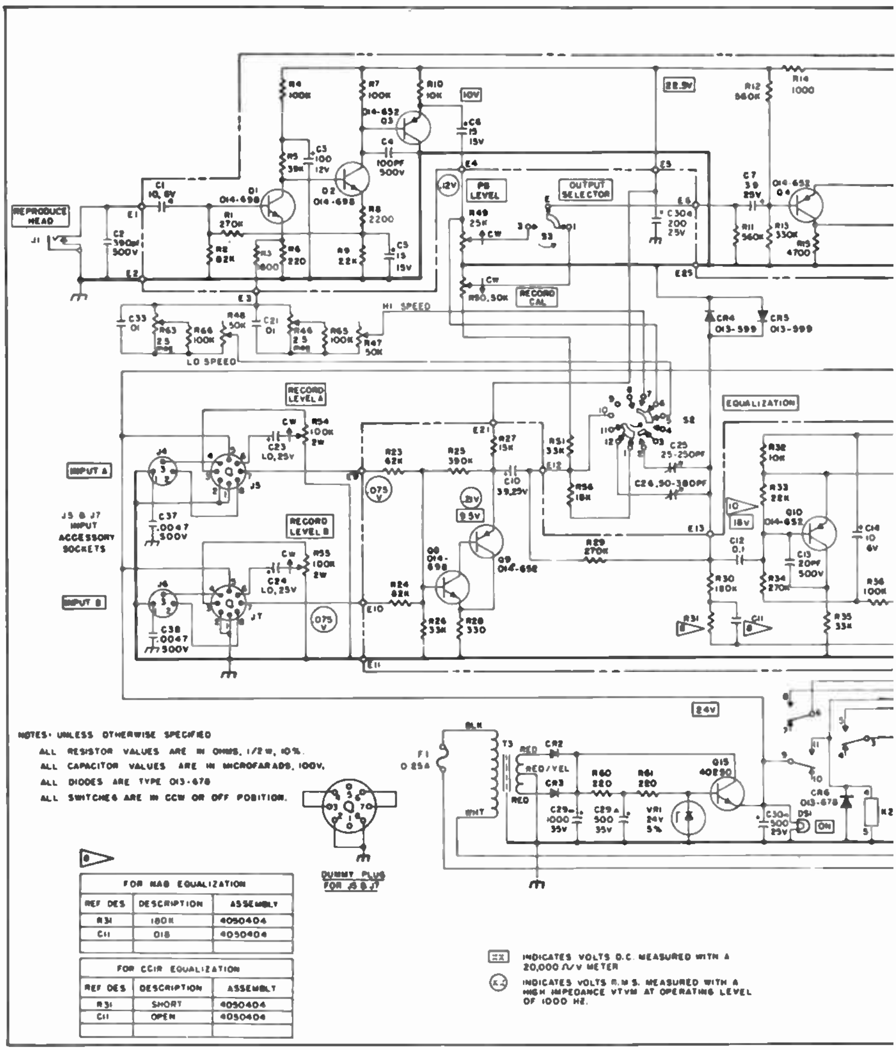
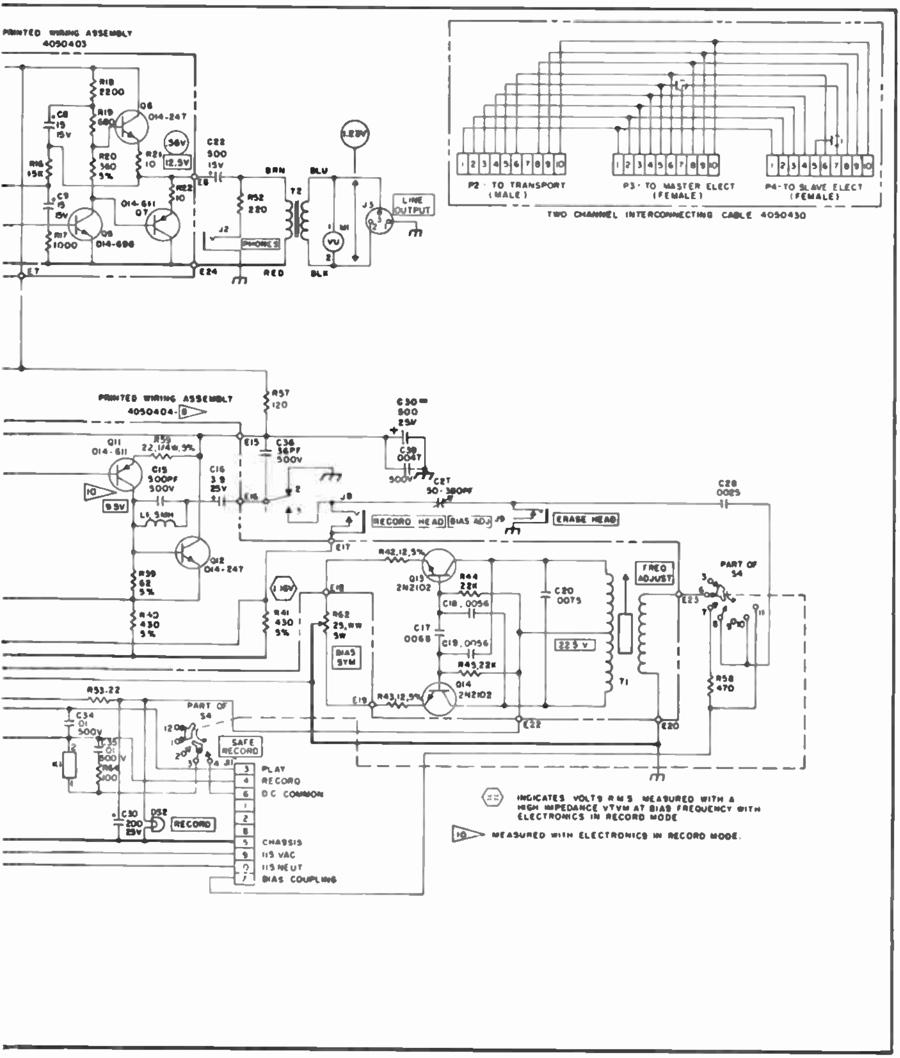


Fig. 5-8. Schematic diagram

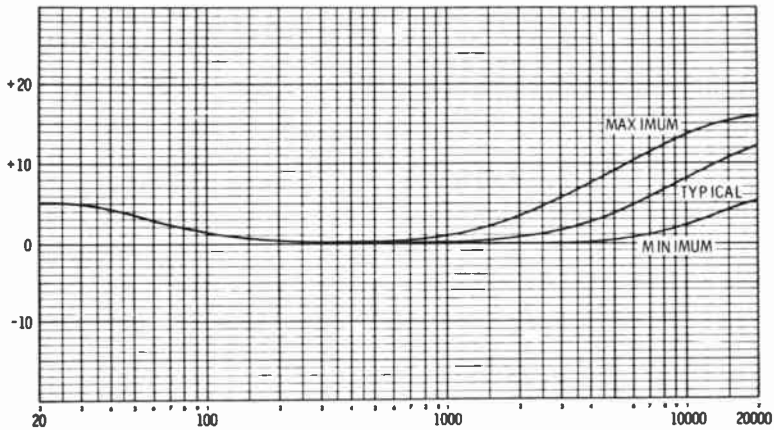
used in maintaining a good signal-to-noise ratio. Proper compensation or de-emphasis is then made in the reproduce curve so as to obtain a linear overall response.

The reproduce signal is built up in level by the second group of amplifiers which drive the output transformer and supply signal to the 600-ohm audio line. A VU meter is connected across the secondary. Headphones can be inserted into the primary circuit of the output transformer. The unit is designed to supply the usual +4 dBm signal to the phone line.

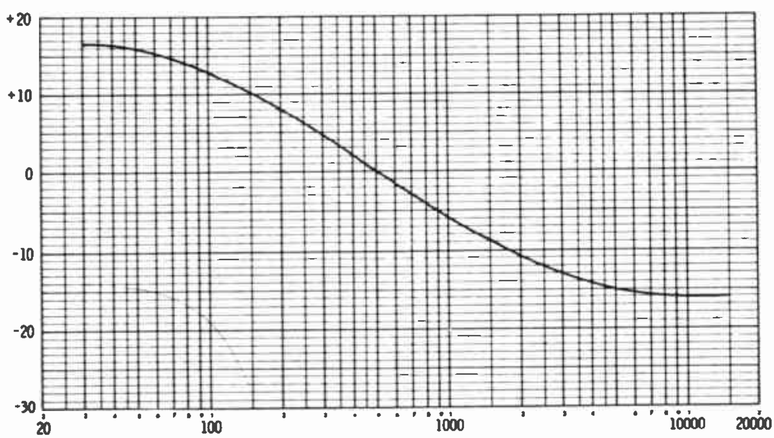


of tape recorder.

Courtesy Ampex Corp.



(A) Record.



(B) Reproduce.

Fig. 5-9. NAB response curves.

5-6. SPECIAL TAPE EQUIPMENT

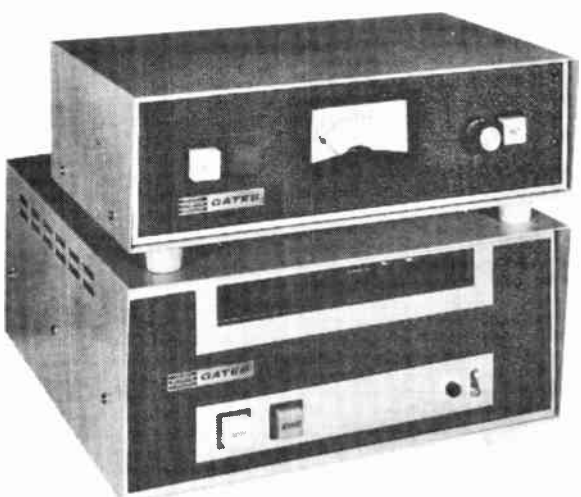
Two unusual tape devices are shown in Figs. 5-10 and 5-11. The *Spot Tape* recorder in Fig. 5-10 is capable of filing 101 announcements, jingles, scenes, station breaks, featurettes, and other programs. Each can last up to 90 seconds, and music of broadcast quality can be included with no loss of fidelity. All information is recorded on a 13-inch wide tape which winds and unwinds onto two cylinders as in an old-fashioned player piano. An index lever is used to choose the desired track. The tape-index scale is calibrated so that all the operator has to do is set the index to the calibration corresponding to a specific com-

Fig. 5-10. A SPOT TAPE recorder.

mercial or other program material. Any track can be erased and new information put on without disturbing any of the other tracks.

A Gates cartridge tape player is shown in Fig. 5-11. Cartridge tapes are available with various amounts of recorded time between 11 and 45 minutes. Commercials, special announcements, background and other program material can be stored on the various tapes. When the material is to be used it is a simple matter to insert the prerecorded cartridge into the slot.

Recorded information can be subdivided into a number of segments on a single tape as long as the total time is not exceeded. A 1000-hertz



Courtesy Gates Radio Co.

Fig. 5-11. Gates tape cartridge system.

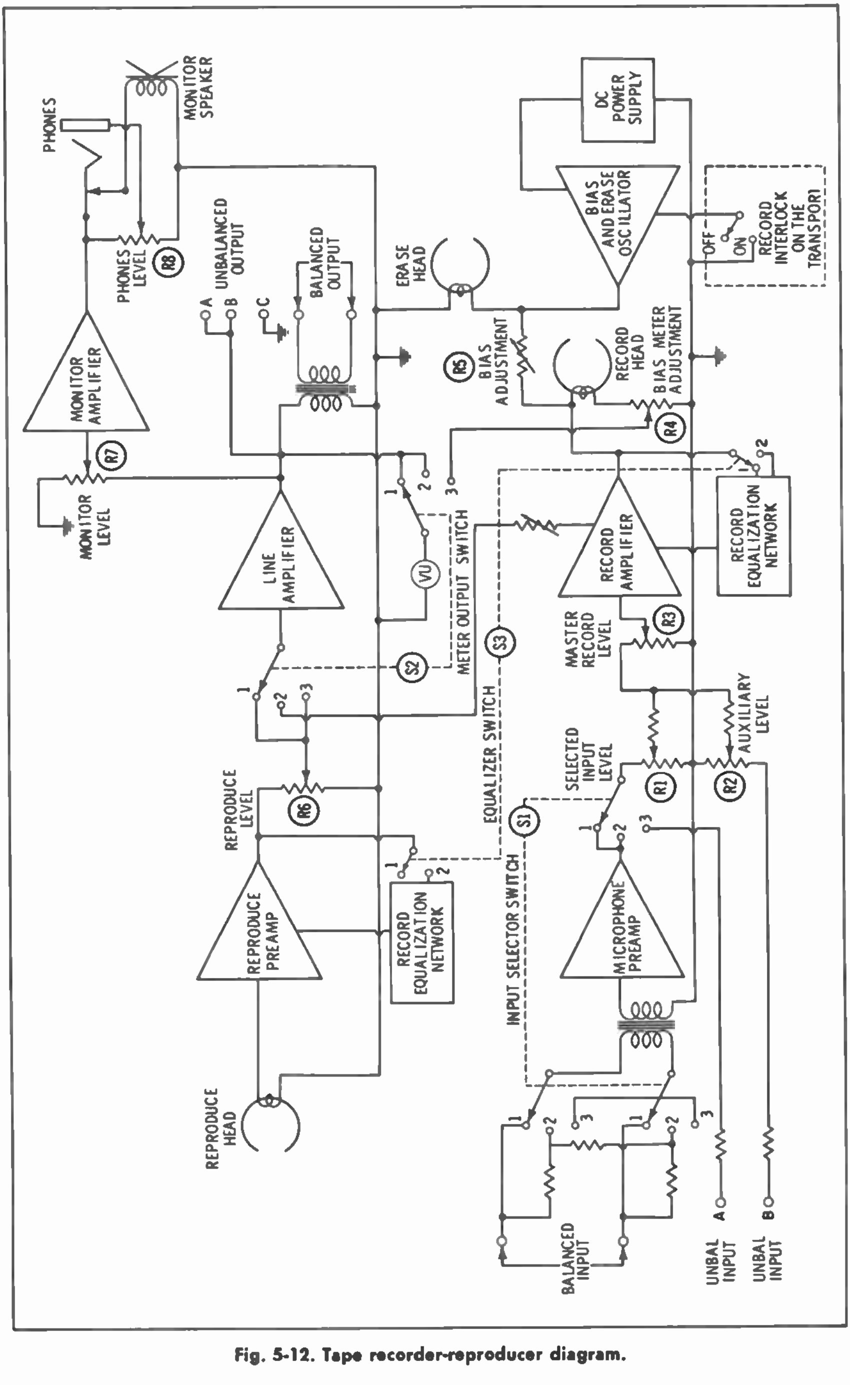


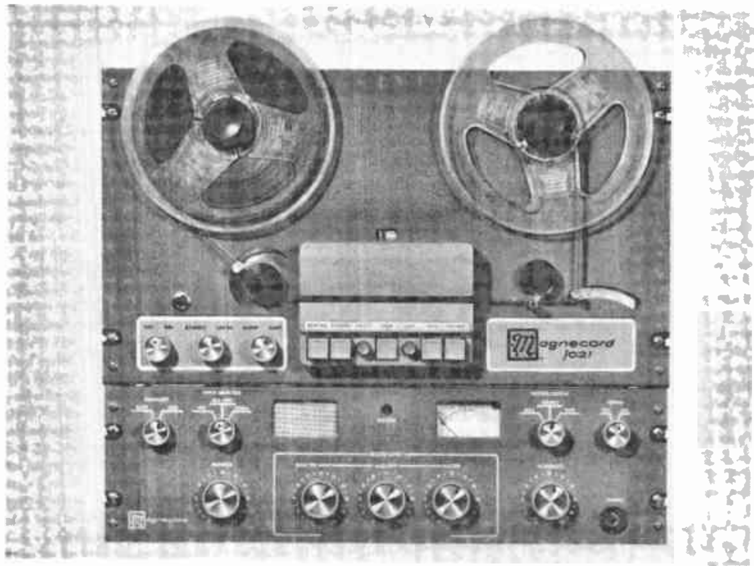
Fig. 5-12. Tape recorder-reproducer diagram.

cue tone is included. Such a tone can be inserted at predetermined spots to stop the tape automatically. This is an aid in maintaining program continuity.

Playback only or record/playback models are available. The latter units would be employed in the production-control room where program material is taped for later broadcast.

An all-transistor broadcast tape recorder and reproducer is shown in Figs 5-12 and 5-13. The unit has a versatile-input arrangement that accommodates balanced or unbalanced line signals. The balanced input is also used for microphone input. The input selector switch (S1) can be used to choose the desired input signal source(s). A selected input level control (R1) is included at the output of the microphone preamplifier as well as an auxiliary-input level control (R2) and a master-level control (R3). Thus two-program signals can be mixed prior to their application to the record amplifier. The output of the record amplifier supplies signal to the record head. The ultrasonic-bias and erase oscillator supplies bias to record and erase heads. An equalizer selector switch (S3) permits the setting of the proper amount of equalization for the slow (Pos. 1) and the fast (Pos. 2) tape speeds in both record and reproduce modes.

In the record mode an output from the record amplifier can be supplied through the second position of the meter and output switch (S2) to the input of the line amplifier. The output of the line amplifier is set by monitor level R7 and supplies signal to the monitor amplifier and the output monitoring phones or speaker. Thus, as the recording is being made the program material can be monitored. The VU meter can be used to check the level of the record signal as it is developed at



Courtesy Midwestern Instruments, Inc.

Fig. 5-13. Magnecord Model 1021 all-transistor recorder-reproducer.

the output of the line amplifier. The line amplifier also provides unbalanced and balanced outputs for simultaneous application of recorded program material to a telephone line or other audio equipment.

In the reproduce mode (Pos. 1) of S2, the reproduced signal level is set by the reproduce level control (R6) and applied to the input of the line amplifier. In turn, the line amplifier output supplies signal to the monitor and the balanced and unbalanced outputs of the unit. The VU meter records the level that is set by the reproduce level control (R6) of the reproduced play-back signal.

When the meter and output switch (S2) is set to position 3 (bias) the playback mode is the same as for position 1 except that now the meter has been switched into the biasing circuit. In this position the VU meter checks out the operation of the biasing circuit of the record head.

CHAPTER 6

Studio and Control-Room Facilities

The essential features of an a-m broadcast station are best described by referring to the functional diagram and floor plan of a typical small station. Such a plan is given in Fig. 6-1.

6-1. SMALL STATIONS

The larger dashed-line block at the center of the diagram outlines the console-component functions. At the left of diagram, you will note the various control-room and studio accessories that include an announce microphone, two turntables, a tape recorder, and three studio microphones. Remote input and network lines are shown on the left side and legend of diagram symbols is shown on the right.

Facilities are provided for three studio microphones. The top three input switches of the console select either the control-room accessories or the studio microphone, and a fourth switch permits a choice between remote and network lines. A jack is provided for inserting a phone into the network line to monitor its signal. Remote input lines are shown at the bottom left.

Preamplifier and mixer gain controls are associated with each of the four console inputs. The two-channel amplifier system includes an audition booster and monitor amplifier plus a program booster and line amplifier. A switching arrangement between the preamplifier system and the dual-channel amplifiers permits either single or mixed incoming signals to be fed to one or the other of the two channels.

An example of possible switching is in relation to the control-room equipment. At the conclusion of a record on turntable No. 1, a changeover from this turntable to the control-room announce microphone may be desired. To do so, the switch of turntable No. 1 is set to the neutral position, and the control-room Announce switch is set to position *P* to supply voice signal into the program amplifier. At the conclusion of the announcement, the control-room Announce switch is set to its neutral position. Turntable No. 2 may then be switched to the *P* position, supplying a record signal to the program amplifier.

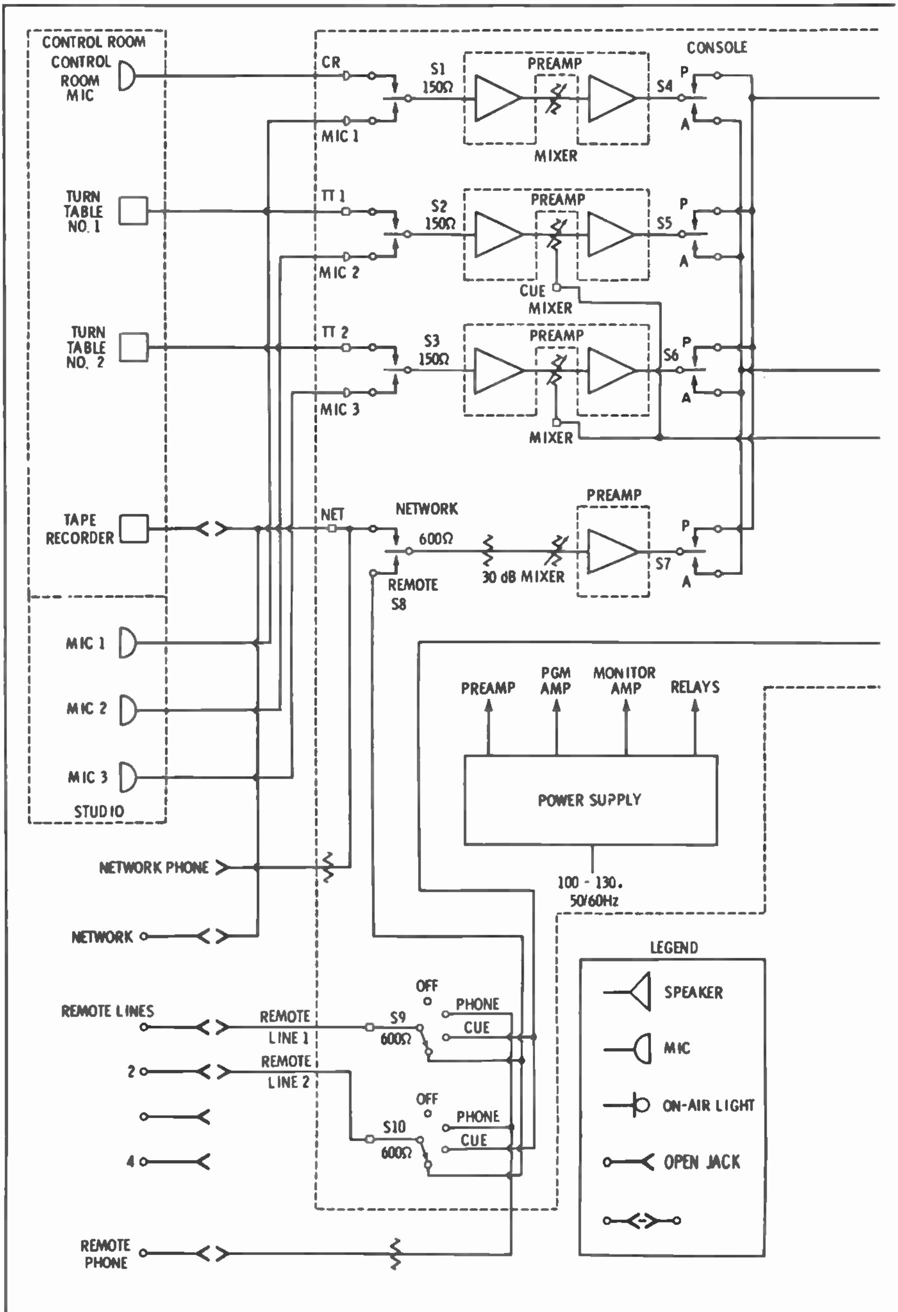
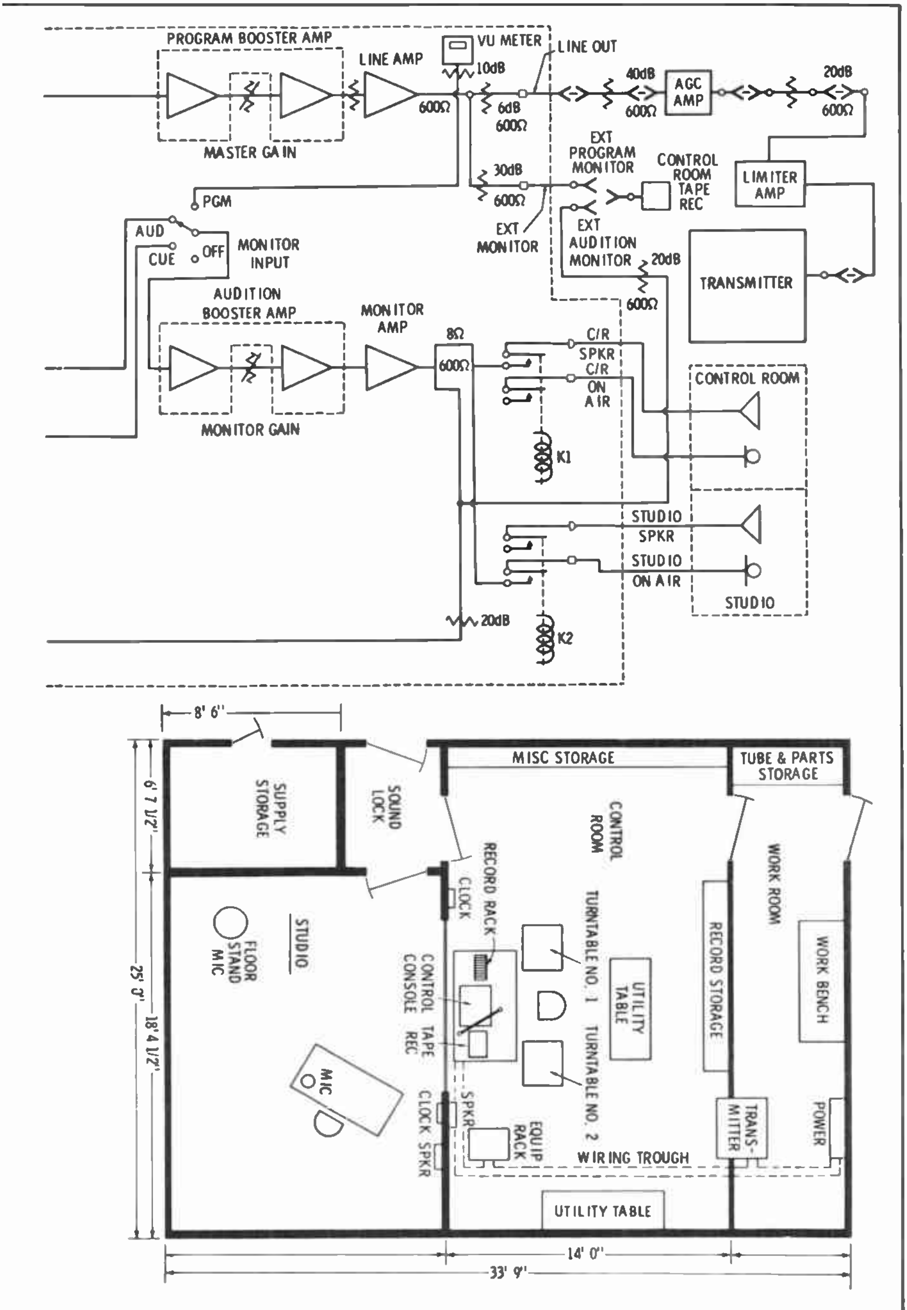


Fig. 6-1. Functional diagram



of a small a-m station.

While the transcription on turntable No. 2 is being played, it is possible to prepare turntable No. 1 for the next selection—perhaps for a recorded spot announcement. The announcement is made ready by using the cue- or audition-booster amplifier. The second channel switch, associated with turntable No. 1, is set to position *A*. The signal from turntable No. 1 is now being supplied to the audition-booster amplifier, and will reach the control-room speaker when the audition-amplifier input switch is set to the AUD position. In other words, the transcription on turntable No. 2 is supplying signal to the program line and transmitter while the control-room operator is setting up the recorded commercial to be played next on turntable No. 1. When the selection on turntable No. 2 is completed, it is switched off and No. 1 is switched to position *P*, supplying the commercial announcement to the program-amplifier input.

Also, remote or network signals coming into the console can be switched either into the program line when the signals are to be transmitted, or into the audition channel when they are to be checked or cued. The two switches associated with the remote lines have four positions. The remote-line inputs can be switched for communications (phone), for cuing, to supply signal to the program channel, and also to OFF.

The four preamplifier-mixer controls make it possible to establish the proper relative levels for signals that may be supplied at the same time to either the program and/or the audition channels. For example, it may be necessary to use microphones 1 and 2 in the studio simultaneously during a live program. The input switches to the preamplifiers are set to the microphone No. 1 and No. 2 positions. Likewise, both preamplifier output switches are set to their *P* positions. Both microphone signals are now being supplied to the input of the program amplifier and have the correct relative signal level.

A monitor speaker in the studio carries the program material except when it is originating "live" from the studio itself. The control-room speaker also carries the program material except when the control room is used for auditions. The studio ON THE AIR light goes on whenever a program is being broadcast from the studio. Likewise, the control-room ON THE AIR light goes on whenever the control-room announce microphone is being used.

The output of the program amplifier supplies signal to a VU meter mounted on the control console. The control-room operator watches the meter to make certain the signal supplied to the line is at the proper level. The operation of the VU meter will be discussed in the following section.

The agc (automatic gain control) amplifier not only relieves the control-console operator from the tedious job of "riding the gain," but also provides a more constant-amplitude signal to the transmitter. As a result, a higher average modulation percentage can be sustained and hence a higher average power output from the transmitter. This is important in obtaining the most reliable coverage over the widest area.

The limiter amplifier prevents the transmitter from being overmodulated by modulation peaks. By so doing, this amplifier also helps main-

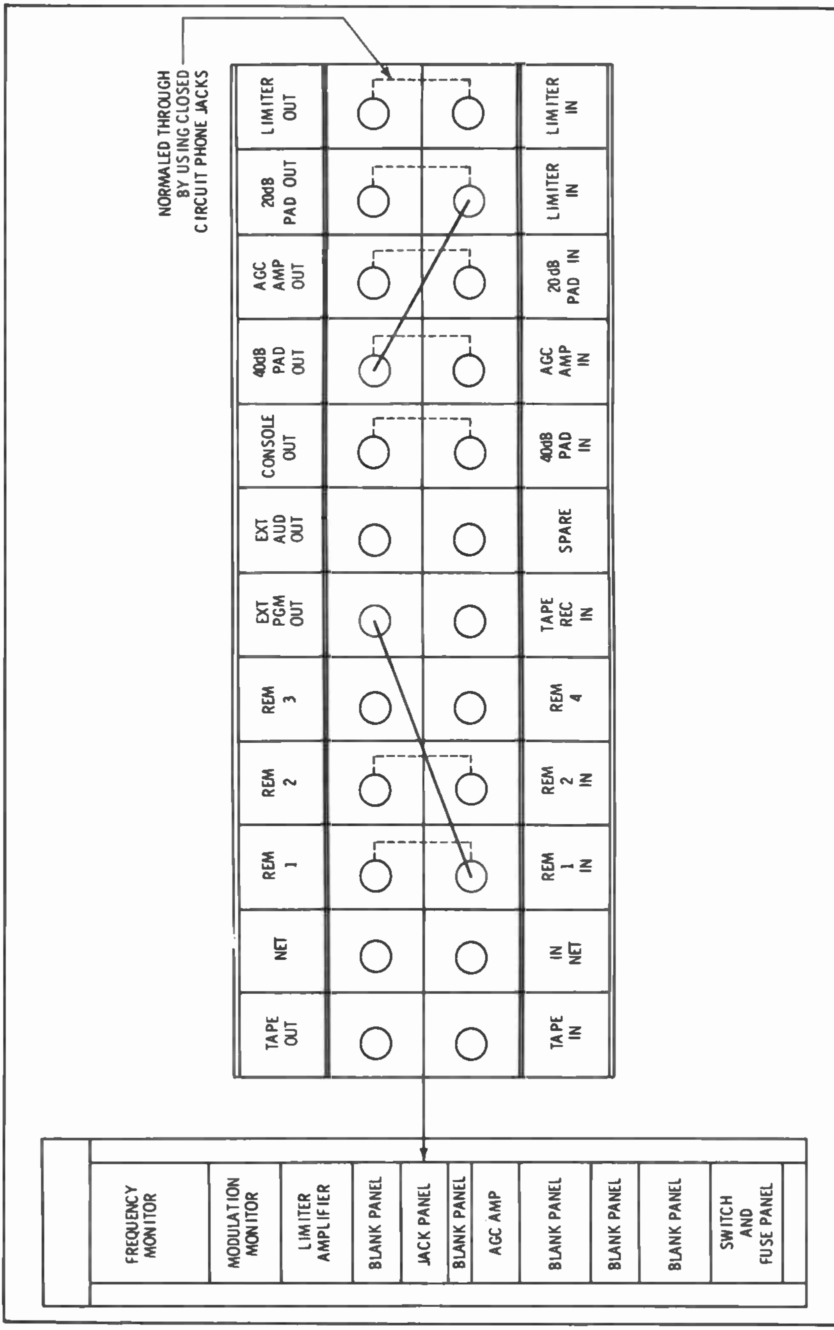


Fig. 6-2. Jack panel and equipment rack arrangements.

tain a higher-average modulation percentage and thus a wider and more reliable coverage.

As shown in Fig. 6-2, the agc amplifier and modulation limiter are mounted in the equipment rack at small stations. When the studio and transmitter are separated, the limiter amplifier is generally part of the transmitter, and the agc amplifier is mounted in the control room. The agc amplifier is discussed later in this chapter, and the limiter amplifier is explained in the chapter on transmitters. A transmitter installation must, by FCC regulations, include a modulation monitor and a frequency monitor. In the small stations these two monitors are mounted in the equipment rack or at the transmitter if it is separate from the studio. These two monitors are discussed in the chapter on monitor equipment.

Notice the jack panel (Fig. 6-2) associated with the equipment rack. Some of the jacks are "normaled through." For example, note that connections have been established between the remote lines No. 1 and No. 2 and their amplifier inputs. The jack (not normaled through) uses open-circuit phone jacks. Patch cords can be used to switch between the various terminations and inputs brought to the jack panel. Let us take two examples of the use of the jack-panel and patch-cord arrangement. Notice that REM 1 and REM 1 IN as well as REM 2 and REM 2 IN are "normaled through," so that connections have already been established between remote lines 1 and 2 and their inputs. Therefore, no patch cord is needed in establishing the connections between these points.

Notice, however, that there is no normaled-through connection between REM 3 and REM 4—the incoming lines terminate at these two jacks. Suppose that REM line 3 must be connected to REM 1 IN of the console. To do so, one end of a patch cord is inserted into REM 1 IN, breaking the connection with REM line 1, and the other end of the patch cord is plugged into REM 3. Incoming REM line 3 is now connected to REM 1 IN of the control console.

A jack-panel and patch-cord arrangement gives added versatility to a station and permits "patch-around" operation in case some unit of the station breaks down. For example, if the agc amplifier failed, it would be possible to bypass it by inserting one end of the patch cord into the 40-dB PAD OUT jack and the other end into the LIMITER IN jack.

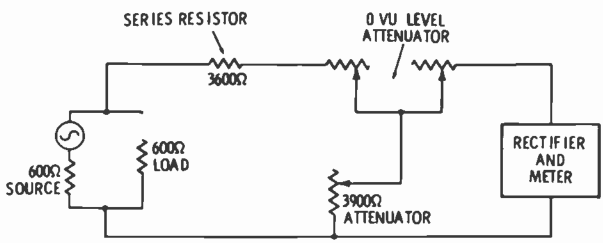
6-2. VU METER

The VU meter, which is standard equipment for broadcast use, is designed to follow average speech levels realistically with relation to human hearing. It is underdamped so that the pointer will pause momentarily in its upward swing. It then starts downward more slowly. Erratic vibrations and jumps are thus eliminated, making it possible for the operator to obtain a better "picture" of the audio waves at all times.

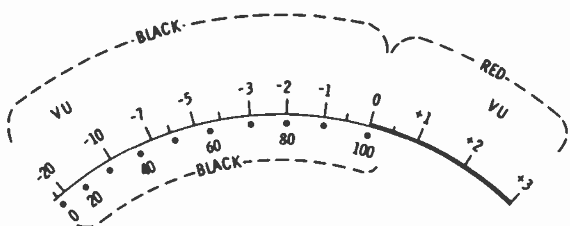
The meter is calibrated in volume units (VU), corresponding to the number of decibels above a standard reference level of 1 milliwatt across 600 ohms. The 600-ohm value was chosen because it is the standard impedance of remote and network lines. Likewise, 600-ohm lines are generally used for feeding between the various sections of the station—for example, from the output of the program amplifier to the input of the agc amplifier, to the input of the limiter amplifiers, and to the input of the transmitter. Notice, too, that the signal to the VU meter at the program-amplifier output is supplied from a 600-ohm audio line.

The VU meter employs a dc movement and a full-wave copper-oxide rectifier. The meter reads the approximate rms value of an applied waveform. Usually an isolation pad and attenuator are inserted between the line and meter for proper calibration and to prevent the meter from overloading the line. The plan given in Fig. 6-3 is standard. The meter is across a 600-ohm signal source in parallel with the 600-ohm load representing the termination of the line. The combination of the series resistor and attenuator provides a parallel impedance of 7500 ohms. The function of the attenuator is to calibrate the meter to read zero when the correct-amplitude signal level is present on the line. For example, with the component values shown, it is possible to calibrate the VU meter so that its zero reading corresponds to the standard signal level of +4 dBm on a phone line. With suitable resistor pads and attenuators, it is possible to calibrate the meter to read zero VU on other standard signal levels as well. A calibrated meter allows the radio operator to maintain a more constant signal level with only an occasional peak swinging over the zero reading. At the same time, the operator can equalize the levels of the various signal sources so that the average sound levels supplied to the line will be adequate and balanced.

The "zero VU" level is normally set so that a zero VU reading corresponds to 1 milliwatt across 600 ohms, and the plus and minus VU calibrations correspond to the dB levels above and below this standard.



(A) Circuit.

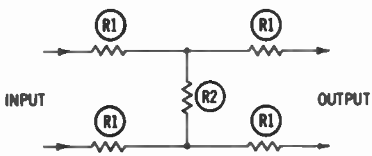


(B) Scale.

Fig. 6-3. VU metering circuit and scale.

6-3. ISOLATION PADS AND ATTENUATORS

Television and radio-broadcast signals must be maintained high enough to exceed the background noise level. However, too high a signal level will introduce cross modulation into other lines and into weak-signal circuits. Since most broadcast-amplifier outputs exceed these safe levels, attenuator pads must be used to reduce the signal strength. By maintaining a high degree of isolation between units and by providing good matching characteristics, these pads prevent frequency-response deterioration and cross talk.



VALUES TO MATCH 600Ω TO 600Ω		
ATTENUATION dB	R1 OHMS	R2 OHMS
1	17.3	5200
3	51	1700
6	100	803
10	156	422
12	180	322
20	245	121
30	282	38
40	294	12

Fig. 6-4. H-pad and sample chart.

A common form of fixed attenuator is the H-pad in Fig. 6-4. The resistor values given in the sample chart are for H-pads that match a 600-ohm input impedance to the same output impedance and provide the dB attenuation indicated on the chart of Fig. 6-4.

Variable attenuators are also used in the broadcast service. A typical example of a variable-T attenuator is shown in Fig. 6-5. As the arm on R1 moves to the right, the arm on R2 moves to the left, and the one on R3 moves toward ground. In the extreme right-hand position of R1, maximum resistance is inserted in series with the line and minimum resistance in shunt. This setting provides maximum attenuation. At the other extreme setting of R1, the series resistance is minimum, and the

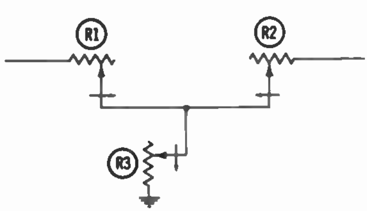


Fig. 6-5. Variable-T attenuator.

shunt resistance is maximum. However, at any attenuator setting the impedances inserted across the input and output to the attenuator remain the same. Hence, the proper impedance match is maintained at all times.

6-4. LINE EQUALIZER

In the broadcast services the better-grade lines rented from telephone companies are already equalized up to specific high-frequency limits. Occasionally it is necessary to use an inferior line, and some form of equalizer will be needed to provide a more uniform frequency response up to the desired high-frequency limit. An adjustable line equalizer like the one in Fig. 6-6 can be used. It consists of a parallel-resonant circuit and a series resistance. The lower the resistance, the greater is the compensation. A high resistance lowers the Q of the resonant circuit, reducing the high-frequency emphasis. Switch resistors, instead of the variable resistors R, are often employed which increase the emphasis in 3-dB steps, as shown in the chart.

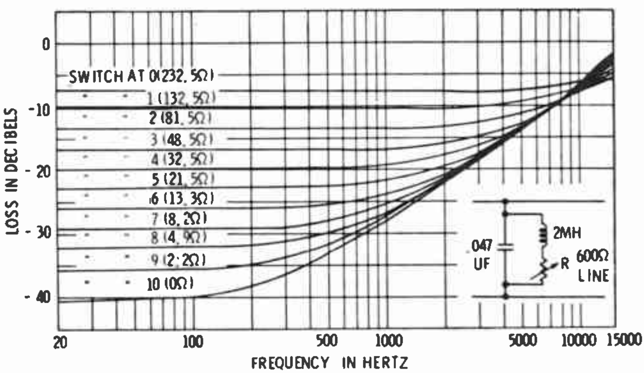
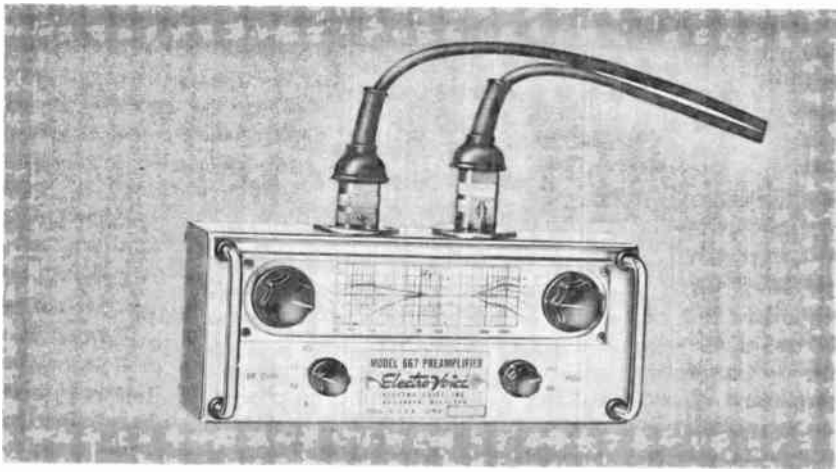


Fig. 6-6. Circuits and characteristics of a line equalizer.

6-5. MICROPHONE PREAMPLIFIER

When extra long microphone cables are employed or special frequency-response characteristics must be established, it is advisable to use a microphone preamplifier. The preamplifier is also useful when the microphone is weak or its line picks up excessive noise. The preamplifier in Fig. 6-7 consists of a two-stage transistor amplifier with frequency-compensating networks inserted between the last transistor stage and the audio-output transformer. The amplifier has a uniform frequency response between 20 and 40,000 hertz. The overall gain is adjustable in steps. The input impedance matches a 50-ohm dynamic microphone, and the output impedances are the standard values. The bass and treble switches permit selection of various degrees of emphasis or attenuation at the low- and high-frequency ends as in Fig. 6-8. Typical rolloff values are +6 dB +2 dB, flat, −5 dB and −9 dB at 100 hertz; and +9 dB, +6 dB, +3 dB, flat, and −6 dB at 10,000 hertz.



Courtesy Electro-Voice, Inc.

Fig. 6-7. Electro-Voice transistor microphone preamplifier.

When such a preamplifier is used for a remote pickup, it is also possible to compensate for high-frequency deficiencies in the remote phone line to the studio.

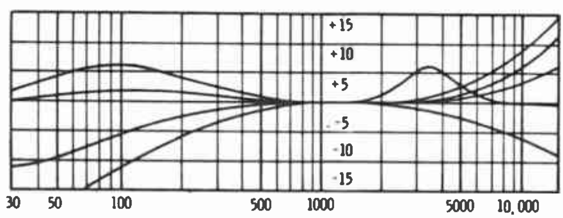
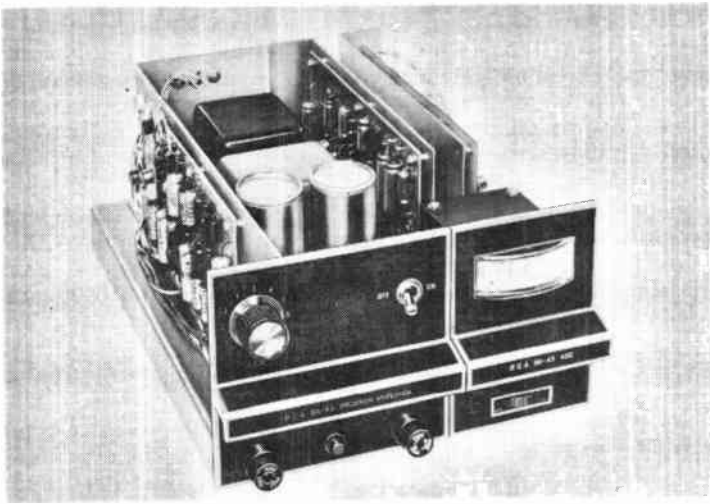


Fig. 6-8. Variable response characteristics of a preamplifier.

6-6. AGC PROGRAM AMPLIFIER

An agc program amplifier, Fig. 6-9, builds up the level of the program signal, processing it for application to the audio lines that deliver the information to the transmitter. The agc action maintains the average output of the program signal at a nearly constant level despite possible wide variations in input levels. It provides expansion of low-level signals and compression of high-level signals. This is an aid when switching among various sound sources of a broadcast station.

The unit is a solid-state model with a three-stage negative feedback preamplifier, followed by a variable gain-control circuit. The output amplifier is a five-transistor affair which drives a multi-impedance output transformer. This output is supplied to the automatic gain-control amplifier which is in the form of a solid-state module that plugs in on the right (Fig. 6-9).



Courtesy RCA Corp.

Fig. 6-9. Program amplifier and agc module.

The agc circuit, when operating under compression, has a fast attack and slow recovery characteristic, permitting it to compress fast, high-amplitude audio peaks. It does so without making gain regulation (gain pumping) and background swishing sounds audible.

The input/output agc characteristic is shown in Fig. 6-10. Note that for the first two curves from the left the compression begins when the

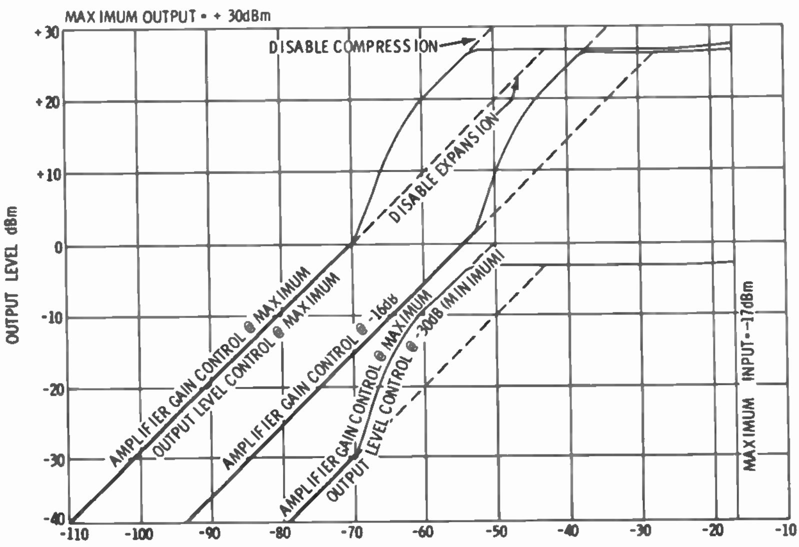


Fig. 6-10. Agc characteristics.

output level reaches 0 dBm. This is called the "threshold level." Up to this level the amplifier output increases linearly as the input increases.

Above the threshold level, however, the output can no longer keep up with the input. This ratio at which the two increase nonlinearly is called the "compression ratio." The two curves show the above conditions with the amplifier gain control set to maximum and also with the amplifier gain control set for −16 dB attenuation.

In the first two cases the output-level control, shown below the compression meter, was set at maximum. The third curve shows the characteristic when the output-level control is set to its minimum position of −30 dB. Compression now begins when the output level reaches −30 dBm and the input signal level is −70 dBm.

6-7. LARGER STATION FACILITIES

In general the larger station employs the same pieces of equipment as a smaller one, only more of them. Switching facilities are more elaborate at the control consoles because of the increased number of signal sources. There may be various types of automatic players, additional recording facilities, and sound-effects gear.

In the plans of Fig. 6-11 and Fig. 3-4 there are separate control rooms for the a-m and fm programming. There is a third production control room that can be used for prerecording and taping. This control room may also double as an auxiliary control point for either a-m or fm programming.

Each consolette has a variety of controllable input facilities for microphones, tape players, turntables, network and remote lines, plus spare inputs. Voice signals from the announce booth also terminate at the a-m and fm control consolettes.

The fm control consolette is designed for stereo transmission and has the required separate left and right channels. The switching facility permits either stereo or monaural operation. The a-m facility is strictly monaural. Additional outputs are provided for audition or other external monitoring. Each consolette supplies audio to individual control-room, studio, and announce-booth loudspeakers.

Consolette program signals are supplied to an agc/limiter amplifier. The RCA program amplifier can be operated with either an agc output module, limiter module (Fig. 6-12), or a combination of both. The plan of Fig. 6-11 uses three separate program amplifiers with both agc and limiter modules. One of these is used in the path between the a-m control consolette and the a-m transmitter. The other two are in the paths of the left and right stereo signals supplied to the fm transmitter.

The functions of a limiter amplifier are to provide abrupt limiting action in the program channels of broadcast transmitters. Such limiters provide an automatic means of holding audio signal peaks at a certain preset level. In so doing overmodulation and overloading of the transmitter are avoided. This process reduces distortion and prevents adjacent channel interference.

In addition, by raising the average modulation percentage several decibels, the transmitter power can be used more effectively. As a re-

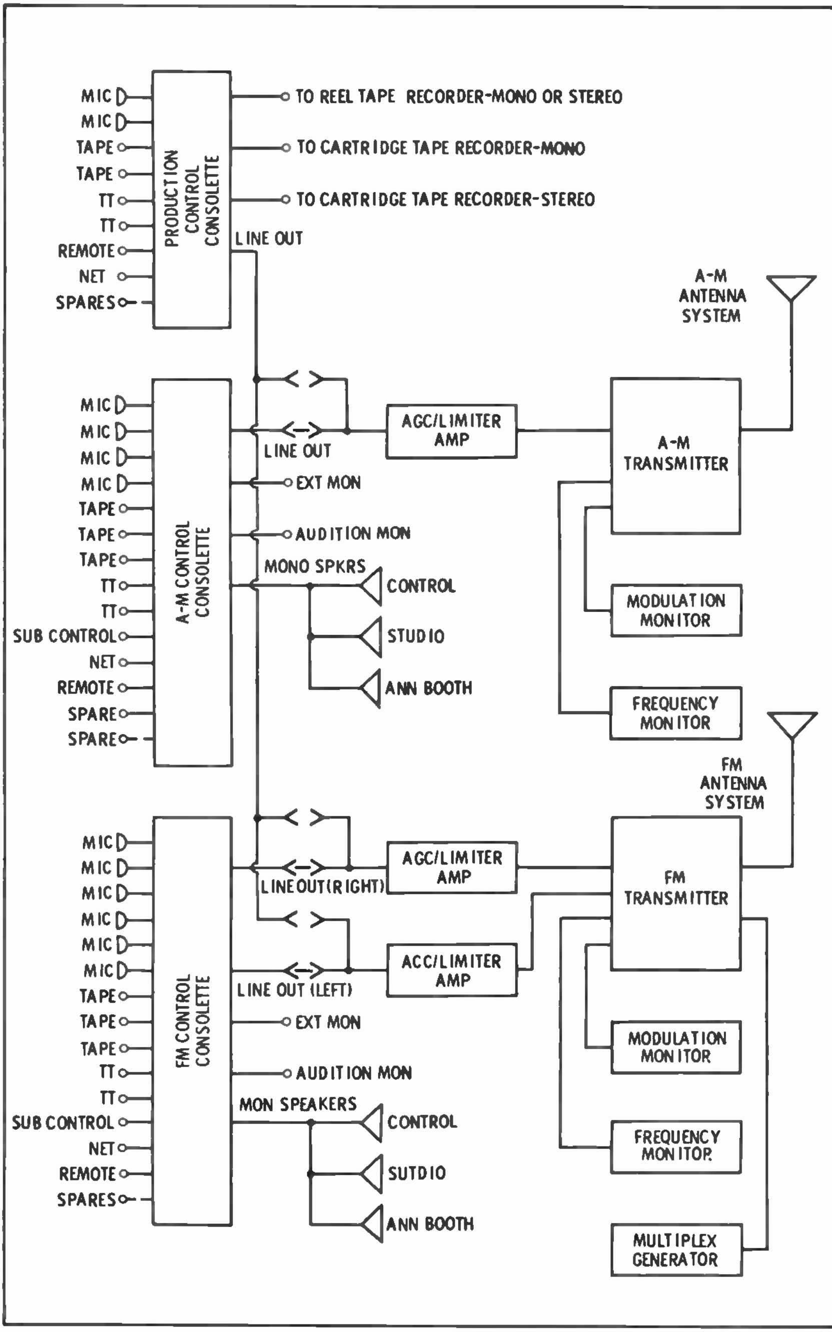
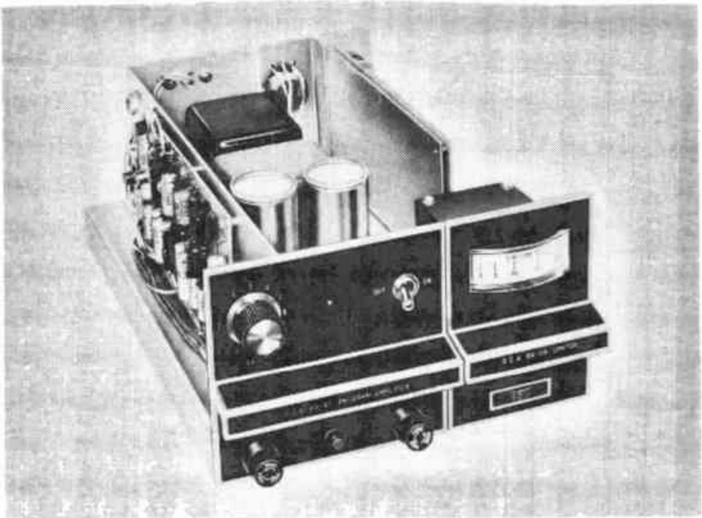


Fig. 6-11. Facilities of a larger station.



Courtesy RCA Corp.

Fig. 6-12. Program amplifier with limiter.

sult overmodulation is avoided on heavy passages of speech or music; at the same time, there is an improvement in signal-to-noise ratio for medium- and low-level audio signals.

Fig. 6-11 also shows the place of the transmitter in the overall broadcast plant. As mentioned previously the transmitters can be located at the same site as the studio or signals can be carried over common carrier lines to a remote transmitter site. Associated with the a-m transmitter are the FCC required modulation and frequency monitors. Similar monitors are required for the fm transmitter. If the station transmits stereo programs or SCA signals the fm transmitter requires a multiplex generator. Transmitters and their associated test equipments are discussed in succeeding chapters.

CHAPTER 7

Remote Facilities

In order to originate programs at locations other than the studio, a-m, fm, and television broadcast stations must have remote facilities. In such a broadcast, the terminal facilities are provided by the station and the transmission facilities may be provided by the station or the telephone company.

7-1. THE REMOTE BROADCAST

The most common method of handling a remote is to transmit the program over a pair of rented telephone lines. One line carries the program, and the second line is used for cuing and for communicating back to the studio. In case of trouble on the program line, the spare line could carry the program sound. If only a single line were used, there would be no direct link between remote and studio once the program is on the air. Also, if something happened to the line, the program would go off the air.

The telephone company must, of course, be notified as to when the program is to be aired and also when to install the lines in time for tests or rehearsals. It is advisable to begin setting up the equipment and checking the lines as early as possible. On occasion it may even be a problem to find the lines, although the telephone company tries to bring them as near the source of the program as possible. Many remotes are strictly "one-shot" affairs, and the lines are installed in a manner that will permit quick removal. When remotes are held at the same location and at regular intervals, more permanent lines are usually installed.

Many radio stations have remote broadcast trucks equipped with an amplifier, turntables, tape recorders, and other facilities. These trucks often broadcast from local athletic events, parades, or shopping centers. Usually the program is conveyed to the studio over telephone lines.

For some on-the-spot remote broadcasts such as on-the-street interviews or at political conventions, small pack-transmitters are often used. The program material is sent to a remote broadcast center a short distance away. From there it is relayed over telephone lines to the studio.

A third type of remote is the prerecorded pickup, usually taped. Because of its versatility it has become more and more popular, especially with small broadcast stations. Moving around is no problem, since there are no trailing wires or cumbersome equipment to handle. All the interviewer carries is a microphone and a good-quality tape recorder. Another advantage is that the tape can be edited to provide continuity to the recorded program. For example, in covering a parade there often are delays between marching units, and it is difficult to keep up an interesting running commentary.

7-2. CHECKING OUT THE REMOTE

As mentioned previously, it is advisable to set up remote equipment early and to check it thoroughly. As you learned, the studio control-room console has the necessary equipment for auditioning the remote lines. In this way, the microphones and other sound sources at the remote can be checked to make certain their signals are at the proper level.

When a musical program is to be broadcast from a remote, it is always helpful to set up the line and equipment in time to rehearse the entire program, or at least its musical segments.

If the noise level on the line is high while the microphones are open, their cable connections and routing should be checked. Occasionally, fluorescent-lighting fixtures will introduce an arcing noise into the line. Also, electrical equipment which radiates strong fields can feed hum into microphone cables. This trouble is no longer as prevalent as it was in the early days of broadcasting, when unbalanced lines and equipment were more common.

Noise on the line while the microphone circuits are closed can mean trouble in the remote amplifier or a high noise level on the phone line. If the latter happens, the phone company should be notified immediately.

Just prior to broadcasting time, the system should be checked once more and communications established with the studio control-room, at which time all watches are synchronized and the cue signals reaffirmed.

Microphone placement is often a problem during remotes. Because of the higher background noise, microphones must be placed as near the sound source as possible, and a unidirectional microphone is almost a necessity. Two microphones can be used—one for announcements and solos, and the other for general pickup—provided the second microphone does not pick up too much background noise to interfere with the first microphone.

7-3. REMOTE AMPLIFIER

Many broadcast components are now transistorized. The remote amplifier of Figs. 7-1 and 7-2 is an example. This unit weighs ten pounds, including the battery pack. Three microphone channels as well as inputs for a high-level tape reproducer and a phono player are

Courtesy Gates Radio Co.

Fig. 7-1. Remote amplifier.

available. It also includes a tone oscillator that is useful in setting levels and checking out the remote lines to the studio.

The three preamplifiers and their individual gain controls are followed by an audio amplifier and an audio power amplifier. A master-gain control is associated with the audio amplifier. The power amplifier supplies signal to the audio line and a monitoring headset. A VU meter is associated with the power amplifier. Audio for a public address

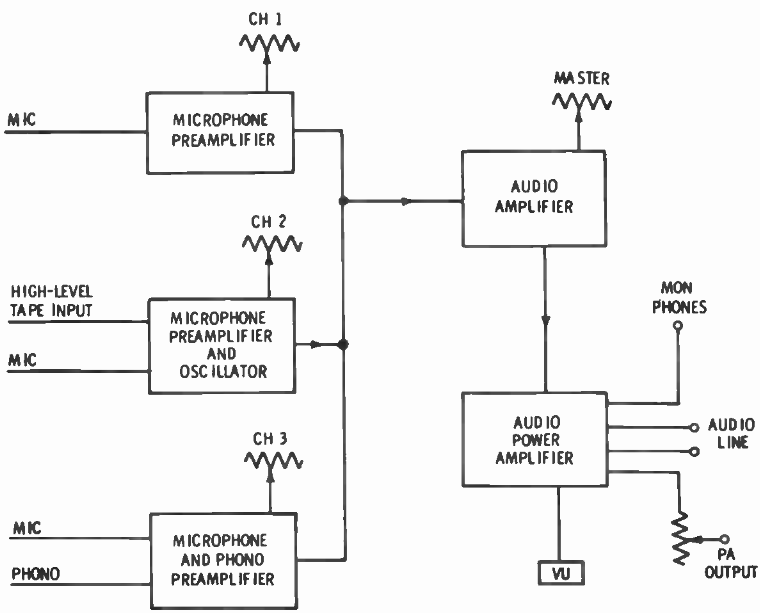


Fig. 7-2. Functional plan of a remote amplifier.

system can also be made available via an individual gain control and output terminals.

The three preamplifiers are quite similar. Each preamplifier consists of two common-emitter stages (Fig. 7-3). Referring to the Channel 1 preamplifier (which is the basic circuit used in all stages except the power amplifier stage) resistors R1 and R2 provide base-divider bias. Resistors R4 and R5 plus capacitor C3 provide emitter stabilization. Thus the operating-point bias is held essentially constant with circuit and temperature variations. Both dc and ac stabilization is used. Notice that the emitter resistors R4 and R9 are not bypassed. Consequently, there is a limited amount of ac degeneration and an improvement in the ac stability and linearity.

The two stages are direct coupled, and there is no need for an interstage RC coupling combination, which could introduce low-frequency degeneration and other disturbances. Overall negative feedback for the input amplifier is provided by capacitor C4 and resistor R7 connected between the collector of the second stage and the emitter of the first stage. The generous use of feedback provides a high order of gain stability and permits linear operation with large input signal levels. Thus transistor-parameter variations have a minimum influence on the operation of the preamplifier. The preamplifier is thoroughly decoupled by the RC filters (C2, R6, C5, R11).

The Channel 1 preamplifier output is removed at the Channel 1 gain control and is supplied, via the isolation resistor R30, to the input of the audio amplifier. This audio amplifier is identical in basic design to the preamplifier. The same feedback arrangements are used to insure high operating stability. The audio-amplifier output is removed at the master-gain control and supplied to the audio-power amplifier.

The other two preamplifiers are modified versions of the first-channel preamplifier. The Channel 2 preamplifier includes a high-level input. Resistors R13, R14, and R15 provide the necessary attenuation of the high-level signal and an appropriate match into the input of the preamplier. With the microphone-oscillator switch in the microphone position, negative feedback exists between the collector of the second stage and the emitter of the first stage, just as in the basic Channel 1 preamplifier. However, when this switch is set to the oscillator position, there is feedback between the collector of the second stage and the base of the first stage. Rather, there is positive feedback to the input base, and the two stages go into oscillation at approximately 400 hertz. A square wave is generated, and therefore the oscillator signal output is rich in harmonics, providing a good distinctive test signal for transmission over the remote line to the main studio.

The third preamplifier channel is identical to Channel 1 with the exception that proper RIAA compensation is provided for a phono signal. A component (R17) is added to the input of the amplifier to provide the correct termination for a magnetic phono cartridge and the necessary high-frequency RIAA equalization. The low-frequency end of the RIAA curve is handled by the feedback network. Notice that the components of the feedback network change when the switch is thrown from the MIC to the MAG PHONO position. The network

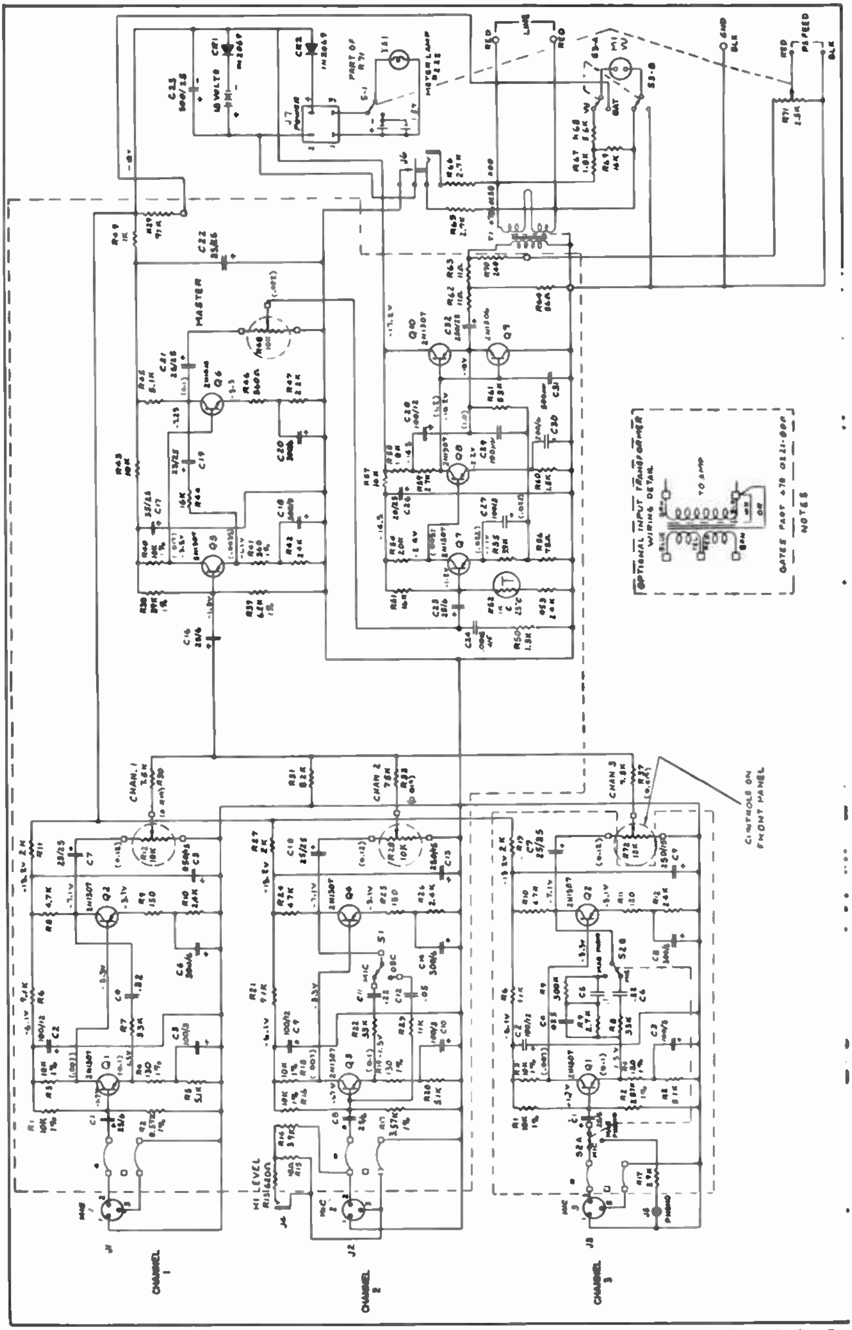


Fig. 7-3. All-transistor remote amplifier.

Courtesy Gates Radio Co.

of capacitors C4 and C5 plus resistors R7 and R9 provide low-frequency boost for RIAA equalization.

The power amplifier is a three-stage, direct-coupled circuit, two voltage amplifiers (Q7, Q8) and a push-pull complementary output stage (Q9, Q10). The last stage operates as single-ended emitter-follower in class-B. Therefore, maximum-power output can be obtained with a minimum battery drain because the output-stage currents vary with the strength of the audio signals. When no signal is passing through the amplifier, the stages draw very little current, and the battery drain is reduced. Likewise, for lower amplitude passages, they draw less current than for the strong peaks of the program signal.

The bases of the push-pull stage (Q9, Q10) are supplied with an in-phase signal from Q8. Since Q10 is a pnp transistor while Q9 is an npn transistor, the output current of one transistor rises while the output current of the other falls during each half-cycle of signal. However, since the emitter currents are in opposite directions, an effective push-pull output signal is developed across the primary of the output transformer (T1) which supplies the signal to the telephone lines. Signal is also supplied to the phone jack J6 through isolation resistors R65 and R66. Likewise, an output is derived for operation of the VU meter. Resistors R67, R68, and R69 have values that calibrate the VU meter for a standard signal level and impedance. The values shown are for a zero VU reading that corresponds to +8 dBm across 600 ohms, a standard level of signal for application to a remote telephone line. A 6-dB isolation pad is provided on the primary side of transformer T1 by resistors R62, R63, and R64.

The three-stage power amplifier also includes negative feedback from the emitter of the output stage to the emitter of the input stage via capacitor C29 and resistors R56 and R61. In fact, the dc operating-point stability of the entire amplifier is aided by this feedback path. Note that the emitter current for the push-pull output stage is also present in the emitter resistor (R56) of the input stage. The input-stage (Q7) dc operating bias and, in turn, the dc bias of the following dc coupled stages is held constant with the use of a thermistor (R52) in its base circuit. This thermistor compensates automatically for any change in the conductance of the Q7 base-emitter junction. This activity is also linked to changes in the two succeeding stages because the current through R56 is, in part, contributed by the latter two stages.

To improve the linearity of the amplifier in the handling of a very strong signal, some positive feedback is employed from the emitters of Q9 and Q19 through capacitor C28 to the collector of Q8. This is often referred to as a positive-feedback *bootstrap connection*. What it does is increase the effective collector voltage of Q8 in accordance with the amplified signal. Thus, as the amplifier signal voltage rises, the positive feedback to the collector of Q8 aids the linear rise of its collector-output voltage. As a result, adequate linear drive to the output stage is maintained when a high-amplitude signal passes through the remote amplifier.

A 1.5-volt battery and connector (J7) for an external 18-volt (dc) power supply is shown at the top right. It is to be noted that the common return (+18v) for all the stages of the remote amplifier is via the phone jack (J6). Power is supplied to the various stages only when a headset or dummy jack is plugged into J6. As soon as such a plug is removed, the power is disconnected from the unit. The lamp (XA1) will light only when the power-supply mating connector is plugged into the remote amplifier. The mating connector (P7) has a jumper between pins 1 and 3.

CHAPTER 8

A-M Broadcast Transmitters

8-1. MAJOR UNITS

The modern low-power a-m transmitter is a compact and integrated unit with a high order of stability and reliability. In many small stations, the transmitter receives a minimum of attention because it is just another unit in a busy control room. Where it is to be remote-controlled, the stability requirements are even more exacting.

Basic designs do not differ greatly among manufacturers. The RCA transmitter in Fig. 8-1 is a good example. No more than 10 to 14 tubes, all air-cooled, are used throughout. Modern broadcast transmitters exceed the FCC requirements for frequency response, frequency stability, carrier shift, distortion, and noise level.

Fig. 8-2A shows the interconnection plan for the major units of a typical transmitter installation with a remote studio.

In almost all a-m broadcasting, the program signals from the studio are sent over telephone lines to the transmitter. A minimum of two program lines should be installed, to allow a spare in case of trouble in the other line.

The incoming signal is normally supplied to a booster or line amplifier first, instead of directly to the limiter amplifier. It is advisable to use a booster amplifier, because it can provide additional amplification in an emergency or if the incoming program signal is weak. In the patch panel of Fig. 8-2B, the booster amplifier is normaled-through to the input of the limiter amplifier.

The major function of the limiter amplifier is the compression of the modulation peaks so they will not overmodulate the transmitter. The output of the limiter amplifier feeds the audio-input stage of the transmitter.

According to FCC regulation, the frequency stability and modulation percentage of a transmitter must be monitored. Two monitoring units which are used for this purpose are shown at the bottom right of Fig. 8-2A.

A monitoring amplifier and speaker plus a versatile switching arrangement are part of most transmitters. These facilities permit the transmitter operator to check the program signal at various key locations throughout the transmitter equipment. In the example of Fig. 8-2A, it is possible for the operator to monitor the incoming program line from the phone company, the output of the limiter amplifier, the audio component derived from the modulation monitor, and an auxiliary monitoring input. Some stations use a remote demodulator, located in the antenna field or other point, to pick up some of the radiated rf energy. This rf signal is then demodulated to supply an audio component to the auxiliary-monitor input.

Fig. 8-1. A 1-kilowatt a-m transmitter.

Courtesy RCA Corp.

Most stations include a VU meter panel in the equipment rack. The meter input is terminated at the patch panel, and a patch cord is used to bridge the meter across key points in the program line. Hence, the monitoring facilities include provisions to listen to the program at key points, and a means of measuring the actual sound level as well.

It is very important that the transmitter operator know the general arrangement of his equipment. Once he does, the monitoring facilities will permit him to isolate a point of signal loss more rapidly. Thus, he can quickly find out whether the program signal is missing from the incoming line, or whether the booster or limiter amplifier is out of order. In many instances he could even "patch around" faulty equipment without having to take the station off the air. For example, it would be no problem to bypass the limiter amplifier by connecting a patch cord between the booster-amplifier output and transmitter input.

Usually the accessory equipment at the transmitter is conveniently mounted in an equipment rack beside the transmitter. A typical equipment rack is shown to the left of the transmitter in Fig. 8-3. From top to bottom are mounted the modulation monitor, limiter amplifier, and frequency monitor.

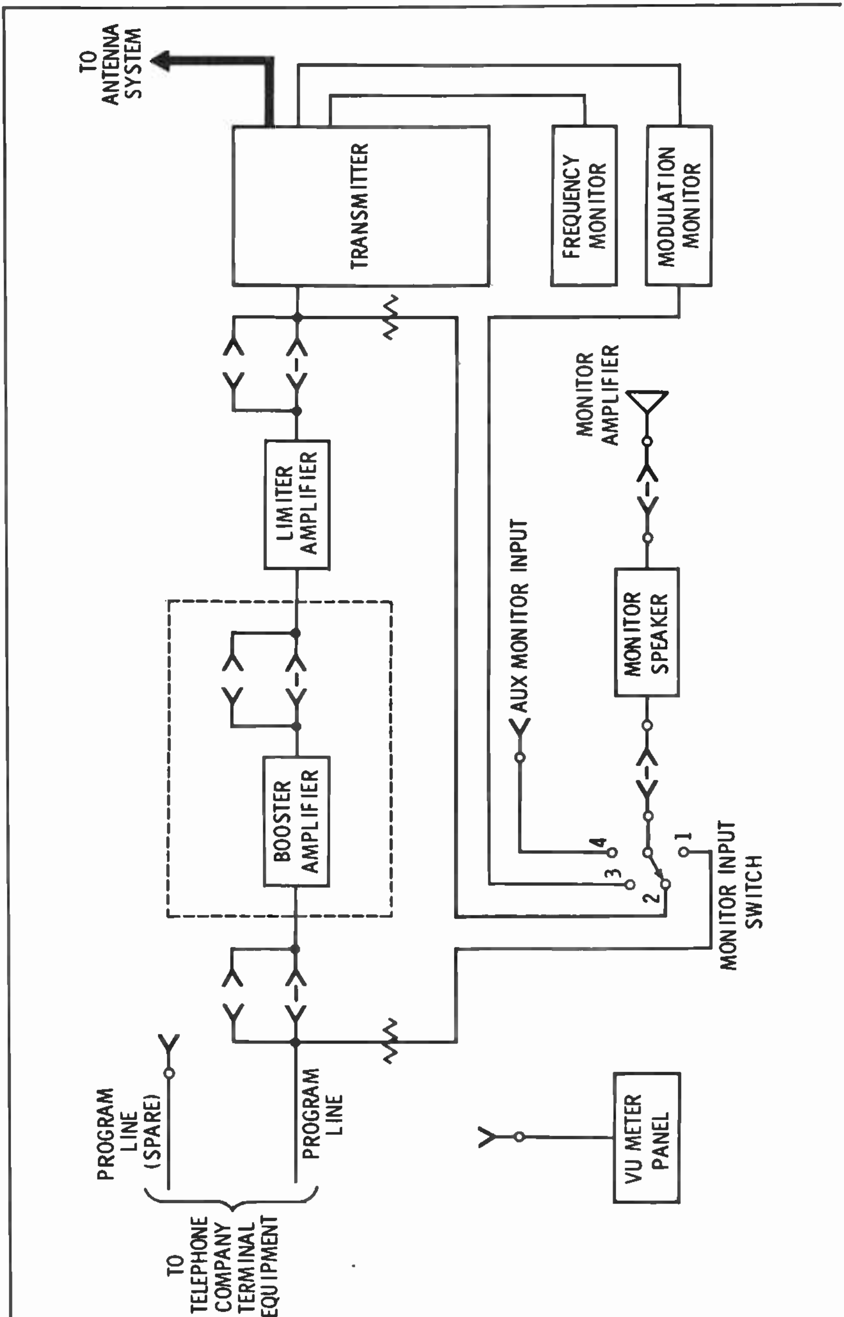
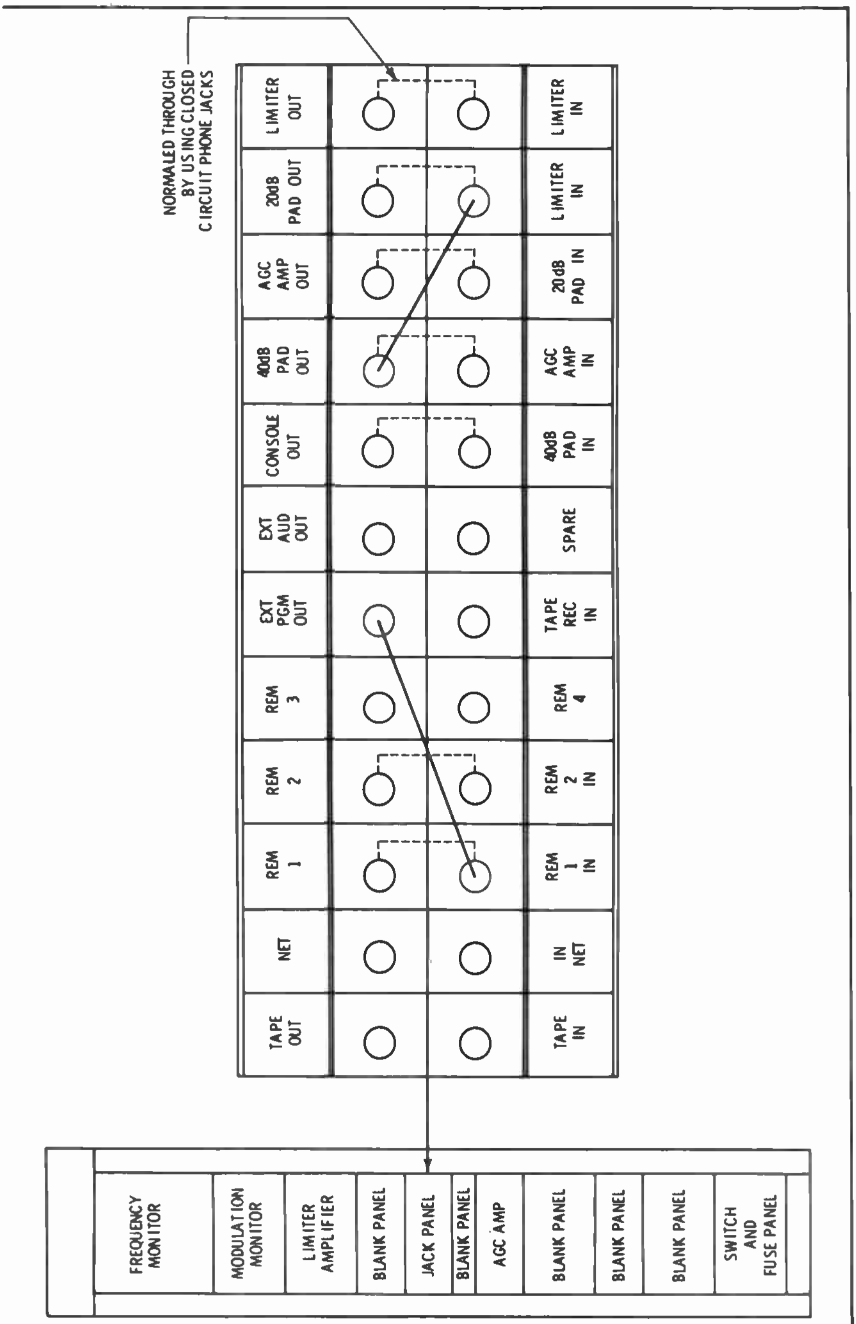


Fig. 8-2. An interconnection plan of the



major units in an RCA transmitter.

Fig. 8-3. A transmitter and associated equipment rack.

8-2. FUNCTIONAL PLAN OF TRANSMITTER

The functional diagram of an RCA transmitter is given in Fig. 8-4. The radio-frequency section starts with a highly stable crystal oscillator. Because of the high stability achieved by modern crystals and their mounts (seldom drifting more than a few cycles), many broadcast transmitters no longer include a crystal oven. However, in those that do (usually the old ones), it is customary to record the oven temperature when the half-hour log readings are taken.

The rf signal is built up by a following buffer and intermediate power amplifier. A single power-amplifier stage develops enough rf energy to drive the antenna system at the rated-power output. Most transmitters use a single-ended rf stage with one or more tubes in parallel as is done in Fig. 8-4, the number depending on the power output desired. A push-pull rf power-output stage is rarely used in modern a-m broadcast transmitters.

Plate modulation is almost universal for the small-station broadcast transmitter. It is even the dominant form of modulation for most higher-powered transmitters. The modulator stage is usually a push-

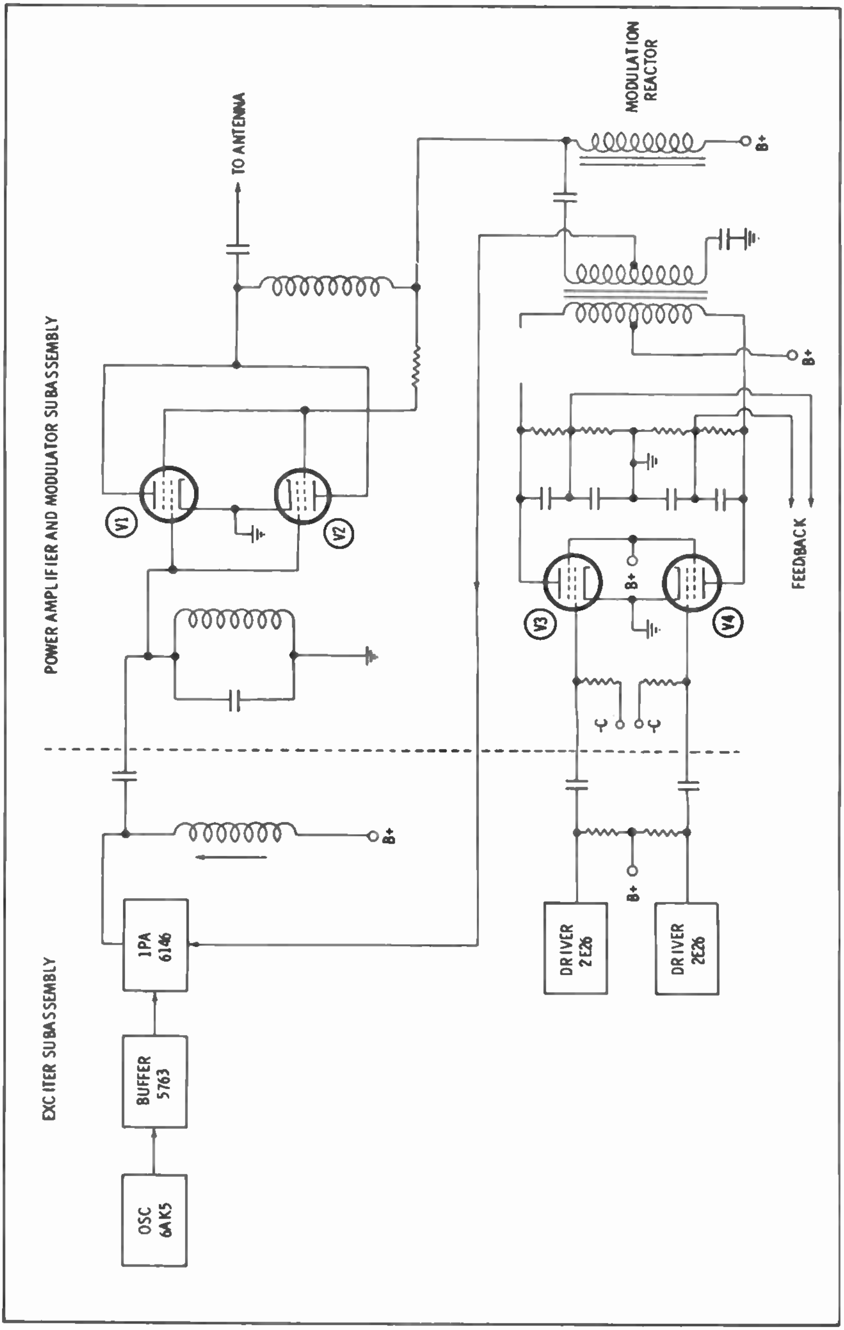
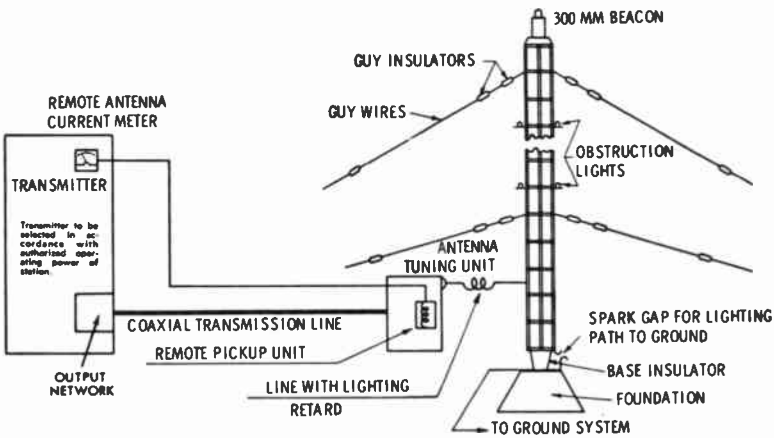


Fig. 8-4. Functional diagram of a typical a-m transmitter.

pull class-B or -AB stage. In the RCA transmitter the modulation reactor is separate from the output transformer. This makes it possible to design two small and highly efficient units capable of linear and full modulation of the final rf stage. In some transmitters a small amount of modulation is also supplied to an intermediate power-amplifier stage to improve both the linearity of the transmitter and its ability to handle the modulation peaks. Inverse feedback is used to extend the frequency response of the transmitter, to stabilize the characteristics of the audio amplifier and modulator, and to provide a well-regulated output.

8-3. MAJOR UNITS OF ANTENNA SYSTEMS

A variety of units are associated with the antenna system of the a-m broadcast station, as shown in Figs. 8-5 and 8-6. The modulated rf signal is usually conveyed over a coaxial transmission line to an antenna tuning box, the function of which is to tune the antenna to

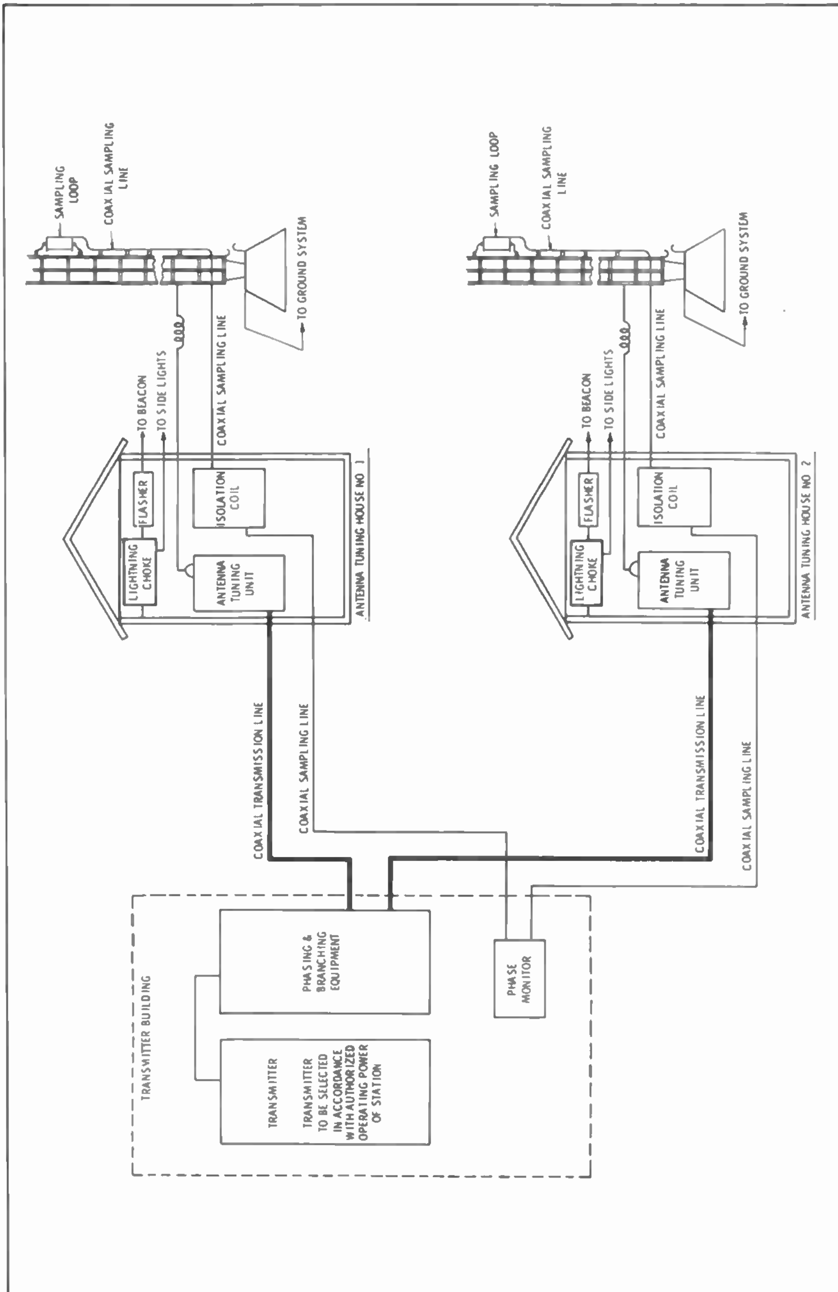


Courtesy RCA Corp.

Fig. 8-5. The major units of antenna systems.

proper resonance and match the transmission line to the antenna (see Fig. 8-5). Often a remote antenna-current meter is associated with the antenna tuning arrangement. Although the pickup device is part of the antenna-tuning unit, the recording meter is often mounted at the transmitter. This reading gives an excellent indication of the operating conditions of the transmission line and antenna system; it soon indicates any line and antenna-system defect or a decrease in the power output of the transmitter.

The antenna must have suitable lightning protection. Usually it is in the form of a spark gap and a retarding inductor. Also, the power line to the obstruction and beacon lights must be isolated properly in order not to disturb the radio-frequency characteristics of the antenna. These accessories must be protected from lightning damage as much as possible.



Courtesy RCA Corp.

Fig. 8-6. The major units of a directional antenna system.

Additional units are required for a directional-antenna system. The arrangement in Fig. 8-6 is typical. The directional-antenna pattern is obtained by proper spacing of the antenna towers and by correct phasing between the existing radio-frequency currents. Correct radio-frequency current relationships are established by a phasing unit generally mounted near the transmitter. These phased currents are conveyed on separate coaxial lines to the respective antenna towers and their associated tuning boxes.

A sampling loop, mounted on each radiator, picks up a small amount of rf current and, through its own line, supplies signal to a phase monitor in the transmitter building. The function of the phase monitor is to evaluate the incoming current components from the sampling loops, and to indicate whether correct relationships have been established at the antennas. The antenna boxes in Fig. 8-6 also show the chokes which isolate the lighting system from the radio-frequency energy, and also the unit that flashes the beacon light on and off in accordance with FCC requirements.

8-4. DUTIES OF TRANSMITTER OPERATORS

The primary responsibility of the transmitter operator is to monitor the transmitter and its associated equipment continuously. He should respond quickly to any indication that there might be loss of air time. If a specific failure takes the station off the air, he should restore service as soon as possible, even if he must do so at reduced power.

The operator must keep the transmitter log, making the necessary notations each half hour according to FCC regulations and station practice.

This logging procedure should guide the operator in anticipating possible sources of trouble. Significant drift or erratic meter readings should alert him to possible trouble and/or the need for immediate inspection and maintenance of a particular segment of the transmitter. If the inspection suggests that the station be taken off the air, he should try to keep the station operating until sign-off, or at least wait until a sustaining (noncommercial) program is being broadcast. However, any trouble serious enough to damage expensive components or violate FCC technical regulations must be corrected as soon as possible, even if it means taking the station off the air. Many stations, particularly the larger, higher-powered ones, have emergency transmitters and/or power supplies that can be pressed into operation in case of trouble in the main transmitter.

A good transmitter operator knows the transmitter and associated equipment down to the smallest detail. He knows the exact location of all stages of the transmitter and its key component parts, or studies instruction manuals and schematics thoroughly until he does. He also knows the wiring plans of the equipment so he can track down power-failure troubles quickly, and learns the switching and patch-panel arrangements so he can "patch-around" a faulty unit of broadcast equipment.

It is a good idea for the neophyte engineer to mentally visualize a course of action to follow in certain emergencies. The chief engineer or a capable, experienced operator can give excellent guidance on emergency procedures. It is customary in some stations to call conferences in order to keep all operators informed of possible malfunctions and the repair procedure. Such meetings can do much to build up the confidence of the inexperienced personnel by teaching them how to keep lost air time at a minimum.

In addition to log keeping, the transmitter operator must keep an eye on sound levels and "ride the gain." Modern broadcast equipment, with its agc amplifiers and modulation limiters, has made this task easier; and if the operator at the control console does a reasonably good job of riding the gain at his end, the transmitter operator may not even have to readjust the gain from sign-on to sign-off of the station.

The limiter and audio gain should both be adjusted to prevent sustained negative peaks that overmodulate the transmitter. For interview programs, "disc jockey" shows, and small musical groups, the average modulation percentage can be kept high to improve coverage. However, for high-fidelity programs such as concert bands and symphonic orchestras, the modulation should not be nearly as compressed. If low-amplitude passages are overamplified, and high-magnitude passages are compressed too extensively, the program will lose its dynamic range (amplitude separation between loudest and softest sounds) and hence much of its realism.

It is important to realize that the sound-level indication will differ at the transmitter and at the control room. The usual VU meter responds to the average level of sound, following peaks less readily, whereas the volume indicators in the limiter and other sections of the transmitter are usually more responsive. This is important because overmodulation is to be avoided at the transmitter. Sometimes it is a bone of contention between the operator at the transmitter and the studio personnel. Occasionally the transmitter operator thinks he is obtaining an inadequate level from the studio; and at other times, when strong peaks come through, he thinks he is getting too much. This differential in meter performance is largely a function of the complex make-up of sound. Some program material has strong peaks and a low average; others are just the opposite. Complex sounds in general have a significantly higher ratio between peak and average than a sine wave has. For a sine wave the ratio between peak and average is always a constant of $1 \div 0.636$, or 1.57-to-1. The ratio for speech or music is generally 10 to 15 dB greater than that of the sine-wave constant, speech usually having the higher ratio.

In summary, the operator must keep a vigil on the sound level to make sure it is not overmodulating the transmitter. At the same time, he must be quite tolerant with the input levels because of the complex make-up of program material.

It is the responsibility of the operator to place the transmitter on the air in the morning, following certain established routines. Usually the operator goes on duty approximately a half hour before air time.

Before warming up the transmitter and putting it on the air, he should make certain the program line is not feeding signal to the transmitter. Similar "get ready" procedures are probably taking place at the studio, and signal may inadvertently be fed over the line and be transmitted. Prior to turning the filaments on, many operators thoroughly inspect the transmitter and associated equipment, including the antenna tuning box, to make certain that some obvious defects have not occurred overnight.

Filaments are then turned on, and in some stations the higher-powered filaments are operated at a slightly lower-than-normal voltage for several minutes. After normal filament voltage has been established, plate voltage can be supplied to the lower-powered stages of the transmitter. After a short interval the higher-powered stages are usually turned on, at a reduced power. Any necessary resonance tuning and voltage adjustments are then made for normal low-power conditions. Finally, full power is turned on and fine adjustments made on the transmitter to establish normal operation.

The engineer at the transmitter is now ready to ask the control-room operator for a test signal, usually a tone or music, so he can check the levels of the signals at the phone-line output and through the amplifier chain preceding the transmitter. (Of course he must make certain this test signal is not being applied to the transmitter.) Finally, both operators synchronize their watches and await the sign-on.

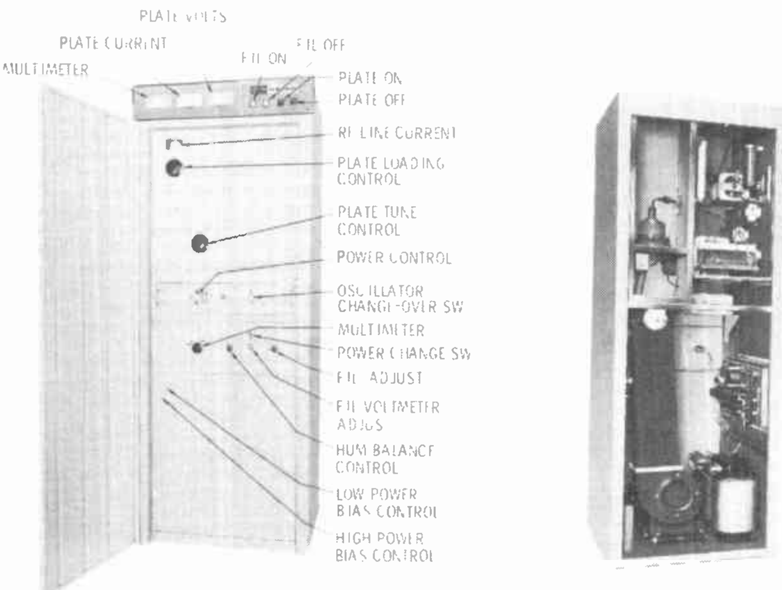
Many transmitter operators are also assigned maintenance duty. Often the workbench is located at the transmitter so that the station equipment can be tested and repaired during the day. A good transmitter operator will familiarize himself with the station equipment so he can lend a hand in solving the inevitable operating and maintenance problems that arise from time to time.

Definite maintenance schedules are followed for the transmitter and its associated equipment. The procedure usually involves a continual round of inspection, cleaning, and tightening. Vacuum-cleaner suction units (or, sometimes, air compressors) help to overcome the ever-present dust menace. Tubes in the transmitter must be checked and spare ones given some operating time occasionally, to keep them from deteriorating on the shelf. Relays and circuit breakers should be watched carefully for signs of sluggishness due to dirt or corrosion. At prescribed intervals, proof-of-performance tests must be made on the station equipment; these various tests will be covered in detail in a later chapter.

8-5. SOLID-STATE BROADCAST TRANSMITTER

The 1-kW broadcast transmitter of Fig. 8-7 is entirely solid-state except for the final rf power amplifier. This single-tube transmitter is rated at 1000 watts and has change-over facilities for reducing power to 500 watts for those stations that require daytime to nighttime power reduction. The frequency response is ±1 dB between 20 to 16,000 hertz; distortion is less than 1.5% at 95% modulation. Frequency stability is at least ±2 hertz with a rated carrier shift of 3% or less.

Transistors are used in each stage of the transmitter up to the final rf power amplifier. There are five separate silicon-diode solid-state power supplies. Two are used by the transistor rf exciter, and there are separate bias, screen-grid voltage and plate-voltage supplies for the vacuum-tube rf power amplifier. The general arrangement of the transmitter including some individual circuit schematics is given in Fig. 8-8.



(A) Front view. (B) Rear view.

Courtesy Gates Radio Co.

Fig. 8-7. Vanguard II transmitter.

The three major divisions of the transmitter can be better seen in Fig. 8-7B. The power transformers, chokes, capacitors, relays, control components, and the blower for air-cooling the power tube are mounted at the bottom of the transmitter. At the center is the transmitter exciter which has been made readily accessible for maintenance and, if necessary, for complete removal. The top part of the transmitter houses the rf power amplifier stage; the anode connection to the power tube can be seen at the left. The row of meters along the top from left to right are multimeter, PA plate current, and PA plate voltage respectively. Below the top row of meters is the rf line current meter. The two controls are PA Load and PA Tune.

At the top right center are the filament and plate power switches. Below are the filament and hum-balance controls for the power supplies. The transistor exciter panel includes two controls. One regulates the rf drive to the vacuum-tube rf power amplifier, which determines

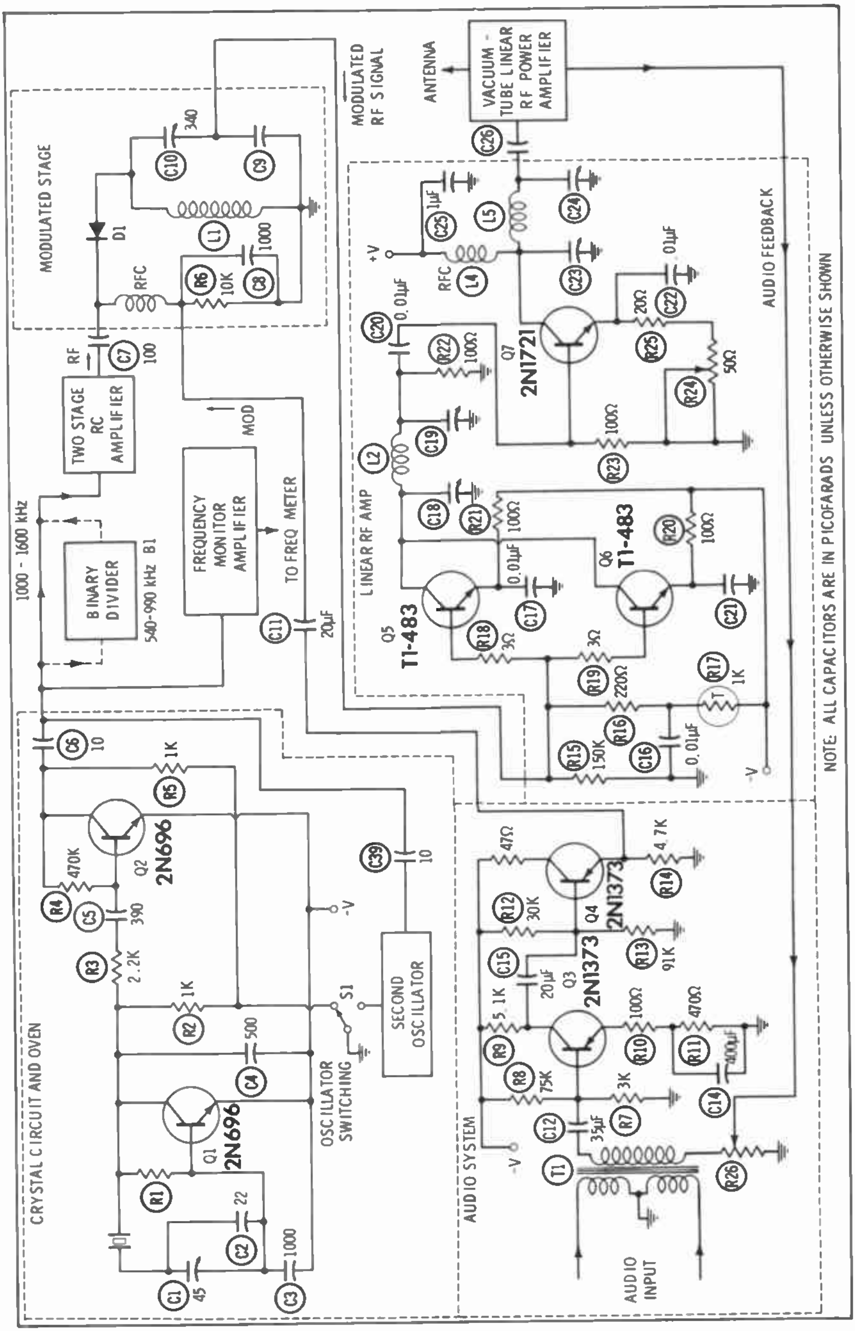


Fig. 8-8. Partial schematic of a solid-state transmitter.

the power output of the transmitter, and a switch that permits the selection of one of two crystal oscillators.

The transistor crystal oscillator is shown at the upper-left corner of Fig. 8-8. There are two such oscillators and associated amplifier mounted in a thermostatically controlled oven. A Pierce-type crystal oscillator is used. This stage is followed by a common-emitter buffer amplifier. Capacitor C1 is used to precisely set the crystal frequency. There are no tuned circuits associated with the crystal oscillator (Q1) and its buffer stage (Q2). In fact, the first resonant circuit encountered in the transmitter is in the modulated stage. A second identical oscillator is shown as a block in Fig. 8-8, the oscillator units are selected by completing their respective circuits to ground through switch S1.

For transmitter operation between 1000 to 1600 kHz, the output of the crystal circuit is supplied directly to a two-stage resistance-coupled amplifier. If operation is in the frequency range of 540-990 kHz, the output of the crystal circuit is supplied to a transistorized binary divider that reduces the frequency by a factor of 2. An output from the oscillator buffer stage is also supplied to a frequency monitor amplifier. This transistor amplifier builds up the level of the signal required to drive the station frequency meter.

The two-stage resistance-coupled amplifier employs no resonant circuits. It operates as a straight-through amplifier taking advantage of the high-frequency capabilities of a transistor when used in a resistance-coupled circuit. It is apparent that solid-state circuitry has made a revolutionary impact on the design of broadcast transmitters and broadcast equipment. Certainly this transmitter represents a substantial departure from the basic concepts of broadcast-transmitter design. Another example is the diode in the transmitter modulator.

A two-stage transistorized audio amplifier (bottom left of schematic Fig. 8-8) builds up the program signal to the level required by the diode modulator for linear modulation of the carrier. The input stage of the audio amplifier is a common-emitter circuit that uses base-divider bias (resistors R7 and R8) and emitter operating-point stabilization (resistors R10 and R11 and capacitor C14). Degenerative ac stabilization is provided by the unbypassed resistor R10. The second stage (Q4) of the audio amplifier is an emitter-follower circuit. It provides a high input impedance, and, therefore, maximum voltage gain can be derived from the first stage. At the same time, Q4 has a very low impedance output and acts as a low-impedance source for the modulating wave applied to the crystal modulator (D1).

A diode modulator operates as a linear modulating circuit when the applied signals are of adequate level and of the proper ratio. In the diode modulator (D1) of Fig. 8-8 the ratio is approximately 3 to 1, or 30 volts of rf carrier input and 10 volts of modulating signal input. A mixing process produces the modulation envelope. If only the rf signal were applied to the diode modulator, the diode current would follow the positive anode alternations. This pulsating current would be filtered out by the output resonant circuit to reconstruct the original rf sine wave. However, when an audio sine wave is applied to the input of the modulator along with the rf wave, a combining action takes place and the peak amplitudes of the peak diode current pulsations depend on the net diode anode voltage at the crest of each radio-frequency cycle. This diode voltage varies up and down with the modulating wave. As a result, the peak diode current varies correspondingly as in Fig. 8-9. The resonant circuit (L1, C9, and C10) because of its energy storing ability reconstructs the opposite alternation of the output voltage variation, forming the familiar a-m modulation envelope.

The input is the simple combining of two separate signals. However, the output wave results from nonlinear mixing or heterodyning and is composed of three radio-frequency components—the carrier frequency plus two side frequencies.

It is significant that the modulation of the transmitter has occurred at a very low power level. If the modulation envelope is not to be distorted, all following rf amplifiers must be operated as linear class-AB or class-B rf amplifiers.

The two final stages of the exciter are the linear rf amplifiers in the lower right side of schematic (Fig. 8-8). The input stage (Q5 and Q6) consists of two transistors in parallel. Base-divider bias is augmented with a thermistor (R17) that compensates for changes in the conductance of the emitter junctions of Q5 and Q6 with temperature. A pi-network resonant circuit (C18, L2, C19) is employed, providing impedance match between the Q5-Q6 output and the input of the final transistor rf amplifier. The final rf stage (Q7) is operated near class-B.

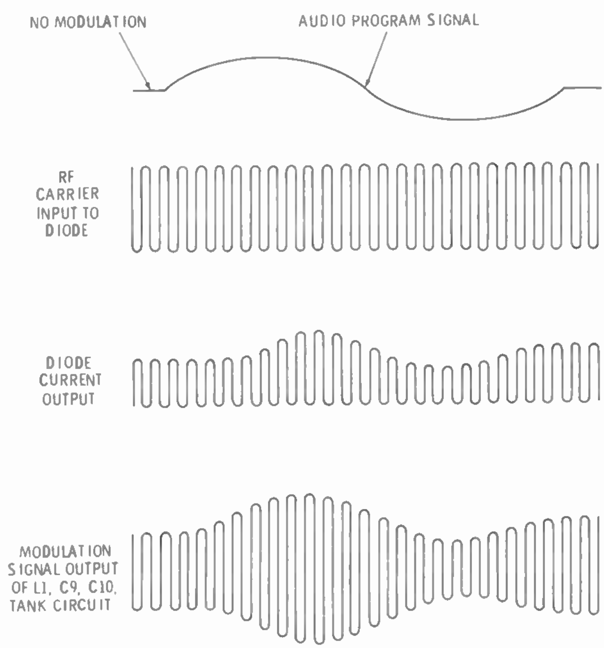


Fig. 8-9. Diode and diode-output tank circuit waveforms.

However, an adjustable emitter resistor (R24) is used to adjust the power output of the exciter and the drive to the vacuum-tube power amplifier. This control (R24) can be adjusted from the front panel of the transistor exciter. A pi-network (C23, L5, and C24) is used to match the output of transistor Q7 to the input of the vacuum-tube power amplifier.

In the transmitter, feedback is used to stabilize the operating parameters of the transmitter and hold the distortion at a low level. There is a feedback path between the vacuum-tube rf amplifier (VI) and the input to the audio amplifier (Q3) of the exciter. An associated control (R26) is used to set the level of the feedback, which is usually 8 dB.

The output of the transistor exciter is supplied through a parasitic choke (L6) and capacitor (C26) to the control grid of the rf power amplifier (Fig. 8-10). Inasmuch as the rf input signal has an a-m modulated envelope, stage VI must be operated as a linear amplifier. External bias is supplied by a separate power supply and is applied to the control grid via the rf choke (L8).

The positions of the three key meters of the transmitter, antenna current (M3), plate voltage (M2) and plate current (M1) are shown on the schematic (Fig. 8-10). Potentiometer R29 is used for hum balancing in the filament circuit to prevent 60-hertz modulation of the carrier. The multimeter (M4) can be used to measure the following parameters: collector current of the final transistor stage (Q7) of the exciter, grid bias, ($-E_c$), filament voltage (Fil), screen-grid voltage (E_{sg}), and screen-grid current (I_{sg}) of the power-amplifier stage (VI).

A pi-T network (L11, C35, C36, L12, C37, L13, and C38) is used to match and transfer power to the antenna system. Inductors L11 (PA tuning) and L13 (PA loading) are continuously variable, and the input-loading coil (L12) uses a shorting tap. Inductor L11 is used to bring the tuned circuit into resonance, while inductor L13 controls the antenna loading and the dc plate current at resonance. If it is not possible to establish the required plate current at resonance, correction can be made by moving the tap on inductor L12.

Capacitor C29 and inductor L9 provide a form of bridge neutralization. Energy for feedback is obtained by mounting a small fixed plate near the air chimney that surrounds the tube in its mounted position. The capacitance removes energy from the anode of the tube and it feeds it back as a neutralization component to the control grid.

A similar takeoff arrangement is used to derive the audio feedback for the transmitter. In this case the energy picked up by the fixed plate near the air chimney is supplied to a diode detector (D2). The audio output is coupled back to the secondary of the audio input transformer (T1) of the exciter.

8-6. HIGH-EFFICIENCY MODULATED POWER AMPLIFIER

A power amplifier which attains an average efficiency of 90%, as opposed to the 70% of the average class-C amplifier under a-m modulation, will be analyzed. This superior efficiency is obtained by con-

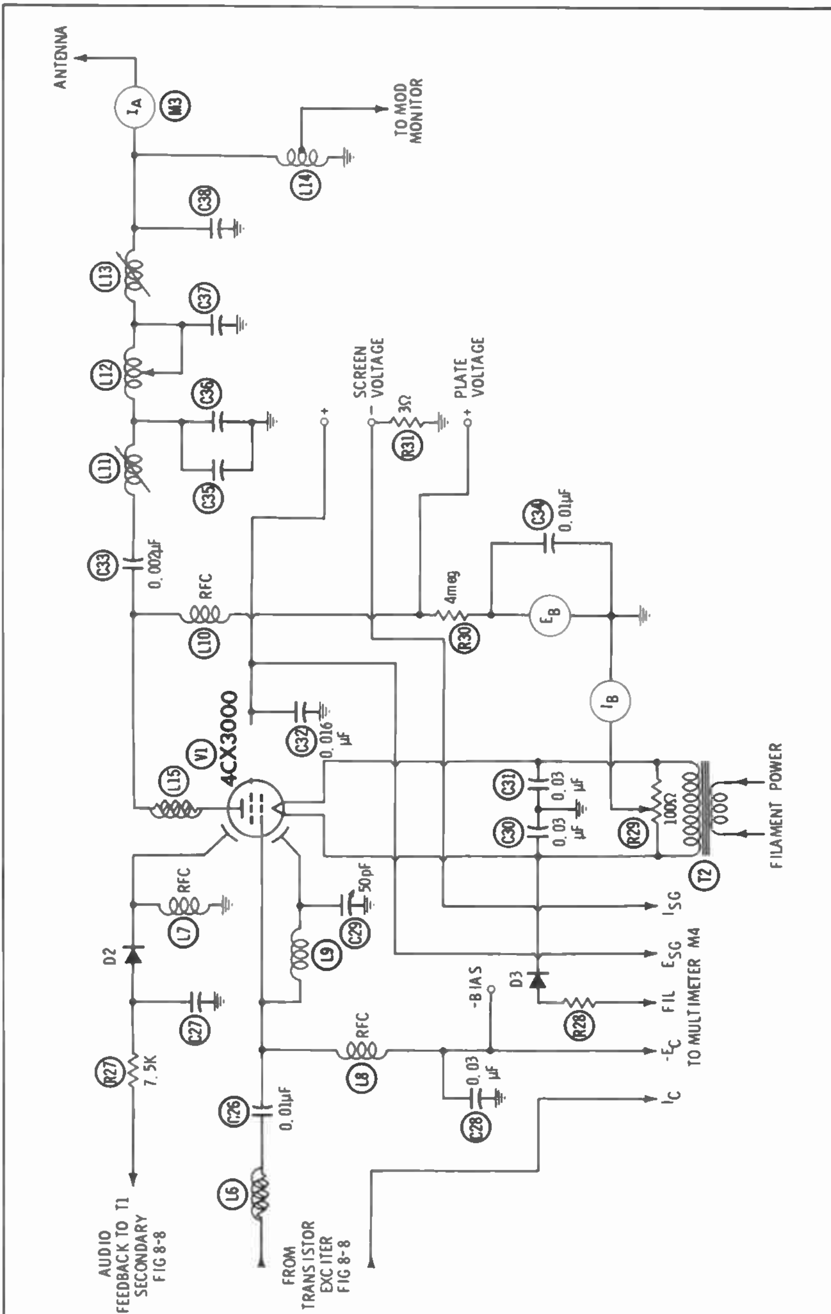


Fig. 8-10. A vacuum-tube power amplifier for a solid-state transmitter.

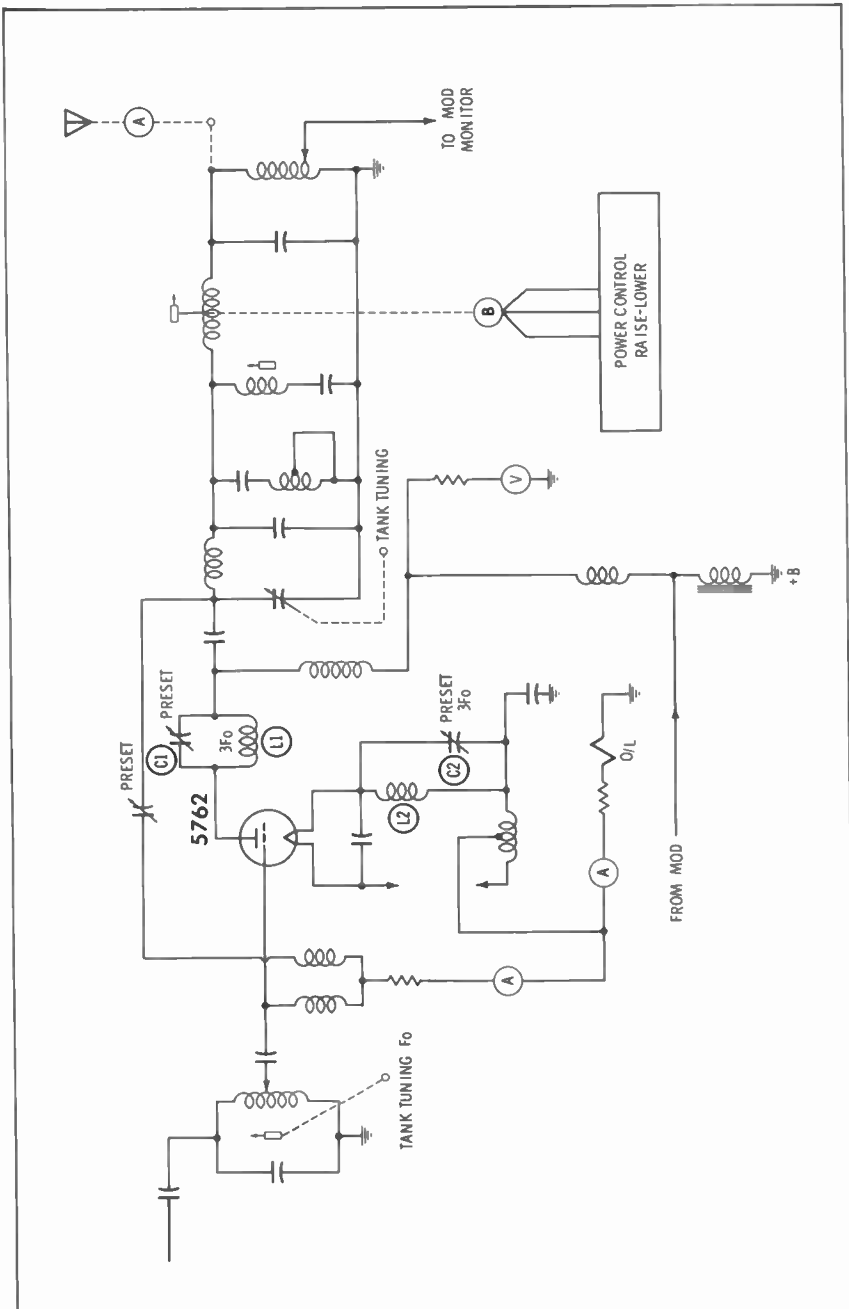


Fig. 8-11. Final power amplifier of a 5-kilowatt a-m transmitter.

trolling the plate-current and plate-voltage waveforms to minimize the plate dissipation.

The circuit and its operating constants are similar to those of a conventional plate-modulated class-C amplifier, except that third-harmonic tank circuits have been added in the plate (L1-C1) and cathode circuits (L2-C2), as shown in Fig. 8-11. These two resonant circuits produce a third harmonic in both the plate and the grid-to-cathode voltages, as can be seen in the waveform of Fig. 8-12.

In a class-C amplifier the angle of tube-current conduction is restricted to that portion of the cycle where the instantaneous plate current is high and the instantaneous plate voltage is low. By controlling the time of this plate current, it is possible to obtain a relatively high output and a reasonably low anode dissipation. However, if a strong, uniform current could be established during this interval, the amplifier would operate at an even higher efficiency. Unfortunately, in normal class-C operation the waveform is sinusoidal and rounds off; thus, a large portion of the power is lost at the anode.

The function of the third-harmonic components, introduced into the plate and cathode circuits, is to square the plate-voltage waveform (Fig. 8-12A) and thus raise the average plate voltage during the conducting interval. The cathode-tank circuit (L2-C2), by contributing a third-harmonic component to the grid-to-cathode potential, modifies the cathode emission to approximately the rectangular wave shown in Fig. 8-12B. In effect, the energy stored in the plate and cathode tank circuits reduces the amplitude and broadens the top of the class-C waveform during conduction. Consequently, there is less plate dissipation for a given power output.

(A) Plate. (B) Cathode.

Fig. 8-12. Influence of third-harmonic components on plate voltage and cathode emission.

8-7. LIMITING AMPLIFIER

As its name implies, the limiting amplifier keeps the audio output below a predetermined value so that program peaks do not overmodulate the signal. The transmitter can therefore be operated at a higher average-modulation percentage, the limiter acting as a safety valve against overmodulation with its consequent distortion and splatter (generation of spurious signals). The limiter amplifier must exhibit minimum distortion so that the quality of the program is not impaired, regardless of the amount of limiting (up to the overload point of the limiter amplifier).

If the limiter amplifier is adjusted to introduce substantial suppression, the dynamic range of the broadcast will be limited. Therefore, in the reproduction of concert music and similar program material where considerable dynamic range is desired, the amount of compression should be kept to a minimum.

A Gates modulation limiter is shown in Fig. 8-13. This limiter provides as much as 30 dB of compression. Usually the amount of limiting employed falls between 5 and 10 dB; sometimes between 15 to 20 dB. Negative and positive modulation peaks can be controlled separately with asymmetrical limiting. Negative overmodulation is to be avoided in a-m broadcast practice. With a 30-to-1 compression ratio the peak negative modulation can be set at 99.5 percent without any danger of overmodulation. At the same time the positive peak modulation can be permitted to rise to 110 or 120 percent without distortion.

If the limiter is to be used with an fm transmitter, symmetrical limiting is used because plus or minus peak excursions beyond the maximum permissible fm deviation must be avoided.

The modulation limiter is said to have a fast attack time. This means that when a modulation peak comes along, the limiting action occurs very quickly and distortion or so-called thumping do not occur.

A functional block diagram is given in Fig. 8-14. The incoming signal is first passed through a variable loss circuit. Signal attenuation in this circuit depends upon the magnitude of the recurrent modulation peaks. It is here that the control action is exerted. An amplifier section follows which builds up the magnitude of the limited modulating signal prior to its application to the output circuit and on to the transmitter.

A portion of the output signal is applied to the control circuit. The control signal circuit responds to signal peaks and develops a dc con-

Courtesy Gates Radio Co.

Fig. 8-13. A modulation limiter.

trol bias that is applied to the variable loss circuit, thus controlling the extent of the signal attenuation.

Positive and negative recurrent peaks are also applied to a comparator circuit. This circuit develops a control voltage that is determined by the relative magnitudes of the positive and negative peaks. Through an automatic peak-phasing circuit the limiter is able to exert an automatic control over the peak polarization that needs the greatest amount of compression.

A schematic diagram is given in Fig. 8-15. The variable loss circuit consists of transistors Q1 and Q2. These two transistors are connected across the secondary of input transformer T1, and the primary of output transformer T2. Their resistances from collectors to emitters are controlled by the dc bias currents applied to their bases. The source of the control bias is the emitter of transistor Q14, center right of the schematic diagram.

The voltage across the Y-WH secondary of limiter transformer T3 is applied through capacitors C14 and C17 to the peak rectifying diodes, CR14 and CR15. Filtering and recovery time is handled by the resistor-capacitor network shown below input transformer T1, at upper left. This same control voltage can also be applied to a second modulation limiter in the case of fm stereo operation.

The control signal is also applied to metering transistor Q13 which, through the front panel meter, indicates the amount of limiting in decibels.

The control signal is amplified by transistors Q14 and Q15, with the emitter circuit of Q14 supplying the control bias current to the bases of variable loss transistors Q1 and Q2.

The relative level of negative and positive peak limiting is a function of the relative biasing of rectifier diodes CR14 and CR15. Equal biasing provides symmetrical limiting; unequal biasing produces asymmetrical limiting. Asymmetrical limiting occurs when S3 is switched to either the 110-percent or 120-percent positions. With program input having a natural imbalance in positive and negative peaks, the unit limits negative peaks to 100 percent, while allowing the positive peaks to reach either 110 percent or 120 percent before limiting occurs.

The limiter includes an automatic peak-phasing circuit. It makes certain with asymmetrical limiting that the modulating peaks of the

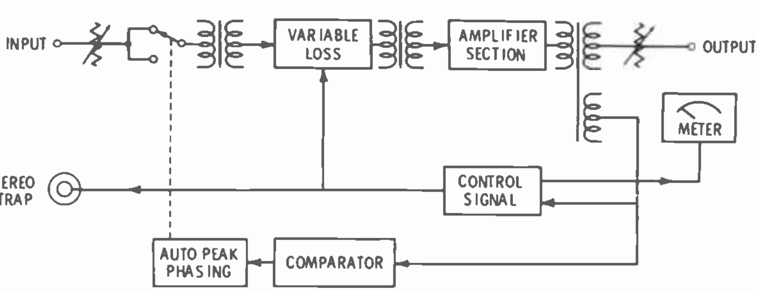
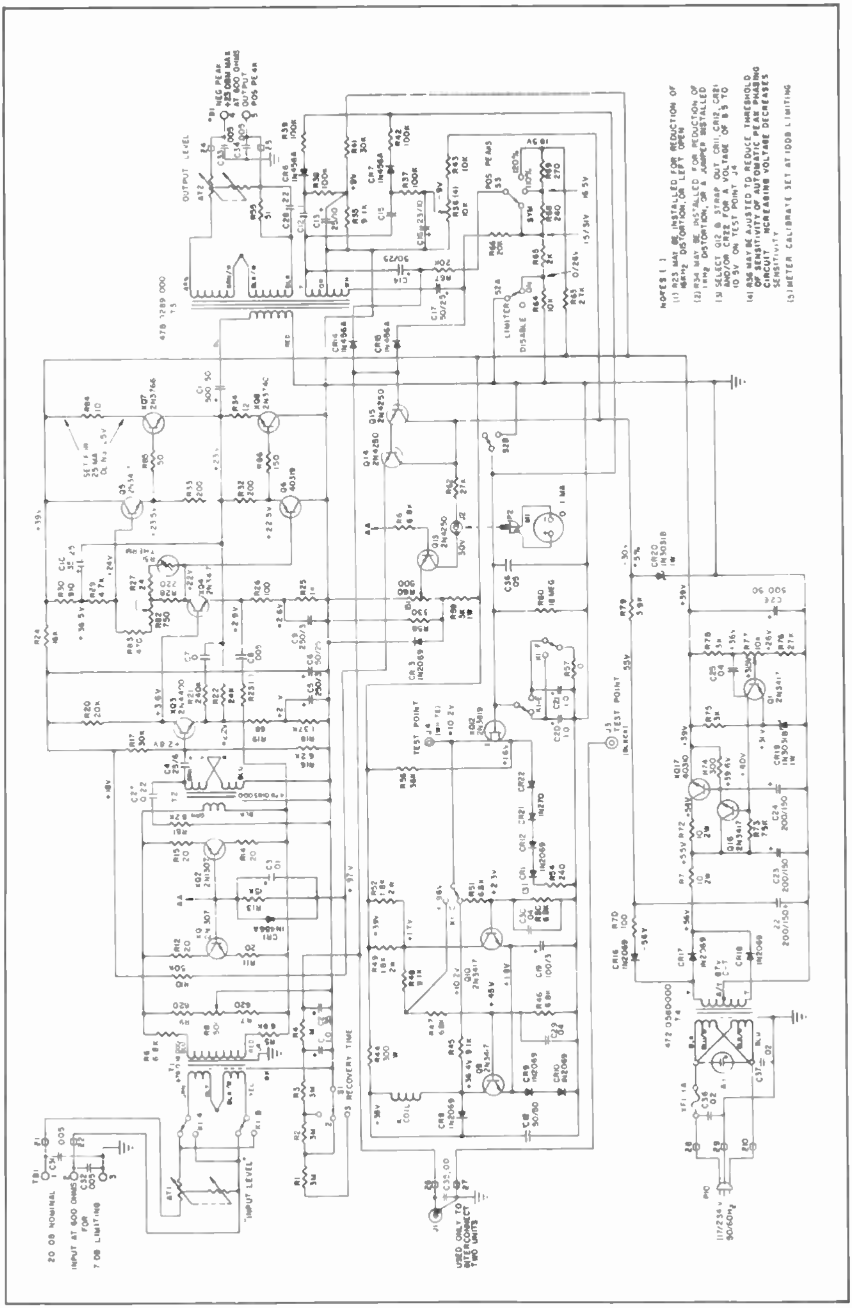


Fig. 8-14. Block diagram of a modulation limiter.



Courtesy Gates Radio Co.

Fig. 8-15. Schematic diagram of a modulation limiter.

greater magnitude cause positive modulation of the a-m transmitter. This is done with the relay terminals that are connected in the primary of input transformer T1. Relay coil K1 is connected in the collector circuit of a flip-flop multivibrator, transistors Q9 and Q10. Whether Q9 conducts or is nonconducting depends upon whether the positive or negative peaks have the greater magnitude across the Y-WH secondary winding of output transformer T3. The negative and positive peak-comparator diodes are CR6 and CR7. Control voltage is applied to the gate of field-effect transistor Q12. It develops the flip-flop triggering voltage for the multivibrator.

CHAPTER 9

A-M Broadcast Antennas and Lines

The antenna system of a modern broadcast station consists of the antenna proper, the transmission line, and the associated components needed for tuning and proper lighting of the antenna structure.

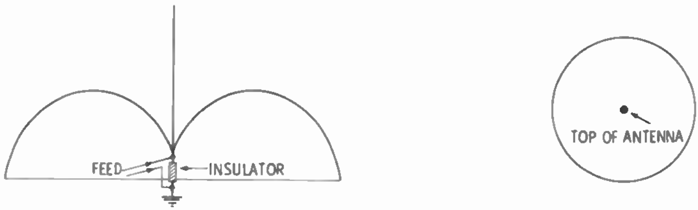
9-1. ESSENTIALS OF A-M BROADCAST ANTENNAS

The vertical antenna is the type most usually employed in a-m broadcasting. In addition to being an economical antenna, its horizontal- and vertical-radiation patterns are favorable to broadcast requirements. The horizontally radiated pattern is omnidirectional; that is, the signal is of equal magnitude in all directions of the compass. Thus, the coverage is essentially uniform over the station's service area, as shown in Fig. 9-1.

On the other hand, the low-angle vertical pattern of the antenna concentrates the energy into a ground wave which is the primary medium for supplying signal to the service area. Such a pattern minimizes sky-wave propagation and thus cuts down fading in the secondary service area, where there is the possibility of interaction between sky- and ground-wave components.

An integral part of any antenna system is the tower, since its height is one of the determinants of the range of the system. The two most common tower structures are shown in Fig. 9-2. The self-supporting tower is more costly. For maximum support, the spacing between its base legs should be approximately one-eighth of the tower height.

Broadcast antennas either are grounded or are mounted on insulators. The grounded version is subject to more variables and hence more matching and pattern problems. The most common broadcast antenna for small a-m stations is the guyed vertical type. It is usually mounted on an insulator and is somewhat taller than a quarter of a wavelength. The guy-wire system must be broken up with insulators to avoid any length that may become resonant and adversely affect the characteristics of the radiating element.

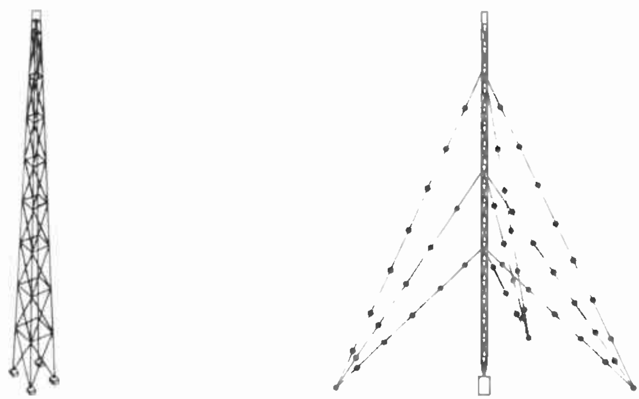


(A) Vertical pattern. (B) Horizontal pattern.

Fig. 9-1. Basic quarter-wave vertical antenna and patterns.

To eliminate variables and thereby establish the most favorable operating conditions, a good ground system is essential for a vertical antenna. This is the reason for the system of wires extending like the spokes of a wheel from the base of the tower. The ground must be tied in properly to the tuning system of the antenna.

A combination of vertical radiators is the ideal method of obtaining any reasonable horizontal-radiation pattern. Two or more vertical antennas can be made to concentrate the rf energy in specific areas. At the same time, deep nulls can be inserted into the horizontal-radiation pattern to prevent interference between stations operating on the same or adjacent channels. The major units of a typical directional-antenna system were introduced in conjunction with Fig. 8-6.



(A) Self-supporting. (B) Guyed.

Fig. 9-2. Basic tower constructions.

9-2. VERTICAL-ANTENNA CHARACTERISTICS

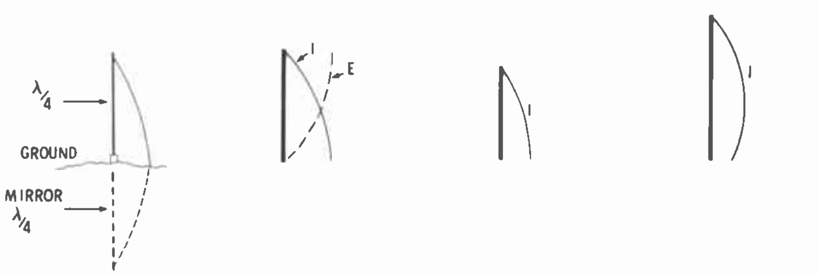
The quarter-wavelength vertical can be considered the basic antenna. Fundamentally it is a half-wavelength antenna, the ground acting as an image quarter-wavelength section, as shown in Fig. 9-3. At an electrical quarter-wavelength, the antenna resistance is theoretically 36 ohms. This "radiation" resistance is not a resistance that can be measured with an ohmmeter; rather, it is the equivalent resistance required to dissipate the same power as the antenna. Whether or not it is exactly 36 ohms is a function of the ground system and the conditions below the antenna. The absolute value is important only in that it must be correctly matched to the transmission-line system from the transmitter.

The theoretical voltage and current distribution is shown in Fig. 9-3. At the top of the antenna, the current is zero and the voltage is maximum. The current becomes maximum exactly 90 degrees down (or at the feed point for a quarter-wavelength vertical). Theoretically, the impedance at the feed point should be entirely resistive. In practice, reactive components are often also present and must be balanced out by the antenna matching system.

The current and voltage distribution along a very thin vertical radiator is essentially sinusoidal. Some departure from this sinusoidal relationship will occur, particularly in self-supported towers having a gradually increasing cross-sectional area toward the base. But for most small stations with their single, uncomplicated verticals, it is safe to assume an essentially sinusoidal relationship in making performance calculations.

The broadcast vertical need not be (and usually is not) an exact electrical quarter-wavelength. The minimum antenna height permitted a Class IV broadcast station (local) is substantially less than a quarter-wavelength, as shown in Fig. 9-4. Notice that over the entire Class IV curve (A), the dimensions are shorter than the quarter-wavelength curve (D). The lower the frequency is, the greater is the height required to obtain a specific minimum field intensity. For Class II and Class III stations, curve B, the minimum height must be more than a quarter-wavelength above 1150 kHz. All Class I antennas, curve C, must be greater than a quarter-wavelength, approaching the half-wavelength electrical dimension of curve E.

When a vertical antenna is less than a quarter-wavelength, it displays both resistive- and capacitive-reactance components, as illustrated in Fig. 9-3C. The antenna tuning unit must, therefore, introduce an equal and opposite inductive reactance to balance out the capacitive component. As before, the tuning unit must match the transmission line to the resistive component of the antenna.



(A) Near quarter-wave. (B) Quarter-wave. (C) Less than quarter-wave (capacitive). (D) More than quarter-wave (inductive).

Fig. 9-3. Characteristics of quarter-wave and near quarter-wave antennas.

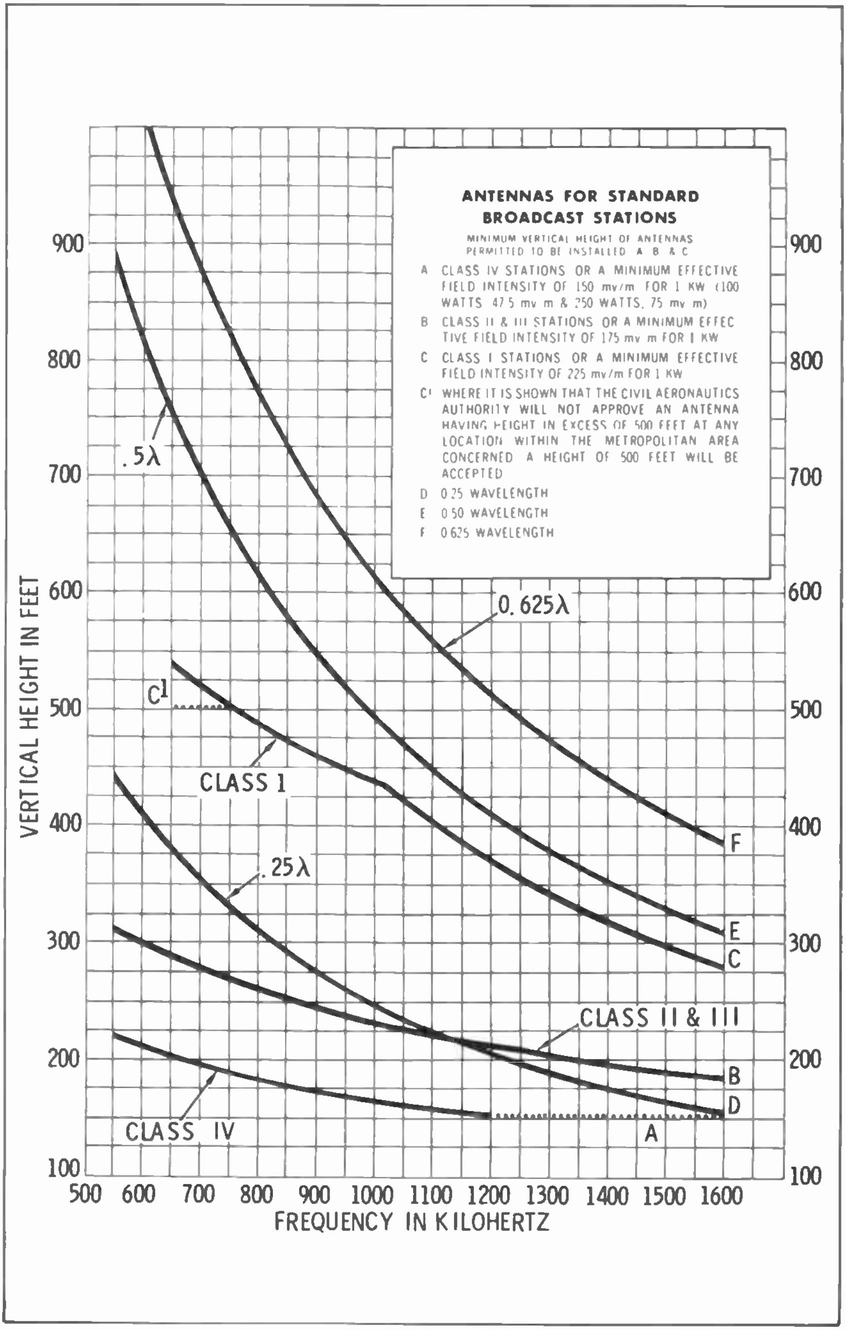


Fig. 9-4. FCC broadcast-antenna dimensions.

The impedance of a vertical antenna is usually expressed in terms of the "j-operator." For an antenna of less than a quarter-wavelength the impedance can be written as follows:

$$Z = R - jX_C$$

which can be written:

$$Z = \sqrt{R^2 + X_C^2}$$

After the antenna and ground system have been installed, this impedance is usually measured carefully with an impedance bridge. A suitable antenna tuning unit is then designed to permit an ideal match between the transmission-line system and antenna, plus a sufficient tuning range to accommodate any variables.

When a vertical radiator is longer than a quarter-wavelength and less than a half-wavelength it displays inductive reactance, as shown in Fig. 9-3D. This component must be balanced out capacitively by the antenna tuning system. The impedance of such an antenna is usually indicated as follows:

$$Z = R + jX_L$$

Theoretically, an antenna exactly a half-wavelength has resistance but no reactance. Above one-half of a wavelength the antenna again exhibits capacitive reactance, and above three-quarters of a wavelength an inductive component is present.

The antenna height influences the vertical-radiation pattern and, hence, the efficiency of the antenna system. For a small local station, an antenna higher than a quarter-wavelength will provide greater concentration of the radiated energy at low vertical angles. However, the loss in efficiency of a shorter antenna can sometimes be compensated for by boosting the transmitter power, as long as FCC field-strength requirements are met. A shorter antenna reduces the cost of installation—a significant item if the antenna is to be mounted on an existing structure like a downtown building. Antenna height might also be a problem if an airport is nearby.

The antenna resistive component also decreases significantly as the height is made less than a quarter-wavelength. Under these conditions the resistive losses associated with the antenna system, although small, become more significant and absorb a greater percentage of the total transmitter output power. Thus, the efficiency of the antenna system is reduced.

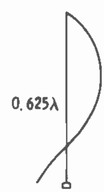
9-3. LONG VERTICALS

Up to now we have discussed the advantages of short antennas. But long verticals have some important advantages, too. In addition to their more efficient radiation of available power, their vertical-radiation pattern concentrates the rf energy at a much lower angle. Typical long-vertical antennas and their radiation patterns are given in Fig. 9-5. Notice how the radiation is concentrated at a lower and lower angle (Fig. 9-5C) between 0.25 and 0.625 wavelength. At 0.625 wavelength a secondary lobe is introduced that begins to direct additional energy skyward. Hence it is advisable to keep antenna heights below this limit.

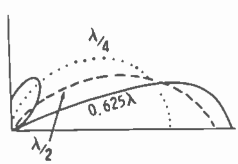
Most Class I and other clear-channel stations have tall vertical antennas. These stations serve not only an extensive area via ground waves, but also a wider area made possible through the use of sky waves. One might assume that a high-angle sky-wave radiation 0.25-wavelength antenna is preferable to low vertical-angle signals in obtaining an extended coverage. However, the apparent advantage gained by the extended coverage is nullified when the reflected sky waves return to earth near the antenna and cause fading due to interference between the ground waves and sky waves. In fact, long (0.625 wavelength or greater) vertical antennas are often referred to as anti-fade antennas because they concentrate the radiation at low angles to prevent the sky waves from returning too near the station.

Figs. 9-5D and 9-5E show two common methods used by many clear-channel stations to gain the benefit of greater electrical length from a physically shorter antenna. One is to add an umbrella-like structure at the top of the mast (Fig. 9-5D). Referred to as a *top-loaded antenna* (or "top hat" for short), it includes sufficient radiating area to increase the effective electrical length of the antenna without having to extend its physical height. Suitably dimensioned, such an antenna will display many of the favorable characteristics of a much taller structure, such as more favorable impedance and matching relationships at the feed point, plus better current distribution (which en-

(A) One-half wavelength.

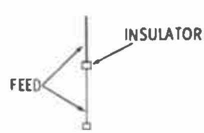


(B) 0.625 wavelength.



(C) Radiation patterns.


(D) Top-loaded.



(E) Collinear vertical.

Fig. 9-5. Long vertical antennas and their radiation patterns.

courages low-angle radiation). A second plan uses a sectionalized tower, usually with one or more insulators to break up the vertical structure into individual radiating elements. Such an antenna is called a *collinear vertical* (Fig. 9-5E), and it is superior to any other antenna if proper impedance and current relationships have been established for the location and coverage desired. In many areas, fading can be reduced substantially with a collinear vertical.

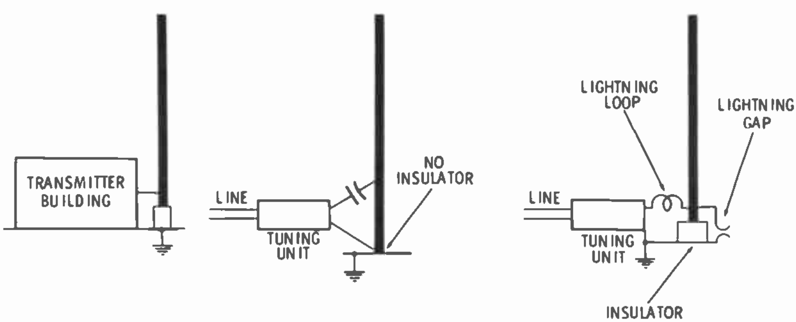
Nevertheless, the short, self-supported vertical is by far the most common for small stations. Also, two or more vertical antennas are employed in directional antenna systems.

9-4. ANTENNA-FEED METHODS

The three most popular feed methods for vertical antennas are given in Fig. 9-6. In many small stations the antenna is just outside the transmitter building (Fig. 9-6A), and only a short transmission line (usually copper tubing) is needed between the transmitter and antenna. The transmission line connects to the antenna at a point which provides an approximate impedance match, and fine tuning of the antenna is accomplished in the output-coupling network of the transmitter.

In the shunt-fed (grounded) tower of Fig. 9-6B, the transmitter and antenna are a substantial distance apart; consequently, an impedance-matching antenna tuning unit is associated with the antenna. The slant-wire feed arrangement is connected to the vertical radiator at a point which will provide an approximate impedance match. The fine tuning of the antenna system is then accomplished with the antenna-tuning network.

Fig. 9-6C shows the most popular system of the three antenna-feed systems. The antenna is fed between the base of the antenna and ground. The antenna tuning unit matches the impedance of the transmission line to the radiation resistance of the antenna, and also tunes out any reactive components displayed by the latter. For lightning protection, the antenna feed line is looped twice, just ahead of the antenna. The loops act as a choke, presenting a high impedance to a



(A) Short transmission line. (B) Shunt fed. (C) Between base and ground.

Fig. 9-6. Antenna-feed methods.

lightning discharge. A second safeguard is the lightning gap, located between the base of the antenna and ground. The gap spacing must be such that a surge of lightning will arc across it but there will be no discharge during modulation peaks in the program.

9-5. TRANSMISSION LINES

The four important operating characteristics of transmission lines are impedance, attenuation, power-handling capability, and ability to withstand weather extremes.

A transmission-line impedance of 50 ohms is almost universal for broadcast transmitters. The power-handling and attenuation characteristics of various lines are given in Table 9-1. Attenuation, a function of the frequency and the distance between transmitter and antenna, is much more important in television and fm broadcasting because of the much higher frequencies, although it also becomes significant in a-m broadcasting when the use of extremely long transmission lines is necessary.

The five basic transmission lines are shown in Fig. 9-7. The RG/U flexible coaxial lines (Fig. 9-7A), using a solid dielectric of polyethylene, are found in nondirectional a-m broadcast stations with transmitters rated up to 1 kilowatt. RG17/U and RG19/U are the two most frequently used coaxial cables. The RG19/U has a higher power-handling capability, as indicated in Table 9-1, and in a well-matched system it can be used for powers of up to 5 kilowatts.

The power-rating figures take into consideration the fact that 100-percent amplitude modulation is used. At 100-percent modulation the power peaks of the modulated carrier signal have four times the average power output ($P_{pk-pk} = 2E_p \times 2I_p = 4E_pI_p$) of the transmitter. The power rating is also given with relation to the standing-wave ratio on the line. Of course, the higher this ratio is, the greater is the voltage stress between outer and inner conductors. An average standing-wave ratio (VSWR) of 2 to 1 is indicated in Table 9-1.

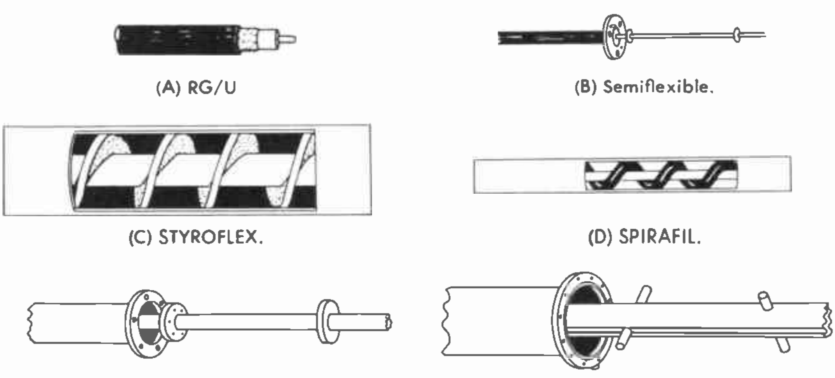


Fig. 9-7. Broadcast transmission lines.

The semiflexible air-dielectric cable of Fig. 9-7B is widely used in directional a-m broadcast arrays and by many medium-powered a-m stations. It consists of outer and inner conductors made of soft-tempered copper and separated by insulators. The ⅞-inch outside-diameter semiflexible cable is the most used size of coaxial cable and can be used to make reasonable bends in the transmission line path provided it is carefully manipulated to avoid kinks which might disrupt the impedance.

Table 9-1. Broadcast Transmission Lines

Type	Ohms	VSWR 2/1
RG		
RG/17U	52	2.9 kW
RG/19U	52	4.25 kW
STYROFLEX		
⅜	50	0.56 kW
½	50	1.12 kW
¾	50	2.52 kW
⅞	50	3.64 kW
1⅛	50	5.99 kW
RIGID COAX		
⅞	50	3.64 kW
1⅝	50	16.25 kW
3⅛	50	52.64 kW
6⅛	50	212.8 kW

The continuous air-dielectric flexible cable in Fig. 9-7C is a recent entry into the transmission-cable field. It consists of a solid or tubular copper center conductor and a tubular aluminum outer conductor. A *Styroflex* laminated helix and an outer belt of *Styroflex* tape maintain the proper spacing and thus provide a high percentage of air dielectric along the entire line at all times. The helical construction also keeps the spacing uniform, even when the line is bent. As shown in Table 9-1, *Styroflex* lines are available for transmission lines up to 6 kW, with diameter of only 1⅛ inch. The *Spirafil* cable (Fig. 9-7D) has a solid copper center, a tubular outer aluminum conductor, and a solid polyethylene helix.

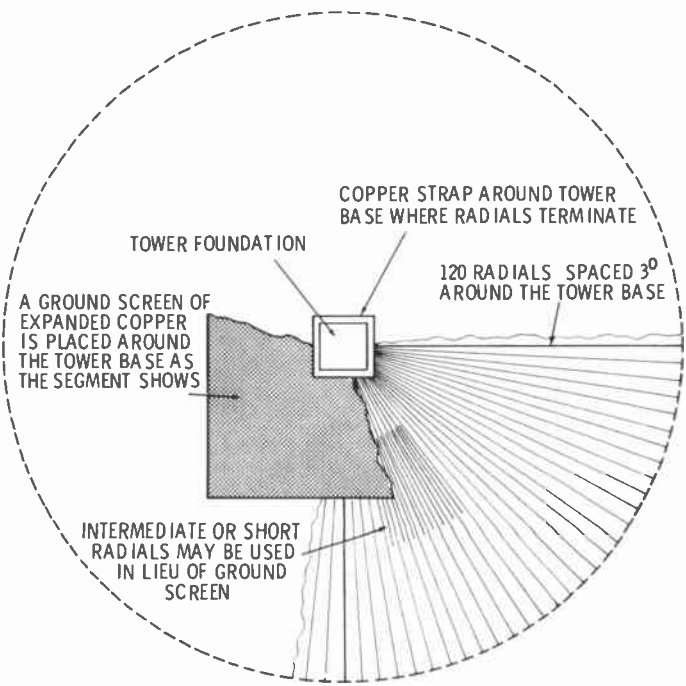
The rigid coaxial line (Fig. 9-7E) is used mainly by high-powered stations. Tubular inner and outer conductors are employed, along with *Teflon*-disc or *Teflon*-peg spacers. These rigid air-dielectric coax lines are as much as six or seven inches in diameter and are capable of handling several hundred kilowatts or more. They are used for high-powered fm, television, and uhf transmitters because of this power capability and low attenuation. Waveguides are used for high powered uhf stations because of their lower attenuation.

To prevent condensation and the resultant interior arcing, *Styroflex* and rigid coaxial lines are often equipped with dehydrator units. An alternate arrangement is to use oil-pumped nitrogen in pressurized lines. If the flanges and coupling connections are airtight, additional nitrogen is rarely needed after the initial filling. To protect transmission lines from the weather, they are often mounted in troughs.

9-6. GROUND SYSTEM

As you learned earlier, power to the antenna system of most small a-m stations is fed across the base insulator, the antenna serving as one terminal and the ground system as the other. Theoretically, the ground system should be a perfect conductor in order to establish the most favorable mirror effect for the antenna system. How close this ideal is approached is a function of the length and number of ground radials, along with the size of the ground screen (ground mat) underneath the tower. A typical ground system, shown in Fig. 9-8, consists of 120 radials spaced 3° apart and extending outward the equivalent of at least one-quarter of a wavelength at the operating frequency. Usually the radial system is buried four to twelve inches underground, and a ground screen or additional short radials are used underneath the tower.

The entire system is bonded to a copper bus or strap around the perimeter of the tower foundation. A permanent ground, in the form of a heavy copper plate or strap, must be attached to the bottom of the base insulator and connected (through a heavy copper cable or strap) to a copper-bus ground at the tower base. A similar plan is required for each tower of a directional-antenna system, with copper bus lines or straps forming the junctions between the radial systems.



Courtesy RCA Corp.

Fig. 9-8. A typical broadcast-antenna ground system.

The radial wires, copper screen, base straps, etc., must all be carefully soldered together in order to provide a good, continuous electrical connection.

9-7. TOWER LIGHTING

In most areas all towers over 200 feet must be lighted, and in some locations this ruling applies to even lower towers. For the usual small a-m station, a beacon light is required at the top and obstruction lights

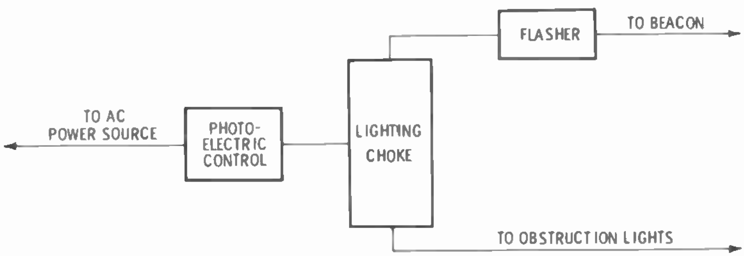
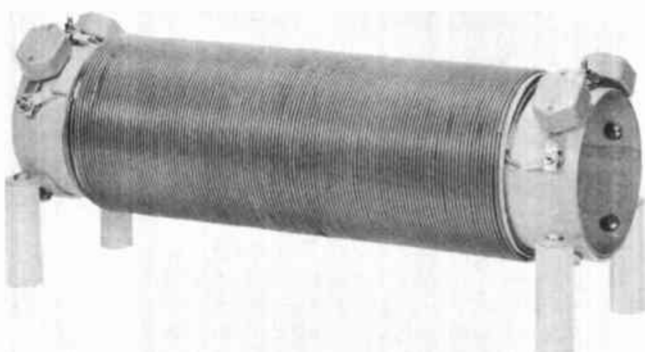


Fig. 9-9. A tower lighting plan.

below it, the number depending on the tower height. A photoelectric device (Fig. 9-9) can be used to turn on the lights automatically before sunset or during dark days.

It is necessary to block the rf potential of the tower from the power line. This is accomplished with a multisection choke similar to the



Courtesy Collins Radio Co.

Fig. 9-10. A Collins lighting choke.

Collins lighting choke (Fig. 9-10) or an isolation transformer like the Austin ring type (Fig. 9-11). The transformer permits coupling of the low-frequency lighting power, but acts as an isolator to rf potentials because of the wide spacing between its coils.

Fig. 9-11. An Austin ring transformer.

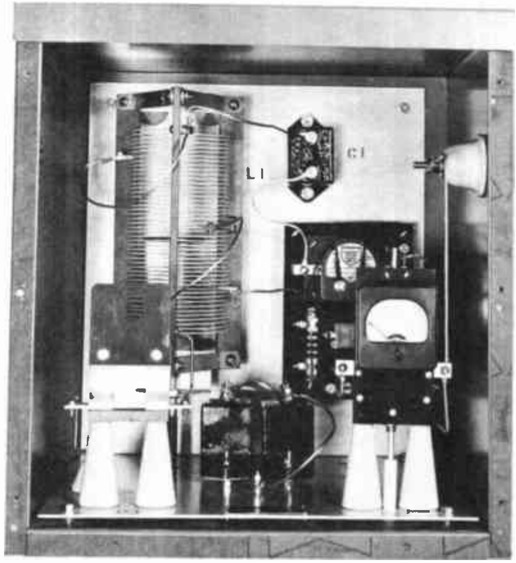
9-8. ANTENNA-TUNING UNIT

A typical antenna-tuning system is the Gates unit in Figs. 9-12 and 9-13. It has a frequency range of 550-1600 kHz and a maximum modulated carrier power of 1000 watts. The network provides correct matching between the transmission line and a vertical antenna, and it also filters out rf harmonics.

The line from the transmitter is connected to the network by way of a feedthrough insulator at the bottom of the tuning unit (Fig. 9-12); the antenna connects to the insulator at the top right. A heavy copper-strap should be connected from a grounding stud (located at the bottom of the unit) to the antenna ground system. The outer conductor of the coaxial line coming from the transmitter must also be grounded to this stud.

The basic part of the tuning unit (Fig. 9-13) is a T-section low-pass filter; key components are the variable inductor L1, C1, C2, and C3. The component values are selected in accordance with the line impedance, the type of vertical antenna and its feed method, and the operating frequency. The function of C1 is to block antenna-static discharge, which is bypassed to ground via L4. The value of C1 is determined by the antenna reactance; if the antenna reactance is inductive, the reactance of C1 must match. If the antenna is short and displays capacitive reactance, the reactance of C1 is made small enough to be negligible.

The values of C2 and C3 are determined by the transmission-line impedance and the antenna-radiation resistance to be matched. For a



Courtesy Gates Radio Co.

Fig. 9-12. A Gates antenna-tuning unit.

90° matching section (comparable to a quarter-wave matching segment), the capacitive reactance must be:

$$X_C = \sqrt{Z_L R_A}$$

where,

Z_L is the line impedance,
R_A is the antenna resistance,
X_C is the total reactance of C2 and C3 in parallel.

Here is the recommended procedure for adjusting an antenna-coupling network:

1. With a bridge, measure the base impedance of the antenna. The coupling unit must match this value to the transmission line. (It is designed with the proper range of adjustments to permit an exact match.)
2. After installing the antenna-tuning unit, connect an impedance bridge across its input. Adjust the tuning unit until the input impedance has a zero reactive component and a resistance equal to the characteristic impedance of the transmission line.
3. Adjust the coil tap at the antenna end of inductor L1 until the resistance at the input to the coupling network equals the characteristic impedance of the line. Next, move the coil tap at the other end of inductor L1 until the input reactance is zero. The transmission line can now be attached to the input of the tuning unit.

A thermocouple meter system or a diode-rectifier meter system can be used to indicate antenna current. In Fig. 9-12 a thermocouple unit can be seen at the right center. In the schematic of this circuit in Fig. 9-13, inductors L2 and L3 and capacitors C4 and C5 act as rf filters. A lead-covered two-pair cable transfers the thermocouple output to the remote meter which is located in the transmitter housing.

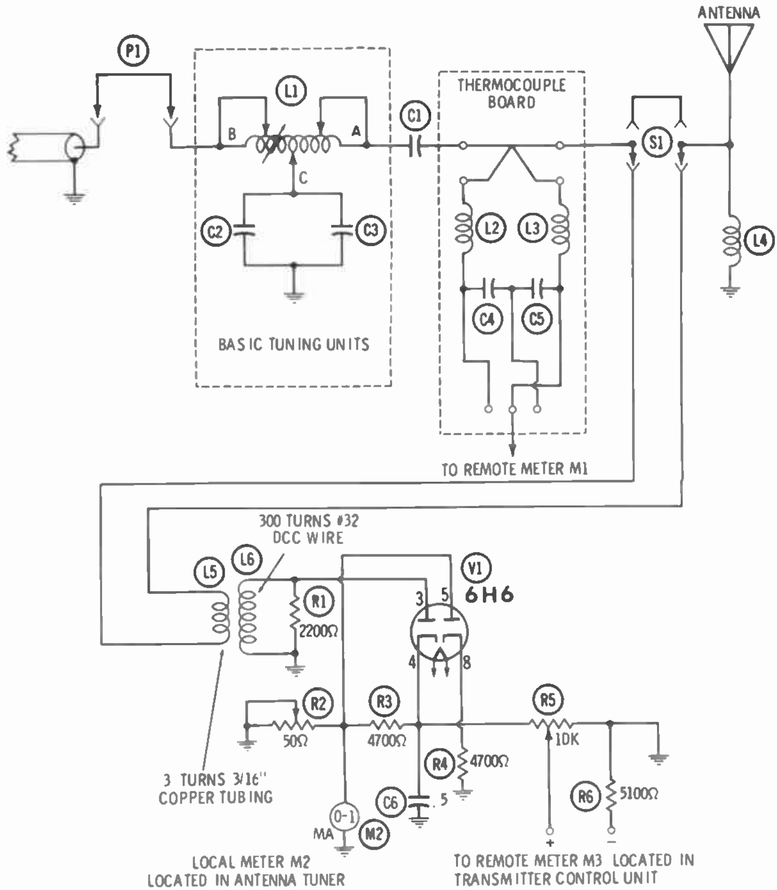


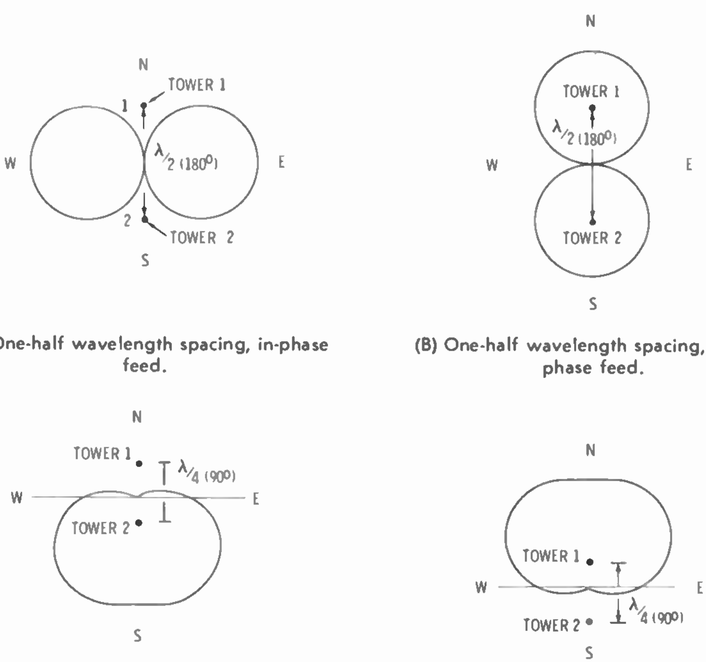
Fig. 9-13. Schematic diagram of an antenna-tuning unit.

In a second arrangement a diode-rectifier meter is connected across meter-switch assembly S1 (Fig. 9-13). The remote meter M3 or meter M2 at the antenna tuning unit can be switched in or out of the transmission system by S1. L5 and L6 in Fig. 9-13 couple energy from the antenna line. L5 is several turns of tubing at one end of the transmission line. The small field built up around these turns is enough to couple energy into the input circuit of the metering unit.

9-9. DIRECTIONAL-ANTENNA SYSTEMS

A directional broadcast-antenna system is used where the rf energy must be concentrated into the service area to be covered. The horizontal radiation pattern is so planned that there is minimum radiation toward the station(s) with which it must not interfere. As mentioned previously, the directional pattern is a function of the number and spacing of the vertical radiators, plus the relative phase and magnitude of their currents. The directivity and general shape of the pattern are determined by the spacing of the vertical antennas and the relative phasing of their currents. The deepness of the nulls is influenced greatly by the relative magnitudes of the radiator currents.

Many stations requiring directional patterns employ only two vertical towers. The technique of obtaining the desired directional pattern from two towers is demonstrated in Fig. 9-14. Let us consider Fig. 9-14A, showing two vertical antennas 180° (one-half of a wavelength) apart and fed by in-phase currents. The towers in Fig. 9-14A are located in a north and south direction, but they could be located in any direction required by the station location and its service area. The radiation from tower No. 2, in traveling toward tower No. 1, goes through a 180° phase reversal and arrives out of phase with the radi-



(A) One-half wavelength spacing, in-phase feed.

(B) One-half wavelength spacing, out-of-phase feed.

(C) Quarter-wavelength spacing, 90-degree lag to No. 2.

(D) Quarter-wavelength spacing, 90-degree lead to No. 2.

Fig. 9-14. Basic two-tower spacing and phasing techniques.

ation from tower No. 1. Consequently, the two fields oppose each other, and there is little or no radiation toward the north. The same condition exists toward the south because the radiation from tower No. 2 likewise goes through a 180° phase shift prior to its arrival at tower No. 1.

If the receiver is due east or west from the towers, both signals must travel the same distance to the receiver. Inasmuch as the radiation is in phase, the two components arrive in phase and are additive. Consequently, maximum signal is radiated east and west. This type of horizontal-radiation pattern is indicated by the figure-8 polar drawing. Two antennas spaced 180° apart and fed in phase are often referred to as a *broadside array* because maximum radiation is perpendicular to the plane of the two antenna towers.

Fig. 9-14B demonstrates how the figure-8 pattern can be shifted 90°, just by feeding the two vertical radiators out of phase. With the two towers located the same as before, the radiation from tower No. 2 will arrive in phase with the radiation from tower No. 1 because, in traveling one-half of a wavelength, it has been restored to the same phase as the radiation from tower No. 1. Consequently, the two components will be additive, and maximum signal will be radiated northward. Likewise, there will be maximum radiation in the southerly direction with the arrival of tower No. 1 signal at tower No. 2.

Because the two signals leave the vertical-antenna elements out of phase, any receiver to the east or west of the elements will be the same distance from both towers. Since the two signal components will have traveled the same distance, they will remain out of phase upon arrival. Consequently there will be minimum radiation toward the east and west. The radiation pattern is again a figure-8, but its maximum direction is now north and south.

Figs. 9-14C and D demonstrate how a unidirectional pattern can be established. The two towers are now separated by only 90°. In Fig. 9-14C, the current supplied to tower No. 2 lags the current of No. 1 by 90°. The energy leaving tower No. 1 and moving toward No. 2 now encounters an additional 90° delay and arrives in phase with the radiation from tower No. 2. Therefore the two signals are in phase, and maximum signal is directed southward.

The radiation from tower No. 2, on moving toward No. 1, also incurs a 90° delay and arrives exactly 180° out of phase with the radiation from tower No. 1. Thus, there is a canceling field and minimum radiation northward. With this method of spacing and phasing, most of the energy is radiated south of the east-west line, with little or none to the north.

In Fig. 9-14D, tower No. 2 is fed a 90° leading current, and so the pattern is shifted through 180°. Now the radiation leaving tower No. 1 will again encounter a 90° delay, but will arrive out of phase with the radiation from tower No. 2. Consequently, there will be minimum radiation toward the south. Tower No. 2 radiation also encounters a 90° delay, but arrives in phase with the radiation from tower No. 1. Hence there will be maximum radiation northward. Now it becomes apparent that most of the energy is forced north of the east-west line, and only a limited amount of energy is radiated south of it.

A wide variety of possible patterns, covering many directional-antenna problems, can be obtained from only two towers, provided they are positioned, spaced, and correctly phased. A typical example appears in Fig. 9-15. The directional pattern shown has been established by spacing two towers 100° apart and by feeding tower No. 2 a lagging 100° current. With this combination most of the radiated energy will be concentrated in the southwest quadrant. The transmitter has been located northeast of the primary area to be covered. The pattern protects other broadcast station service areas approximately north-northeast and another area slightly south and to the east of the transmitter. The depth of these two nulls is a function of the magnitude of the currents. Notice that tower No. 2 is being supplied a lower current (0.8) than the unity current of tower No. 1.

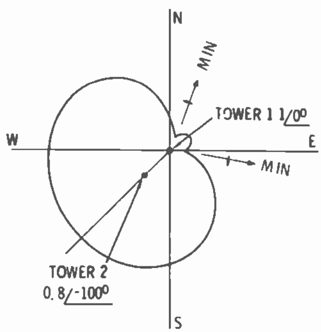


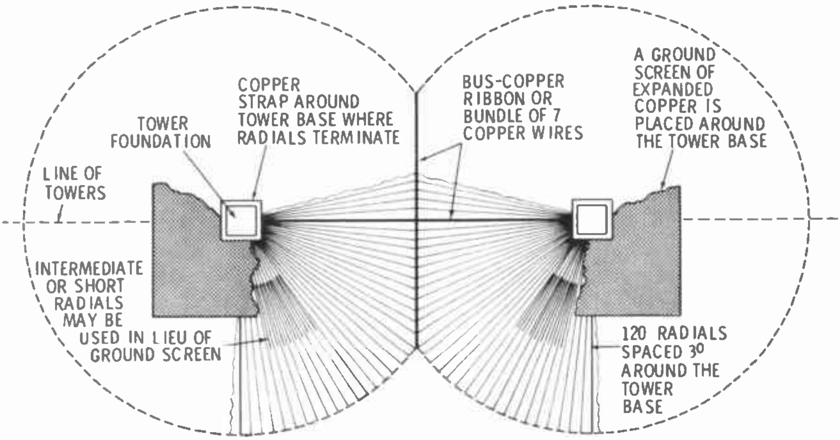
Fig. 9-15. Typical two-tower directional pattern.

The angle of the minima (Fig. 9-15) can be finely regulated by a phasing adjustment. As the phase difference is increased, the two minima will separate further, as per the small arrows. Conversely, the angle can be reduced by decreasing the phase difference. By repositioning the towers, it is possible to rotate the pattern without changing its shape—to meet a particular geographical situation.

Effective reliable performance cannot be derived from a directional-antenna system unless each tower is properly grounded. Fig. 9-16 shows a typical ground system for a two-tower installation. The same grounding plan of a single tower in Fig. 9-16 is also used for each tower when more than two towers are used for a directional system. Each tower must have its own ground screen and radials. In addition, a copper strap, ribbon, or bundle of wires must link the bases and also the junctions of the radials of adjacent towers.

9-10. POWER-DIVIDING AND PHASING ARRANGEMENT

A two-step process is involved in preparing the excitation for the two or more towers of a directional system. A power divider is needed in each line to establish the proper magnitudes between antenna currents, and a phase-shift network must be included in each line to estab-



Courtesy RCA Corp.

Fig. 9-16. A two-tower ground system.

lish the correct phase relationship between antenna currents. In some two-tower directional systems, the phase-shift network is included in only one of the transmission lines to the towers. The most common arrangement is shown in the block diagram of Fig. 9-17.

One factor in establishing the required phase relationship between currents is the difference in electrical length of the lines feeding the antenna towers. For example, if the current from the first tower travels through an additional 75° of transmission line before reaching the second tower, this 75° must be considered in establishing the overall phase differential required between the currents of the two towers.

In determining the electrical length of a transmission line, its velocity factor (ratio of the speed at which the signal travels along the line, to the speed at which it travels in free space) must be taken into account. The velocity factor of RG17/U is 0.66; in other words, an *electrical* half wavelength of such a cable is 0.66 times the free-space half wavelength. This means that a radio-frequency current traveling along a transmission line which has a *physical* length of one-half wavelength goes through a phase shift substantially greater than 180°.

If the antennas of a two-tower installation are fed over the same length and type of cable, a phasing network must develop the required phase shift. Usually the transmission lines are of different lengths, and

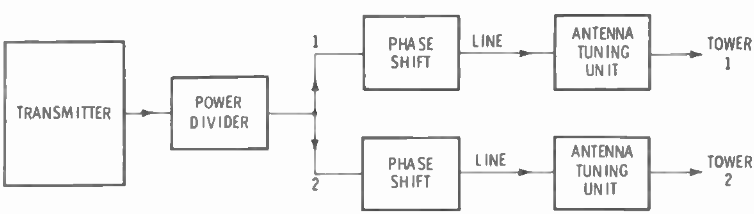
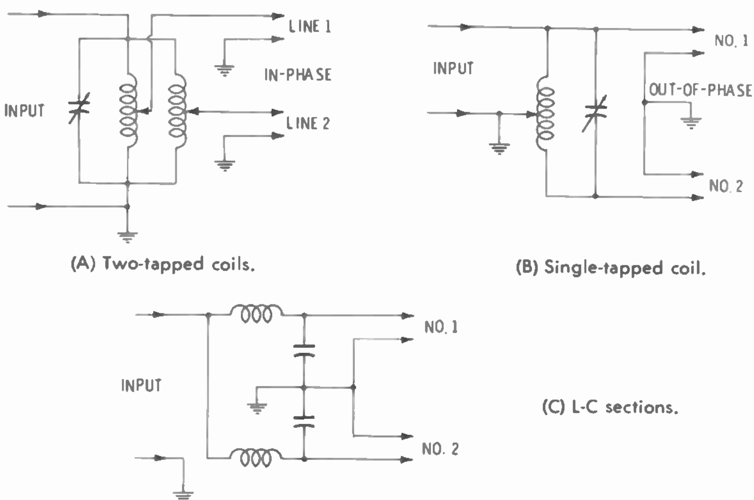


Fig. 9-17. A functional plan of a directional-antenna feed system.

the resultant phase difference between the two lines must be considered in the design of the phasing network. Several power-divider arrangements are shown in Fig. 9-18. In Fig. 9-18A, two in-phase signals must be supplied to lines 1 and 2.

From the block diagram in Fig. 9-17 you will notice that the phase-shifting network comes after the divider point and is usually designed on the basis that the two signals will be exactly in phase or exactly out of phase at the divider output. This arrangement permits in-phase signals to be put on the two lines. Their relative magnitudes can be established with the taps A and B on the output inductors (Fig. 9-18A).



(A) Two-tapped coils.

(B) Single-tapped coil.

(C) L-C sections.

Fig. 9-18. Basic power dividers.

The arrangement in Fig. 9-18B demonstrates how two signals exactly 180° out of phase can be placed on the two lines. Here the relative magnitudes are determined by the position of a single tap on the inductor. This division can also be accomplished with LC sections, as shown in Fig. 9-18C. The constants are selected to establish the proper current division.

Most power dividers are also designed to maintain an impedance match between the transmitter, phasing networks, and/or transmission lines. In more complex arrangements, however, impedance-matching networks must be placed ahead of the power divider. Often the output tuning system of the transmitter can be adjusted to match the input of the power divider.

The phase-shift network follows the power divider as shown in Fig. 9-17. Several typical phase-shift networks are shown in Fig. 9-19. Although the examples show T networks, pi networks can be used for phasing adjustment as well as impedance matching. At the same time, the proper current lag or lead is established by placing inductors or capacitors in the series path to retard or advance the current flow. With inductors, a large-angle lagging network is established; and with capacitors, a large-angle lead network. A combination of the two in the series path permits a small-angle lead or lag, as desired.

In a directional-antenna system the correct phase relationship is established by proper use of both the phasing networks and the required transmission-line lengths. Usually some means of controlling the phase shift over a limited number of degrees must be incorporated so that variables and other day-to-day fluctuations can be tuned out. A basic 90° phase-shift network, such as that shown in Fig. 9-19E, is usually used. A change of several degrees can be accomplished without an adverse influence on impedance matching.

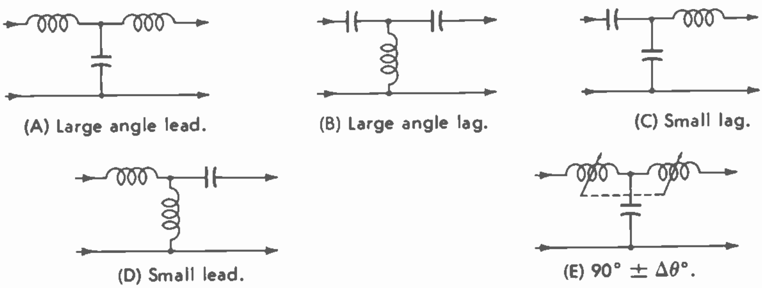


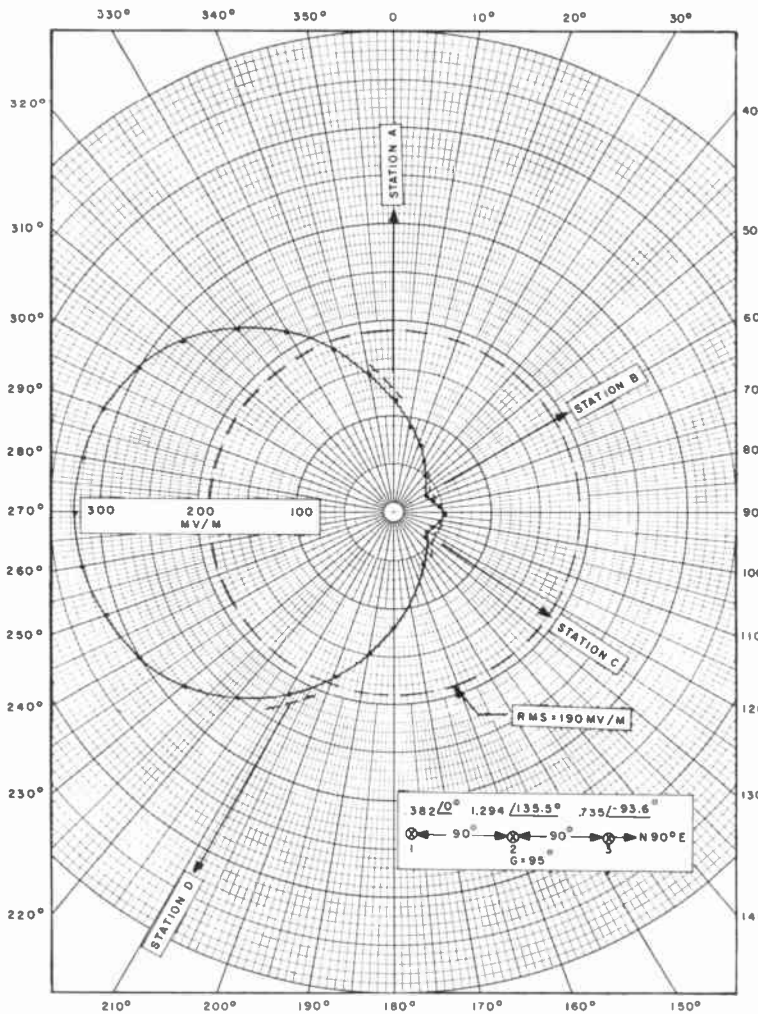
Fig. 9-19. Basic phasing networks.

The phase monitor of a directional-antenna installation allows the operator to constantly keep an eye on the magnitude and phase of the currents. Samples of the current are taken from the vertical antenna, as demonstrated in Fig. 9-5, and supplied to the monitor. The readings are recorded periodically in the transmitter log. When suitably calibrated, the phase monitor is useful in tuning and in indicating early trouble in the directional performance of the antenna system.

9-11. MULTIPLE-TOWER SYSTEMS

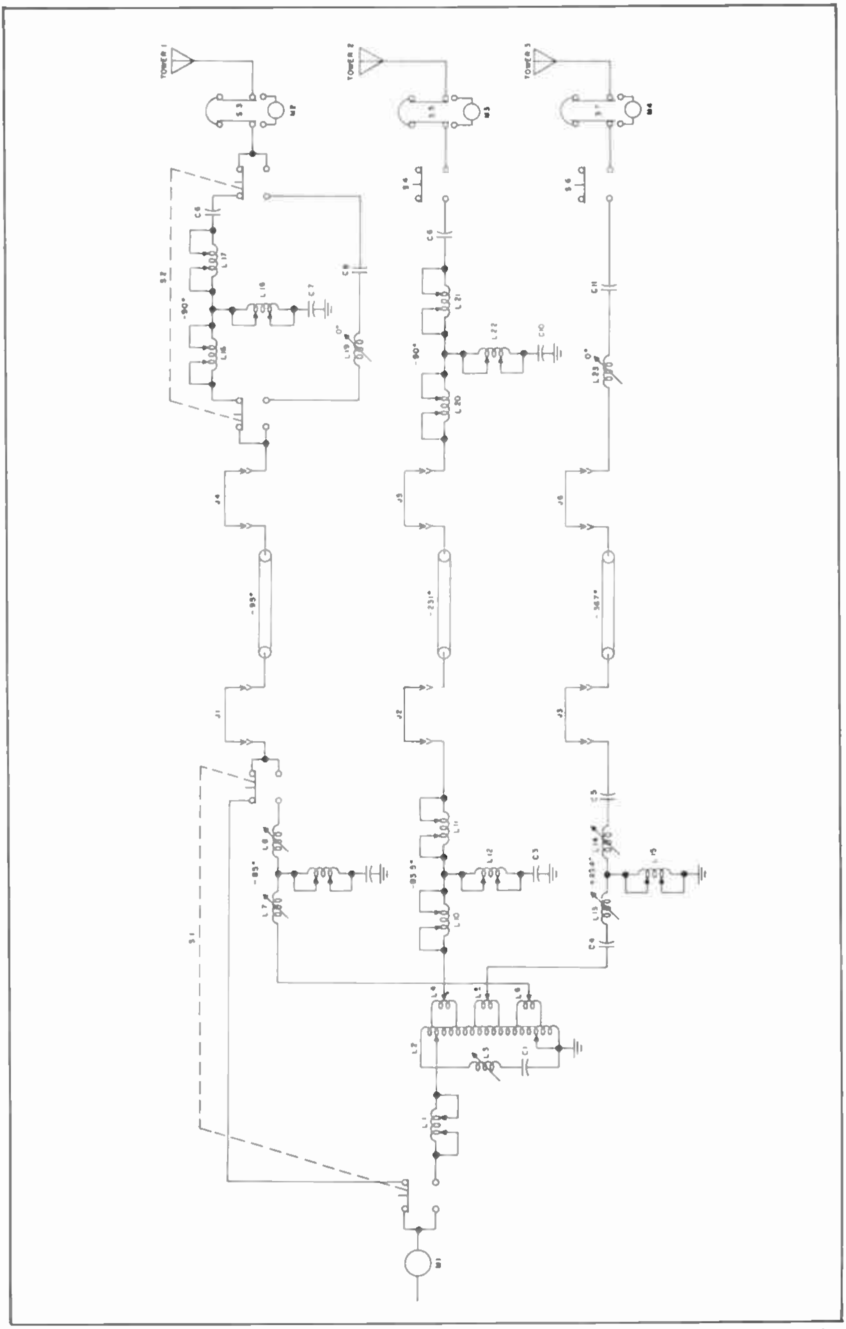
Three or more directional elements are usually employed by high-powered stations to obtain a particularly complex pattern. Sometimes such highly directional patterns are used in order to concentrate the rf energy and thus provide blanket coverage of the area, even though a less-directional pattern would satisfy the FCC ruling about interference.

A highly concentrated pattern that prevents interference with the radiation of four other stations (A, B, C, and D) is illustrated in Fig. 9-20. It can be obtained with three towers, using the spacing, phasing, and magnitudes indicated. The towers are mounted in a straight line running east and west (90° -270° in Fig. 9-20). The wavelength in degrees between each tower, the current of each tower and their phase angles in relation to tower No. 1 (polar coordinates), and the geographic location of the station towers are given in the lower right corner of Fig. 9-20. Fig. 9-21 is a functional diagram of the phasing equipment required to obtain such a pattern.



Courtesy Collins Radio Co.

Fig. 9-20. A typical three-tower directional pattern.



Courtesy Collins Radio Co.

Fig. 9-21. Circuit of a three-tower phasing system.

Many stations operate directionally during nighttime only, because of the wider coverage at nighttime and hence the greater risk of interference. For nondirectional operation using tower No. 1, switches S1 and S2 must be in the positions shown. The transmitter output will now be supplied directly to tower No. 1.

For directional operation the transmitter output is supplied, through a matching network, to a power divider consisting of L4, L5, and L6 across matching network coil L2. The taps (on L4, L5, and L6) are made in accordance with the currents supplied to the three towers. Tower No. 2 receives the highest current (1.294 amp/135.5°) and No. 1 the lowest (0.382 amp /0°), with tower No. 3 falling in between (0.735 amp /−93.6°), as shown in Fig. 9-20. The angles indicated at each tower are the phase angles of each tower in relation to tower No. 1. The input phase-shift networks (1 and 3) are adjustable to permit a fine setting of the phase to towers 1 and 3. These networks also contribute a certain amount of absolute phase shift and provide an impedance match to the individual transmission lines. Additional phase shifts are contributed by the transmission lines (the line to tower No. 3 supplying the most). However, 90° shifts are also contributed by the matching networks between towers No. 1 and No. 2 and their lines. A zero phase-shift network is in the path between tower No. 3 and its line.

The power divider and the adjustable segments of the phase-shift networks are usually mounted near the transmitter. Meter M1, at the top of the phasing-unit cabinet, is associated with the input to the phase-shift network and measures the joint current. M2, M3, and M4 in Fig. 9-21 are located in the respective tuning units of the three towers.

The sensors for remote meters can be installed at the antenna and read at the transmitter-building phase monitor. In addition to a remote phase-monitor, individual current meters for each line are used in tuning the antenna-coupling networks. During normal operation the antenna-current meters are switched out of the circuit to protect them from being damaged by lightning.

CHAPTER 10

FM Transmitters

10-1. DIRECT FM TRANSMITTERS

The direct fm transmitter (Fig. 10-1) uses a self-excited oscillator stage (tube or solid state) that is frequency deviated by a reactance device. The electronic reactance is connected so that its output displays a capacitive or an inductive reactance across the oscillator. When an audio signal is supplied to its input, the output reactance follows the audio variations. In other words, the reactance circuit functions as either a variable capacitor or variable inductor across the frequency-determining circuit of the oscillator. Hence, the oscillator frequency varies with the applied audio signal.

The limits of frequency change (deviation or modulation) depend on the amplitude of the applied audio signal—the greater the amplitude, the greater the frequency change. The rate of frequency deviation depends on the frequency of the applied audio—the higher the audio frequency, the faster the deviation rate of the oscillator frequency.

In fm broadcasting, carrier frequencies are assigned in the 88–108-MHz band. The maximum permissible fm deviation is ±75 kHz; this constitutes 100-percent modulation. The FCC requires that an fm transmitter must deviate linearly over a 100 kHz range. In so doing, a very linear deviation over the ±75 kHz range is ensured despite drift or other variables.

The extent that an oscillator can be deviated linearly is limited, particularly when a high order of center-frequency stability is to be maintained. Consequently, the frequency-modulated oscillator usually operates on a frequency substantially lower than the final carrier frequency of the transmitter. A group of multiplier stages follows the oscillator, multiplying both the center frequency and the deviation. In the example shown in Fig. 10-1, the total multiplication is 18. To operate on a frequency of 90.1 MHz would require that the center frequency of the oscillator be 90.1 ÷ 18, or 5.505 + MHz. For 100-percent modulation the maximum deviation must be ±75 kHz ÷ 18, or approximately ±4.16 kHz.

After the fm signal passes through the multipliers and is made equal to the assigned carrier frequency, it is amplified by the intermediate and final power amplifiers. It is then conveyed through a transmission-line system, to the fm antenna.

The power output of an fm broadcast station is based on its effective radiated power (ERP). This value is the product of the power delivered to the antenna and the antenna power gain or:

$$ERP = P_{Ant} \times \text{antenna power gain}$$
$$ERP = (P_{Transmitter} - P_{line\ Loss}) \times \text{power gain}_{Ant}$$
$$ERP = P_{Ant} \times (\text{field gain}_{Ant})^2$$

The FCC requires that the center frequency of each fm broadcast station be maintained within 2000 hertz of the assigned frequency. Therefore, some means of precise frequency control must be used.

In the direct fm plan shown in Fig. 10-1, a portion of the modulated-oscillator output is supplied to the frequency divider of an automatic frequency-control (afc) section. The output of the frequency divider is compared in the phase detector with one-fifth of the output frequency of the reference crystal oscillator. If the center frequency drifts, a dc error voltage is developed by a phase detector and supplied to the reactance device. This dc bias component determines the exact center frequency of the oscillator. This operation in no way influences the normal deviation of the oscillator. In most transmitter designs, the frequency stability is much better than the 2000-hertz FCC limit.

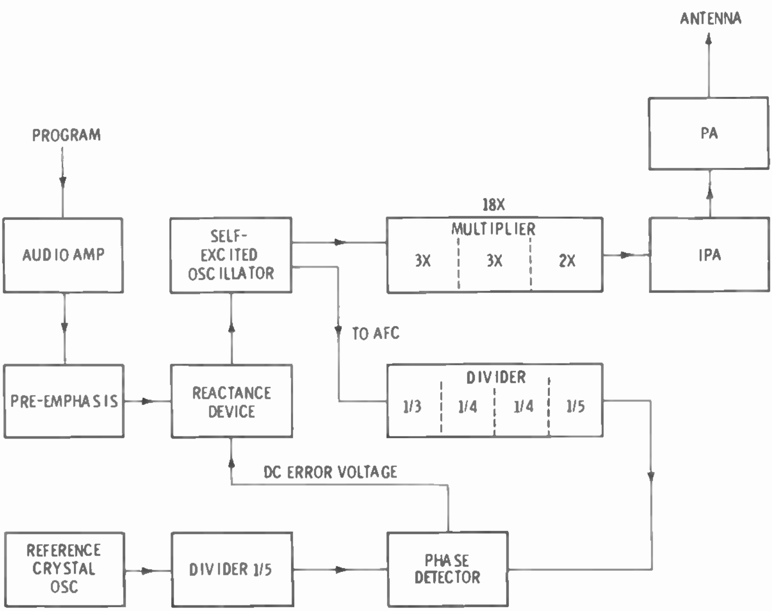


Fig. 10-1. Block diagram of a direct fm transmitter.

In some fm transmitters, the comparison circuits in the afc system control a motor that is linked mechanically to a variable capacitor in the oscillator tank circuit. Any drift in the oscillator center frequency causes the motor to rotate the variable capacitor the amount required to restore the proper center frequency.

In the plan shown in Fig. 10-1, the center frequency is supplied to a 240-to-1 frequency divider ($5 \times 4 \times 4 \times 3$). The frequency output of the last divider would be 5.005 MHz $\div$ 240, or 20.8$^+$ kHz.

The maximum deviation would also be divided down by a like amount: $\pm 4.16^+ \div 240$, or $\pm 17^+$ hertz.

This value of deviation is now so slight ($\pm$17 hertz) that it cannot adversely influence the operation of the afc circuit. The comparison signal for the afc activity is developed by a stable crystal oscillator which supplies signal to a 5-to-1 divider. The crystal oscillator operates at approximately 140 kHz, developing a 20.8-kHz reference signal at the divider output. The phase detector develops a dc error voltage that is a function of the extent and the direction of the center-frequency drift with respect to the crystal-controlled component. This dc error voltage, as mentioned, corrects the oscillator frequency by way of the reactance tube.

10-2. INDIRECT FM TRANSMITTERS

The indirect fm transmitter shown in Fig. 10-2 uses phase modulation (pm) to generate an fm wave indirectly. A crystal oscillator can be employed in the phase-modulation process. Thus, the center-frequency stability is controlled without an afc system.

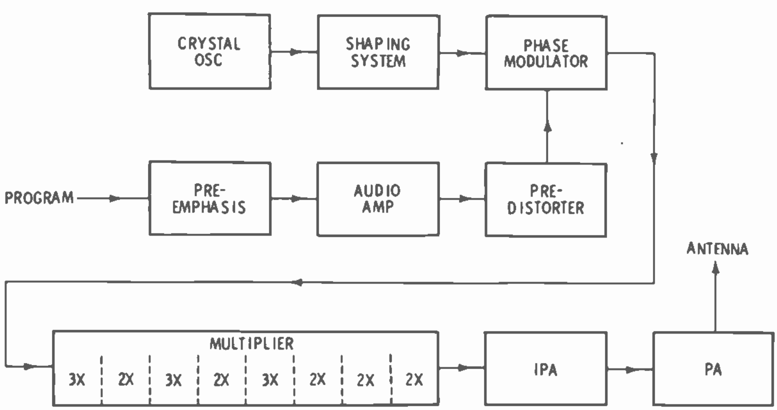


Fig. 10-2. Block diagram of an indirect fm transmitter.

A phase-modulation system does have limitation with regard to deviation. If a linear deviation is to be established using the pm process, there is a limit to which the center frequency may be phase-shifted—perhaps several hertz at a center frequency of several hundred kilohertz, using some of the older methods. In fact, it was necessary to multiply the deviation to a greater extent than the center frequency in order to obtain the ±75 kHz desired. The development of special tubes for phase modulation, plus new circuit techniques, have eliminated this additional complexity. However, even in the modern phase-modulated transmitters the modulation process begins at a center frequency in the 100-kHz range.

As in the case of the direct fm transmitter, a series of multiplier stages follows the modulated stage. Several additional multiplier stages are required by the phase-modulated transmitter because of the lower frequency at which modulation has taken place. However, the phase-modulated transmitter requires no afc system. In a typical phase-modulated transmitter, the total multiplication of the stages might be around 850.

10-3. DEVIATION AND BANDWIDTH

In the fm process a number of sideband pairs are generated according to modulating frequency and deviation. This is unlike the a-m process, which generates only one pair of sidebands. The number of significant sideband pairs generated is a function of the modulation index, which has the following relation:

$$\text{Modulation Index} = \frac{\text{Deviation (kHz)}}{\text{Modulating Freq. (kHz)}}$$

The higher the modulation index is, the more sideband pairs there are. As shown in Fig. 10-3, the sidebands are displaced from the center frequency by multiples of the modulating frequency. In comparing Figs. 10-3A and 10-3B, notice that the greater the deviation (increase in the audio amplitude), the more sideband pairs are generated and the greater is the bandwidth occupied by the transmitted fm signal. The higher the audio frequency, the greater is the separation between sideband pairs and the greater is the bandwidth of the transmitted signal (compare Figs. 10-3A and 10-3C).

The *maximum bandwidth* of a transmitted fm signal is a function of the modulation index at *maximum permissible deviation* (100-percent modulation) and *highest audio frequency*. The sideband distribution for a deviation of ±75 kHz and an audio frequency of 15,000 hertz is shown in Fig. 10-3D. For a modulation index of 5, the number of significant sideband pairs is 7. These would occupy a span of frequencies some 210 kHz wide.

The FCC channel assignments are only 200 kHz wide. However, we have considered the bandwidth extreme in the example. Seldom is a maximum-amplitude high-frequency note transmitted in the usual program material. High-frequency components are low in amplitude and cause a correspondingly lower deviation. Furthermore, the very high-frequency notes occur quite infrequently for most high-fidelity programs. Consequently the assigned 200-kHz bandwidth is adequate for high-fidelity broadcasting.

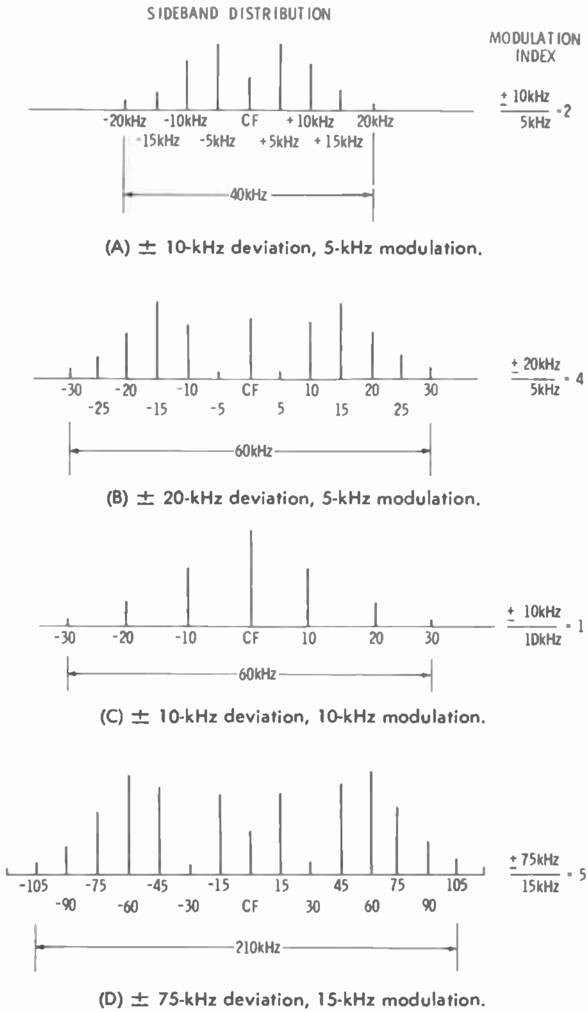


Fig. 10-3. Frequency and energy distribution for four values of modulation index of an fm signal.

10-4. PRE-EMPHASIS AND DE-EMPHASIS

A major advantage of an fm transmission system is that it can be designed to reject amplitude noise components. Inasmuch as most interference is of the amplitude-varying type, an fm system has a more favorable signal-to-noise ratio. However, noise and interference can also produce fm components, and so the system is not completely noise-free. Usually the deviations of the fm signal, caused by the desired modulating wave, are much greater than deviations caused by interference.

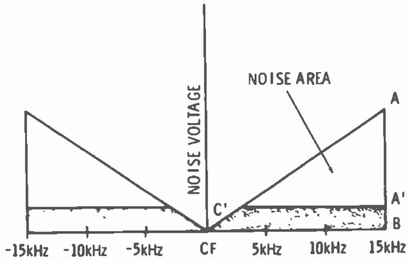


Fig. 10-4. Noise with and without pre-emphasis as related to center frequency.

In an fm system, according to Fig. 10-4, the noise interference has less effect when it exists at low audio-sideband frequencies near the center frequency. If the interference beat occurs at a higher frequency, a greater unwanted deviation of the fm signal occurs. Thus the noise-rejection characteristics of the fm system decreases in the direction of a higher interference frequency.

The noise-rejection characteristic of an fm system can be improved by pre-emphasis of high-frequency audio components. The pre-emphasis circuit, as shown in Figs. 10-1 and 10-2, is inserted in the audio-amplifier section of the transmitter. The pre-emphasis network displays a decreasing attenuation as the audio frequency increases, as in Fig. 10-5. Consequently, higher-frequency components produce a greater deviation of the broadcast signal than lower-frequency components of the same amplitude. By so modulating, the system is made less subject to high-frequency interference because the desired high-frequency modulation now causes a greater deviation of the fm signal. This reduction in high-frequency noise susceptibility produces a flatter overall signal-to-noise relation, as indicated in Fig. 10-4.

The overall frequency response of the fm system is restored to a linear relation by the use of a de-emphasis network in the receiver (Fig. 10-5). This network has an attenuation characteristic equal but opposite to that of the transmitter pre-emphasis circuit. Although the de-emphasis network in the receiver reduces the amplitude of the high-frequency audio components, the noise components are reduced by the same amount.

The pre-emphasis network at the fm broadcast transmitter has been standardized as one having a time constant of 75 microseconds. If a simple RC combination is used as a pre-emphasis network it must have a value of 75 microseconds as obtained from the following formula:

$$TC = R \times C$$

where,

TC is the time constant in microseconds,
R is the resistance in ohms,
C is the capacitance in microfarads.

The de-emphasis network must have the same time constant, but an opposite attenuation characteristic, in order that the exact correction of the frequency response can be obtained when the network is inserted in the circuit.

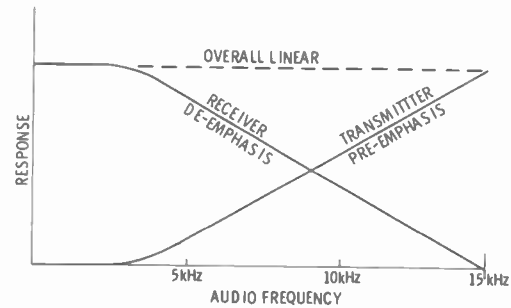


Fig. 10-5. Pre-emphasis at transmitter, de-emphasis at receiver, and overall frequency response.

10-5. FM MULTIPLEX

In a multiplex system, the fm carrier can be modulated by more than one sound signal simultaneously. Multiplex operation has become increasingly popular among fm broadcasters, especially for supplying background music to markets, department stores, industrial plants, etc. Stereophone broadcasting also involves the transmission of a separate but related audio signal on the same fm carrier.

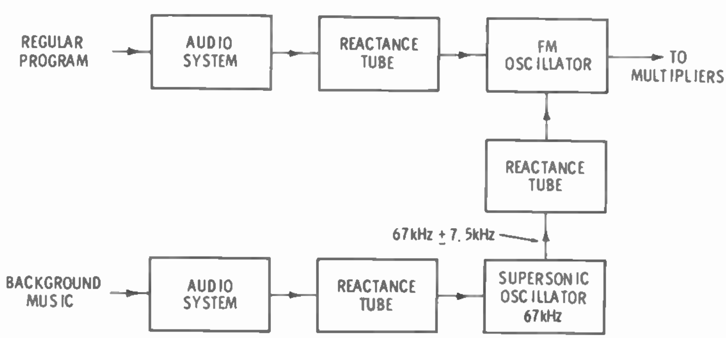


Fig. 10-6. Block diagram of a multiplex transmitter.

In the multiplex system one program will frequency-modulate the fm carrier in the conventional manner. This is the main program channel used for broadcasting to the general public. As shown in Fig. 10-6, a second sound signal can be used to modulate a supersonic carrier. This frequency-modulated subcarrier is then used to frequency modulate the main carrier. The subcarrier is supersonic so that it does not interfere with the main program channel.

A multiplex process must in no way degrade the regular program material, or adversely affect the operation of standard fm receivers when receiving regular fm broadcasts. The FCC technical standards for multiplex operation are:

1. Frequency modulation of the subcarrier must be used.
2. The instantaneous subcarrier frequency must at all times lie within the 20-kHz to 75-kHz range.
3. Modulation of the main carrier by the subcarrier must not exceed 30 percent. This means the maximum permissible deviation of the main carrier by the subcarrier can be only ±22.5 kHz (0.3 times ±75 kHz).
4. The total modulation of the main carrier, including the subcarrier, must be maintained as high as possible consistent with good transmission quality and good broadcast practice, but never less than 85 percent nor more than 100 percent on peaks.
5. Frequency modulation of the main carrier caused by the subcarrier operation must be at least 60 dB below 100-percent modulation in the frequency range between 50 and 15,000 hertz.

In the example of Fig. 10-6, a 67-kHz subcarrier has been selected. This subcarrier is frequency-modulated with perhaps a 100-percent modulation limit of ±7.5 kHz. The frequency-modulated 67-kHz subcarrier is used to frequency modulate the main carrier. At no time may the subcarrier frequency modulation of the main carrier exceed ±22.5 kHz.

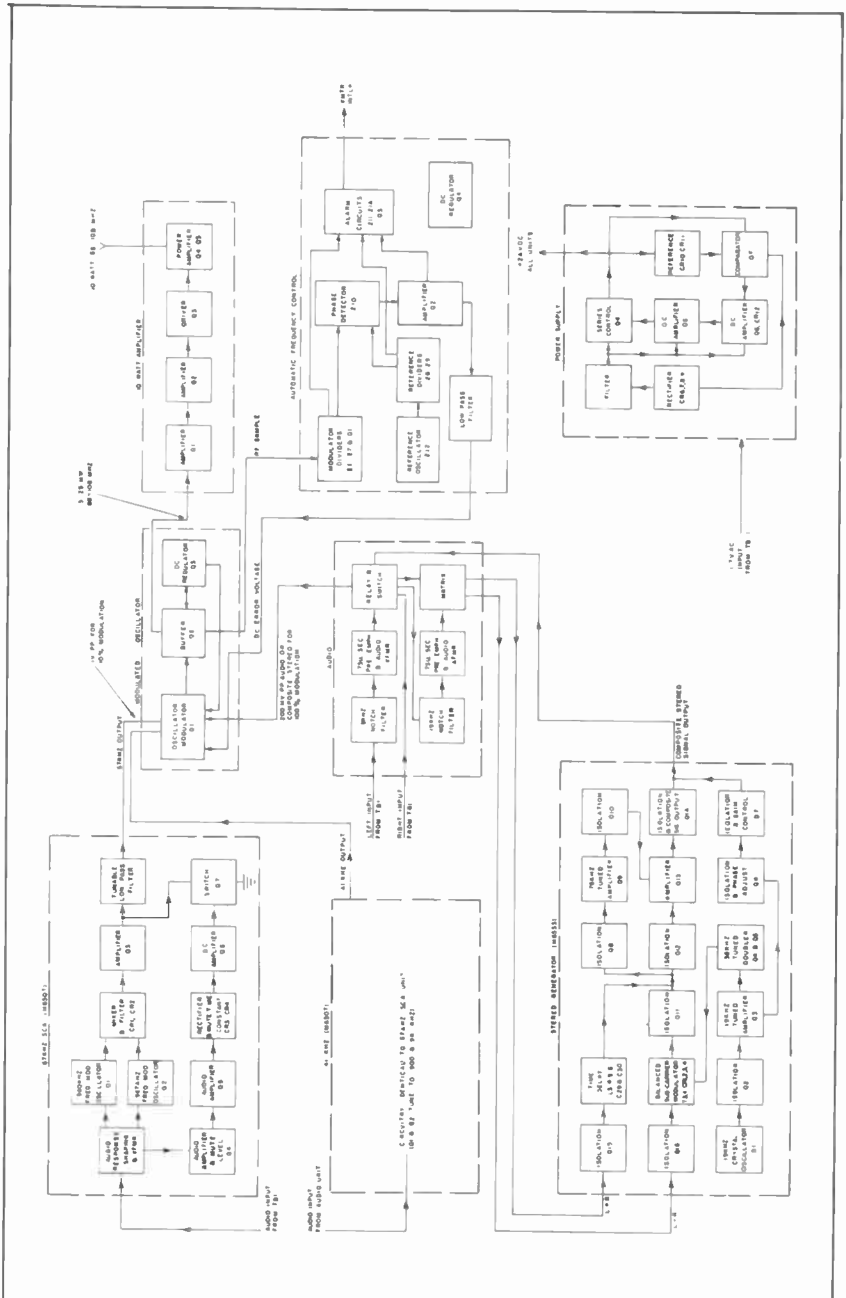
Insofar as a standard fm receiver is concerned, it operates normally in receiving regular program material. Such a receiver does not respond to the subcarrier frequency because of the latter's supersonic range.

A multiplex receiver includes the necessary channel for removing and amplifying the 67-kHz subcarrier. It will then be supplied to a separate fm demodulator and recovered for distribution over an associated music system.

10-6. DIRECT FM EXCITER

A functional block diagram of a Gates 10-watt direct FM exciter is given in Fig. 10-7. The frequency-modulated oscillator is shown at the top center, and consists of the modulated oscillator and a succeeding buffer plus a dc voltage regulator. The 15-25 milliwatt oscillator output is stepped up to the 10-watt level by a succeeding 4-stage amplifier shown at the top right. The oscillator operates on the FCC-assigned frequency.

The automatic frequency control at right center is also supplied with a signal from the buffer output of the modulated oscillator. Its frequency is dropped down to approximately 6000 Hz and applied to a frequency-comparing phase detector. A reference oscillator which is crystal-controlled, operates on an approximate frequency of 1.5 MHz. Crystal oscillator frequency is also divided down to the 6000 Hz range. The divided-down frequency from the modulated oscillator and the divided-down frequency of the reference oscillator are compared in



Courtesy Gates Radio Co.

Fig. 10-7. Functional block diagram of Gates fm exciter.

the phase detector. The output of the phase detector corresponds to any phase displacement (frequency difference) between the two components. This reference develops a dc error voltage which is supplied to the modulated oscillator to keep it on the proper center frequency. By FCC regulation, the center frequency may not drift more than 2000 Hz in the fm broadcast service. The automatic frequency control system also includes alarm circuits which indicate functional failures.

The audio module at the center of the diagram contains the preemphasis networks and additional circuits needed for processing audio signals for use in stereo broadcasts or SCA transmissions. SCA and stereo generator functional blocks at the left will be described later.

The modulated oscillator (Fig. 10-8) consists of a stable frequency-modulated oscillator, an isolating buffer amplifier, and a power supply regulator. The oscillator, transistor Q1, in a common-emitter configuration is connected as a Clapp circuit. Three pairs of stabilizing capacitors are employed according to the frequency of operation. These capacitors are highly stable, reducing the influence of external capacitance and compensating for any frequency drift resulting from temperature variations. Voltage-variable capacitor diodes, CR1, CR2 and CR3, permit controlled changes in the frequency of operation of the oscillator.

Such diodes have a capacitance that is a function of the dc voltage present across their elements. The capacitance change of diode CR3 is in response to the dc error voltage contributed by the afc unit. Its function is to maintain the oscillator on a correct center frequency. Recall that the dc error voltage is a result of the comparison between the divided frequencies of the modulated oscillator, and the reference frequency of the crystal oscillator in the afc unit. The actual oscillator comparison voltage is removed at the collector of buffer transistor Q2, and is supplied through capacitor C18 to the afc unit.

Diodes CR1 and CR2 produce the actual frequency modulation of the oscillator, deviating the oscillator frequency on each side of center frequency in accordance with the variations of the modulating wave.

The various signal inputs are shown at the left. The two inputs at the top are for the SCA signals (two blocks at the top left of the functional diagram in Fig. 10-7). The fm program signal is supplied to the third terminal. This can be a monophonic or stereophonic signal.

Program signals are applied to the junction of the two voltage-variable capacitor diodes and cause their capacitances to change in a balanced manner with the program signal variations. Since these capacitances are a part of the resonant circuit of the oscillator there is a linear deviation of the oscillator frequency in accordance with the voltage variations of the program signal.

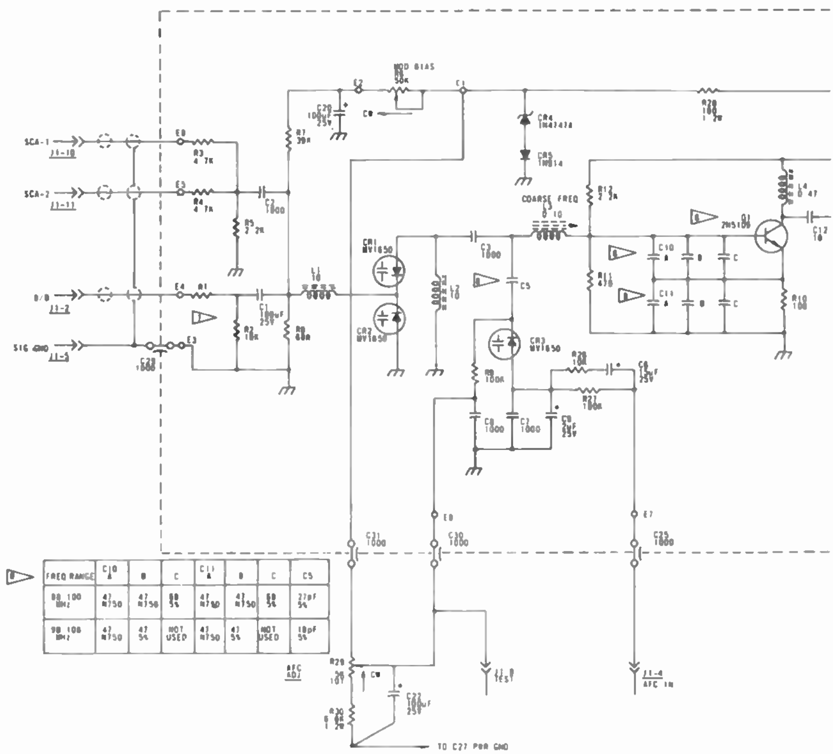
The frequency of the resonant circuit is also determined by inductor L3 which is used as a coarse frequency adjustment. Two potentiometers, R6 and R29, also have an influence on the modulated oscillator performance. Potentiometer R29 is, in effect, a fine frequency control which sets the dc voltage felt across the voltage-variable capacitor CR3. This provides a fine adjustment of the center frequency of the fm transmitter. Potentiometer R6 applies the proper dc bias to the voltage-variable capacitors to which the program material is applied. Balance is set in such a manner that the diodes respond in a linear manner to the audio variations, thus producing a linear deviation of the oscillator frequency.

The collector output of the modulated oscillator is applied to the base of the buffer through an isolation network. The modulated oscillator supplies a moderately strong output and it can be attenuated and still provide enough drive for the buffer. The attenuator provides good isolation between the buffer and the oscillator, and prevents changes in circuit operations from influencing the frequency of the modulated oscillator.

The collector output of the buffer is supplied through a low-pass filter (inductor L8 and capacitors C23 and C24) to an output attenuator. From here the frequency-modulated signal is supplied to the input of the succeeding 10-watt amplifier.

The afc output was mentioned previously. Also, diode CR8 rectifies a portion of the output of the buffer. The resultant dc component is applied to the monitor output of the modulated oscillator. It provides a check of the rf output of the modulated oscillator.

Zener diodes CR4 and CR6 provide regulation in the dc bias circuit of the voltage-variable capacitors and in the base of the voltage regu-



FREQ RANGE	C10 A	B	C	C11 A	B	C	C5
88–100 MHz	47 N750	47 N750	68 5%	47 N750	47 N750	68 5%	22pF 5%
98–108 MHz	47 N750	47 5%	NOT USED	47 N750	47 5%	NOT USED	18pF 5%

Fig. 10-8. Modulated

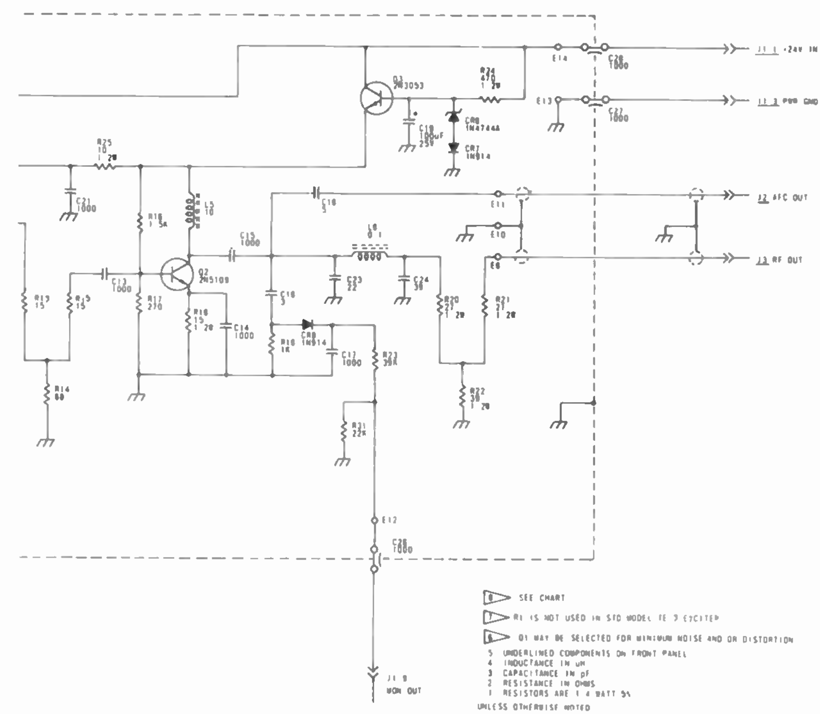
lator Q3. The use of the transistor regulator permits the regulation of the higher currents drawn by the collectors of transistors Q1 and Q2.

The 10-watt amplifier (Fig. 10-9) is a four-stage affair. The output stage uses two transistors connected in parallel to provide a 10-watt output when the input signal power to the amplifier is only several hundred milliwatts. Input signal is applied through an rf drive potentiometer, R11; the setting of R11 determines the rf power output of the amplifier.

The first two stages are reasonably the same and use interstage transformers T1 and T2 which match low-impedance base circuits to the higher-impedance collector circuits. Resonance and impedance-matching adjustments are made with capacitors C4 and C7.

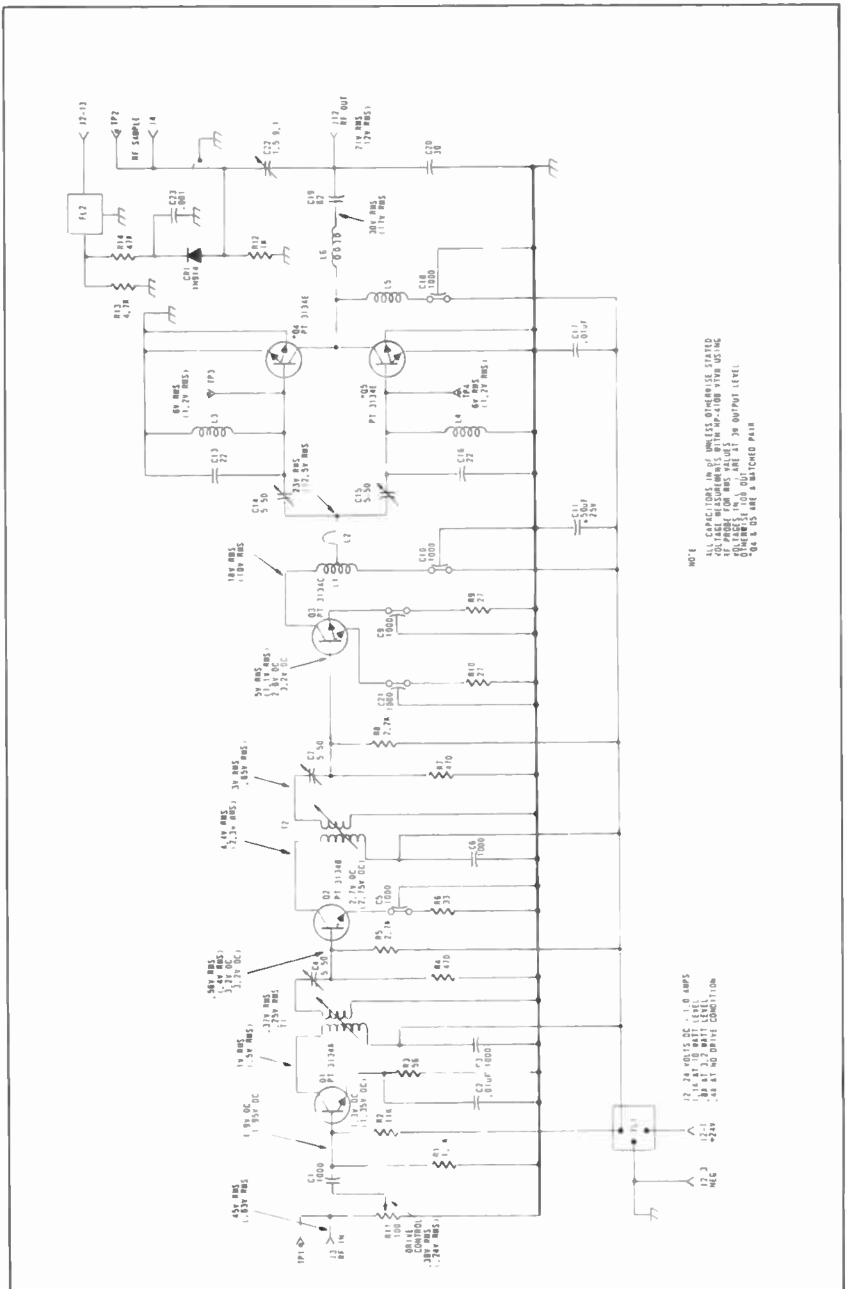
The driver transistor Q3 and the parallel-connected output transistors Q4 and Q5 are vhf types with balanced-emitter configurations. Low capacitances result and permit good stage efficiency despite the high operating frequency. Resonance and impedance matching are handled by inductors L1 and L2, along with capacitors C14 and C15. The output circuit is a modified pi network using inductors L5 and L6, plus capacitors C19 and C20.

Rf samples for monitoring and adjustment are removed by way of capacitor C22. A small rf component is rectified and filtered by diode



Courtesy Gates Radio Co.

oscillator.



Courtesy Gates Radio Co.

Fig. 10-9. A 10-watt amplifier.

CR1 and a resistor-capacitor output combination, forming a dc monitoring component that is a function of the rf output level of the amplifier.

The Gates afc unit is shown in Fig. 10-10. The output of the buffer stage of the modulated oscillator is supplied to input receptacle J1 at the top left. A series of seven integrated-circuit flip-flop multivibrators follow. The first four provide an overall countdown of 16; the latter three provide counts of 16, 16 and 4 respectively. Therefore the total countdown is 16,384 ($16 \times 16 \times 16 \times 4$). The output, in the 6-kilohertz range, is supplied to an integrated-circuit phase detector, Z10.

The reference crystal-controlled oscillator uses an integrated circuit, Z12. The first two transistors are connected in multivibrator fashion with common-emitter coupling. The crystal itself is a high-stability unit enclosed in a temperature-controlled oven. Coarse frequency is set with capacitor C27, while a fine frequency adjustment is accomplished with potentiometer R48 which sets the bias for the voltage-variable capacitor CR10.

The oven itself is in the form of a solid-state circuit that maintains the oven temperature at exactly 60°C. The arrangement consists of an integrated circuit dc differential amplifier Z13 which responds to changes in the resistance of thermistor RT1. Its dc output, through transistor Q5, determines the current drawn through oven heater resistor R38.

The third transistor of integrated circuit Z12 serves as a buffer, developing the necessary drive for the two counters Z8 and Z9. These counters provide a total countdown of 256 (16 each). The output of the second counter is applied to the phase detector integrated circuit Z10.

If the two signals at the inputs of the phase detector (divided-down center frequency from fm exciter and divided-down frequency from reference oscillator) are the same, the output of the detector is a square wave with equal positive and negative segments (50-percent duty cycle). This output provides a reference component for application to the amplifier and detector transistor Q2. Output is filtered to obtain a reference dc voltage.

The duty cycle of the squared wave at the output of the detector is proportional to the difference in the two input frequencies. The dc component of current drawn by transistor Q2 responds to this change in duty cycle, and the dc output voltage shifts above or below the refference value in accordance with any tendency of phase shift between the two incoming frequencies. This *dc error voltage* is applied back to the modulated oscillator to keep the center frequency of the fm broadcast transmitter on its FCC-assigned frequency.

The factors monitored by the alarm system are the outputs of the reference and modulator-oscillator frequency dividers and the so-called out-of-lock condition. Output from the reference divider is rectified by diodes CR1 and CR2. The dc component is amplified by integrated-circuit Z11 and applied to the alarm circuit. A similar arrangement exists for monitoring the output of the modulated-oscillator divider chain. Either dc component operates integrated circuit Z14 and turns on transistor Q3 which will draw current through the alarm light and relay coil K1.

If the modulated oscillator should drift out of the frequency control range of the afc circuit there is a large ac component developed at the collector of transistor Q2. This large ac component applied to section A of integrated circuit Z14 is detected by diodes CR12 and CR11. The resultant dc voltage turns on section B of integrated circuit Z14 and transistor Q3, thus setting off the alarm system.

10-7. SCA SUBCARRIER GENERATOR

An SCA generator permits an fm broadcast station to transmit special background music and other subscription program material in addition to the regular fm program. The SCA generator is a part of the fm exciter, as shown in Fig. 10-7. The most common SCA subcarrier frequency is 67 kHz. Although the fm station is transmitting stereo

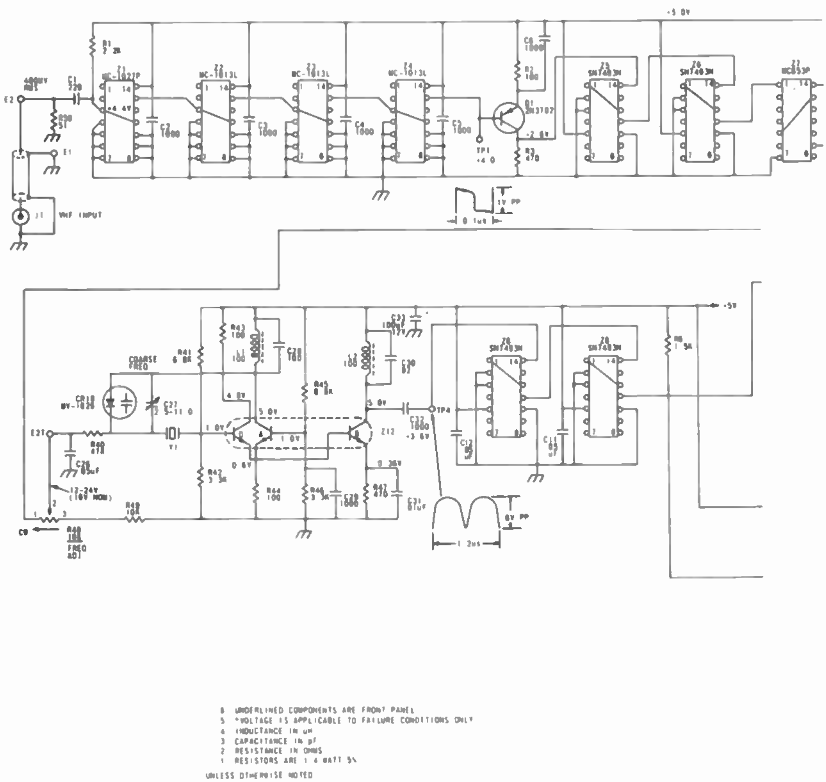
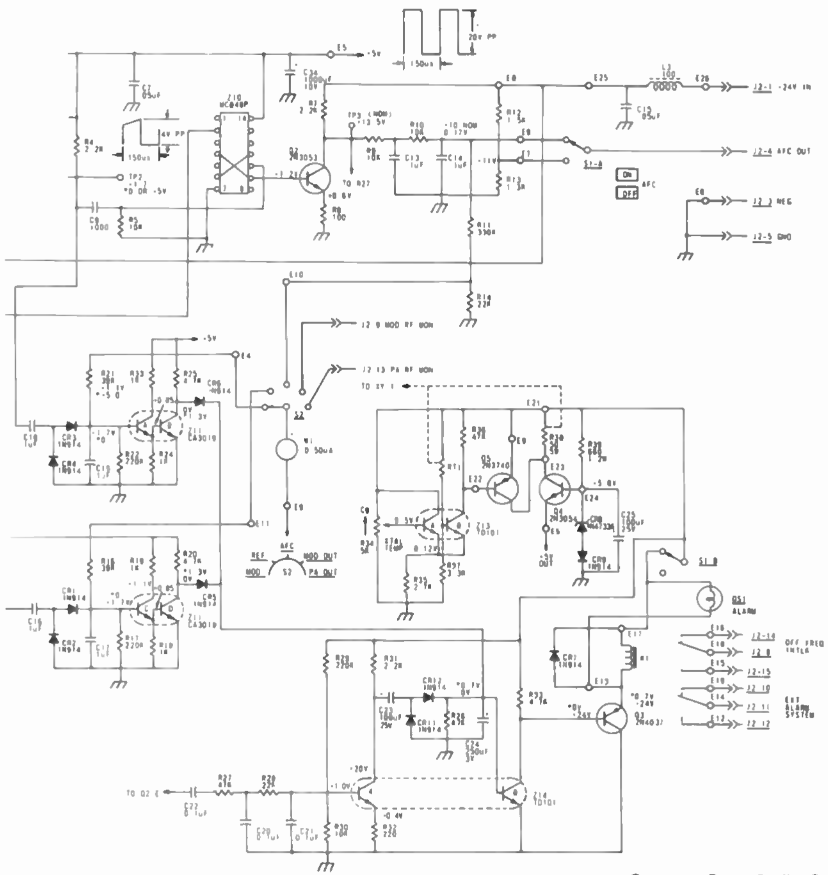


Fig. 10-10. The

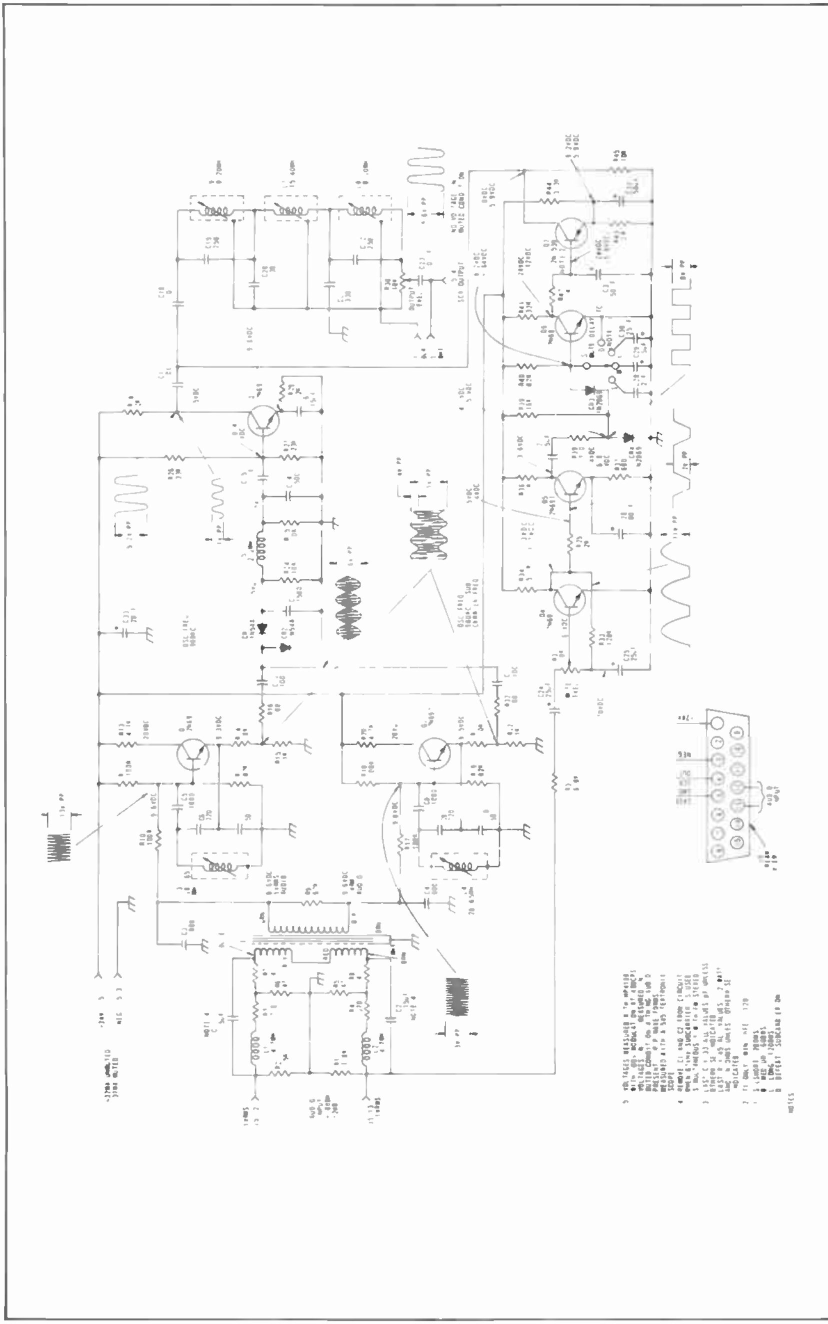
programs, an SCA signal can be conveyed simultaneously. Another SCA subcarrier frequency is 41 kHz, which can be used when the station does not transmit a stereophonic fm signal and wishes to transmit two SCA signals

An SCA generator is shown in Fig. 10-11. This generator permits the selection of either of the SCA subcarrier frequencies of 41 kHz or 67 kHz. The Colpitts oscillator circuit associated with transistor Q1 operates on 900 kHz, while the circuit of transistor Q2 can be operated on either 941 or 967 kHz. The actual subcarrier frequency is then the difference between the two oscillator frequencies. Note that the two outputs are mixed in the CR1 and CR2 diode mixer circuit. The output filter network selects the difference frequency and attenuates harmonics of the subcarrier frequency and the two oscillator frequencies as well. After amplification by transistor Q3 the signal meets a very elaborate tunable low-pass filter which removes all harmonics of the subcarrier frequencies.



Courtesy Gates Radio Co.

Gates afc unit.



Courtesy Gates Radio Co.

Fig. 10-11. An SCA generator.

The subcarrier is frequency-modulated by applying the audio variations to the bases of the two oscillators. Such voltage variations at the bases cause corresponding changes in the effective base-emitter capacitance of each of the oscillators. In turn, the capacitance variations deviates the frequency of each of the Colpitts oscillators.

The audio modulation is applied by way of transformer T1. Since the modulating information is fed out of phase to the bases of the two oscillators and the outputs of the two oscillators are in parallel, there is a two-fold increase in the net deviation as compared to the frequency modulation of just one of the oscillators. An audio shaping circuit is present in the primary circuit of the transformer. It controls audio response to obtain a linear deviation and a rolloff of the frequency response above 5 kHz.

The four transistors at the lower right are part of a so-called muting circuit. When audio is applied to the input of the generator, the muting control transistor Q7 is nonconducting. The modulated subcarrier signal can be removed at the SCA output. However, when there is no modulating information applied, the control transistor Q7 conducts and places a low resistance shunt to common from the junction of capacitors C17 and C18. This reduces the magnitude of the unmodulated subcarrier signal some 50 to 60 dB.

The arrival of modulating information at the base of transistor Q4 initiates formation of a squared wave. This wave applied to transistor Q6 establishes a nonconducting state for transistors Q6 and Q7. As a result there is no muting of the output circuit. The removal of the program material removes the squared waves and transistors Q6 and Q7 conduct.

10-8. FM ANTENNA SYSTEMS

The horizontally polarized antenna is universal in fm broadcasting, whereas most a-m broadcast stations use a vertically polarized antenna. Although an fm broadcast antenna includes a tower, it is only a support for the radiating elements of the antenna; but in a-m broadcasting, the tower is actually the radiator. In many fm/a-m stations, the tower serves as both the vertical radiator for a-m operation and the support for the radiating elements of the fm antenna system. Currently a number of fm stations transmit both horizontally and vertically polarized components. The vertical components improve reception on fm car radios and small fm radios using whip and line-cord antennas.

The radiating elements of an fm antenna are usually modified dipoles, spaced one above the other to provide the desired antenna power gain. Typical gains for the vertically spaced horizontal dipoles used in fm broadcasting are given in Table 10-1. It is these power gains times the antenna input power that determines the effective radiated power (ERP) of a given fm station.

In fm broadcasting it is advisable to concentrate the vertical radiation at very low angles, to provide the best coverage of the service area. Any vhf energy radiated at high vertical angles represents wasted power because it does not return to earth. The stacking of horizontal

Table 10-1. Typical Antenna Power Gains

Bays	Power Gain
1	0.9
2	1.6—2
3	3
4	3.7—4.1
5	5.1
6	6—6.3
7	7—7.3
8	7.3—8.3

dipole elements concentrates the radiated power into low vertical angles. The horizontal- and vertical-radiation patterns of a simple half-wavelength horizontal dipole are given in Fig. 10-12A. The vertical radiation pattern looking into the end of a single dipole is circular. However, by stacking dipoles in bays it can be elongated at low angles (Fig. 10-12B).

The doughnut-shaped radiation pattern of a dipole is a figure 8 in the horizontal plane. This is not desirable for uniform coverage at all

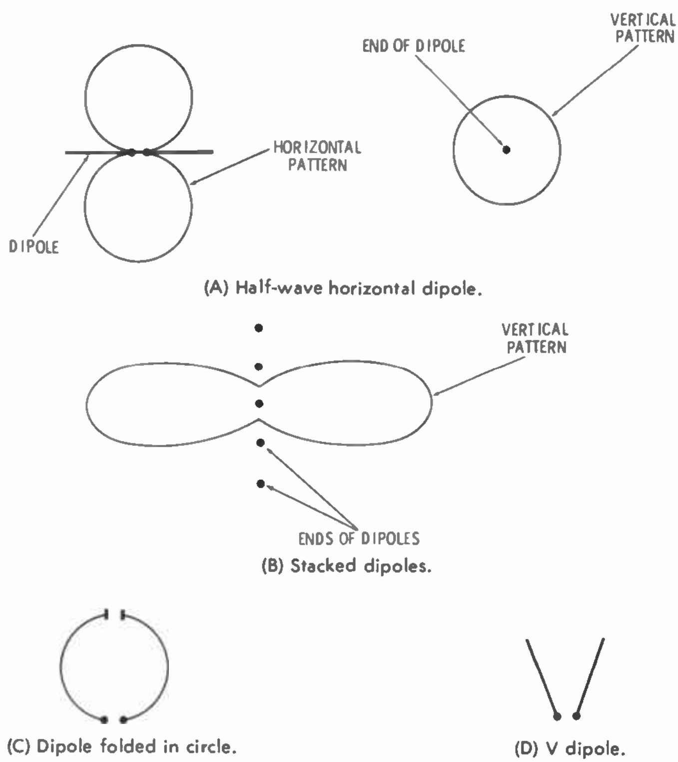


Fig. 10-12. Basic fm (dipole) antenna types and modulation pattern.

compass angles. Two steps can be taken to make the horizontal-radiation pattern more circular. The dipole can be folded around in a circle, as shown in Fig. 10-12C, to make its horizontal-radiation pattern more omnidirectional. In the arrangement of Fig. 10-12D, the dipole is cut for several megahertz higher than its operating frequency. This tends to broaden the lobes of a basic figure-8 pattern, making the antenna more omnidirectional. Forming the dipole into a V-configuration permits additional improvement of the omnidirectional characteristics. The use of stacked dipoles of circular or V shape permits an fm antenna system to have an essentially omnidirectional horizontal pattern and a low-angle vertical pattern.

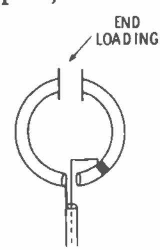
It is common practice in fm antenna systems to space the dipoles at approximately one wavelength along the vertical axis. They are fed in phase by making certain the transmission-line section between each dipole is exactly one electrical wavelength. Because of the velocity factors of the cable, the dipoles are usually not spaced a full wavelength physically.

The impedance of each dipole is made greater than the transmission-line impedance by the number of bays. For example, if a 50-ohm transmission-line system were being used to feed four bays, the radiation resistance of each dipole would be approximately 200 ohms. Since the four bays are connected in parallel, their total impedance is 50 ohms.

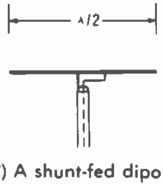
The high velocity factors of the most common forms of fm transmission lines (air-dielectric, rigid, and semiflexible types) permit the bays to be spaced by almost a full wavelength.

10-9. FM ANTENNA TYPES

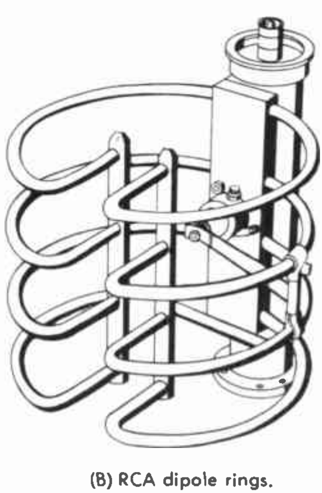
Three popular fm broadcast antennas are the stacked ringed dipole, curved dipole, and V dipole. Fundamentally, the Collins (Fig. 10-13A)



(A) Collins circular dipole.

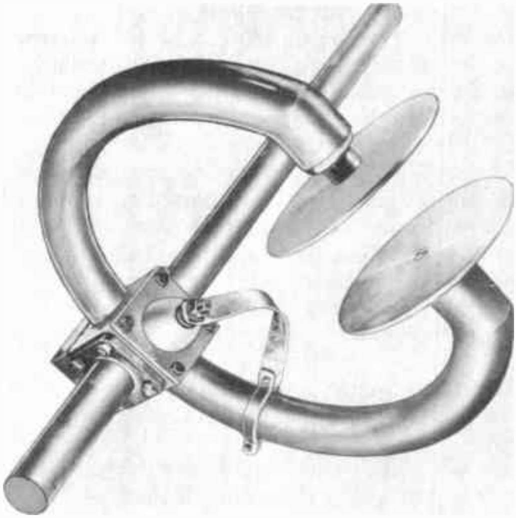


(C) A shunt-fed dipole.



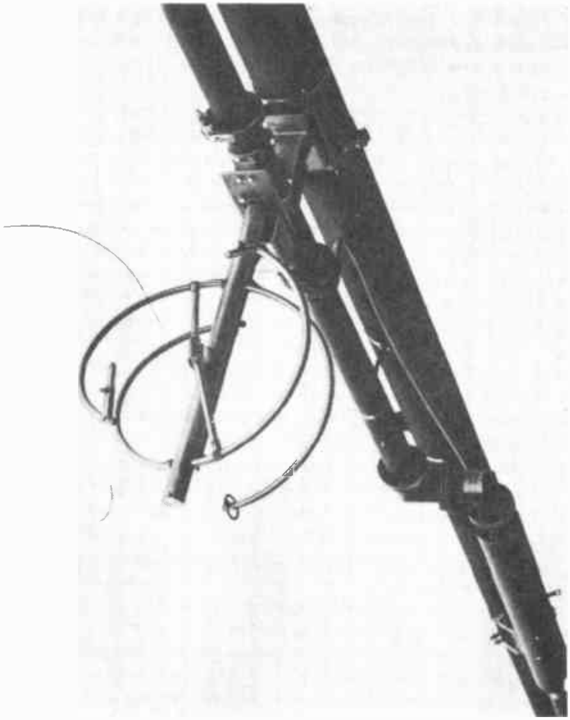
(B) RCA dipole rings.

Fig. 10-13. Shunt-fed dipole and two popular antenna types.



Courtesy Collins Radio Corp.

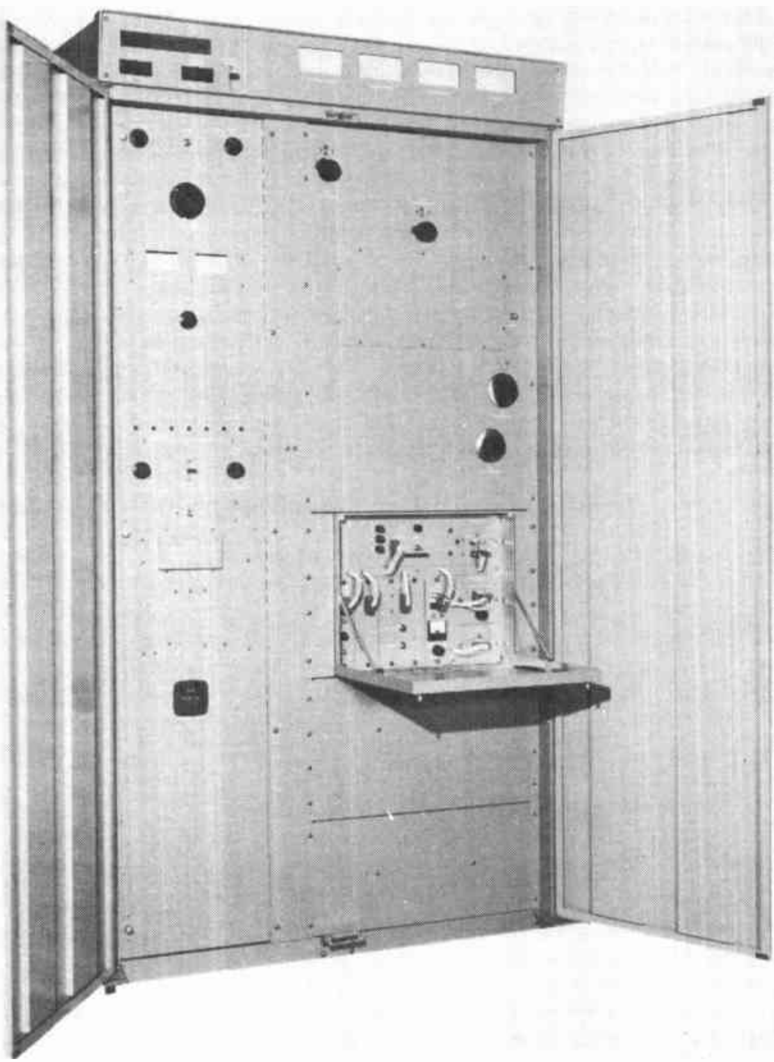
Fig. 10-14. Collins fm transmitting antenna.



Courtesy RCA Corp.

Fig. 10-15. An fm antenna with circular polarization.

and RCA (Fig. 10-13B) antennas are shunt-fed dipoles as shown by the basic dipole (Fig. 10-13C). The inner conductor of the coaxial cable is attached to a point on one of the quarter-wave sides of the antenna to provide the proper impedance match. Most fm broadcast antennas are pretuned to a specific frequency. The necessary bandwidth is obtained by lowering the Q of the dipole with either a large-diameter circular element (Fig. 10-14) or a multiple-ring arrangement (Fig. 10-13B). These types of construction permit the antenna elements to be



Courtesy Gates Radio Co.

Fig. 10-16. A 20-kilowatt fm transmitter.

supported by the rigid coaxial transmission line that feeds the individual dipoles.

To obtain the necessary omnidirectional pattern, the Collins dipole is folded around and end-loaded. The capacitance across the ends provides a more uniform current along the antenna length, the physical length of the antenna being shortened considerably with relation to a free-space half-wavelength because of the presence of the end-loading. Thus there is more uniform horizontal radiation. The capacitive plates at the ends of the Collins circular dipole in Fig. 10-14 are adjustable for critical resonance.

The circularly polarized antenna of Fig. 10-15 avoids the need for separate vertically and horizontally polarized antennas. A simpler transmission-line feeding system and mounting arrangement are possible. Equal power is radiated in the horizontal and vertical polarization planes. In effect, the transmitter power can be doubled without exceeding the licensed horizontal plane effective radiated power. The power delivered by the transmitter and transmission-line system is in effect split equally between the two planes of polarization.

Additional effective radiated power can be obtained by increasing the number of bays. Each antenna is shunt-fed through an insulator mounted on a short horizontal section of transmission line. The main vertical transmission line then continues on up to the next bay where there is a similar feed arrangement. The power gain of two bays in both the horizontal and vertical planes is twice the power gain of a single bay; a three bay antenna has approximately three times the power of a single bay, etc.

10-10. A 20-KILOWATT FM TRANSMITTER

The transmitter of Fig. 10-16 is a three-tube affair capable of supplying a 20-kilowatt power output. It can be driven directly by the

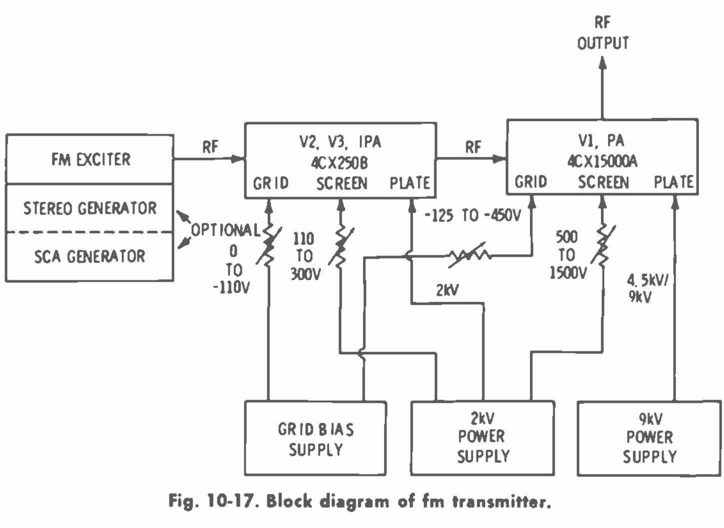


Fig. 10-17. Block diagram of fm transmitter.

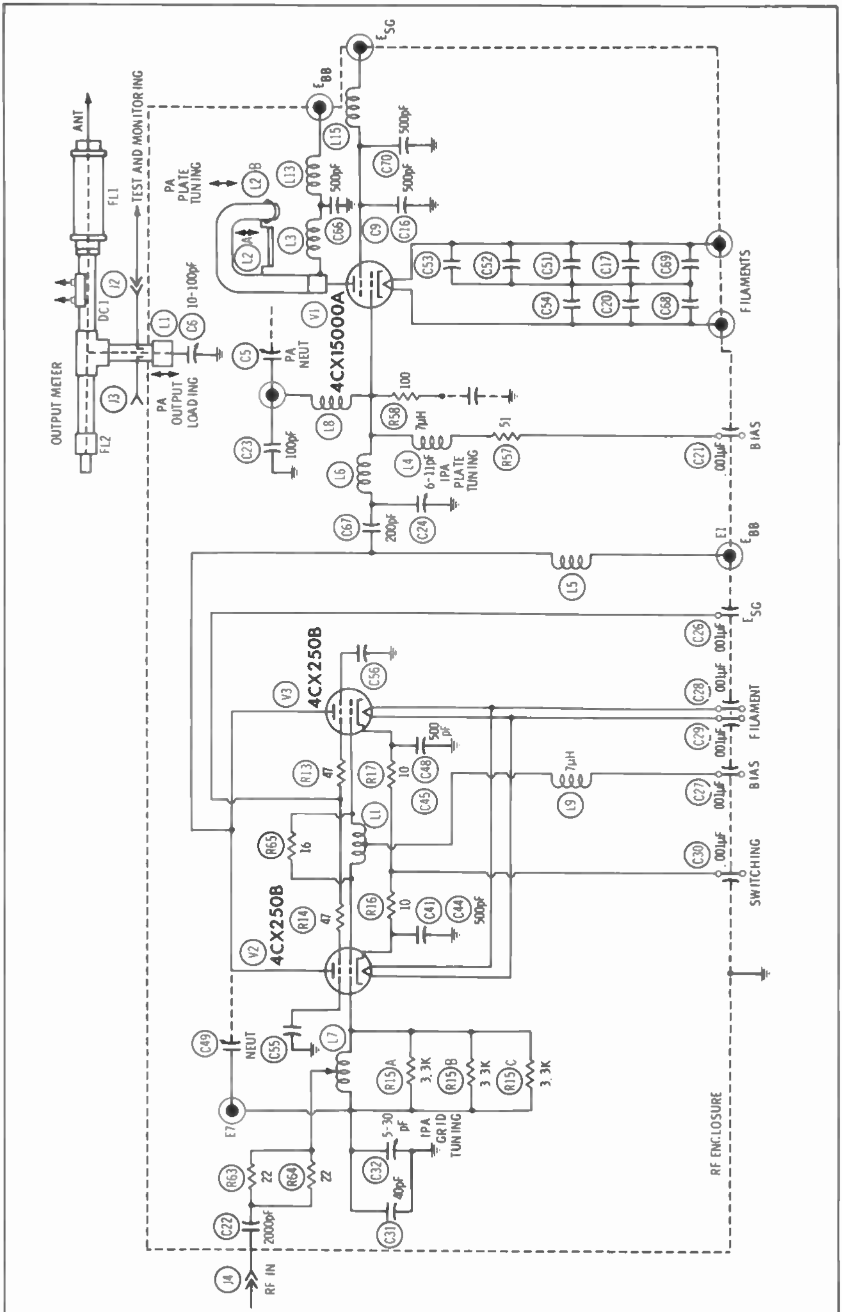


Fig. 10-18. Schematic of the rf amplifier.

10-watt amplifier of the fm exciter (Fig. 10-9). The fm exciter, stereo, and SCA generators mount directly in the transmitter case, with the fm exciter supplying fm modulated drive signal to the first vacuum-tube stage (Fig. 10-17).

The rf signal level is increased in magnitude by the two paralleled tubes of the input stage which develops the input power required by the final power amplifier. Three separate power supplies are included. There are separate plate supplies for the intermediate power amplifier and final power amplifier. These are three-phase supplies using silicon rectifiers. A third silicon-rectifier supply develops the grid bias for both stages.

Four meters at the top of the transmitter monitor filament voltage (both PA and IPA), PA plate current, PA plate voltage and a combination VSWR (voltage standing-wave ratio) and power output. A multimeter arrangement inside the doors permits monitoring of the PA grid current and the IPA grid, cathode, and screen-grid currents.

A schematic diagram of the rf stages is given in Fig. 10-18. The two stages are mounted within a shielded rf enclosure. The input stage employs grid neutralization. There are a number of resistors shunted across the input resonant coil which establish the proper bandwidth for the input circuit. A pi-network links the plate signal to the grid of the power amplifier.

The plate circuit of the power amplifier is a half-wave resonant line. The length of the inner conductor is adjustable and is set for that inductance which, along with the output capacitance of the tube, resonates at the desired transmit frequency. There is both a coarse and a fine frequency adjustment of the resonant line. A capacitive coaxial coupler transfers signal from the resonant circuit to the transmission-line system. Coupling is adjustable and acts as the power-amplifier loading control.

Two filters are included in the output system. Filter FL1 is a coaxial low-pass filter which reduces transmitter harmonic input. There is also a more selective filter FL2 which provides additional attenuation of the exact second harmonic of the transmitter output. It is referred to as a second harmonic notch filter. These filters are useful in minimizing interference to television and other radiocommunication services.

CHAPTER 11

Stereophonic FM Broadcasting

Hundreds of fm broadcast stations are now equipped to broadcast stereo programs. Such facilities are a part of a high percentage of the small independent fm stations. Consequently the beginning broadcast technician should know something about stereo broadcast principles because it is quite likely that stereo broadcast gear will be in operation at his first place of employment.

11-1. STEREO BASICS

Stereo broadcast stations use a form of subcarrier multiplex frequency modulation. One audio signal frequency-modulates the fm carrier; the second audio signal amplitude-modulates a subcarrier. The subcarrier, in turn, frequency-modulates the fm carrier, as in the block diagram of Fig. 11-1.

At the receiver, the regular fm detector demodulates one audio signal and the subcarrier fm signal. The subcarrier signal is supplied to an a-m detector (called a *subcarrier detector*). The output of the subcarrier detector is the second audio signal.

A more detailed functional diagram is shown in Fig. 11-2. In a stereo broadcast system, as in stereo systems in general, there are two fundamental audio signals which correspond to the audio variations picked up from the left and right sides of the program source. These two audio components are commonly referred to as the left-channel and right-channel signals. In stereo reproduction the left and right signals power the left-hand and right-hand speakers, respectively. Thus, the directional sound output is comparable to that which is present at the pickup location.

In a stereo broadcast system the left-channel and right-channel audio signals, L and R, are applied to a transmit matrix circuit. Here the two signals are united in a manner that will produce both sum (L + R) and difference (L − R) components of the audio signals. In the transmitter section of Fig. 11-2, three basic circuits comprise the matrix section. These are called an adder No. 1 (L + R), a phase inverter, and an adder No. 2 (L − R). In the No. 1 adder the L and R signals are combined in phase. The output of this adder is L + R component, one of the basic audio signals.

In the phase inverter the polarity of the R signal is reversed. When it is combined with the L signal a difference component will be present at the output of the L − R adder. It is this L − R signal that forms the second basic audio signal.

The L + R signal is used to frequency-modulate the fm transmitter in a conventional manner. It should be understood that the L + R signal is comparable to the audio variations picked up by two microphones, one on each side of the studio. It is basically a monophonic signal of the type formed in conventional broadcasting by using two microphones and combining their outputs in phase in the mixer.

This L + R signal can be handled by a standard monaural fm receiver. It will reproduce as a good monaural program, comparable to that transmitted by any monaural fm broadcast station. This is the important compatibility feature of the FCC-approved method of stereophonic broadcasting. Inasmuch as the L + R signal frequency modulates the fm carrier directly, a standard monaural fm receiver, as shown in Fig. 11-2, demodulates this signal in conventional manner. The monaural L + R signal drives its speaker. The L + R signal is handled in exactly the same manner by a stereo fm receiver, except that the L + R signal at the output of the fm detector is applied to a receive matrix section.

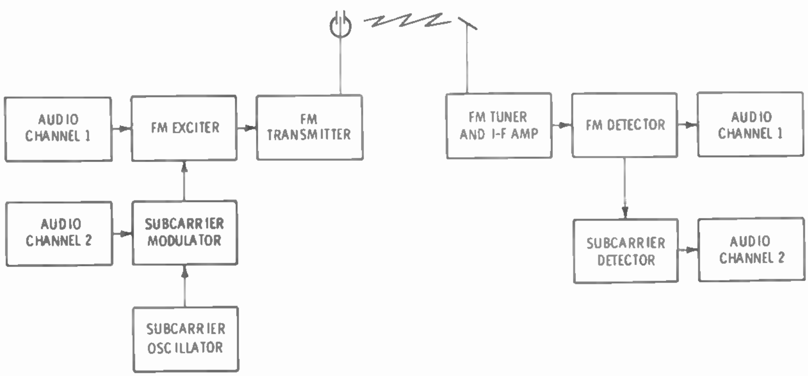


Fig. 11-1. The basic stereo system.

Just how is the L − R signal conveyed from the fm station to the stereo broadcast receiver? The L − R signal at the output of the transmitter matrix is applied to a subcarrier a-m modulator. In fact, it is applied to a so-called "balanced modulator." The function of the balanced modulator is to cancel out the carrier. The subcarrier is initiated by an accurate 19-kHz oscillator. A follow-up doubler forms the 38-kHz subcarrier signal. The 19-kHz oscillator is not only the source of the carrier but also forms a so-called "pilot frequency" which will be discussed later.

In the balanced modulator, the L − R component and the 38-kHz component produce a-m side frequencies on each side of 38-kHz. Since the 38-kHz carrier is cancelled out only the a-m sidebands are conveyed between the output of the balanced modulator and the f-m

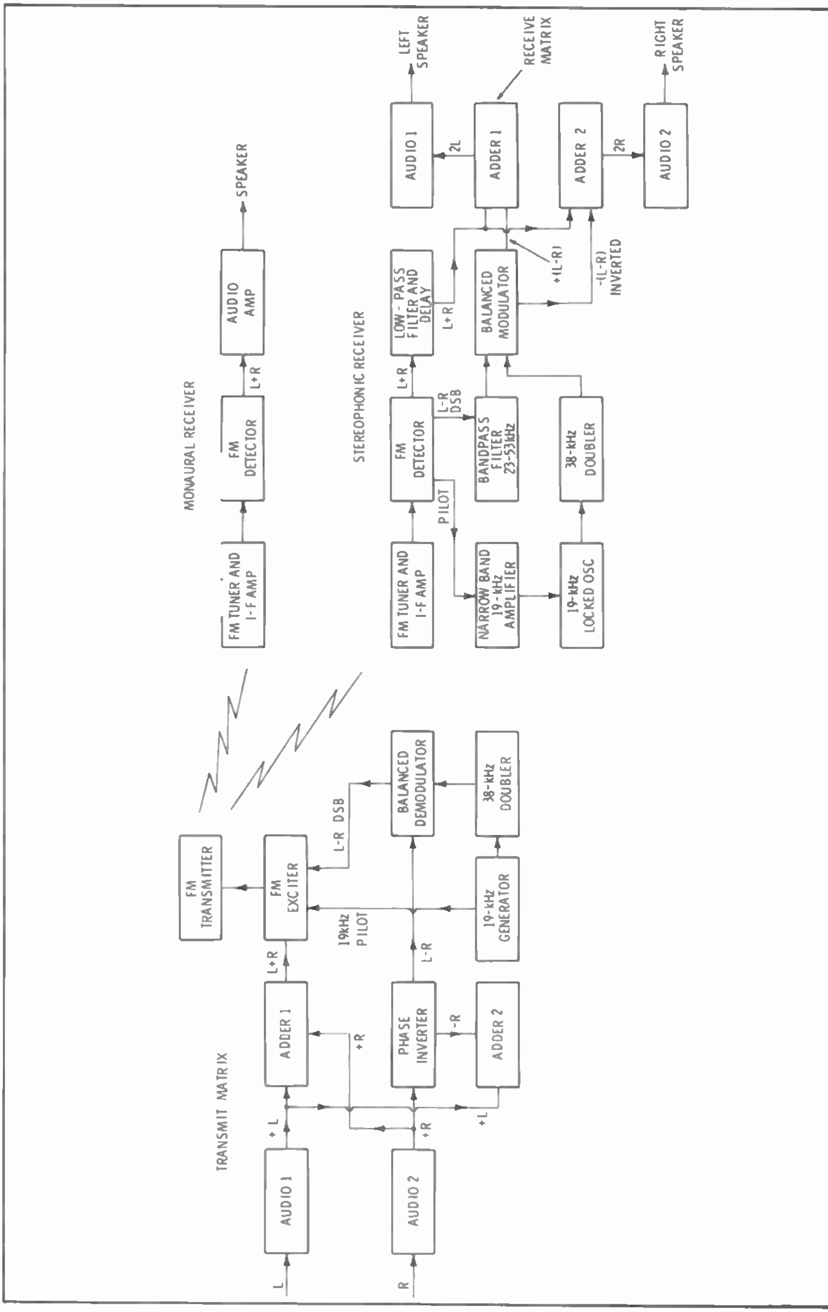


Fig. 11-2. A compatible fm stereo system.

transmitter. Therefore, the L − R information is in the form of a double-sideband signal (DSB) which, in turn, frequency-modulates the fm transmitter. Its sideband components span outward from the 38-kHz frequency but do not extend into the sideband spectrum of the L + R signal. The spectrum distribution is given in Fig. 11-3.

Why is the subcarrier frequency removed? All of the information conveyed by an a-m system is contained in the sidebands. Hence the carrier is not needed and the carrier removal means that the substantial amount of power usually contained in the carrier is not required. Furthermore, when there are two carriers present in a common circuit there is a definite trend to heterodyning and the formation of undesired signal components. Since more power can be concentrated in the sidebands by the removal of the subcarrier, there is an overall improvement in the signal-to-noise ratio.

What receiving problem arises with the removal of the subcarrier? To properly demodulate the subcarrier sidebands of their L − R information at the receiver, it is necessary to reinsert a carrier. The stability of the inserted carrier must be high for true demodulation. This imposes a receiver problem. However, the problem is greatly reduced with the transmission of the 19-kHz pilot carrier.

The 19-kHz pilot carrier is generated at the transmitter and is transmitted at low amplitude between the transmitter and each receiver. At the fm stereo receiver, the 19-kHz pilot signal is used to synchronize a

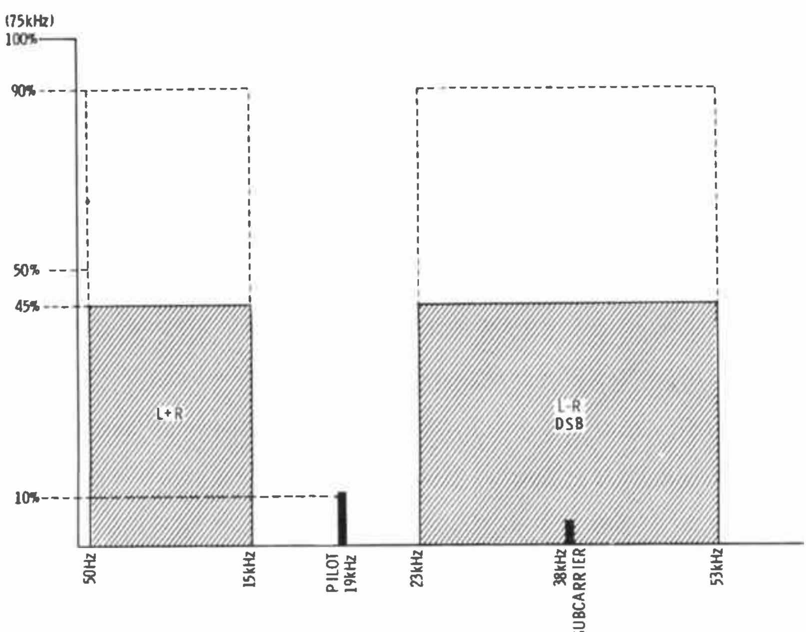


Fig. 11-3. The modulating frequencies and maximum deviations for fm stereo broadcasting.

19-kHz oscillator. The output of this oscillator in turn drives a frequency doubler which generates the 38-kHz component used for carrier reinsertion. This component is thus controlled in both frequency and phase by the transmitted pilot signal. Therefore, it forms a stable carrier for the balanced demodulator of the receiver. In the balanced demodulator there is mixing of the L − R subcarrier sidebands and the locally generated 38-kHz carrier; the original audio No. 2 (L − R) is extracted at its output.

11-2. RECEIVER ACTIVITY

Three types of information (Fig. 11-3) are conveyed between the stereo broadcast station and each stereo receiver. These are the L + R signal, the pilot frequency, and the L − R subcarrier sidebands. How are these three components deployed at the receiver? All three components, as shown in Fig. 11-2 appear at the output of the fm detector of the receiver. The L + R signal can be applied directly to the receiver matrix. However, it is first passed through a low-pass filter. The responsibility of this filter is to block the 19-kHz pilot frequency and the L − R subcarrier sideband from the L + R channel matrix. The L + R channel also includes a delay circuit that holds up the L + R signal an amount that matches the delay encountered by the L − R information in its more elaborate demodulation process. Thus, the L + R and L − R signals arrive in the same time relationship at the input of the receive matrix as they did at the input of the transmit matrix.

The 19-kHz pilot frequency is applied through a very narrow bandpass filter to a 19-kHz amplifier. As mentioned previously, the 19-kHz output of this amplifier is used to lock in the frequency and phase of the 19-kHz oscillator. The L − R information is applied through a bandpass filter that passes the subcarrier sideband spectrum, but rejects frequency components above and below its range. Hence, only the subcarrier sidebands reach the balanced demodulator.

In the receiver matrix there are two adders and a phase inverter. When the L + R and L − R signals are combined in phase (adder No. 1), the resultant output is the original L signal, since $(L + R) + (L - R) = 2L$. When the L + R and L − R signals are combined out of phase in the second adder, the resultant output signal is the original R signal, since $(L + R) - (L - R) = 2R$.

The individual L and R signals are now amplified in the L and R channels of a stereo audio amplifier as per conventional stereo high-fidelity practice. The two signals drive the separate left- and right-channel reproducers.

11-3. SIGNAL ACTIVITIES

The operation of the stereo broadcast system can be understood in greater depth by considering some typical input and output signals that might be present at the transmit and receive matrices. Let us first assume that a signal is present at the left channel, but none is present at the right.

Assume that a unit of L audio signal is being applied to the input of the transmit matrix as in Fig. 11-4A. Under these conditions, what is the output of the transmit matrix? Without an R signal present there will be half-unit L signals at the L + R and L − R outputs of the transmit matrix. These two half-units of L signal will be transmitted between the transmitter and the receiver. Half-unit L signals will appear at the input of the receiver matrix. Since the output of the left channel of the receive matrix has a value of 2L, its signal level will be unit L ($2 \times 1/2L$). Since the output of the right channel of the receive matrix is 2R, there will be zero R signal output (2×0) because zero R signal has been transmitted.

Let us consider what happens when there is a unit of R signal, without an L signal, at the input of the transmit matrix, as in Fig. 11-4B. Under this condition the outputs of the transmit matrix will be half-units of R with opposite polarity. This will also be their relationship as they are applied to the input of the receive matrix. In the adder (L + R) of the receive matrix the two components will be of equal amplitude and opposite polarity; L output will be zero. In the adder (L − R), however, the R signal will have been shifted in polarity. Therefore, it will add in phase to produce a unit R output ($2 \times 1/2R$).

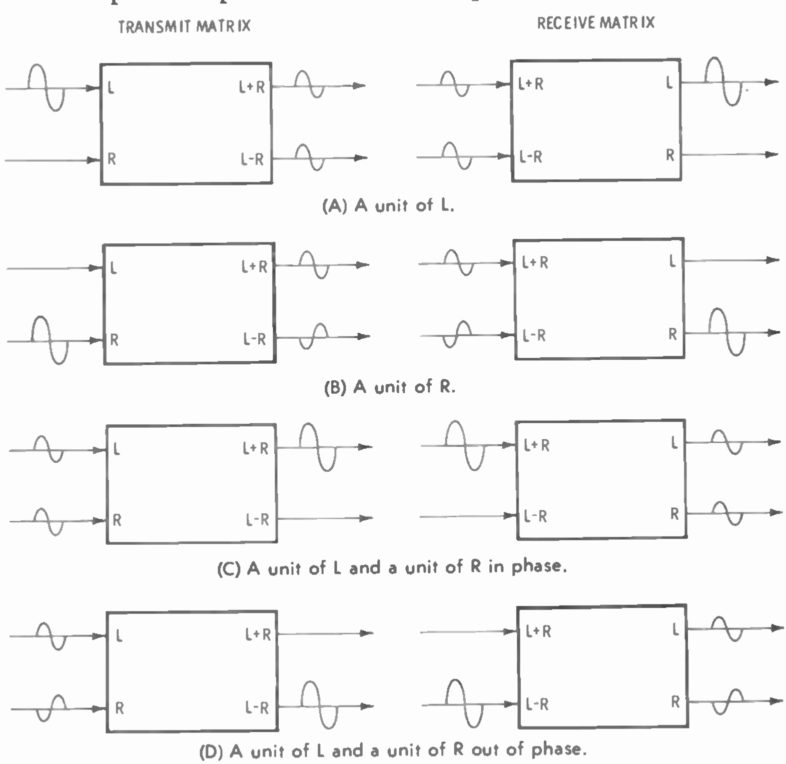


Fig. 11-4. The audio signal possibilities at the receiver-matrix input and their transmitter-matrix outputs.

Let us next consider two input signal possibilities that may occur on occasion. In Fig. 11-4C, the left- and right-input signals are of equal half-unit amplitude. When combined in-phase assume they produce an L + R output of unit amplitude. When combined out-of-phase (in the L − R adder), they will cancel and there will be no L − R output. The input to the receiver matrix will be a unit-level L + R signal; there will be no L − R signal. The output of the receive matrix, therefore, will be two signal components of half-unit amplitude for both the right and left channels. The relationships are as follows:

$$(L+R) \pm (L-R) = (L+R) + 0$$

L AND R DIVIDE EQUALLY IN-PHASE
OUTPUT IS 1/2 ON L SIDE AND 1/2 ON R SIDE

Hence, the reconstructed voltages at the inputs of the left and right channels correspond to the original signals at the transmit matrix.

The other extreme would be to transmit signals of opposite polarity as in Fig. 11-4D. In this case, there would be no output from the L + R side and a unit output from the L − R side. A t the receive matrix only an L − R signal is being applied to the input. As a result, there will be signals of opposite polarity developed at the L and R outputs of the receive matrix. Relations are as follows:

$$(L+R) \pm (L-R) = 0 \pm (L-R)$$

L AND R DIVIDE EQUALLY OUT-OF-PHASE
OUTPUT IS 1/2 L AND −1/2 R

Again the left and right audio channels are driven by reconstructed signals of opposite polarity comparable to those at the input of the transmit matrix.

Of course, actual program material will vary continuously and will seldom match the extremes demonstrated in Fig. 11-4. In actual stereophonic broadcasting it is improbable that one channel will be alive and the other completely dead. Nor is it likely that each channel will carry identical information, either in phase or out of phase. Nevertheless, the consideration of these signal extremes gives you an understanding of the activities for the more practical intermediate-signal conditions.

11-4. SCA BROADCASTING

Many fm stations also transmit SCA (Subsidiary Communications Authorizations) broadcasts in the form of storecast (store background music) or other special music services. These are also transmitted on a subcarrier. In fact, it is possible to combine the SCA service with stereophonic broadcasting, as shown in Fig. 11-5. The SCA assignment is made in a frequency spectrum higher than the L − R sideband frequencies. The SCA channel uses frequency modulation with a total permissible deviation of ±7.5 kHz about the subcarrier frequency of 67 kHz. The highest audio frequency for frequency modulation of a

67-kHz subcarrier is 8 kHz. Since the modulation index is so low at these limits (7.5 kHz ÷ 8 kHz) the resultant sidebands are confined between 59.5 and 74.5 kHz. Consequently there is no overlap into the sideband spectrum of the L − R (double-sideband) signal. Likewise, sideband components will not exist outside of the 200-kHz bandwidth limitation required by the FCC for an fm broadcast channel.

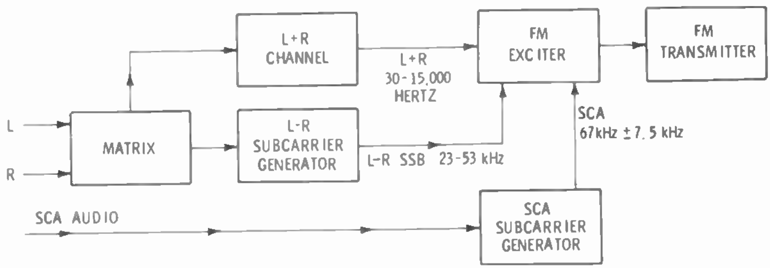


Fig. 11-5. Block diagram of an fm stereo SCA transmitter.

11-5. DEVIATION CONSIDERATIONS

In an fm system the total deviation of the carrier is considered as the arithmetic sum of the deviations caused by the individual signals and subcarriers that comprise the transmitted information. The maximum permissible deviation of a stereophonic and combined stereo-SCA broadcast carrier is ±75 kHz. The modulation-frequency spectrum chart (Fig. 11-3) shows the frequency distribution of the signals that make up the transmitted data and the maximum deviation values as well, without SCA. The modulating-frequency distribution is shown on the horizontal axis; the maximum permissible deviation as a percentage is shown on the vertical axis. In the main channel (direct modulation by the L + R signal) the maximum deviation may not exceed 45 percent of the total permissible deviation for a stereophonic broadcast station, assuming that only an L signal (or R signal) is present. Likewise, the modulation of the L − R double sideband channel may not exceed 45%, assuming that only an L signal (or R signal) is present. The L + R or L − R channels have a capability of 90-percent modulation when both R and L signals are present. The pilot subcarrier at 19 kHz (±2 Hz) deviates the main carrier to the limit of 8 to 10 percent. The arithmetic sum (10 percent + 45 percent + 45 percent) of the three deviations approaches 100 percent or full ±75-kHz deviation.

In the case of combined stereo and SCA transmission (Fig. 11-6) it is necessary to reduce the L + R or the L − R subcarrier deviations to a maximum of 18 percent, while the pilot carrier is assigned a 9-percent deviation. SCA subcarrier and sidebands are assigned a maximum 10 percent deviation so as not to cause a maximum deviation greater than 100 percent (10 percent + 9 percent + 40.5 percent + 40.5 percent). 10 percent of 75 kHz is ±7.5 kHz, the maximum permissible deviation of the SCA 67-kHz subcarrier.

In the transmission process, the standard 75-microsecond pre-emphasis and de-emphasis circuits are used. The compensation and correction must be made in both channels. In fact, to minimize cross modulation between channels the frequency response must be held within 3.5% of unity at all levels of signal and frequency between 50 and 15,000 hertz. Furthermore, the phase difference between the main channel signal and the stereophonic subcarrier sideband envelope shall not exceed ±3% for audio modulating frequencies between 50 and 15,000 hertz.

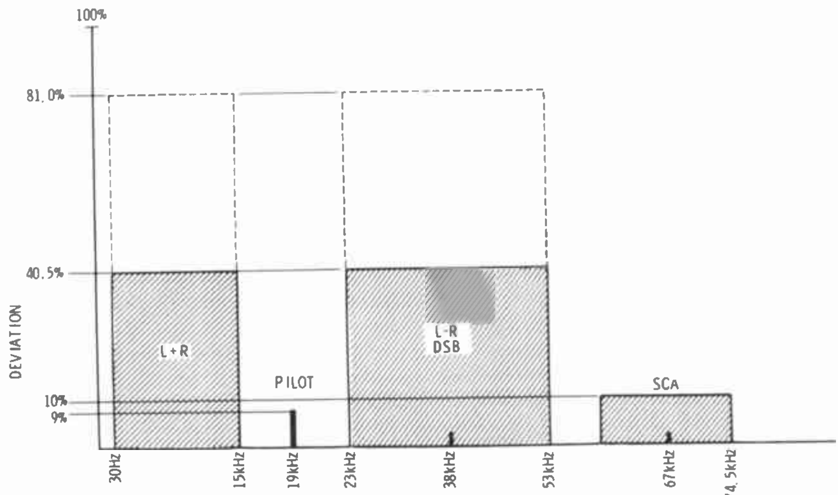


Fig. 11-6. The modulating frequency spectrum of the combined stereo and SCA fm signals.

11-6. STEREO BROADCAST EQUIPMENT

The cost of new broadcast stereo equipment is not prohibitive. Furthermore, an important advantage of the FCC stereo standards is that existing fm stations can be converted readily to stereo operation. Many of the fm exciters that are a part of fm transmitters have been planned for SCA or fm multiplex operation. These transmitters may require only the addition of a stereo generator. Often space is set aside for the installation of such a generator.

The studio requires a number of stereo signal sources, such as a stereo phono player and/or stereo tape player. A combined stereo recorder and player is shown in Fig. 11-7. Such a stereo tape recorder and associated stereo microphones can be used to prerecord live stereo-program material for later transmission by the station.

A very basic and compact solid-state stereo console is shown in Fig. 11-8A. The unit can be used for either monaural or stereo fm broadcasting and includes individual left and right channel inputs, controls, and VU meters as shown in Fig. 11-8B. In the functional block diagram (Fig. 11-8B) there are dual inputs for stereo microphones, two stereo phono players, and an auxiliary dual input with multiple contacts for a stereo tape player, remote lines, etc. Cuing switches "TT-1" and "TT-2" permit cuing of the phono channel not in use. The two solid-state amplifiers have individual program gain controls for setting of proper relative levels of the left-channel and right-channel microphones. Program monitoring and cue output terminals and separate audio amplifiers are included. Monitoring can be done in program line, audition line, or off the air.

A dual-channel console of the master control type is shown in Fig. 11-9A. This Gates unit can handle almost any monaural or stereo program situation with regard to program control and switching, as well as versatile use of a number of stereo signal sources. Eight mixing channels are provided for 22 audio inputs consisting of 13 monaural sources, 6 stereo sources, plus inputs for automatic programming equipment, and an SCA audio source. Included, and as shown in Fig. 11-9B, there is a master-control switcher that can be used to channel program information to a-m, fm and stereo-fm transmitters. The arrangement is ideal when it is advantageous to control a-m, fm, stereo-fm and SCA from one control point during part or all of the broadcast day. There is separate metering for a-m and both fm channels.

Courtesy Midwestern Instruments, Inc.

Fig. 11-7. A stereo tape recorder/player.

Fm transmitters like a-m types employ modulation limiters. They function as amplitude compressors and peak limiters. In the case of fm broadcasting, only a limited amount or no compression is advisable for high quality music reproduction. However, for speech and less exacting musical programs for which full dynamic range is unimportant or not advisable, the fm modulation limiter can introduce a controlled amount of compression so as to increase the average modulation of the fm transmitter. Another function of the limiter in either a-m or fm service is to limit voice and music peaks so as not to cause overmodulation of the transmitter. This limiting of peaks in fm practice prevents fm deviation in excess of ±75 kHz.

An example of an fm limiter is the Gates model shown in Fig. 11-10. Two such limiters are employed for stereo-FM broadcasting. In this case, they can be synchronized together in their operation. Of course, in stereo broadcasting there should be identical limiting of the left and right program information.

The fm limiter is a bit more complex than the a-m limiter because of the use of pre-emphasis. Therefore, there must be suitable circuits in the fm limiter that compensate for this manner of operation when the program material is compressed and especially in setting the limit for maximum deviation regardless of the audio frequency.

Courtesy Sparta Electronics Corp.

Fig. 11-8A. A solid-state stereo console.

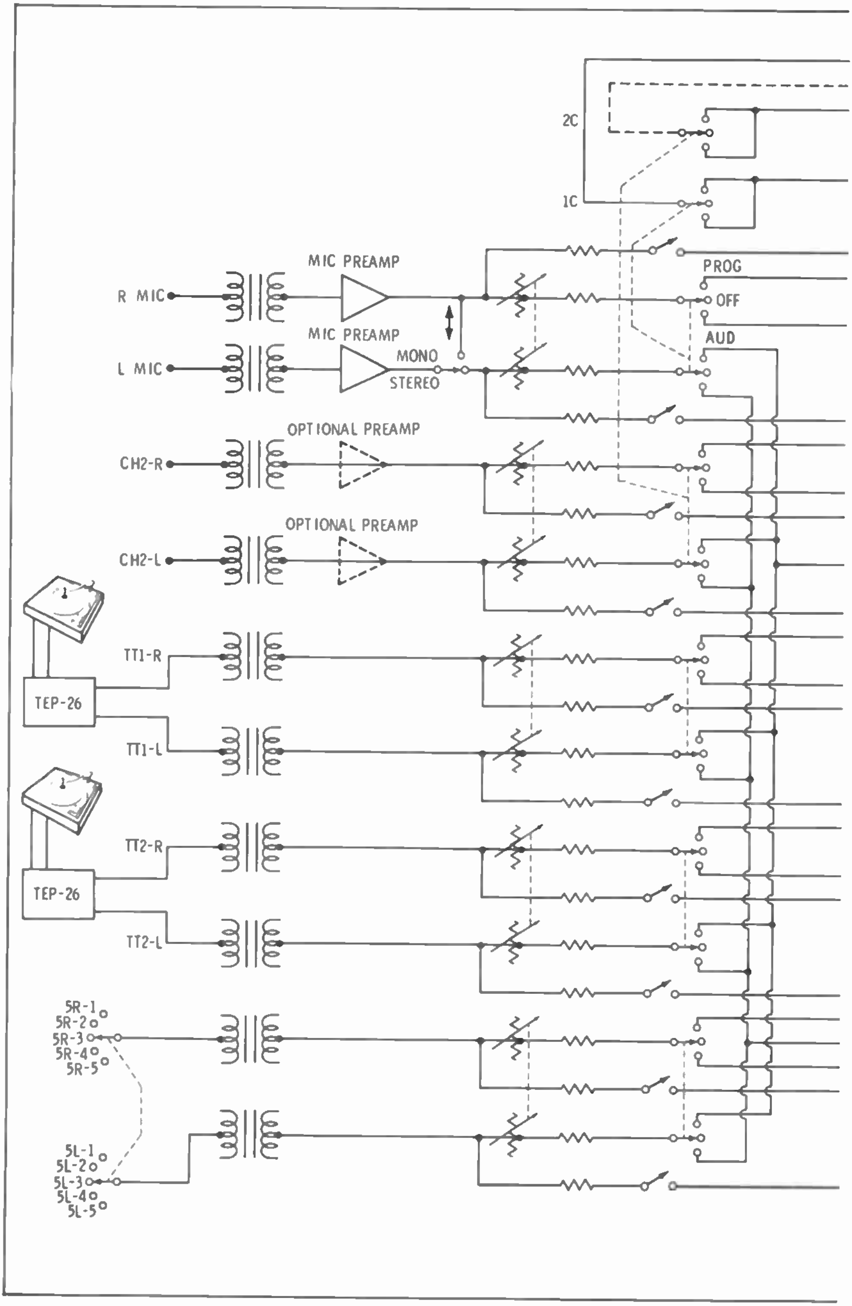
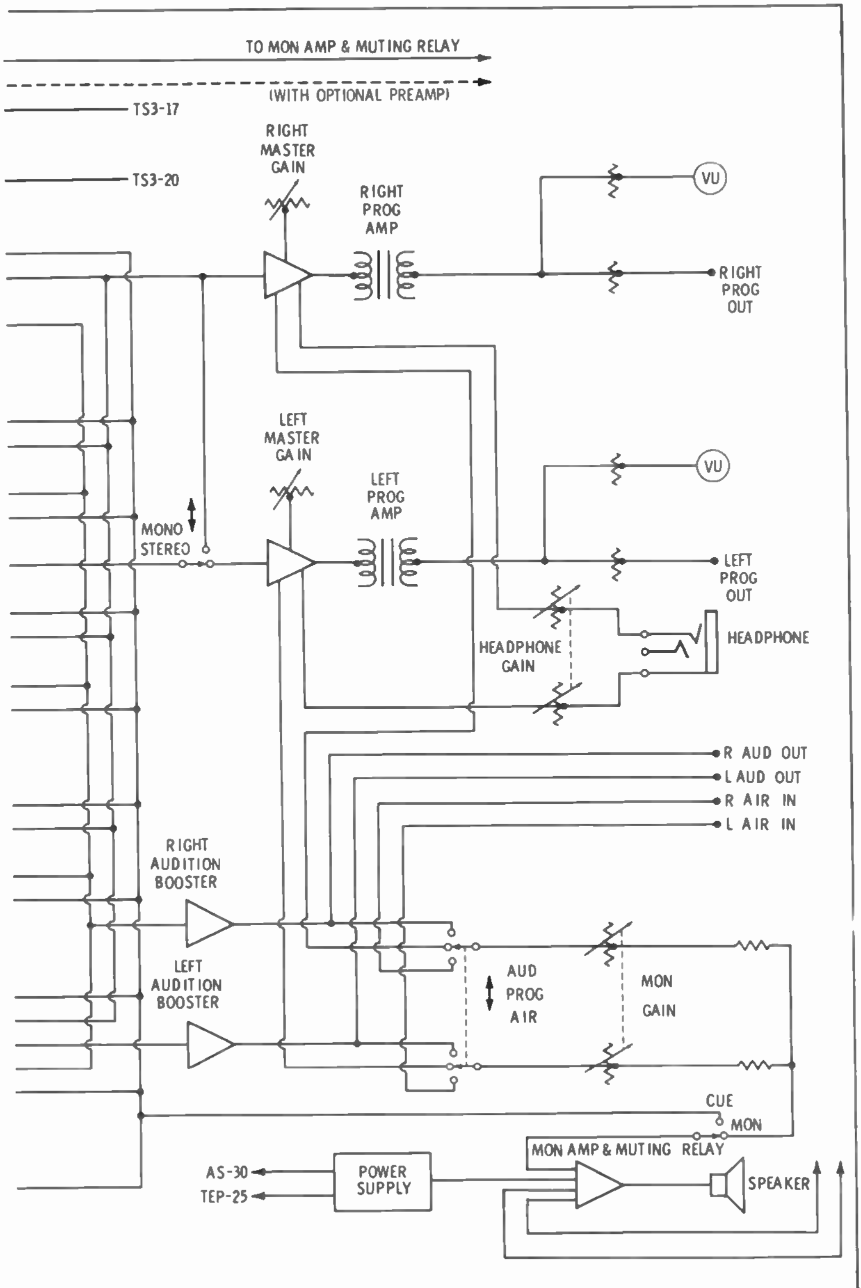
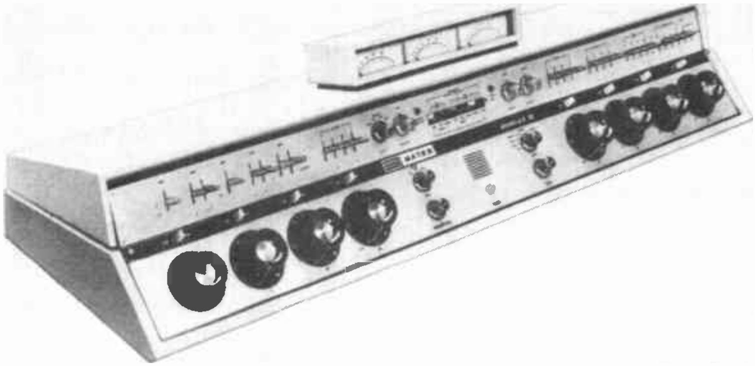


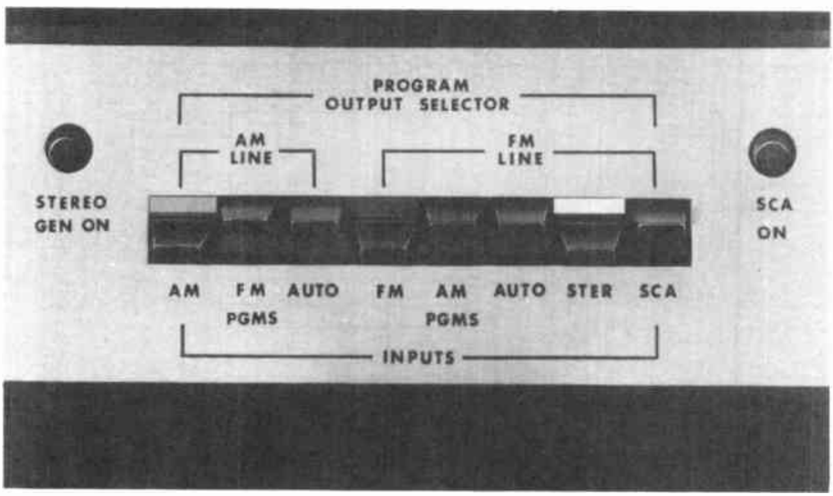
Fig. 11-8B. A solid-state



stereo console (continued).



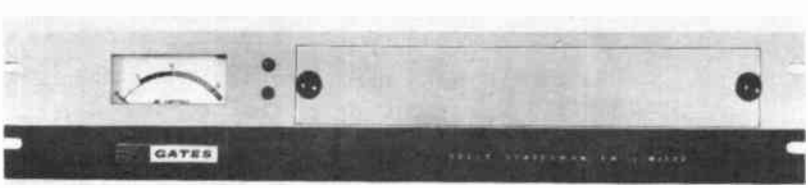
(A) Console.



(B) Program selector.

Courtesy Gates Radio Co.

Fig. 11-9. A master-control type dual-channel console.



Courtesy Gates Radio Co.

Fig. 11-10. An fm limiter.

11-8. FM STEREO GENERATOR

The Gates stereo generator (Fig. 11-11) is a solid-state model. Its functional block diagram is shown at the lower left of Fig. 10-7. At the center of the block diagram is the audio module and the separate left and right channel inputs. The left and right program signal is applied to a 19-kHz notch filter and on to the 75 microsecond pre-emphasis network. The notch filter clears the 19-kHz spectrum because the pilot frequency will eventually be inserted in this region.

Finally, the left and right program signals are applied to the matrix network. Here the signal components are added and subtracted to form the L + R and L − R modulating waves needed for the compatible multiplex system of transmission. Recall that the L + R signal is really a two-channel monaural signal that can be demodulated by a nonstereo fm receiver.

The L + R and L − R signals are applied to the stereo generator through the isolation input stages of the stereo generator, transistors Q15 and Q16 at the left centers of Fig. 11-11. The L + R signal is passed through a time-delay network. Intentional delay is necessary to match the delay encountered by the L − R component in the subcarrier process. Individual gain-control facilities are included in the emitter-follower output circuits of the isolation transistors.

The L + R signal is applied to the output level control, potentiometer R53. A three-stage amplifier follows including an emitter-follower isolation stage, transistor Q12; a voltage amplifier, transistor Q13; and the emitter-follower output stage, transistor Q14.

The L − R signal from transistor Q16 is applied to a four-diode ring-balanced modulator. The 38-kHz subcarrier frequency is applied to the same diode modulator arriving at the network of resistors R46 and R47 plus potentiometer R48.

The 38-kHz subcarrier is applied in phase to the ring modulator while audio components are 180° related. In operation the 38 kHz subcarrier will cancel out and be suppressed. This removal is accomplished efficiently when the ring modulator is balanced precisely. Balance potentiometer R48 permits the minimization of the level of the 38-kHz subcarrier in the output.

The operation of the ring modulator is unbalanced relative to the changes in the L − R audio signal. Therefore sideband frequencies are generated and do develop in the output. In effect the L − R signal has amplitude-modulated the subcarrier frequency. However, the subcarcarier signal itself has been removed. A double-sideband and suppressed-carrier signal is developed.

Through the isolation transistor Q11 this double-sideband signal is also applied to the output level control, R53. Here it combines with the L + R signal.

Let us consider, next, the formation of the subcarrier signal and the pilot frequency signal. The field-effect transistor Q1 at the top left of Fig. 11-11 is connected in a crystal oscillator circuit. The frequency of operation is 19 kHz. This component is applied to a buffer stage which includes a pilot gain control in its emitter circuit. The output is amplified by transistor Q3 and a 19-kHz sine wave is developed across the primary of transformer T1. Transistors Q4 and Q5 are connected in a push-push doubler circuit. Note that the 19-kHz sine wave is applied in push-pull to the bases. However, the collectors are connected in parallel, a favorable manner of connection for developing a strong even harmonic of the 19-kHz signal—this, of course, is 38 kHz. A 38-kHz sine wave develops across the primary of transformer T2. The secondary winding supplies the 38-kHz subcarrier component to the balanced ring modulator.

A 19-kHz sine-wave component is taken off the primary circuit of transformer T1 and applied through capacitor C8 to the isolation transistor Q6. In the coupling system between transistors Q6 and Q7 the

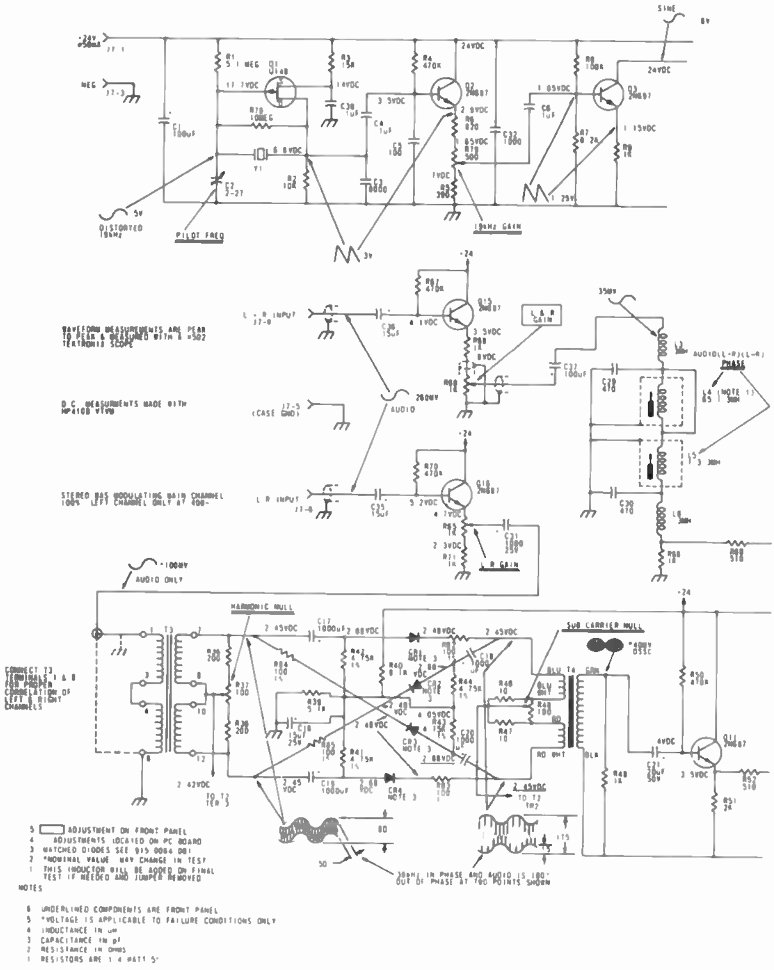
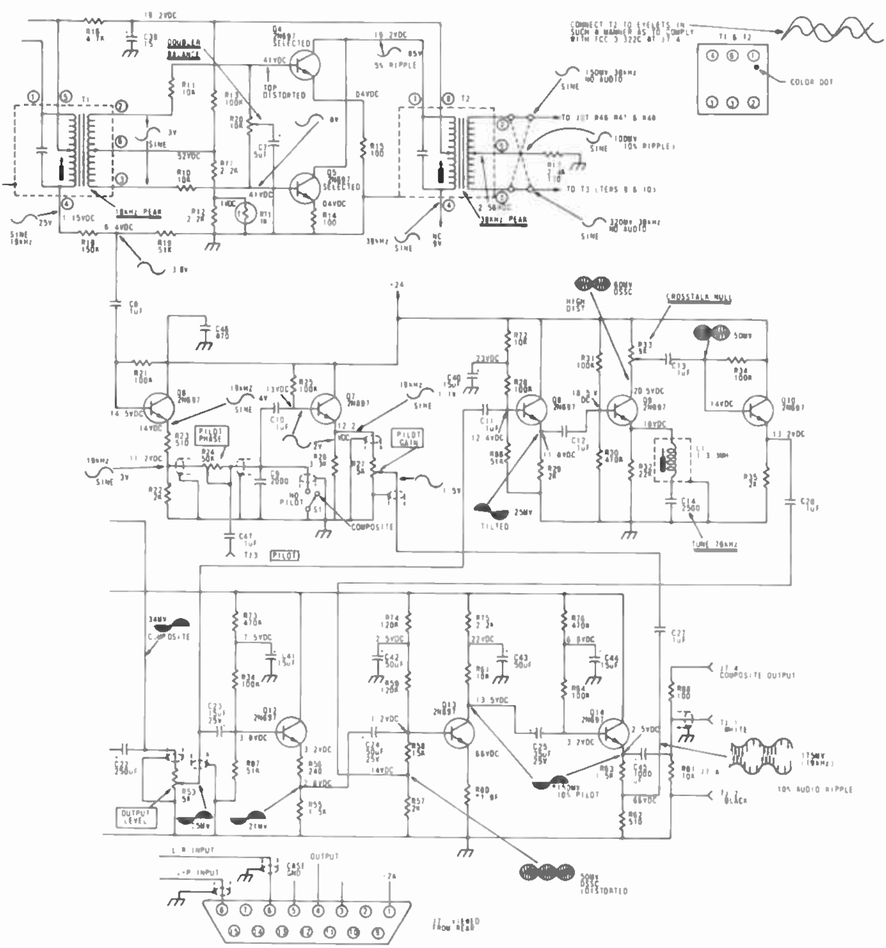


Fig. 11-11. Schematic of Gates

phase of the pilot frequency can be adjusted. This is important because there must be the proper phase relationship between pilot and subcarrier components at the receiver demodulator. The positive rise of the pilot frequency away from the zero axis must match in time the positive rise of the subcarrier component away from the zero axis for alternate subcarrier cycles. This is important to the synchronization of the demodulation process.

The pilot frequency component through the pilot gain control R27 is applied to the emitter of the composite output transistor Q14 (lower right of Fig. 11-11). Thus, at the output of transistor Q14 the composite stereo-fm signal is present consisting of the L + R component, L − R *dsb* component and the pilot frequency.



Courtesy Gates Radio Co.

solid-state stereo generator.

A special circuit is included to remove any 76-kHz second harmonic of the 38-kHz subcarrier frequency. Note that a portion of the signal present in the input of transistor Q12 is applied through capacitor C11 to transistor Q8. An out-of-phase component is present across the cross-talk-null potentiometer R33 in the collector circuit of transistor Q9. This out-of-phase component is applied to the junction of resistors R57 and R58 in the base circuit of transistor Q13 through emitter-follower transistor Q10. The function here is to cancel out undesired harmonics including the 76-kHz component. The removal of the second harmonic is particularly important because it falls in the bandpass of the 67-kHz SCA signal. This would cause crosstalk between the stereo and SCA modulating information.

CHAPTER 12

Transmitter Monitor and Test Equipment

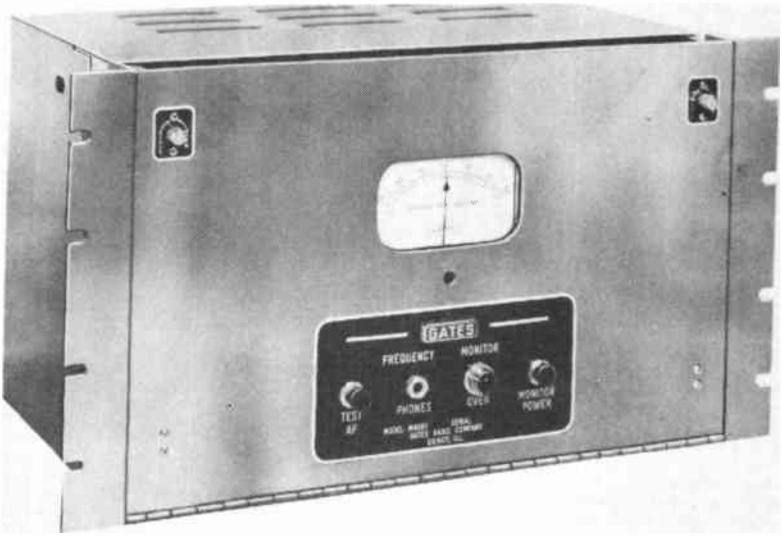
A-m and fm broadcast stations are required by the FCC to monitor their frequency and modulation continuously. Moreover, they must stay within a specified number of hertz of their assigned frequency (20 hertz for a-m, and 2000 for fm stations). The frequency monitors must be independent of the transmitter frequency control, and have a high accuracy to measure well within the tolerance limits. Consequently, the monitoring equipment used by broadcast stations must be FCC-approved.

In a-m broadcasting, the modulation percentage must be maintained as high as possible, consistent with good quality of transmission. It should not be less than 85 percent on peaks nor more than 100 percent on negative peaks of frequency recurrence during any selection which is transmitted at the highest level of the program. It is the responsibility of the a-m monitor to continuously indicate the modulation percentage and warn the operator of any sustained negative modulation peaks over 100 percent.

The modulation percentage of fm broadcast stations must be maintained as high as possible, consistent with good quality of transmission and good broadcast practice. It should not be less than 85 percent nor more than 100 percent on peaks of frequent recurrence during any selection which is normally transmitted at the highest level of the program. An fm monitor must be provided to measure the frequency deviation continuously. It must give the operator a suitable indication so he will know if the deviation is in excess of the maximum ±75 kHz.

12-1. A-M FREQUENCY MONITOR

An a-m frequency (deviation) monitor is shown in Figs. 12-1 and 12-2. The monitor can be located at the transmitter, or as far as several miles away for remote control operation. When operated at the transmitter it is supplied with signal from the frequency monitor output of the transmitter. An input signal range between 5 millivolts and 5 volts is acceptable; with appropriate attenuator pads, even higher input



Courtesy Gates Radio Co.

Fifg. 12-1. An a-m frequency monitor.

voltages can be handled. The carrier signal is amplified by an rf amplifier and then fed to a mixer. The local injection signal for the mixer is generated by a highly stable crystal oscillator, and a succeeding amplifier. The crystal oscillator is set on a precise frequency 990 Hz below the transmitter frequency. The crystal and the plate tank circuit are mounted in a temperature-controlled space.

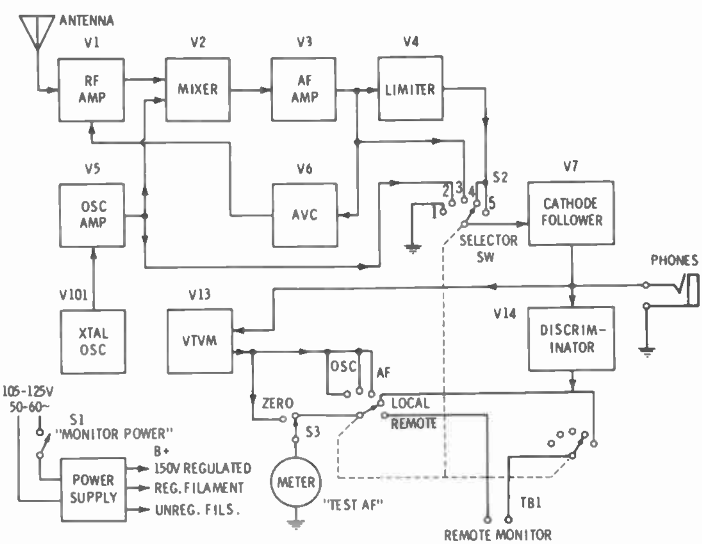


Fig. 12-2. Functional block diagram of a-m frequency monitor.

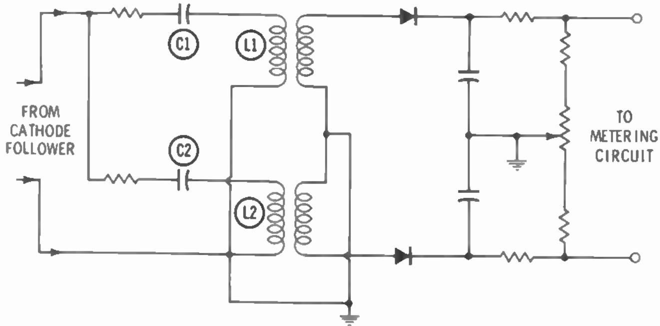
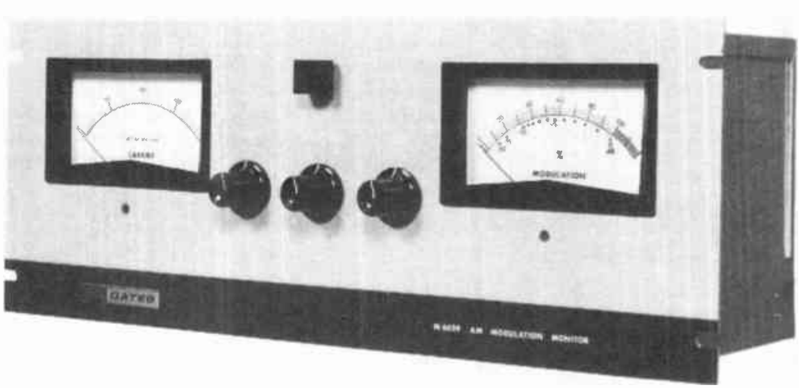


Fig. 12-3. Carrier frequency discriminator.

If the transmitter carrier is on frequency, a 990-Hz difference component is developed at the mixer output. When the transmitter carrier frequency drifts, the mixer output will be either more or less than 990 Hz, depending on the direction of frequency drift. The mixer signal is supplied to an audio amplifier and limiter circuit. The function of the limiter is to form the mixer signal into a square wave before it is applied, via a cathode follower, to a discriminator and a succeeding calibrated metering circuit. The same meter in association with a vtvm tube and selector switch can be used to check key monitor circuits.

The discriminator (Fig. 12-3) contains two fixed-tuned circuits. One circuit is tuned slightly above 990 Hz and the other slightly below. At 990 Hz, the rectified outputs of the discriminator are equal and opposite; the net output is zero, and the deviation meter reads zero. When off frequency, the output across one tuned circuit increases while that across the other decreases; diode operation then develops a net voltage other than zero across the output. The polarity of the voltage is a function of the direction of frequency drift while the magnitude



Courtesy Gates Radio Co.

Fig. 12-4. An a-m modulation monitor.

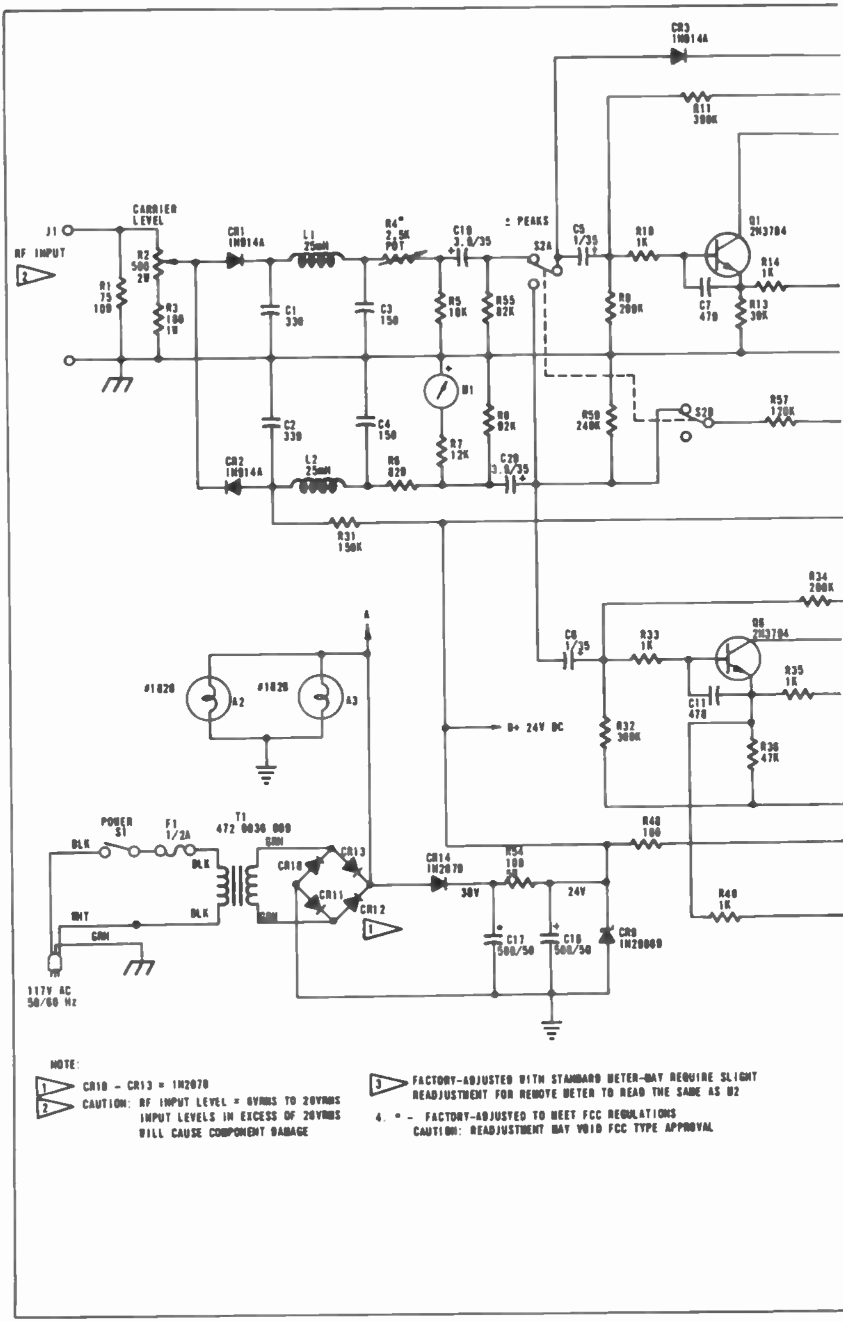
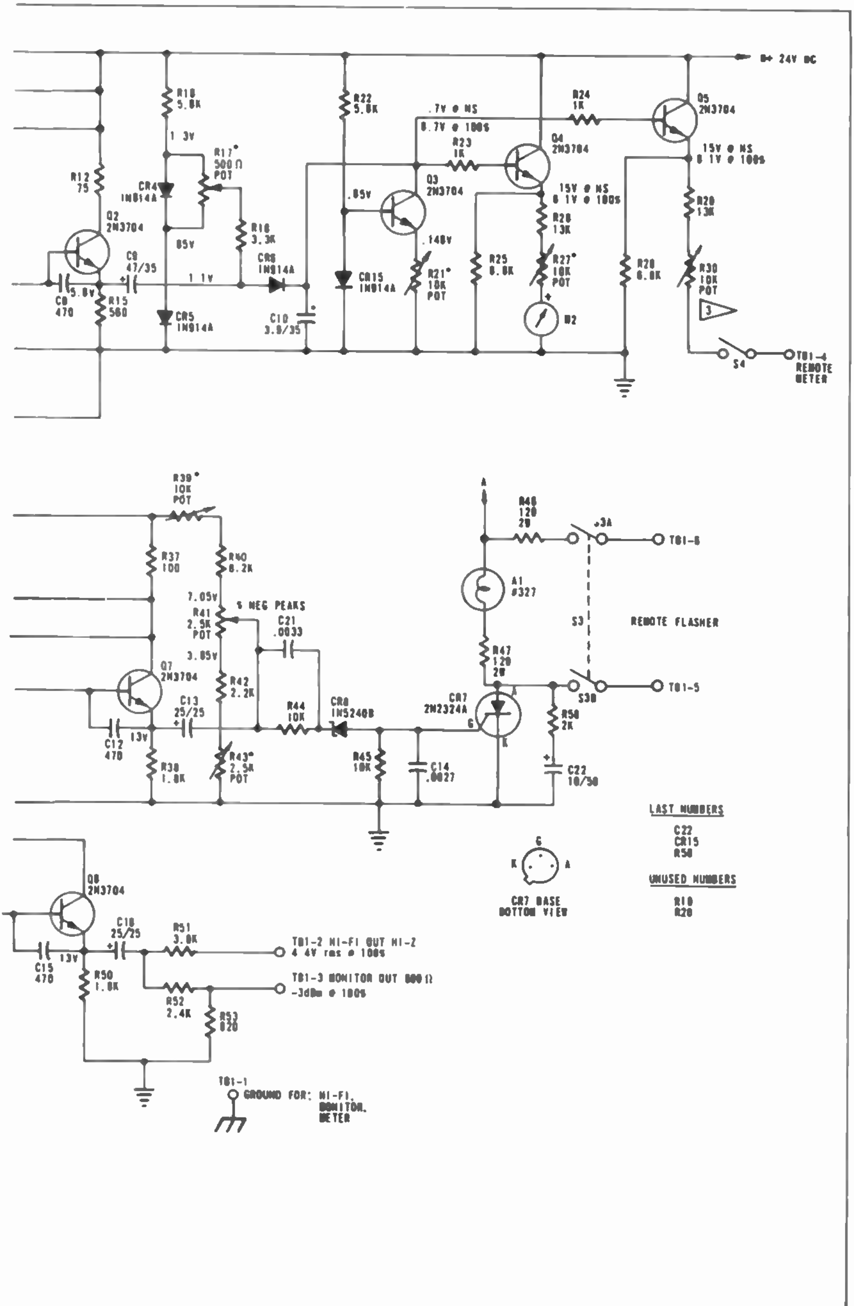


Fig. 12-5. Schematic of an a-m



Courtesy Gates Radio Co.

modulation monitor.

of the dc voltage is a function of the extent of the frequency drift. An associated metering scale is calibrated in hertz deviation from the assigned transmit frequency.

12-2. A-M MODULATION MONITOR

A solid-state a-m modulation monitor is shown in Fig. 12-4; the schematic diagram is given in Fig. 12-5. The modulation monitor provides a continuous metering indication of positive or negative modulation peaks which can be selected by a front panel switch. A visual flasher indicates when negative peaks are in excess of a predetermined level (as set by the percentage negative peaks control).

A carrier-level meter indicates that the proper signal is being applied to the monitor. Incoming signal level is adjusted until the carrier meter reads on the red line (100). This meter also indicates the average carrier level and shows any change in the carrier level with modulation. Hence it provides a relative reading of carrier strength, and will indicate modulation defects that may cause a positive or negative carrier shift.

Signal from the monitor-out terminal of the transmitter is connected to the rf input of the a-m modulation monitor, top left of Fig. 12-5. Potentiometer R2 is used to set the carrier level to the red line. Two separate diode detectors, connected with opposite polarity, are used to evaluate the positive and negative modulation peaks. The diode at the top responds to the positive audio variations on the upper half of the modulation envelope. These variations correspond to positive modulation peaks.

Diode CR2 is so polarized that it responds to the positive variations of the lower half of the modulation envelope. Since these variations occur immediately below the zero axis of the modulation envelope they correspond to the negative modulation peaks. Either the negative or positive modulation peaks can be selected for evaluation with the proper setting of the peak switch S2A at the output of the demodulator. M1 is the carrier level meter.

It should be stressed that whether the negative or positive modulation peaks are being observed, the peak information desired is to be found in the positive level of the audio signal that is transferred through capacitor C5 to the two direct-coupled emitter-follower stages, transistors Q1 and Q2. The output of transistor Q2 is a low impedance one and supplies the audio variations to peak rectifier diode CR6.

The charge placed on capacitor C10 is a measure of the peak amplitude of the demodulated audio. Therefore, it corresponds to either the positive or negative modulation peaks as determined by S2A position. This reading is shown on meter M2 located in the emitter circuit of transistor Q4. Peaks information is also supplied to the base of transistor Q5. Its emitter circuit can be connected to a remote modulation meter.

Positive variations corresponding to the negative modulation peaks are transferred through capacitor C6 to the direct-coupled emitter-follower stages, transistors Q6 and Q7. These peaks are supplied to a peak-rectifier diode CR8 which is in the gate circuit of the modulation flasher. When the modulation is high enough to overcome the diode bias set by the negative peaks control, the bias developed across the resistor-capacitor combination (R45 and C14) fires the silicon controlled rectifier CR7. As a result current turns on flasher bulb A1. Facilities are included for attaching a remote flasher as well.

The audio variation developed across emitter-resistor R36 of transistor Q6 is applied to a second emitter-follower stage, transistor Q8. This stage provides two outputs for monitoring and measurement.

12-3. FM DEVIATION AND MODULATION MONITORS

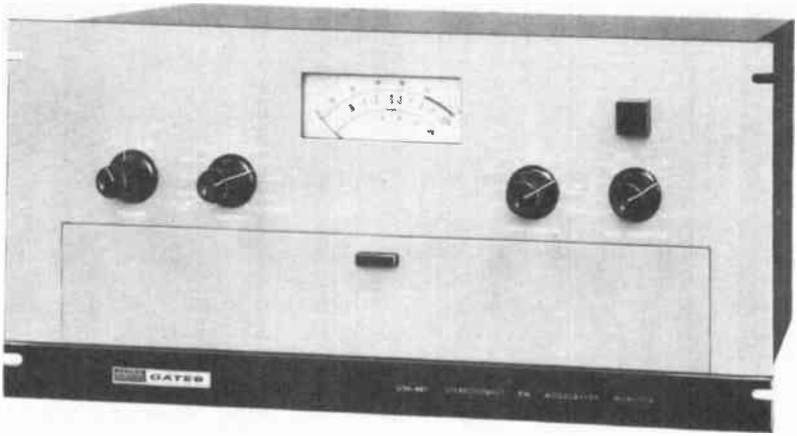
Frequency of operation and modulation level must also be monitored continuously when operating an fm broadcast transmitter. The modulation monitor (Fig. 12-6A), like an a-m type, provides continuous monitoring of modulation peaks. However, instead of amplitude peaks these are frequency-deviation peaks in excess of a modulation percentage set by the modulation peaks control. Recall that for the fm broadcast service 100-percent modulation corresponds to a peak deviation ±75 kilocycles away from the assigned center frequency. A polarity switch permits the evaluation of positive or negative deviation peaks. A flasher indicates when the deviation in either direction exceeds the value that was preset with the modulation percentage control.

An fm frequency monitor is shown in Fig. 12-6B. In the fm service, this type of meter is often referred to as a deviation meter rather than a frequency monitor. Its function is to provide an indication of any deviation of the center frequency of the fm signal away from the FCC assigned carrier frequency. In the fm broadcast service this may not be in excess of 2000 hertz. Note that the deviation or frequency meter is calibrated in kilohertz (± kHz on each side of 0). If the reading is −1 it indicates that the transmitted center or carrier frequency is 1000 Hz below the FCC-assigned value.

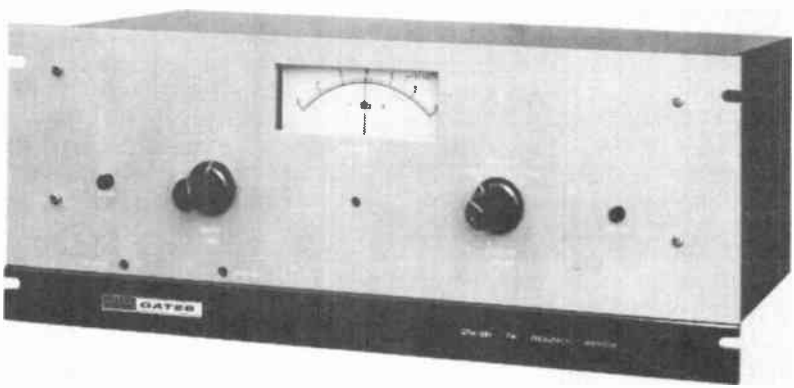
The functional plan of the fm modulation monitor is shown in Fig. 12-7. Basically an fm modulation monitor is a fixed-frequency, high-quality receiver. A sample of the fm signal is applied through a variable attenuator to a mixer. A crystal oscillator and multiplier develop a local oscillator injection signal which is on a frequency 500 kHz higher than the assigned frequency. A portion of the incoming signal is also applied to a noise detector and to an output which permits a measurement of the a-m noise content of the fm signal.

The output of the i-f amplifier is applied to a wideband demodulator mounted on a so-called pulse-counting demodulator card. The various functional systems of the fm modulation meter consist of solid-state devices and integrated circuits mounted on individual printed circuit boards, referred to as cards (Fig. 12-8). These cards are readily replaceable when faults develop.

The output of the pulse-counting demodulator is applied to a phase splitter through a 25-kHz filter which removes any spurious harmonics that are generated during the demodulation process. The phase-splitter makes available positive or negative peaks to the metering circuit. It also supplies signal to the peak flasher. This flasher operates whenever the modulation is greater than the value set by the modulation percentage switch.



(A) Fm modulation monitor.



(B) Fm frequency-deviation monitor.

Courtesy Gates Radio Co.

Fig. 12-6. Modulation monitor and frequency-deviation monitor.

Signal from the phase splitter is supplied to a preamplifier stage through a 15-kHz low-pass filter which removes frequency components above the desired audio bandpass. The output of the preamplifier is increased by a succeeding audio amplifier, which includes a de-emphasis network that can be switched in and out of the circuit. Measurement and monitoring outputs can be removed from this assembly.

Output of the preamplifier is also passed through a filter and a sensitivity switching arrangement to a metering circuit amplifier. From here

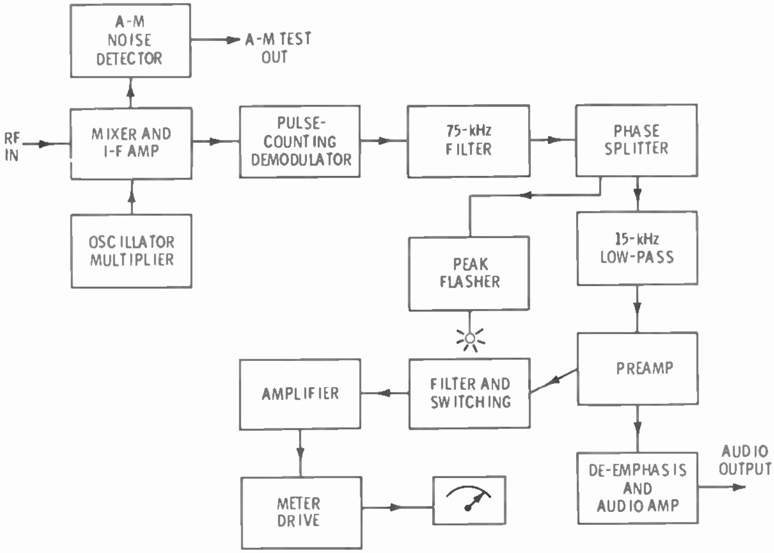
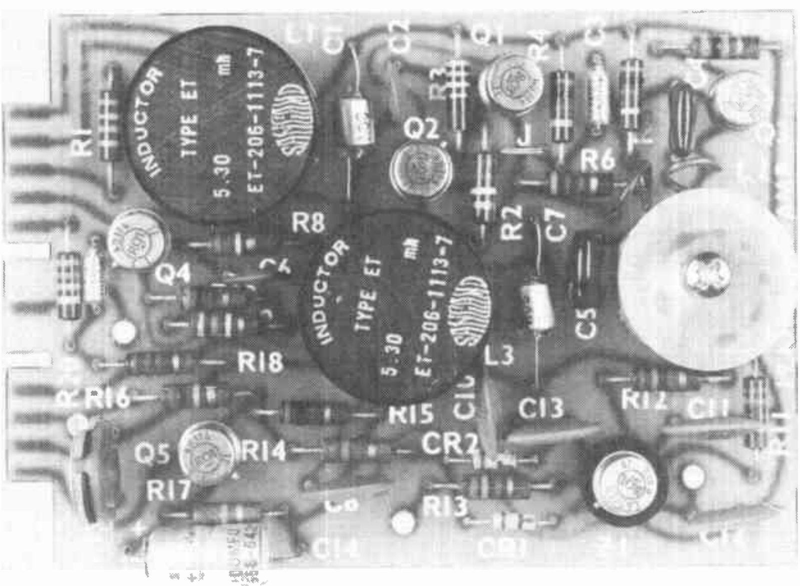


Fig. 12-7. Functional plan of an fm modulation monitor.

it goes to the meter driver which incorporates peak reading and average voltmeter circuits. A dc component that corresponds to the modulation peaks is supplied to the modulation meter.



Courtesy Gates Radio Co.

Fig. 12-8. Typical transistor and IC card.

12-4. FM-MULTIPLEX MONITORING

Additional monitoring facilities are needed if the fm station transmits SCA and/or stereo signals. Several typical instruments for multiuse application are shown in Fig. 12-9. The monitor of Fig. 12-9A is a combination frequency and modulation monitor. The meter at the left registers the center-frequency deviation away from the FCC-assigned carrier frequency. The second meter indicates the percentage of fm modulation. To its right is the peak-flasher and the associated switch that determines the percentage at which the flasher will operate.

In multiplex fm transmission recall that the total deviation caused by the modulating signal may not exceed ±75 kHz. It is this combined modulation that is indicated by this meter.

An SCA monitor is shown in Fig. 12-9B. This monitor is used in addition to that in Fig. 12-9A. Its frequency meter records the deviation of the SCA subcarrier frequency from the assigned value. A set of push buttons located beneath the small panel at the bottom permits a selection of four subcarrier channels that can be monitored. The second meter records the extent of the modulation of the subcarrier in accordance with the setting of the modulation switch on the far right. This switch is used to establish 100-percent modulation in accordance with the required maximum deviation of the subcarrier. A percent-modulation switch and a modulation flasher are incorporated.

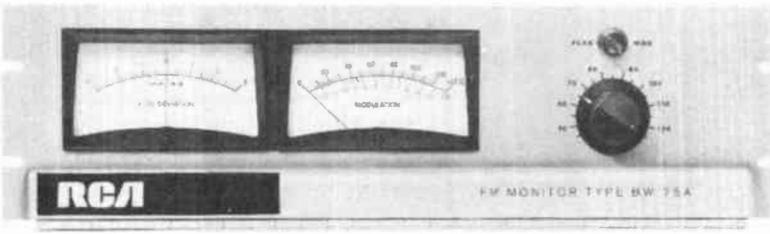
The stereo fm broadcast monitor is shown in Fig. 12-9C. It also includes a frequency meter that monitors the 38-kHz subcarrier frequency. This instrument includes versatile stereo monitoring and test functions. Note from the function switch that it is possible to monitor the subcarrier and pilot-frequency fm modulation, the individual left and right channels, as well as L − R and L + R components. Various a-m and fm noise measurements can also be made. This instrument also operates in conjunction with the basic monitor shown in Fig. 12-9A.

12-5. AUDIO OSCILLATOR

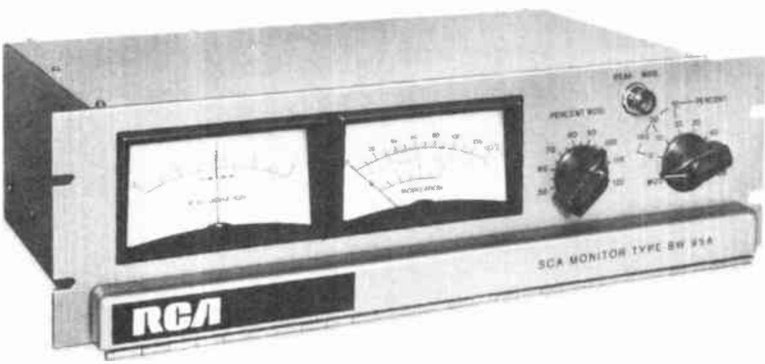
The audio oscillator, an essential piece of test equipment for the broadcast station, can be used as a signal source when measuring gain or frequency response and when localizing audio or modulation defects. If the audio oscillator meets FCC specifications for high stability and is free from harmonics, noise, and hum, it can also be used in making proof-of-performance checks.

A typical broadcast-quality audio oscillator is the Barker and Williamson unit shown in Fig. 12-10. Its specifications are as follows:

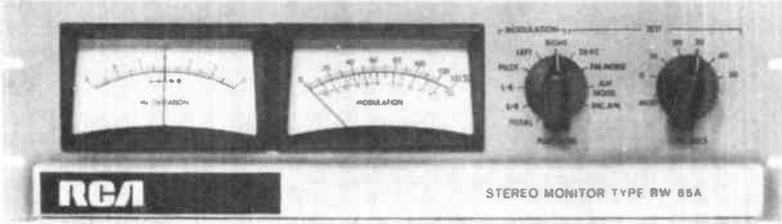
Frequency Range: 10-100,000 Hz in three ranges.
Output: 10 volts into 600-ohm load.
Waveform: At full output, the harmonic distortion is less than 0.3 percent from 50 to 20,000 Hz. A reduction of the output voltage to 5 volts decreases the distortion to less than 0.2 percent from 50 to 20,000 Hz.
Noise Level: At a 5-volt output, the noise level is better than −70 dB.



(A) Fm monitor.



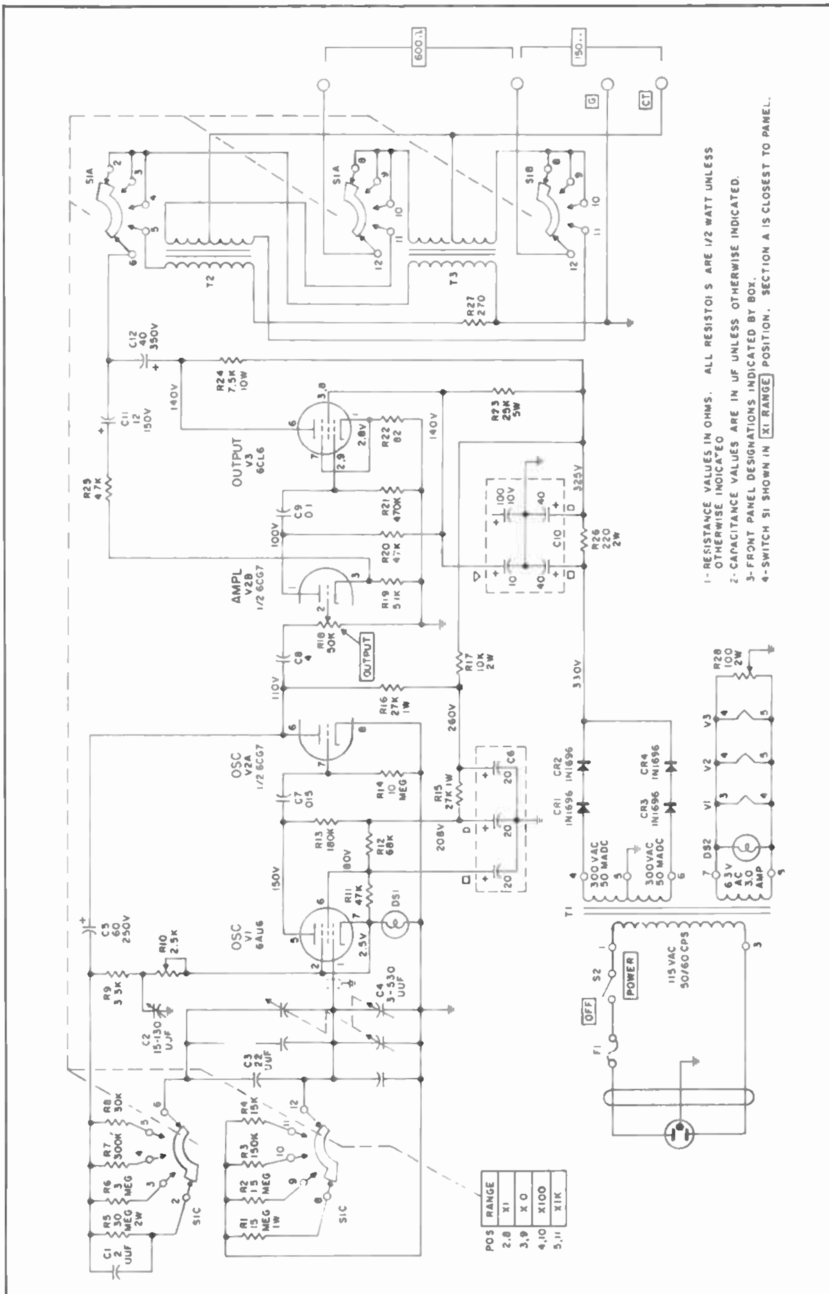
(B) SCA monitor.



(C) Fm multiplex monitor.

Courtesy RCA Corp.

Fig. 12-9. Several typical monitors.



Courtesy Barker and Williamson, Inc.

Fig. 12-10. Wien-bridge and oscillator.

Output Impedance: 600 ohms balanced.
Calibration: ±1 percent over entire range.
Frequency Characteristics: The output level is flat within ±1 percent over entire range when working into rated load.

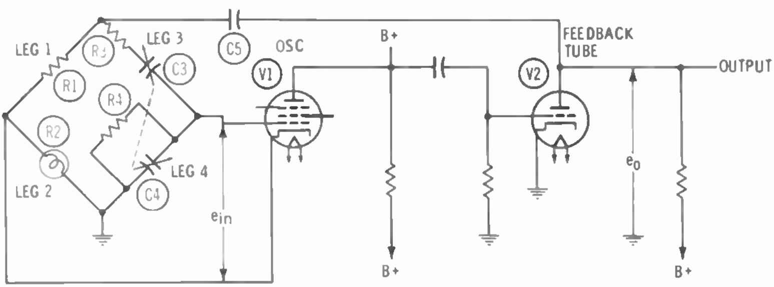


Fig. 12-11. Simplified schematic of a Wien-bridge oscillator.

The audio oscillator consists of a Wien-bridge feedback oscillator, audio amplifier, and cathode-follower output stage. The Wien-bridge network and tubes are capable of generating an essentially pure sine wave of high stability. The bridge network, as shown in the simplified schematic of Fig. 12-11 consists of balanced series and shunt RC combinations. At one particular frequency, this series network presents a minimum impedance to the feedback signal from the plate of the phase-reversing triode to the oscillator grid. At this same frequency the parallel network presents a high impedance from the grid of the oscillator tube to ground. The feedback factor is highest for this single frequency, establishing the exact oscillating frequency. Off the operating frequency the series network presents a rising impedance, and the shunt network a falling impedance. Oscillations can not be established because of less favorable feedback.

The oscillator resonant frequency can be changed by switching the value of the fixed resistor (for coarse frequency adjustment) and tuning a variable ganged capacitor C4 (for fine-frequency adjustment). To stabilize the oscillator insofar as operating constants and output level are concerned, some negative feedback is used between the plate of the triode and the cathode of the pentode section of the oscillator. Such feedback is also of considerable importance in generating a pure sine wave with a very minimum of harmonic content. The small lamp in the cathode circuit also helps to stabilize the output. Its resistance varies with the current flow, exerting a self-regulating action in the cathode-bias circuit.

A triode voltage amplifier builds up the signal amplitude to the level needed to drive the pentode output stage. An output level control is located in its grid circuit. The output is coupled through a capacitor to the output transformer to remove any dc component from the transformer primary. In fact, two output transformers, designed for optimum low- and high-frequency operation, are used. These are selected by the range switch. Transformer T3 covers the frequency range between 10 Hz and 10 kHz; transformer T2, between 10 kHz and 100 kHz.

Again, distortion is held to a minimum level with the use of some negative feedback via capacitor C11 from the output circuit to the cathode of the audio amplifier driver. Also, the cathode-bias circuits are unbypassed to provide additional negative feedback. The audio transformer provides a 600-ohm balanced output, center-tapped. The center tap or either side of the 600-ohm output may be grounded. It is also possible to match into a 150-ohm termination.

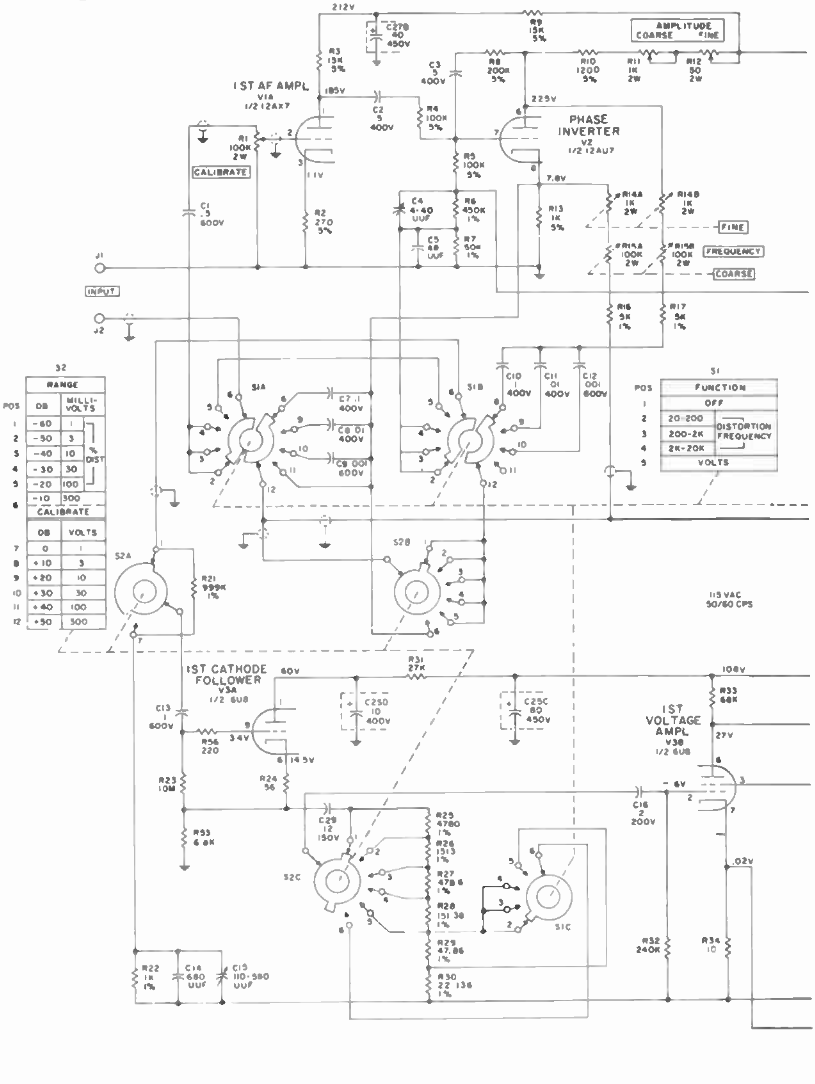
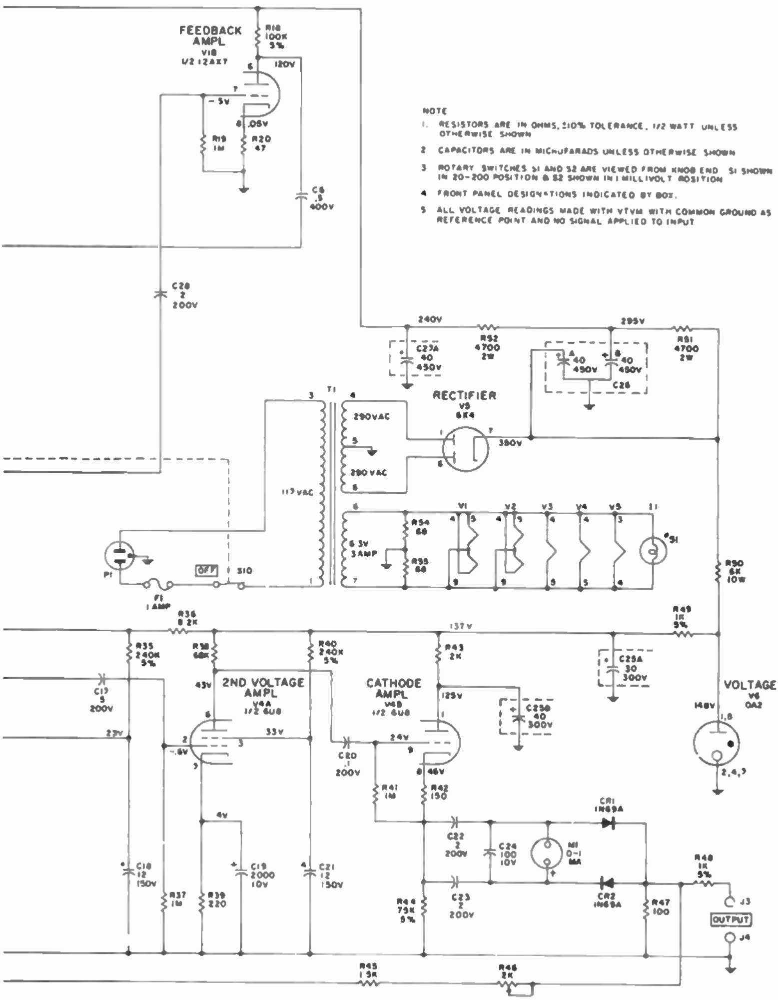


Fig. 12-12. Schematic of a meter for

The power supply uses a silicon rectifier connected into a full-wave circuit. A hum-balancing control (R8) is located in the filament line.

12-6. DISTORTION METER

A distortion meter developed for broadcast use is the Barker and Williamson unit shown in Fig. 12-12. The instrument is used for measuring distortion and noise in radio transmitters and audio systems, and as an ac vacuum-tube voltmeter or dB meter. It consists of a variable-fre-



Courtesy Barker and Williamson, Inc.

measuring noise and distortion.

quency Wien bridge connected in a negative-feedback amplifier, a calibrated attenuator, and a high-gain vacuum-tube voltmeter. The method of measuring distortion and noise involves suppression of the fundamental and then reading the rms amplitude of all unwanted frequencies (including noise) as a percentage of the rms value of the applied fundamental.

The distortion meter is attached to the output of the particular audio system under check. A tone signal of appropriate frequency is applied to the audio-system input. The distortion-meter frequency control is adjusted in such a manner that the fundamental at the amplifier output is suppressed. The instrument passes all other frequency components and then measures the combined rms amplitude. Such unwanted frequencies can consist of noise, hum, and harmonics of the fundamental tone.

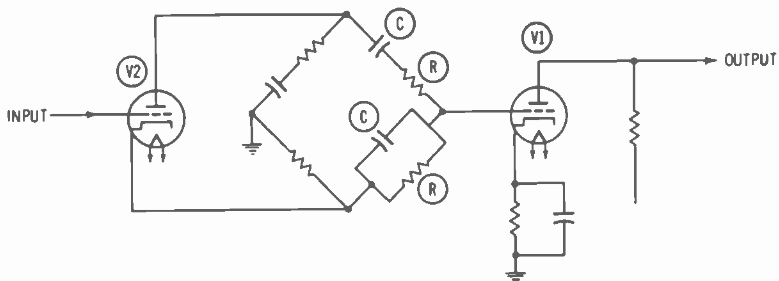


Fig. 12-13. Simplified schematic of the Wien-bridge network.

The signal to be measured is applied to the input terminals (Fig. 12-12). The output of voltage-amplifier stage V1A is coupled, through capacitor C2, to the grid of tube V2. V1B and V2 are part of the Wien-bridge feedback amplifier. Opposite-polarity signal components are supplied from the plate and cathode of V3 to the Wien-bridge network. The network in turn drives the control grid of V1B.

In making a distortion measurement, the audio signal at the output of the amplifier under test is supplied through section A of function switch S1 and calibrate potentiometer R1 to the grid of the first audio amplifier. The basic function of the succeeding phase inverter and feedback amplifier is to reduce the fundamental frequency to zero. Notice that the cathode output of the phase inverter is supplied to the grid of the feedback amplifier via frequency controls R14 and R15, and capacitor C28. The output of the feedback amplifier is fed back to the grid circuit of the phase inverter via capacitor C6. It will appear as a reference signal at the junction of resistors R5 and R6.

The Wien-bridge circuit displays a high impedance at the frequency to which it is tuned. As shown in the simplified schematic of Fig. 12-13, the path from the plate of V2 to the grid of V1B is by way of a series RC combination, while a parallel RC combination links the cathode of V2 and the grid of V1. At the operating frequency of the bridge, these two paths contribute equal-value but opposite-polarity signal components, causing cancellation at the grid of tube V1B. Thus, at this point the fundamental has been removed. What remains are the harmonics, hum, and noise components which are supplied via section B of function switch S1 and range switch S2 to the cathode-follower input circuit of the voltmeter section.

12-7. INTERMODULATION DISTORTION

The recent emphasis on high-fidelity and stereophone broadcasting has made intermodulation distortion an important factor. Any amplitude nonlinearity in an amplifier will cause interaction or intermodulation between the various frequency components. As a result, new frequency components not in the original signal are produced. For example, interaction between a 5000-Hz and a 50-Hz note would produce intermodulation distortion components on frequencies of 5050 (500 plus 50) and 4950 (500 minus 50) Hz.

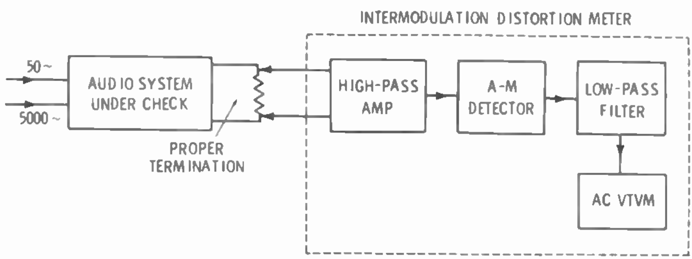


Fig. 12-14. Block diagram of an intermodulation distortion analyzer.

Analyzers are available that permit the measurement of intermodulation distortion. In a typical arrangement, as shown in Fig. 12-14, two audio signals of rather widely separated frequencies are applied to the input of the amplifier under test. The amplifier controls are set for normal operation or to produce a standard reference output across a proper termination. The intermodulation distortion analyzer removes the measurement signal from across this termination.

Let us assume that a 50-Hz and a 5000-Hz audio tone are being applied to the amplifier under test. It will be the responsibility of the distortion analyzer to remove the two fundamental components and make a measurement of the intermodulation components that remain. First, the signal to be measured is applied to a high-pass amplifier. Its responsibility is to remove, in our example, the 50-Hz or low-frequency, fundamental component. However, the 5000-Hz component will pass undisturbed to a detector. If there were intermodulation distortion in the amplifier, there would also be two intermodulation frequency components at 5050 Hz and 4950 Hz. In effect, these would be modulating the 5000-Hz note. The nonlinearity in the amplifier has caused the 50-Hz note to modulate the 5000-Hz note, producing sidebands at 4950 and 5050 Hz. These, too, would pass unattenuated through the high-pass amplifier and on to the detector.

The detector is an a-m type and treats the 5000-Hz components as a carrier and will demodulate the signal and produce a 50-Hz output. This 50-Hz component is not the original 50-Hz fundamental, but is the result of intermodulation distortion in the amplifier.

This demodulated 50-Hz component is now applied to a low-pass filter that ensures the complete removal of the original high-frequency fundamental 500-Hz note. At the output of the low-pass filter the only signal components that remain are those that result from intermodulation distortion in the amplifier. This signal component is supplied to an ac vacuum-tube voltmeter.

Intermodulation distortion is given as a percent of the high-frequency test signal. Modern amplifiers are available with harmonic and intermodulation distortion of several percent of high-frequency test signal, and, in special amplifiers, the levels are down to only a fraction of 1 percent of this test signal.

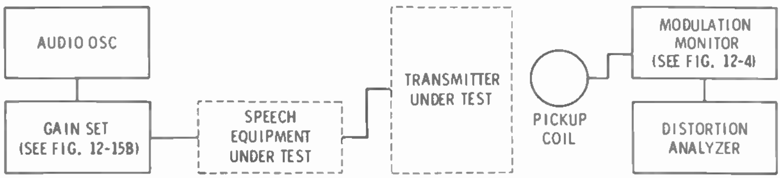
12-8. PROOF-OF-PERFORMANCE MEASUREMENTS

The FCC requires that the broadcast station equipment meet specific requirements concerning frequency response, harmonic content, carrier shift, carrier hum and noise level, and spurious radiation. It is also necessary for each station to take yearly measurements that must be made during the four month period preceding the date of filing for license renewal. The measurements can be made by any qualified engineer and, if suitable test equipment is available at the station, by the engineering personnel of the station. It is advisable, however, to have the measurements verified every few years by a consulting engineer.

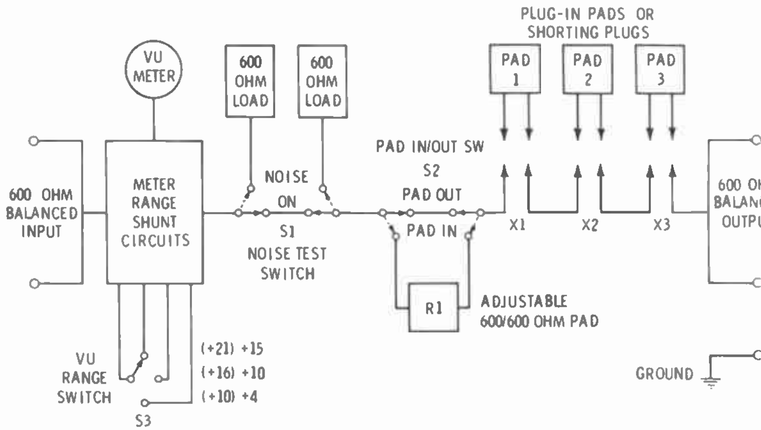
Specific proof-of-performance data must be obtained and kept on file by the broadcast station. These records not only permit compliance with FCC rules and regulations, but also serve as an indication of the overall performance of the station. By making yearly or even more frequent comparisons, it is possible to disclose any signs of deterioration of station equipment. If such conditions exist, remedial steps should be taken, even though the performance still lies within FCC tolerances. The actual regulations, as they appear in the FCC Rules and Regulations, can be found in Appendix I, Sec. 73.47 and Sec. 73.254. Read over these requirements and specifications carefully.

Certain basic test equipment is required in making proof-of-performance measurements. An audio oscillator with a fundamental frequency range between 30 Hz and 17-kHz is needed. The audio oscillator itself must have a very low harmonic content and a high accuracy. An instrument similar to the Barker and Williamson oscillator described in this chapter operates well within FCC specifications.

Attenuator pads or variable attenuators are helpful in establishing correct signal levels and accurate measurements. Calibrated attenuators are often built into audio oscillators and distortion meters. Isolation and matching transformers are necessary for these measurements. Usually unbalanced and balanced inputs and outputs are available on the better-quality test equipment which is designed for making broadcast measurements.



(A) Transmitter proof-of-performance arrangement.



(B) Functional diagram of gain set.

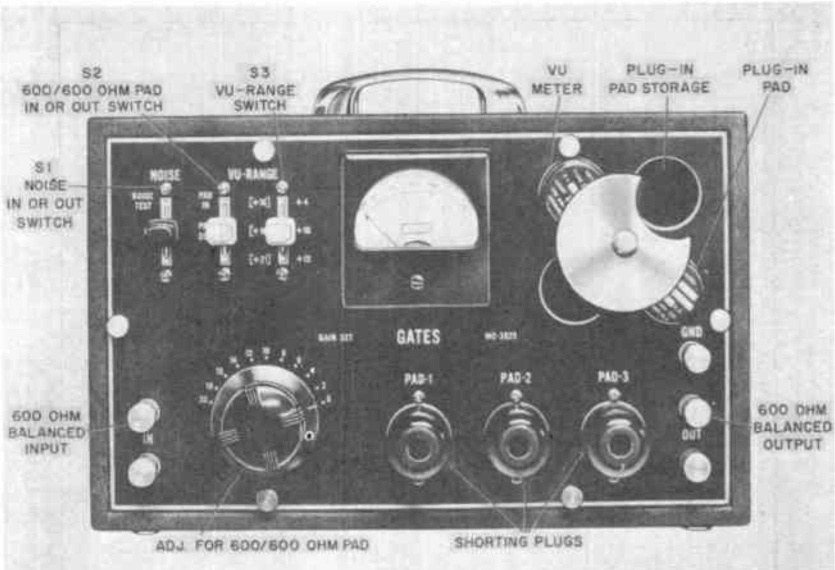
Courtesy Gates Radio Co.

Fig. 12-15. Proof-of-performance test arrangement.

A good distortion-and-noise meter is essential, and usually this same instrument has an a-c vacuum-tube voltmeter which can be used for frequency response measurements. A panel VU meter is usually an essential unit of a broadcast station, and can be used as the volume and output-level indicator for these tests. Although an oscilloscope is not a necessity for proof-of-performance measurements, it is useful in analyzing signal waveforms and in adjusting the test equipment.

Since frequency and modulation meters are essential pieces of monitoring equipment at all transmitters, these meters can be used in the proof-of-performance measurements. The modulation monitor (Fig. 12-4) provides low-distortion audio output jacks to supply a signal to a distortion and noise meter. A field-strength meter and a good quality communications receiver are useful in measuring transmitter fundamental and harmonic outputs and other spurious radiations.

Proof-of-performance measurements are made with station equipment adjusted for normal broadcast operation. All equipment between the microphone and antenna output should be included in the measurements procedures. Test equipment should be interconnected with balanced 600-ohm circuits. The test equipment and broadcast units should be matched correctly and precautions taken to minimize hum pickup from test equipment. The chassis of the test instrument should have a good ground connection to the station ground system. Only short power



Courtesy Gates Radio Co.

Fig. 12-16. A proof-of-performance gain set.

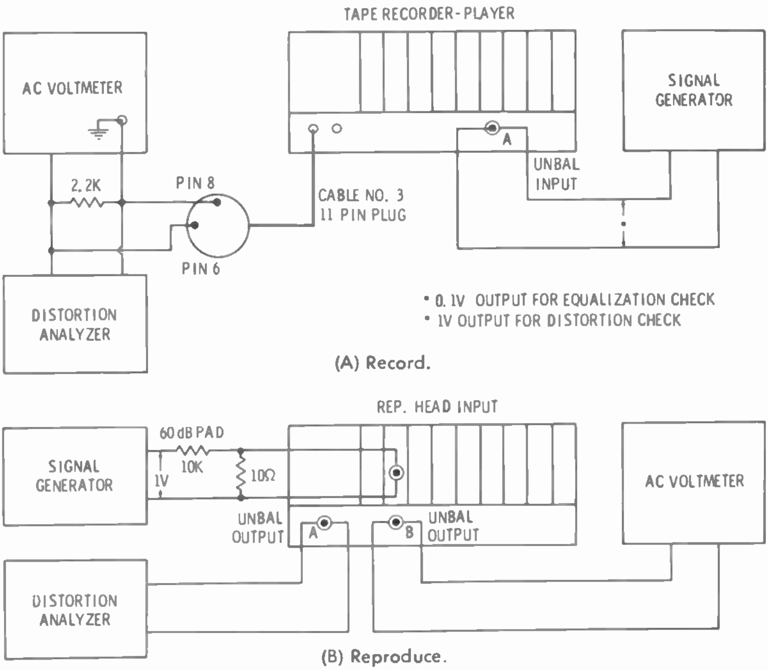


Fig. 12-17. Arrangement of equipment for checking tape recorder/player.

leads should be used to the test equipment, and these leads should have a power-line filter. Short signal leads are required to supply signal to input stages of the broadcast units that normally operate at low signal levels. At the transmitter, the test leads must ofen be isolated from the rf energy by using chokes and rf filter capacitors. In some of the performance measurements it is necessary to patch around the limiter and compression amplifiers of the transmitter.

A typical proof-of-performance test setup is shown in Fig. 12-15; the speech equipment and transmitter to be tested are shown in the dashed-line blocks. In this arrangement a pickup coil is placed in the vicinity of the transmitter output circuit. A linear detector recovers the modulation and applies it to a distortion analyzer. In another test setup arrangement it is possible to attach the distortion analyzer directly to the audio test output terminals of the modulation monitor. In this case the modulation detector is a built-in part of the modulation meter.

The signal source is a good-quality audio oscillator followed by a so-called gain set. Such a gain set is shown in Fig. 12-16; it is specifically designed for use in making proof-of-performance measurements. It includes the proper impedance matching versatility, a VU meter, and a range switch. Also a part of the gain set is a versatile arrangement for making noise tests which require switching between a properly terminated source of signal and a like input termination of the input without presence of signal.

Fig. 12-15B shows the functional plan of a gain set. Facilities are included for additional switch pad arrangements or plug-in type shorting plugs and pads. Such facilities permit a precise setting of applied signal level as well as precise changes in magnitude of the applied signal.

The same test equipment can be used to check out the performance of various other broadcast amplifiers and program sources. Proper interconnection of test equipment for testing a tape unit on its record and reproduce functions is shown in Fig. 12-17.

CHAPTER 13

Television Broadcasting

Television broadcast stations are more complex than fm and a-m broadcast stations because of the additional equipment required for video broadcast service. The higher frequencies of the television signal, particularly in the uhf television band, require advanced techniques that also increase the complexity of the station facilities.

13-1. GENERAL

The television broadcast station is a two-channel facility—picture and sound. Each television broadcast station is assigned a 6-MHz channel. The sound carrier is located at the high-frequency end of the spectrum and is separated from the picture carrier by 4.5 MHz. The sound carrier is frequency-modulated; from microphone to atenna, the sound equipment is almost identical to that of an fm broadcast station with the exception that 100-percent modulation constitutes a maximum frequency deviation of ±25 kHz. Many of the broadcast microphones associated with a television-studio facility are mounted on long booms so that they can be suspended overhead, out of view of the cameras. The same antenna is used to radiate both the picture and the sound carriers and sidebands; a "diplexer" provides the necessary isolation between sound and picture signals at the antenna.

The source of the television picture (video signal) is the camera. The camera contains a lens system and a camera tube that forms a "video" signal which corresponds to the brightness detail of the image focused on it. The camera contains other basic circuits which have to do with amplification of the video signal released by the camera tube, plus circuits which control the orderly release of this information.

A television studio is a maze of cameras, microphones, cables, lights, and props, as shown in Fig. 13-1. The video signals from the cameras and the audio signals from the microphones are supplied to a control room such as the one shown in Fig. 13-2. Separate picture- and sound-control consoles are part of the control rooms. Some of the operations are so highly technical that licensed personnel are used. However, it is not mandatory that the studio and control-room technicians be licensed. In addition to the video and audio operators in the control room, there are positions for additional personnel such as program

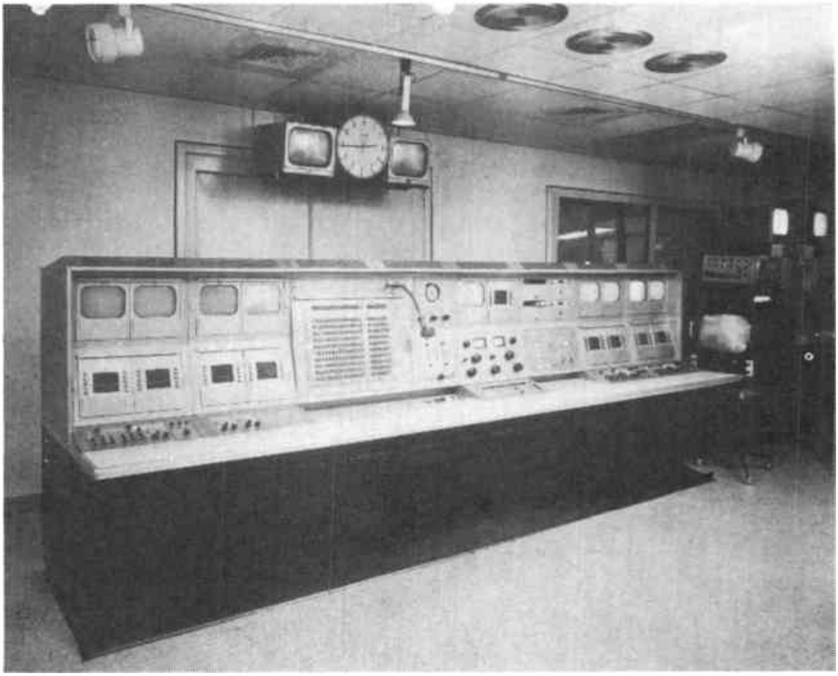
Courtesy RCA Corp., Broadcast Systems Division

Fig. 13-1. A two-camera pickup.

director and technical operations director. The technical director is often a licensed operator.

On the studio floor there are cameramen, microphone boom operators, and lighting personnel. Many of these technicians are also licensed so they can perform a variety of duties around the television station. Particularly in the smaller television station, a licensed technician is preferred because he can take on any of the station's technical assignments. Of course there are a variety of program personnel such as production directors, floor managers, prop men, etc. In the smaller stations the technical personnel often contribute to the actual programming activities as well.

A very large percentage of the broadcast time of a small station is filmed or taped (Fig. 13-3). The basic film-projection equipment consists of a dual projector, a television film camera and control unit, and one or more slide projectors. The various projectors are operated by a motion picture projectionist; usually the television-film camera control unit is in the control room and is operated by one of the video operators. Television tape facilities are part of practically every station. Programs can be taped when convenient and then put on the air at the most appropriate time.



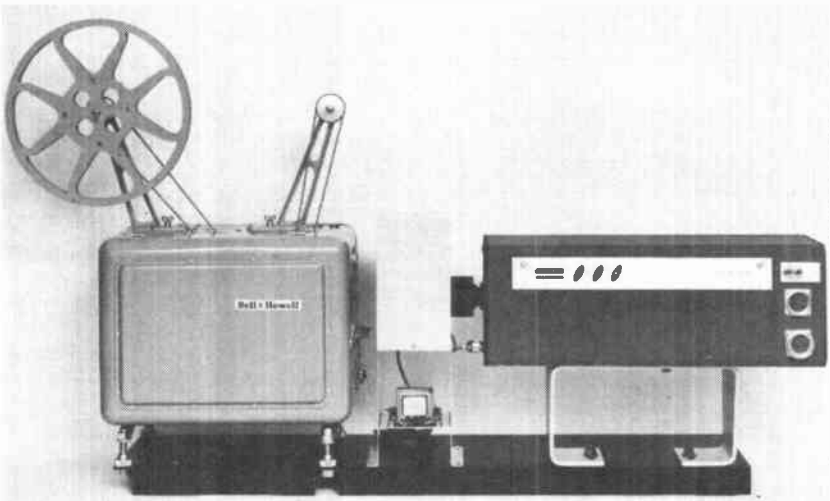
Courtesy RCA Corp., Broadcast Systems Division

Fig. 13-2. A modern television control room.

Lightweight portable television equipment consisting of cameras, control units, and usually a microwave transmitter for on-the-spot coverage, is available. The microwave transmitter sends the signal back to the main studio or directly to the transmitter. At this location, a microwave receiver picks up and demodulates the television signal and then applies it to the regular video program line of the station. The audio portion of the remote telecast can be multiplexed on the same microwave carrier, or conveyed over telephone facilities to the studio or transmitter.

The control room is an elaborate monitoring and switching center. Here the various video- and sound-signal sources from projection room, network, studio, tape machine, or remote are selected and placed on the program line. The control room contains numerous picture monitors, operating panels, and racks of equipment. Here, the basic pulses needed to synchronize a television system are formed and channeled to the many pieces of equipment that use these pulses to time, or synchronize, circuit activities. It is here that the complete television signal is prepared for conveyance to the transmitter.

The very same control room must have facilities for handling all the sound sources. Each type of video program has its accompanying sound which must be handled concurrently. When a video changeover between two program sources is made, there must be a coinciding sound changeover as well. There must be a high order of coordination between video and sound operations.



Courtesy Cohu Electronics

Fig. 13-3. A TV camera and film projector.

Usually the television program material is conveyed between studio control and transmitter over the video-cable facilities of the telephone company. If a transmitter is located on a mountain top or other isolated site, a studio-transmitter link (stl) conveys the program material over a microwave facility.

Most network programs are now carried over microwave links that operate from coast to coast, although considerable program material is still handled over long-distance coaxial-cable systems.

The transmitter room houses the two transmitters (picture and sound) and their associated control and monitor equipment. A licensed first-class operator must be on duty continuously whenever the television transmitter is on the air. Because of the more complex and larger amount of equipment needed at the television transmitter, many stations keep at least two operators on continuous duty.

13-2. TELEVISION BROADCAST PRINCIPLES

A thorough discussion of television broadcast theory and equipment is beyond the scope of this handbook. However, the fundamentals of television transmission will be presented. This information does cover television transmission principles in substantially greater detail than is required for passing the first-class radiotelephone license examination.

A functional block diagram of a television transmission system is given in Fig. 13-4. Also shown are the functional units of the accompanying sound. This segment of television broadcast equipment will not be elaborated upon because of its similarity to fm broadcasting.

The very first step in gaining an understanding of television transmission is to realize that individual television pictures are not sent as an entirety. It is true, in modern television broadcasting, that thirty complete pictures are sent each second. However, each of these pictures is broken down into several hundred thousand elements which are sent in a sequential order. The image of a television scene is broken up by a cathode-ray electron scanning beam at the camera tube, and then reassembled by another scanning beam at the receiver.

The scanning technique is demonstrated in Fig. 13-5A. The camera tube contains a photosensitive area, or target, composed of hundreds of thousands of isolated and light-sensitive elements, on which an optical-lens system focuses the scene into an image. A camera-tube scanning beam moves over this surface, in accordance with a standardized motion, releasing a video signal corresponding to the brightness detail of the image. This video signal is released element by element and line by line as the beam moves across the image and down. It is standard to transmit a picture four units wide by three units high—the picture is said to have a 4:3 aspect ratio.

The picture-tube scanning beam in the receiver follows the same motion over the fluorescent screen. As the beam moves across the screen, its electron density is varied by the video signal supplied to the control grid of the picture tube. The fluorescent screen of the picture tube glows in accordance with the strength of the scanning beam striking each individual element. Since the strength of the beam is varied as it scans over the fluorescent surface, the original brightness detail is recovered element by element. In this manner the original transmitted image-brightness pattern is reproduced on the fluorescent screen of the receiver.

It is apparent that if a scene is to be reconstructed exactly, the motions of the picture- and camera-tube scanning beams must be identical—the beams must be synchronized. By so doing, the image will be reconstructed at the picture tube, at the same rate and in the same order that the video information was released from the image focused on the camera tube.

In a television station a sync generator is used to form the pulses that synchronize the motions of the camera- and picture-tube beams. Insofar as the station equipment is concerned, the synchronizing information is sent over a cable directly to the camera circuits that control the motion of the camera-tube scanning beam. Similar pulses are in-

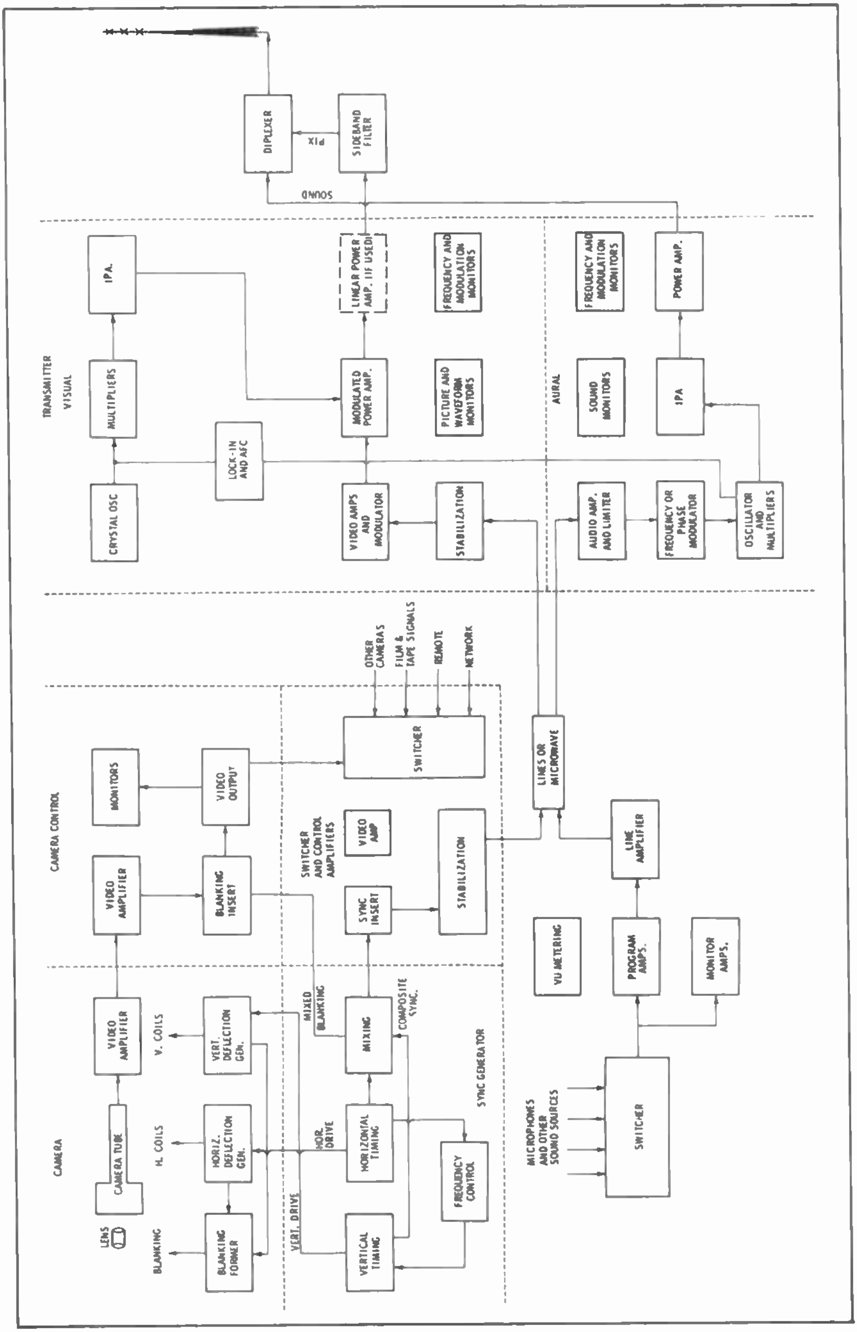
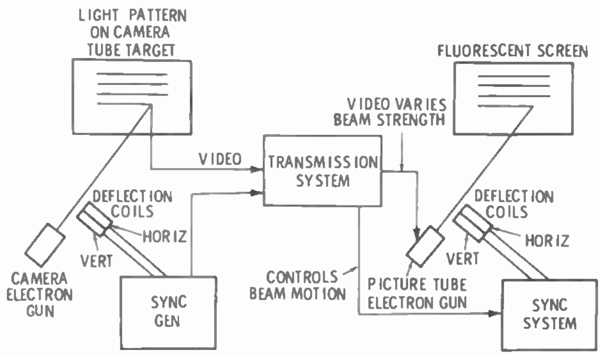


Fig. 13-4. A functional block diagram of a monochrome broadcast station.

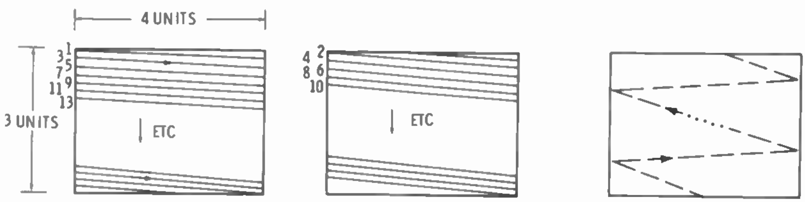
serted into the television signal that is transmitted. It follows, then, that it is necessary to send not only the video signal from the transmitter to the receiver, but also a group of pulses to synchronize operations at the receiver.

13-3. THE SCANNING TECHNIQUE

It is standard in television broadcasting to transmit thirty complete pictures per second, each picture made up of 525 lines. Thus 15,750 lines (525 × 30) are transmitted each second. This is referred to as the "line rate" or "horizontal rate" of the television system. However, the 525 lines are not scanned sequentially from the top of the image



(A) Functional diagram of scanning.



(B) Odd-line scanning. (C) Even-line scanning. (D) Without blanking, retrace path is visible.

Fig. 13-5. Television scanning at television camera and picture tube.

to the bottom. Rather, there are 262½ lines scanned from top to bottom for a first vertical scan. The scanning action then returns quickly to the top and covers the in-between lines down the screen, as shown in Fig. 13-5. This method of first covering the odd-numbered lines and then returning (retrace) to cover the even-numbered lines is referred to as "interlace scanning." The *purpose of interlacing* is to reduce *flicker.*

A complete television picture is called a *frame;* it is composed of an odd- and an even-line field. The screen is made to go black during all retraces to prevent spurious bright lines from appearing in the picture. This action is called "blanking."

In a motion-picture theatre, individual scenes are flashed on the screen at the rate of 24 per second. Because of the retentivity of human vision, it is possible to create the illusion of moving pictures. To prevent the screen from flickering, however, each scene is cut on and off twice by the film projector. The more frequent interruption of the motion-picture frames (48 times per second) prevents human vision from observing the light interruption as each new frame is moved into position and the beam is shuttered off for a split second.

In a television system if the scanning activities were shut down to only 30 times per second, there would be a noticeable flicker in the reproduced picture. With the use of interlace and its two shorter vertical-retrace (blanking) intervals for each frame, the brightness is interrupted 60 times per second and flicker is not apparent. The 60-Hz rate of interruption is known as the "field" or "vertical rate" of the television system. It is important to realize, in summary, that 30 complete pictures are sent each second, but that each picture is broken up into two fields.

In the camera circuits a horizontal-deflection waveform causes the electron scanning beam to move from left to right across the sensitive surface, releasing the brightness information along that line. When the scanning beam reaches the right side, it is shut off. The retrace period of the horizontal-deflection waveform in the camera now quickly reorients the deflection field from right to left. Hence when the camera-tube beam is turned on again, it starts scanning at the left side of the image.

There is also a vertical-deflection waveform which tends to pull the scanning beam down the image. Consequently when the beam is turned on again at the left side, it will be just slightly below its starting position for the first line described above. Thus, as the scanning activity continues from left to right and back to left at a fast rate, a slower vertical motion of the scanning beam causes a series of lines to be traced from the top of the image to the bottom. Hence the video information is released element by element along each line, and then line by line down the sensitive surface of the camera-tube target.

When the scanning beam reaches the bottom it is turned off. The vertical-deflection field of the camera tube (vertical retrace) is then reoriented as quickly as possible, so that when the scanning beam is turned on again it will appear at the top left of the image, ready to start a new scanning cycle.

The retracing of the field vertically requires a finite amount of time; therefore, during this interval a number of horizontal scanning cycles could take place as shown in Fig. 13-5D. However, the scanning beam has been cut off during this time and no horizontal lines are evaluated.

During the motion of the scanning beam, line after line, from top to bottom of the image, the video signal is released. These are referred to as the *active lines* of the television picture. Inasmuch as the horizontal motion during the vertical-retrace interval did not produce any active lines of video, these are called *inactive lines*. In our modern telecasting system there are approximately 525 lines—500 active and approximately 25 inactive lines.

In monochrome telecasting, four basic *rectangular pulses* are conveyed from the sync generator to each camera. There is the *horizontal-sync pulse* (usually called a horizontal-drive pulse in relation to the station equipment), whose purpose is to synchronize the horizontal motion of the scanning beam. A companion *horizontal-blanking pulse* is needed to shut off the scanning beam during the horizontal-retrace interval, to prevent the generation of spurious signals. A *vertical-sync pulse* (vertical-drive pulse) synchronizes the vertical motion of the scanning beam. A companion *vertical-blanking pulse* shuts off the camera-tube beam during vertical-retrace intervals.

Six individual signal components (see Sec 73.699, Fig. 7 in appendix I) are sent between the transmitter and each receiver. First there is the *video-signal*, which conveys the brightness detail of the image. A *horizontal-sync pulse* is sent out to the receiver to time the horizontal motion of the picture-tube scanning beam, synchronizing it with the horizontal motion of the camera-tube scanning beam. A *horizontal-blanking pulse* also shuts off the picture-tube scanning beam during horizontal-retrace intervals, to prevent retrace lines on the fluorescent screen. *Vertical-synchronizing pulses* are sent to the receiver to synchronize the vertical motion of the picture-tube scanning beam; a corresponding *vertical-blanking pulse* shuts off the beam for retrace. A sixth signal conveyed between transmitter and receiver is a group of *equalizing pulses*. Their function is to maintain a rigid interlace so that the lines on the receiving picture-tube screen are equally spaced—the even lines exactly midway between the odd lines from top to bottom of the screen.

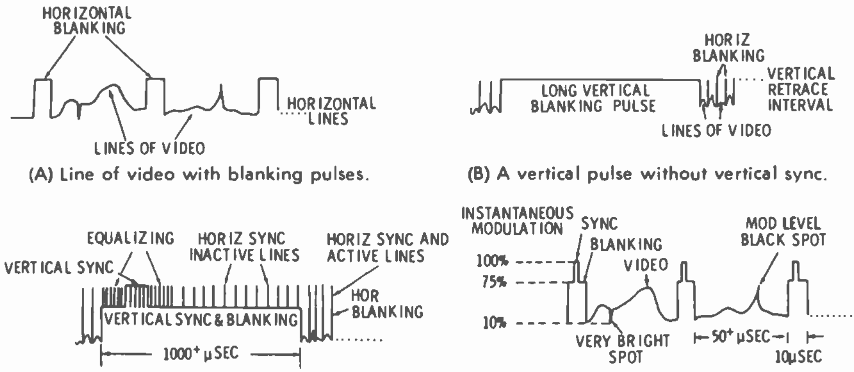
13-4. FORMING THE COMPOSITE SIGNAL

The sync generator is the timing center of the television system (Fig. 13-4). Notice the horizontal- and vertical-drive pulses that are sent to the horizontal- and vertical-deflection systems of the camera. Blanking pulses (mixed horizontal and vertical) are also sent to each camera to shut off the scanning activities during horizontal- and vertical-retrace intervals.

A video amplifier that increases the signal level follows the camera tube. The video amplifier includes circuits for correcting the nonlinear frequency characteristics of the camera tube. The output of the camera supplies signal to a camera control unit.

The control unit, in association with picture monitors and waveform monitors (built-in oscilloscopes), permits the necessary adjustments needed in obtaining a picture of the desired contrast and brightness. In this section of the television equipment, combined vertical- and horizontal-blanking pulses of the composite signal are inserted from the sync generator.

At the output of the control amplifier, the television signal has the appearance of the waveforms in Fig. 13-6. In Fig. 13-6A, a horizontal-blanking pulse is inserted at the end of each video line. In the same manner a longer vertical-blanking pulse is inserted at the conclusion of each field (Fig. 13-6B).



(A) Line of video with blanking pulses.

(B) A vertical pulse without vertical sync.

(C) A composite television signal.

(D) Modulation levels.

Fig. 13-6. Makeup of a composite television signal.

The combined video and blanking signals are then supplied to a switcher unit. The responsibility of the switcher is to make the necessary changeovers among the various cameras of the station and the various signal sources such as film-projection room, remote, tape machine, or network programs. Picture monitors in the control room permit the video operators to observe the video signal placed on the program line, as well as the pictures derived from other cameras and signal sources. Thus pictures can be made ready for switching to the program line.

The switcher output is supplied to a stabilization and line amplifier. In this section the signal is further controlled and made ready for conveyance to the transmitter. Here the composite sync signal is added, consisting of horizontal-sync, vertical-sync, and equalizing pulses, as shown in Figs. 13-6C and D.

The waveforms show two lines of video and a vertical-retrace interval. Notice in Fig. 13-6D that a horizontal blanking pulse is inserted at the conclusion of each line. The horizontal sync pulse is inserted on top of this blanking pulse, which serves as its pedestal. The time required to convey a complete line of video (from the beginning of one line to the beginning of the next) is 63.5 microseconds:

$$\text{Line Time} = \frac{10^6}{\text{line rate}} = \frac{10^6}{15{,}750} = 63.5 \text{ microseconds}$$

The video portion of the line has a time slot of approximately 50 microseconds; the sync and blanking interval takes up the remaining time of the line.

At the conclusion of each field a vertical-blanking pulse is inserted, upon which are placed the vertical-synchronizing and vertical-equalizing pulses as shown in Fig. 13-6C. The time of each field is 1/60th of a second. The vertical-blanking period, some 1000 to 1200 microseconds, occupies just a small segment of this total field time.

The video operator must establish the proper relative amplitudes among the various signals that make up the composite television signal.

In terms of transmitter modulation, the blanking level must occur at 75 percent of peak amplitude. In other words, if the sync tip causes 100 percent modulation, the blanking level must cause 75 percent modulation. This blanking level is also the black level of the transmitted scene. Ten percent of maximum amplitude represents the white level of any transmitted scene.

13-5. TRANSMITTER AND RECEIVER

The composite television signal is now conveyed, by coaxial cable or microwave relay link, to the transmitter. At the transmitter the signal is passed through additional video lines and stabilization amplifiers. Additional corrections are made on the signal, and its amplitude is increased to the proper level for application to the transmitter proper. Picture and waveform monitors, associated with the transmitter, allow a continuous watch to be kept on the picture as well as the electronic makeup of the television signal.

The composite video signal amplitude-modulates the television transmitter. The sync tip constitutes 100 percent (or nearly 100 percent) peak modulation. When a very bright part of the scene is being transmitted, the modulation is in the vicinity of the 10-percent level as shown in Fig. 13-6D.

The output of the transmitter is fed, through a sideband filter and diplexer, to the single antenna. The function of the diplexer unit, as mentioned previously, is to permit using the same antenna for radiating the picture and sound signals. The single-sideband filter removes that portion of the lower sideband which is not to be transmitted in accordance with the FCC transmission standard for a television station.

At the receiver, a multiplicity of functions is performed on the incoming picture and sound signals. A tuner amplifies and converts the incoming picture and sound signals to an intermediate frequency in the 40-MHz region. Picture and sound signals are then separated, the sound signal going to its own i-f amplifier, fm demodulator, audio amplifier, and speaker. The picture carrier and its sidebands are amplified by an i-f system and supplied to an a-m video detector. Two signals are taken off at the following video amplifier, as shown in Fig. 13-7; one goes to the video amplifier and picture tube, and the other to the sync system.

A sync-separator circuit removes the combined synchronizing pulses from the composite television signal and separates them into vertical- and horizontal-sync pulses. These pulses are then supplied to the separate horizontal- deflection and vertical-deflection systems of the receiver.

The incoming sync pulses time the horizontal- and vertical-deflection circuits. Consequently the waveforms present in the horizontal- and vertical-deflection coils of the picture tube cause the beam motion to follow exactly the scanning activities at the camera tube. Simultaneously, the video signal derived at the camera tube is supplied to the control grid of the picture tube. The deflected and modulated beam then reconstructs the original image.

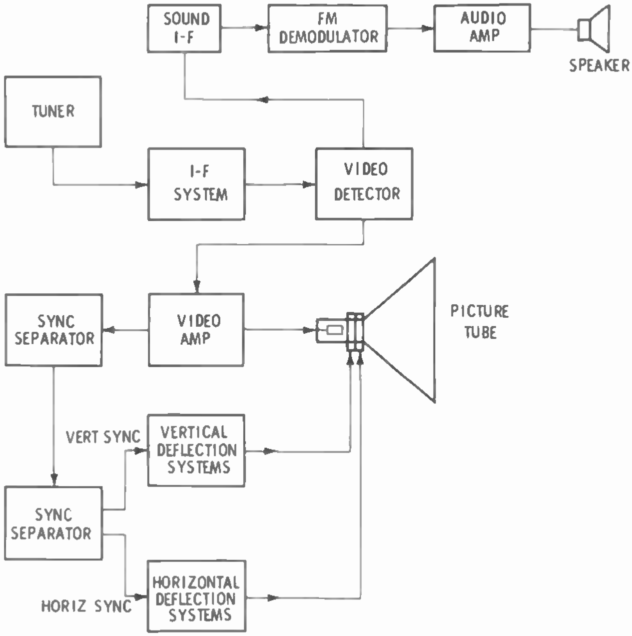


Fig. 13-7. A block diagram of a television receiver.

13-6. CAMERA AND PICTURE TUBES

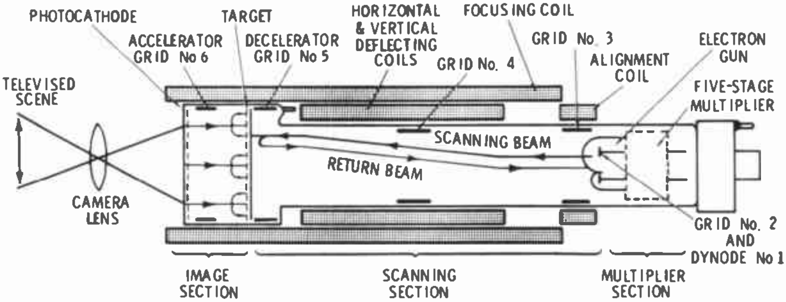
Two basic types of camera tubes are used in modern television broadcasting—the image orthicon and the vidicon. The image orthicon develops a very high-resolution picture and is used mainly for live-television pickup (on-the-air or tape). Image orthicons are also mounted in many of the remote television cameras, although vidicon remote cameras are more popular. The vidicon camera tube, because of its small size, can be used in the construction of very small and lightweight cameras. It is used in most television film cameras.

13-6-1. Image Orthicon

The image orthicon (Fig. 13-8) consists of three major sections—image, scanning, and multiplier. Light from the scene is picked up by an optical lens system and focused on the photosensitive photocathode surface directly behind the face of the tube. This surface emits electrons in accordance with the strength of the light pattern. These electrons are accelerated to the target surface.

The target contains hundreds of thousands of individual elements. Secondary electrons are removed from these elements in accordance with the strength of the arriving primary electrons. The displacement of secondary electrons, according to light intensity, sets up on the surface of the target a varying positive charge that corresponds to the light pattern. The charge distribution on the target is now evaluated by a scanning beam.

The back of the target is scanned by an electron beam generated by the electron gun at the tube base. This electron beam is moved over the target surface by the horizontal- and vertical-deflection waveforms supplied to the deflection coils. As you learned, this motion of the beam is timed by the drive pulses supplied from the sync generator to the horizontal- and vertical-deflection systems of the camera tube. Hence the beam moves across the target surface in accordance with the standard interlaced scanning pattern.



Courtesy RCA Corp.

Fig. 13-8. The image orthicon tube.

The arrangement of the gun elements, and their relative voltages, slow down the electrons to nearly zero just short of the target. The electrons return to the base of the tube except when they approach an element which has a positive charge. If an element has a positive charge when the beam is over it, the beam deposits enough electrons on the target to neutralize the positive charge. The remaining electrons return toward the gun. It is important to realize that the beam returning to the gun has been modulated because of the presence of the varying positive charges on the target. These charges have removed electrons from the beam in accordance with their individual potentials. Thus as the scanning beam moves across the target element by element, the returning electron beam is modulated in a sequential manner by the light pattern originally impressed on the photocathode.

The returning electron beam is attracted to the various multiplier dynodes which surround the gun at the rear of the tube. The electron multiplier dynodes, because of their secondary-emission characteristics and rising potentials, amplify the applied video signal. Consequently the video-signal variation at the multiplier output is substantially greater than the minute variations present in the beam returning from the target surface.

Some video amplification has occurred within the image-orthicon tube. Therefore the signal at the output of the tube, with suitable circuit design, is able to dominate any noise components in the output circuit of the tube and the input circuit of the first amplifier stage. Thus a picture with a high signal-to-noise (masking) ratio can be established.

13-6-2. Vidicon

The vidicon (Fig. 13-9) is a small camera tube (one inch in diameter and six inches in length; some models are even smaller) capable of generating a video signal of good resolution and stability at low ambient light levels. It is a very sensitive camera tube, consisting of an electron gun, deflection and focusing system, and image section.

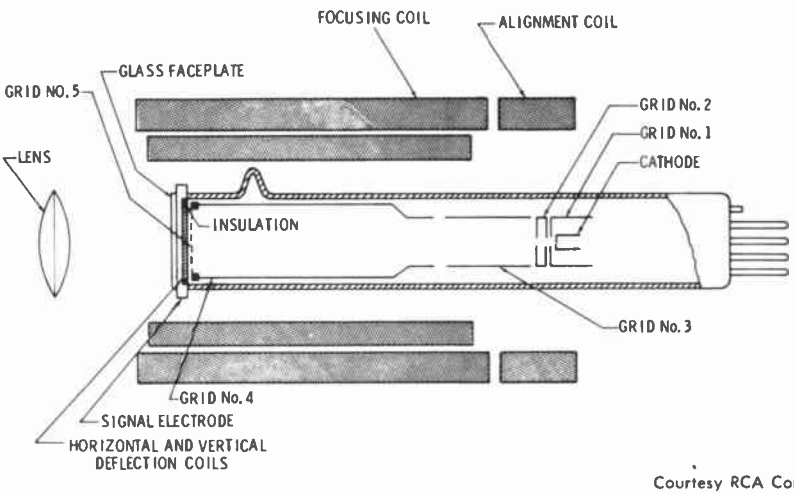
The image section contains a photoconductive layer and a signal plate. The image of the scene is focused, through a lens system, onto the photocathode surface. The presence of the light energy determines the degree of conductivity through to the signal plate of the hundreds of thousands of individual elements on its photocathode surface. A bright spot establishes a higher conductivity than a dark spot. Thus each signal-plate element is charged in proportion to its related light intensity.

Again the scanning beam deposits electrons on the signal-plate surface in accordance with the charge pattern. As each element is restored to equilibrium during the scanning process, a sequential signal flows from the signal plate, via the signal electrode, into the output circuit.

A bright element causes high conductivity. Hence, the presence of the scanning beam over the element causes a great many electrons to be deposited, and a strong output current flows. For darker spots there is a lower conductivity and a lesser output current. As the scanning beam moves across the elements, the changing signal produced in the output represents the light pattern of the image.

13-6-3. Picture Tube

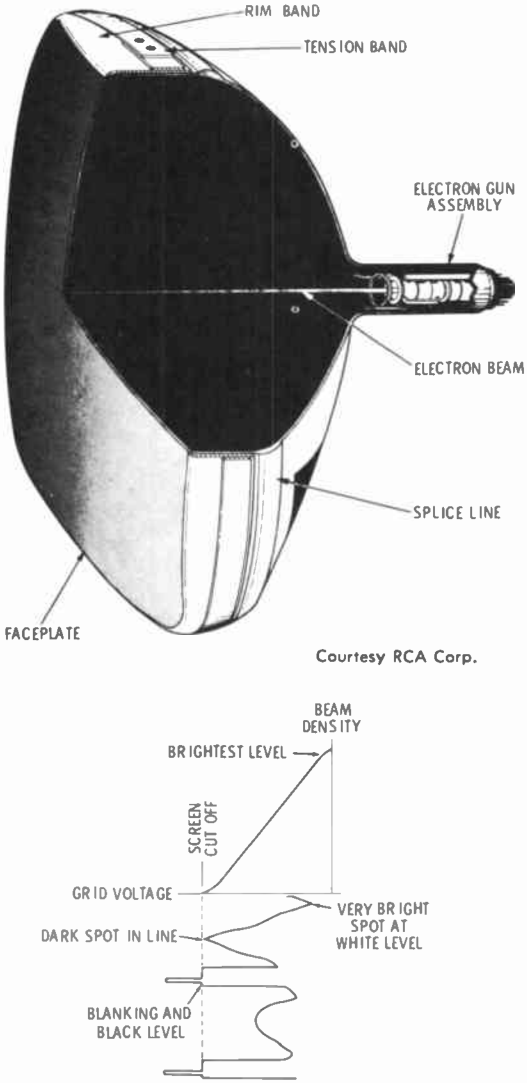
A television picture tube (Fig. 13-10A) consists of an electron gun and a fluorescent screen that glows in accordance with the strength of the electron in the scanning beam from the gun. A focusing system,



Courtesy RCA Corp.

Fig. 13-9. A vidicon camera tube.

magnetic or electrostatic, focuses the beam into a very fine point at the fluorescent screen. Two deflection systems, similar to those used by the camera tube, move the scanning beam from left to right and down the screen in accordance with a corresponding beam motion at the camera tube. The motion of the beam horizontally and vertically is controlled by the synchronizing pulses from the transmitter when applied to the horizontal- and vertical-deflection systems associated with the picture tube.



(A) Picture tube.

Courtesy RCA Corp.

(B) Curve.

Fig. 13-10. The television picture tube and beam-current curve.

If the scanning beam is of constant strength as it strikes the fluorescent screen, the individual lines that make up the pattern (raster) will be illuminated at uniform intensity by the density and momentum of the electrons hitting the screen. If the scanning beam is modulated so that its density varies, the number of arriving electrons at the screen will change as the beam travels over its established path. Thus the illumination along each line will vary with the changing strength of the beam. The average illumination of the individual lines from top to bottom of the screen will also be a function of the average number of electrons that are contained in the beam throughout the scanning cycle.

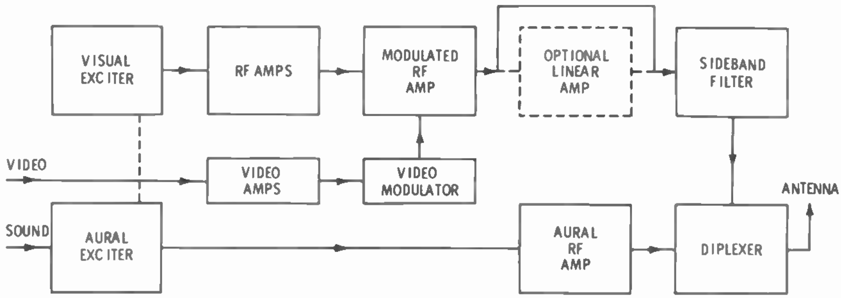
The electron-beam current is varied by the video signal supplied to its control grid, as shown in Fig. 13-10B. The signal is applied to the electron gun as a grid-voltage variation. Just as the control-grid voltage variations supplied to a conventional vacuum tube cause a change in plate-current flow, so does the video signal on the grid of the electron gun produce a corresponding change in the beam-current flow. As the scanning beam moves across the fluorescent screen, the individual elements that make up that screen will glow in accordance with the density of the scanning beam at a given instant. Thus the changing video signal on the control grid of the picture tube causes the intensity of the elements along each line to vary, reconstructing the light pattern of the original image line. This restoration occurs for each active line to reproduce the original image completely.

Notice that the blanking pulse (Fig. 13-10B) swings far enough negative on the control grid of the electron gun to reach beam cutoff. This amount of voltage establishes the black, or darkest, spot in the reproduced scene. In fact, the function of the blanking pulses is to shut off the scanning beam during retrace intervals. Likewise the black portions of the scene swing negative to this level to reproduce the black elements that are contained in the scene being televised.

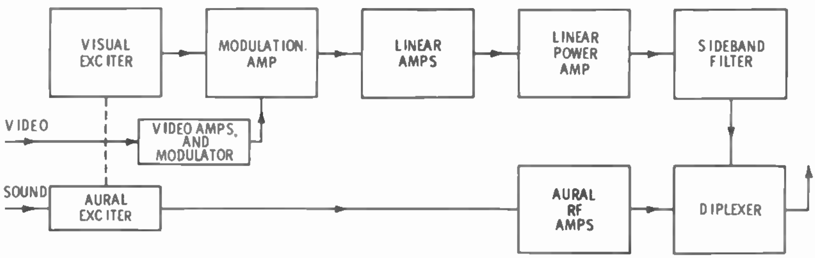
Greater amounts of beam current will flow when the control-grid voltage is made less negative. Consequently, a full range of brightness level is recreated from black, through the gray scale (halftones), to the brightest illumination possible. An extremely bright spot is reproduced when the grid is made the least negative, as indicated by the white spot in Fig. 13-10B. The range of brightness levels between the whitest white and black determines the halftone *contrast* of the reproduced picture. The average illumination of the screen surface is determined by the dc component of grid bias supplied to the gun, which is adjusted by the brightness control.

13-7. TELEVISION TRANSMITTERS

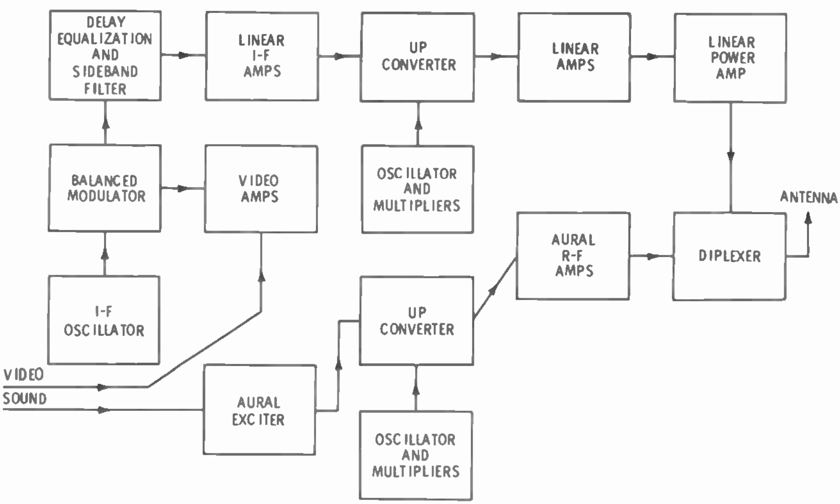
Television transmitters are available with power output levels ranging from several kilowatts to 50 kilowatts or more. The three basic arrangements are shown in the functional block diagrams of Fig. 13-11. An example of high-level modulation is given in Fig. 3-11A. Modulation occurs in a high-powered rf amplifier stage. In some case this power stage is the final amplifier of the transmitter, while in other



(A) High-level modulation.



(B) Low-level modulation.



(C) I-f modulation.

Fig. 13-11. Basic functional plans of TV transmitters.

cases it may be followed by a high-powered linear amplifier. Usually grid modulation is employed because of the difficulties of building up the video signal to a high-power level and of matching the modulator into the modulated amplifier. This can be done at substantially lower power when grid modulation is employed.

The final amplifier is followed by a vestigial-sideband filter. The filter consists of an appropriate arrangement of high- and low-pass filters and special sharp attenuating notch filters. These are constructed of appropriate sections of coaxial lines instead of lumped coils and capacitors, as shown in Fig. 13-12. The sideband filter attenuates the low-frequency sideband, as specified in the FCC standards, without disturbing proper impedance match or efficient transfer of rf energy to the antenna system.

The sound transmitter is an integral part of the television transmitter. Often there is a lock-in system between the sound and picture sections of the transmitter. Its function is to keep the picture- and sound-carrier frequencies exactly 4.5 MHz apart. By FCC regulations the difference-frequency tolerance is ±1000 Hz.

When low-level modulation is employed it occurs in an early stage of the transmitter as shown in Fig. 13-11B. The rf power level may only be several watts. Hence the video signal power level is very much lower and some of the difficulties of power modulation are avoided. However, this type of transmitter requires quite an array of succeeding linear amplifiers. It is the responsibility of these amplifiers to build up the weak video-modulated TV signal to the assigned power.

Inasmuch as modulation has already occurred these stages must have a wideband frequency response, and must also have the proper phase response and delay characteristic that will not disturb the qual-

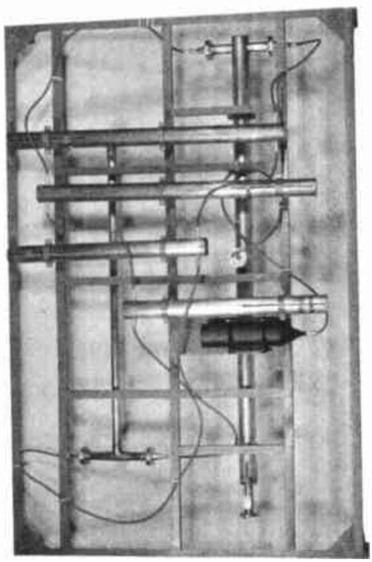


Fig. 13-12. A vestigial-sideband filter.

Courtesy Gates Radio Co.

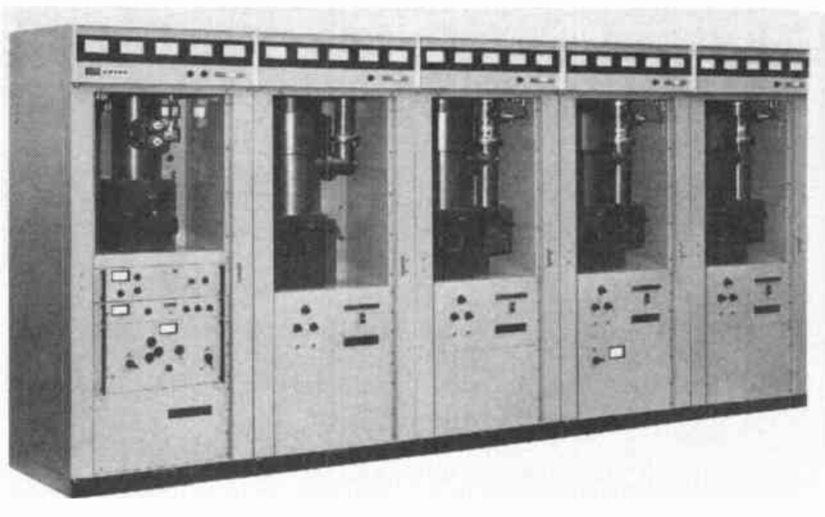
ity of the video-modulated signal they must amplify. After amplification, the modulated signal is applied to the sideband filter and on the diplexer. The diplexer unit is used at the output of the television transmitter to feed both the picture and sound rf signals to a single antenna system.

The third method is known as i-f modulation (Fig. 13-11C). In this system the modulation occurs very early and at a power level substantially less than 1 watt. In fact, the power-output level of the visual exciter is only 1 watt peak. The modulation occurs at a lower frequency than the eventual transmit frequency of the transmitter. In the case of the Gates i-f modulation transmitter of Fig. 13-13, this frequency is 37 MHz. After modulation the signal is passed through an appropriate phase and delay equalizer and then to a vestigial-sideband filter. A high-powered sideband filter and various equalization circuits are not necessary at the output of the transmitter when using the i-f modulation process. Also, the same visual exciter is used regardless of the eventual transmit frequency of the transmitter.

The next step in processing the visual signal is to convert its output frequency to the transmit frequency. This is done with a separate oscillator and multiplier which supplies a signal of the appropriate frequency to the up converter. The video modulated signal is applied to the same converter. The sum of the two components will be on the assigned carrier frequency of the television station. The output of the exciter is 1 watt visual.

One, two, or three linear amplifiers build up the signal to the assigned power. Final output is applied directly to the diplexer.

The same basic plan is used for the aural exciter, except that the oscillator is frequency-modulated rather than amplitude-modulated.



Courtesy Gates Radio Co.

Fig. 13-13. Television transmitter.

Modulation occurs on a frequency of 32.5 MHz, about 4.5 MHz lower than the oscillator frequency of the visual exciter. The up-conversion technique is used to raise the frequency of the sound signal to the assigned value.

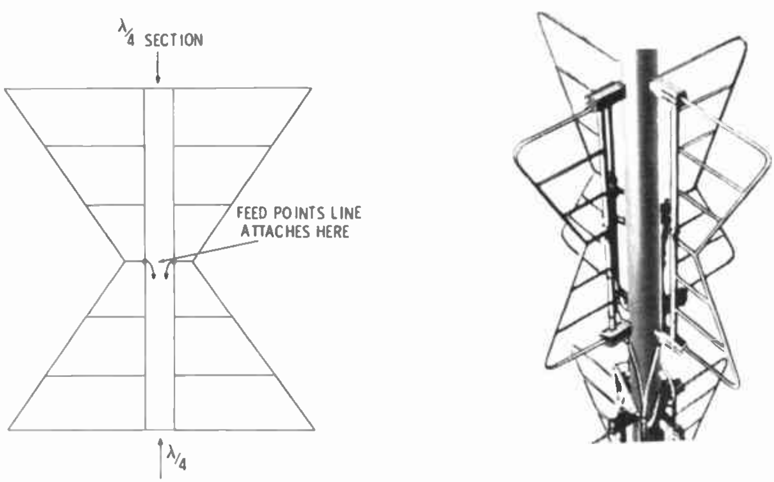
In television broadcasting most transmitters are designed with a visual power output that is approximately five times greater than the sound power output. This equalizes the coverage of the two transmitters and, therefore, the sound signal is usually not sent out any further than the distance over which an acceptable picture can be transmitted. The video bandpass is many times wider than the sound emission bandwidth.

The transmitter of Fig. 13-13 has a 35-kW visual power output and 7-kW sound. Both the visual and aural exciters are mounted in the first rack along with a linear amplifier. The visual power output at this point is 1.3 kW, and sound power output is 260 watts. The next rack mounts an aural linear power amplifier. Only one is needed because the sound signal is narrow band and is not built up to the same level as the visual rf signal. The final three racks include visual driver and two visual linear amplifiers which build up the picture signal to its final power level of 35 kW.

13-8. TELEVISION ANTENNA

As in fm broadcasting, horizontal polarization is used in TV broadcasting. The radiating elements are stacked on a tower. Usually the horizontal-radiation pattern must be essentially omnidirectional; the vertical radiation is concentrated at low vertical angles.

A television transmitting antenna must radiate a broadband signal. Consequently the basic dipole is modified in a manner that will permit



(A) Bat-wing dipole. (B) Turnstile arrangement of bat wing.

Fig. 13-14. Broadband vhf television antennas.

wideband operation. A popular television transmitting antenna uses the bat-wing shown in Fig. 13-14A. The quarter-wave sections, on each side of the feed point, add parallel resonance to the basic series-resonant characteristics of a dipole. This damping extends the bandwidth, and the special taper of the element provides a uniform radiation over the desired bandpass.

To obtain a more uniform horizontal-radiation pattern, television broadband dipoles are usually mounted in a turnstile arrangement (Fig. 13-14B), the two perpendicular dipoles being fed in quadrature to obtain a good omnidirectional pattern. The necessary power gain is obtained by stacking the turnstiles in bays.

Several other types of broadband dipoles and antenna styles are used in television broadcasting. The helical-antenna principle is used with one type. Slot dipoles and traveling-wave construction can also be used for vhf and uhf telecasting.

13-9. COLOR TELEVISION

An understanding of coloring transmission requires a knowledge of some of the basic fundamentals of colorimetry. First of all, color is composed of three basic attributes—brightness detail, hue, and saturation. Brightness detail, as its name implies, has to do with the relative brightness among all the elements that make up a scene, regardless of hue and saturation. It is this brightness detail, between white and black over the gray scale, that makes it possible to transmit a black-and-white picture. The black-and-white picture you observe on your monochrome television screen or magazine page is nothing more than a brightness pattern. The breaking up of a scene into many, many elements of differing brightnesses permits the reconstruction of a scene in detail.

In a color television system it is necessary to convey this brightness detail, just as it is in a monochrome television system. In fact, the brightness detail is conveyed in exactly the same manner as in the monochrome system. By suitable choice of transmission methods this technique permits a color signal also to be reproduced in black and white on the screen of a monochrome receiver.

In transmitting a picture in color, it is also necessary to convey hues and saturation data. Hue is often referred to quite loosely as color, because it represents red, green, yellow, etc. Saturation has to do with how pure a given hue is, and how much it has been desaturated by the presence of white. A pure green is a fully saturated hue, whereas a desaturated green is a pale green because it contains a high percentage of white light. An absolutely pure green is one which contains no white.

The scores of recognizable hues and saturations would at first suggest that it is almost impossible to convey all possible combinations of hue and saturation. If each color had to be transmitted as an entity, color transmission would be extremely difficult—if not impossible. However, human vision is able to interpret bands of colors, and the proper levels of two or more basic colors (primary colors) can be dis-

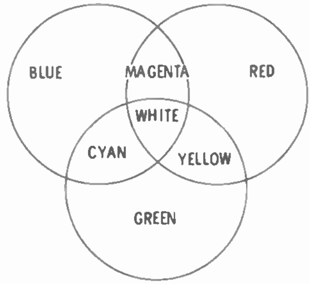


Fig. 13-15. Basic tristimulus color circles.

played in such a manner that a very useful range of other hues and saturations (secondary colors) can be duplicated. The extremely simplified circle chart of Fig. 13-15 demonstrates this characteristic. In this chart there are the three basic primary colors—red, blue, and green. By mixing equal-intensity levels of red and green, we obtain a yellow; blue and red, a magenta; blue and green, a cyan. Yellow magenta, and cyan are called secondary colors. The combination of equal intensities of red, blue, and green reproduces white. The use of three primary colors to reproduce an extensive range of hues and saturations is referred to as a *tristimulus* color system or presentation. This tristimulus method of conveying color is used in our color television broadcast system.

A very basic color system, as shown in Fig. 13-16, *would* consist of three camera tubes. A filter, associated with each camera, *would* make certain the camera tube evaluates the color scene with relation to the red, green, and blue ranges. Three signals are formed, one representing the brightness detail in red, the second in blue, and the third in green. Each signal is then conveyed separately from the transmitter to the receiver. At the receiver the three original color signals *would* be recovered and superimposed on a screen. Inasmuch as all hues and saturations of the original scene have been interpreted in terms of the three primary colors, their superimposition *would* provide a faithful reproduction of the original color scene.

As shown in Fig. 13-16, the three color images are not exactly superimposed. Rather, each signal excites the proper series of phosphor dots on the picture-tube screen In this activity the incoming red signal ex-

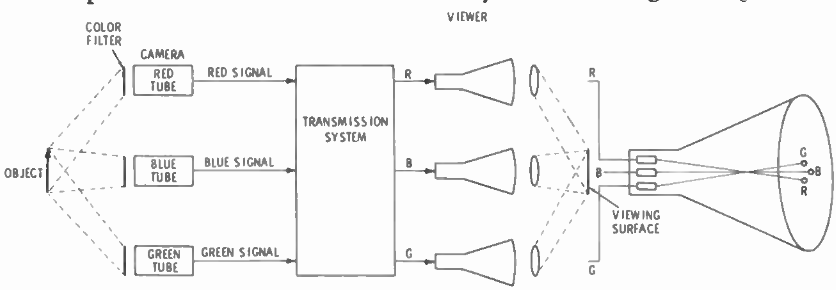
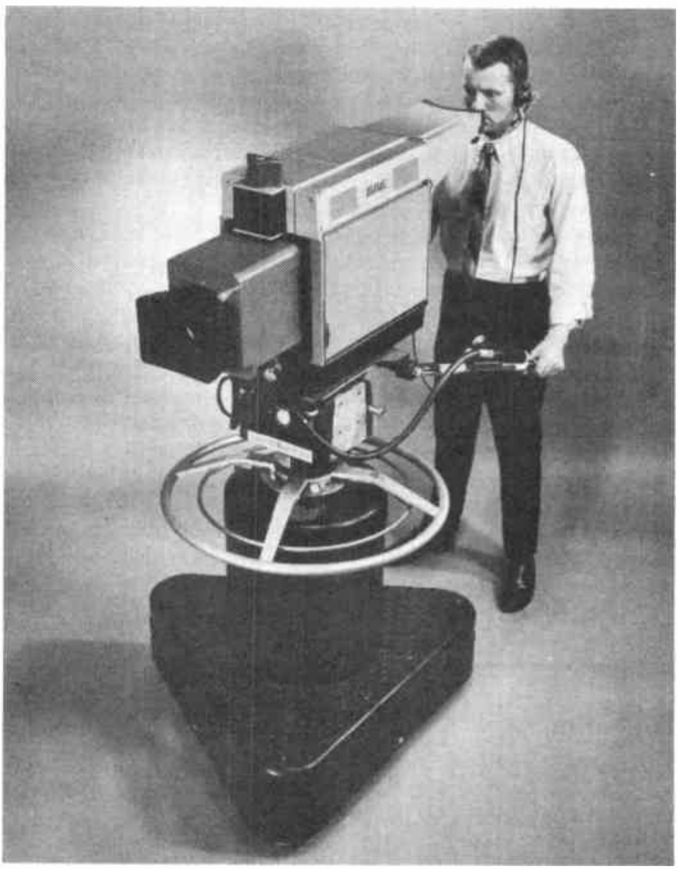


Fig. 13-16. A basic functional diagram of a color-television system.

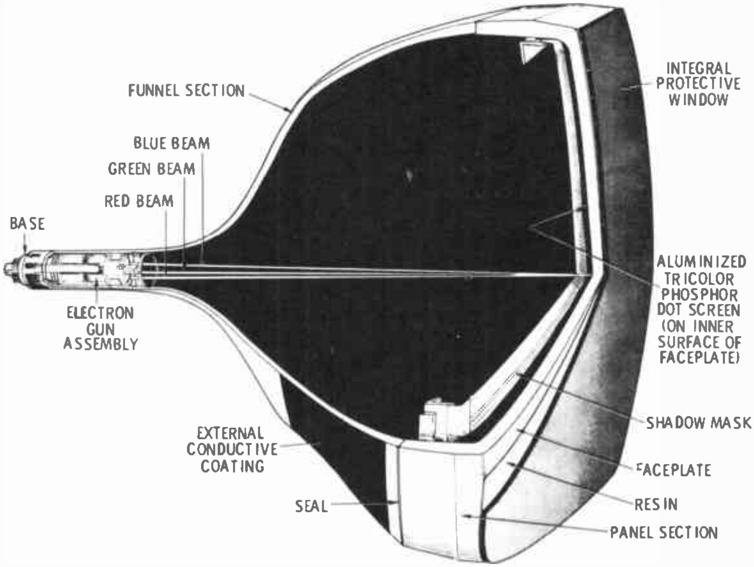
cites only the red dots, the blue signal the blue dots, and the green signal the green dots. Nevertheless the screen is made up of so many hundreds of thousands of dots that, insofar as human vision is concerned, we see them superimposed. Hence we have tristimulus excitation of the eye and are able to perceive a wide range of hues and saturations.

Three separate camera tubes *are* mounted within a color television camera (Fig. 13-17). The camera operates in the manner previously discussed, producing three signals—red, green, and blue. These three signals are processed and used to modulate the picture carrier. At the receiver, the three primary color signals are recovered and presented to their associated guns of the color picture tube (Fig. 13-18). The focusing and deflection system of the color picture tube directs these three beams to the appropriate color phosphor dots. In this manner the three images are reproduced.

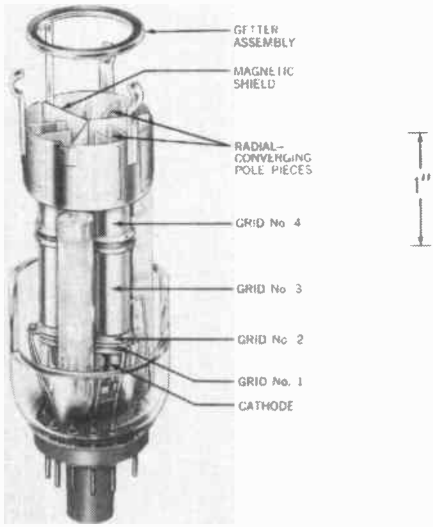


Courtesy RCA Corp.

Fig. 13-17. A color-television camera.



(A) The complete tube.



(B) Electron-gun assembly.

Courtesy RCA Corp.

Fig. 13-18. A color picture tube.

13-10. THE COLOR TRANSMISSION METHOD

If all three color signals had to be conveyed at full detail on separate carriers, a wide band of frequencies would be needed to transmit a high-resolution color picture. This use of a wide band of frequencies is avoided in modern color telecasting by breaking up the three signals into basic color attributes before transmission.

As shown in Fig. 13-19, a block diagram of the major units of a color broadcast system, the three signals are broken up into brightness details, hue, and saturation. The one signal that conveys the brightness detail is transmitted at full bandwidth. It is this signal component that determines the resolution of the reproduced picture, because definition is related directly to brightness detail whether color or a monochrome picture is being transmitted. In color television broadcasting this is referred to as the *luminance* (Y) signal because it has to do with brightness detail.

Hue and saturation are less directly related to detail; consequently, they can be sent between transmitter and receiver with less brightness detail. Therefore, not a wide a frequency response is needed. In fact, the hue and saturation (I and Q signal components) are combined into one signal, called the *chrominance* signal, and used to modulate a subcarrier frequency much as a second sound signal can be used in a multiplex arrangement to modulate an fm broadcast carrier with two separate audio signals. In television broadcasting the subcarrier frequency of 3.58 MHz is modulated by the chrominance signal, and the modulated subcarrier in turn amplitude-modulates the main video carrier.

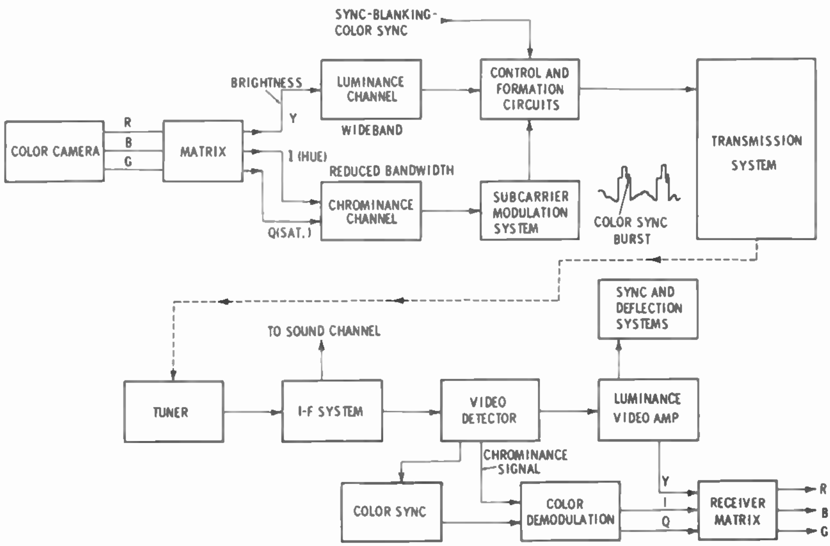


Fig. 13-19. A block diagram of a color-television system.

The sync and blanking pulses, and the luminance video signal, modulate the video transmitter carrier in the same manner as in monochrome television practice. Hence, in the color transmission a multiplex system is employed, with brightness detail and synchronizing information being conveyed in the conventional manner, and hue and saturation conveyed by way of subcarrier.

The modulation system is so designed that saturation is determined by the amplitude of the resultant chrominance subcarrier. The hue is present on the subcarrier as a phase-modulated resultant between the I and Q components. In effect, there has been a dual modulation of the subcarrier with saturation and hue data.

It is necessary to synchronize the receiver color circuits with the color activity at the station. Consequently, one additional signal component must be transmitted—a color sync burst at the 3.58-MHz subcarrier frequency is placed on the back porch of the horizontal-blanking pulse, as shown in Fig. 13-19. Except for a very slight departure in horizontal and vertical frequencies, the same type of horizontal and vertical sync and blanking and the same equalizing pulses are used in color as in monochrome telecasting.

At the receiver, the color sync burst is removed and used to synchronize the color demodulation activity. Here the hue and saturation components are recovered and are then broken down into copies of the original three primary color signals. The red signal is applied to the red gun, the green signal is applied to the green gun, and the blue signal is applied to the blue gun. The color picture is then reproduced on the screen.

13-11. VIDEO TAPE RECORDING

The video tape recorder has brought about great changes in telecasting. A high-quality video tape recording defies detection from the live telecast. An understanding of the video tape recording process can best be gained by first considering the limitations of the conventional audio tape recorder. In an audio tape recorder, variations in the audio signal at the tape head magnetize the coating on the tape as it is moved past the head gap.

The high-frequency response is limited by the speed of the tape and the width of the head gap. The higher the frequency that must be reproduced, the narrower the gap required and the faster the tape speed. Tape speeds of 7½ inches per second and higher are used in the reproduction of 15,000-Hz signals. To make a similar magnetic impression of a 4-MHz video component would require a tape speed of 2000 inches per second—or 113 miles per hour! It is apparent, therefore, that the conventional method of tape recording used for audio is certainly not feasible for recording and reproducing high-frequency video components.

The Ampex video tape recorder shown in Fig. 13-20 uses video tape heads mounted on a rotating drum. These heads are moved across the tape, rather than, as more conventionally moving only the tape past the head. Hence the combination of moving head and moving tape

Courtesy Ampex Corp.

Fig. 13-20. A video tape recorder for TV station.

provides a much higher head-to-tape velocity at a substantially lower reel-to-reel tape speed.

In a typical video tape machine, there are four heads mounted at 90° intervals on the periphery of a drum two inches in diameter. The drum is rotated at 14,400 rpm, and a head-to-tape velocity of approximately 1500 inches per second across the two-inch magnetic tape is obtainable. This fast effective motion of head and tape permits the recording of high-frequency video components.

As each head moves across the tape it records a track 10 mils wide as shown in Fig. 13-21. There is a separation of 5 mils between each recorded track. In conjunction with the rotational speed of the head

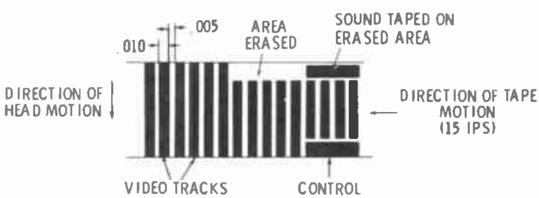


Fig. 13-21. The video tracks on a video tape.

drum, a reel-to-reel tape speed of 15 inches per second supplies proper track separation as well as 64 minutes of playing time from a reel of tape 12½ inches in diameter.

It is important to recognize that, as each head rotates, it picks up one track across the tape. The forward speed of the tape and the rotation speed of the tape head are such that a tape head moves into position just five mils away from the previous track. In fact, before one video head leaves the tape, the succeeding head has made contact on the opposite side. Thus there will be some identical information recorded at the bottom of one track and the top of the next track.

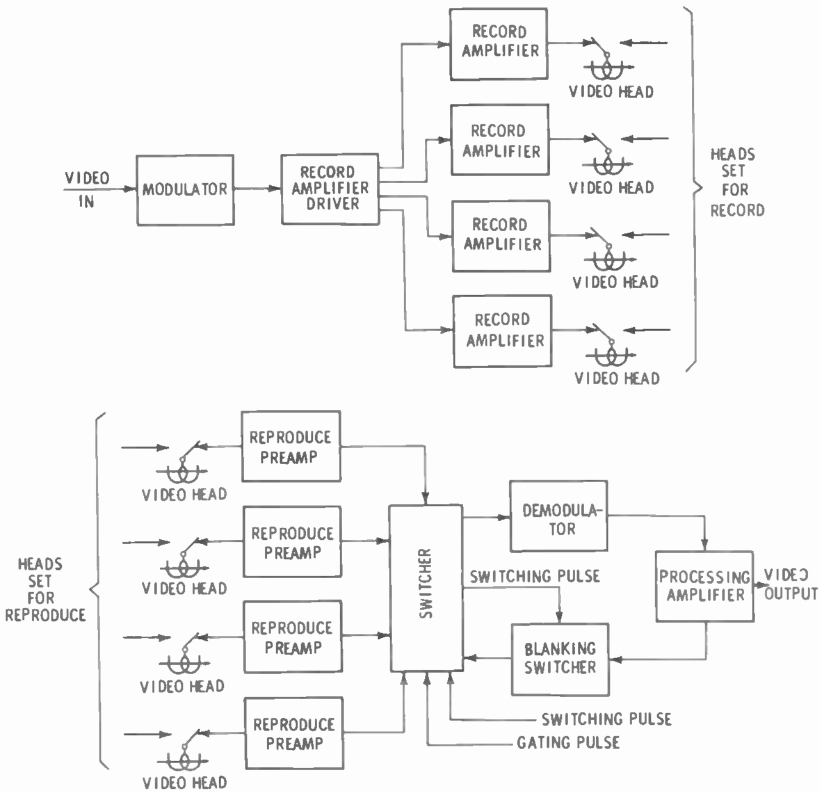


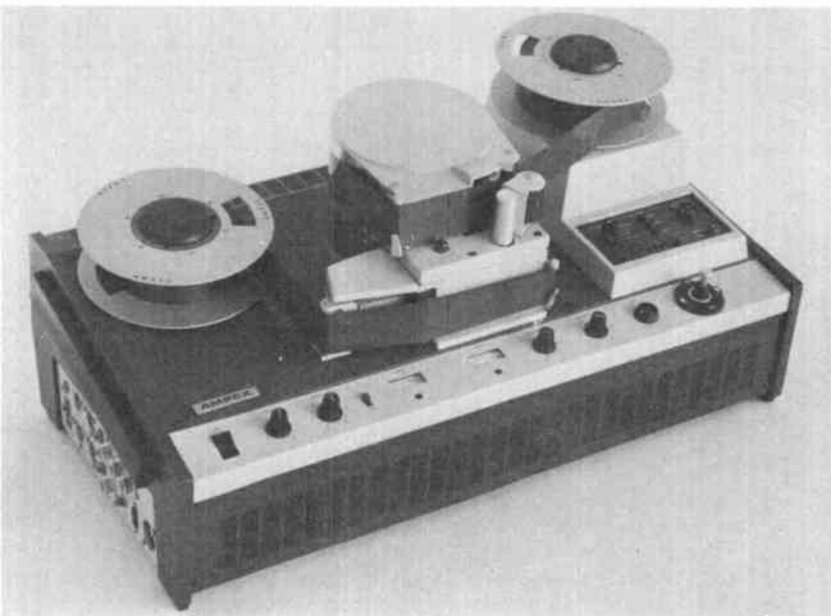
Fig. 13-22. A block diagram of a video tape recorder.

The subsequent magnetic recording of audio and control information on the same tape destroys some of this duplication. However, enough is retained so that electronic switching from head to head must be made in the associated circuitry of the tape recorder, to prevent signal overlap in reproduction. The audio signal is recorded in the conventional manner. Of course, there must also be associated control information, to make certain the video tape machine is synchronized correctly with respect to the television signal.

To counteract some of the problems of recording very-low frequencies with such a very fast head-to-tape velocity, a frequency-modulation process is employed as shown in Fig. 13-22. The modulator converts the incoming frequency range of the video signal (10 Hz to 4 MHz) to a sideband spectrum that extends between 750 kHz and 7 MHz. This frequency-modulated signal is amplified and applied to the record amplifiers, which supply drive signals to the video heads. Each head is moved over the tape by the rotating drum and makes its contribution on one track. It is then inactive for three tracks while the three remaining heads are moved into position. Inasmuch as all four heads are supplied with an identical signal, the information is placed on the tape in the proper order.

In the reproduce position, the motion of the video tape beneath each of the reproduce heads generates a signal that is applied to its associated reproduce preamplifier. One of the heads is always in position over the tape; consequently, each track supplies a signal to the reproduce preamplifier section. The four separate signals are applied to a switcher unit which has the responsibility of preventing any signal overlap. As a result, the switcher output signal is the same continuous signal that was supplied to the record-amplifier driver.

This signal component must be demodulated to recover the original video signal for use in the processing amplifier. The video output then



Courtesy Ampex Corp.

Fig. 13-23. A portable broadcast video tape recorder.

constitutes a reproduction of the original video signal with a frequency range between 10 Hz and 4 MHz.

As the tape moves, audio and control signals are also recovered. By so doing, the motion of the tape and tape heads are made to coincide with their activities during the recording process. The video output signal complies with the FCC standards for a television signal. In fact, the reproduced composite television signal is a good replica of the television signal as it would have appeared if it had been applied directly to the video program line of the station instead of being used in the intermediate taping step.

Smaller and lighter videotape recorders are under development. Remote video recorders (Fig. 13-23) are available and can be taken on the spot to video-tape local events. The program can then be put on the air at the most appropriate time.

CHAPTER 14

Fundamentals and Audio Circuits

This is the first of five chapters (14 through 18) covering the questions of FCC Study Guide for Element IV. Chapters 14 through 17 can be used to evaluate your technical preparation for the Element IV examination. Similarly, your retention of the FCC rules and regulations can be evaluated by Chapter 18.

14-1. FUNDAMENTALS

1. List the fundamental frequency and the first ten harmonic frequencies of a broadcast station licensed to operate at 790 kilohertz.—They are as follows:

790 kHz	Fundamental
1580 kHz	Second Harmonic
2370 kHz	Third Harmonic
3160 kHz	Fourth Harmonic
3950 kHz	Fifth Harmonic
4740 kHz	Sixth Harmonic
5530 kHz	Seventh Harmonic
6320 kHz	Eight Harmonic
7110 kHz	Nineth Harmonic
7900 kHz	Tenth Harmonic

2. Show by a simple graph what is meant when it is said that the current in a circuit leads the voltage. What would cause this?—A current lead is shown in a waveform drawing of Fig. 14-1. A current lead exists when the impedance of a circuit is capacitive. The higher is the capacitive reactance in comparison with the resistive component of a series circuit the greater is the current lead (same as voltage lag) up to a theoretical maximum of 90°, where the circuit is entirely capacitive and has no resistance.

3. What effect does mutual inductance have on the total inductance of two coils connected in series?—If two series coils are not coupled mutually, the total inductance is the sum of the two inductance values. However, if they are mutually coupled, the total inductance is more or less than this amount, depending on whether their respective fields are mutually aiding or mutually opposing. Stated as an equation:

$$L = L_1 + L_2 \pm 2M$$

In the equation M is the mutual inductance; its sign is + for aiding fields and − for opposing fields. Refer to Fig. 14-2.

4. Each coil of two series-connected inductances has a value of 200 millihenrys. If the mutual inductance is 50 millihenrys with fields aiding, what is the total inductance?—

$$L = 200 + 200 + (2 \times 50)$$
$$= 500 \text{ millihenrys}$$

5. In relation to ac circuits what is the relationship between (1) rms values, (2) maximum and minimum values, (3) peak values, and (4) peak-to-peak values?—The peak amplitude of a sine wave of voltage or current is that voltage or current measured between the zero axis and either the positive or negative crest of the sine waveform. (Refer to Fig. 14-3.) This peak value of a sine wave is referred to as the maximum value, E_{peak}, or E_p.

$$E_{rms} = 0.707\ E_{peak}$$
$$I_{rms} = 0.707\ I_{peak}$$

This is an important level of voltage because it is related to ac power. The product of the two rms values, voltage and current, represents the *power* in the circuit or:

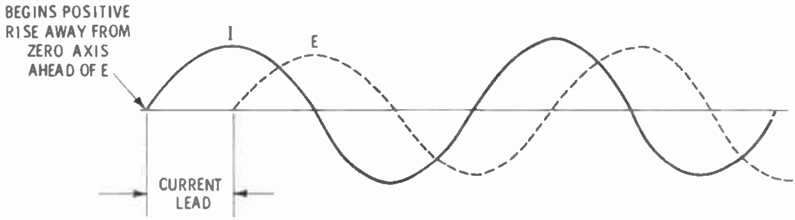


Fig. 14-1. Waveforms showing current leading the voltage.

$$P = E_{rms} \times I_{rms}$$

The peak-to-peak amplitude corresponds to the voltage or current differential between positive crest and negative crest. Therefore it has a value which is twice the peak value, or:

$$E_{pp} = 2E_p = 2 \times \frac{E_{rms}}{0.707} = 2(1.414E_{rms})$$
$$= 2.828E_{rms}$$

In many transistor and vacuum-tube circuits the ac sine-wave voltage is superimposed on a dc voltage as shown in Fig. 14-3B. In the example the absolute maximum value of the voltage is the dc value plus the peak value of the sine-wave voltage:

$$|E_{max}| = E_b + E_p$$

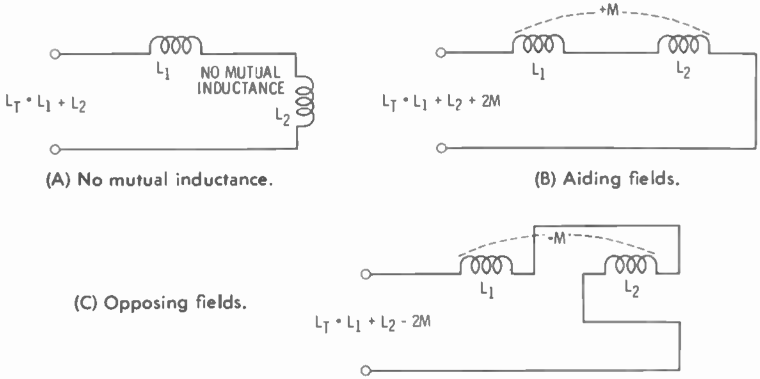
The absolute minimum value corresponds to a value that is the dc voltage minus the peak value of the corresponding voltage:

$$|E_{min}| = E_b - E_p$$

6. Show by diagrams the delta-method and the wye-method of connecting transformer secondaries in a power distribution system. Show also how various output voltages might be obtained from each.—In Fig. 14-4, the delta- and wye-connected transformer secondaries are used to obtain three-phase and/or single phase power outputs. A three-wire, common-ground, power distribution system can be set up by using a grounded winding junction in the wye-connected secondary of the transformer.

A three-wire system is common in transmitter plants or in other locations in a broadcast plant that require a considerable amount of power.

7. List some precautions to be observed when soldering transistors and repairing printed circuits.—In soldering transistors, avoid applying excessive heat to transistor leads. It is most important that some form of heat-dissipating surface (heat sink) be connected to the transistor lead between the transistor body and the solder joint. A pair of long-nose pliers or metal clamps, which are designed for soldering transistors, can be used as a heat sink. The maintenance of transistor and printed circuits should be based on two main precautions—minimum heat and maximum care. Here is a list of precautions:

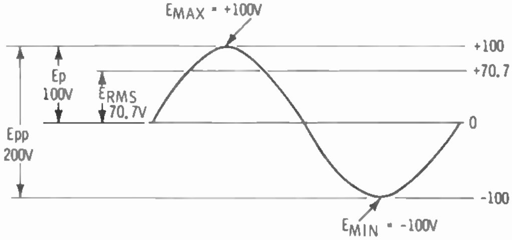


(A) No mutual inductance.

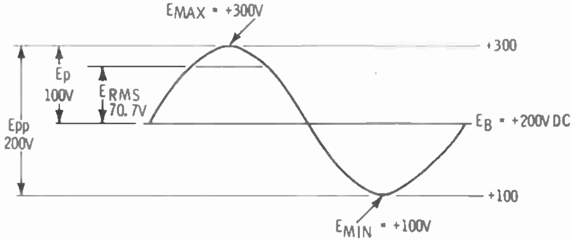
(B) Aiding fields.

(C) Opposing fields.

Fig. 14-2. Series-connected coils and mutual inductance.



(A) Sine wave.



(B) Sine wave superimposed on a dc voltage.

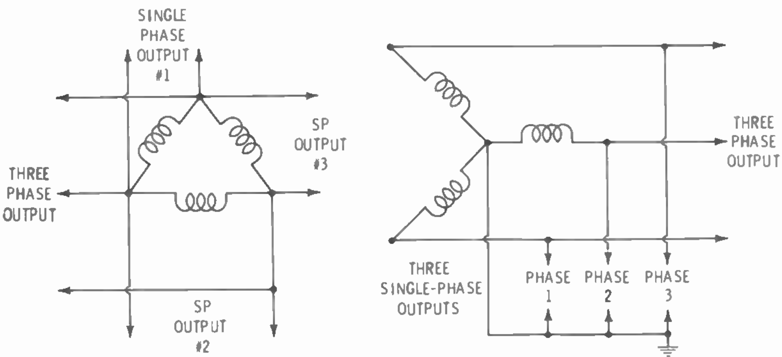
Fig. 14-3. Relationships among ac circuit values.

(1) Do not overheat transistors or printed-circuit wiring.
(2) Use rosin-core solder with a low melting point.
(3) Use a low-wattage pencil-tip soldering iron and a good spray-on contact cleaner for cleaning the repaired areas.
(4) Avoid excessive solder and use a wire brush or a soldering aid to remove drippings.
(5) Use a heat sink when soldering transistors and other small critical components.
(6) A thin coat of lacquer can be applied to printed circuits to provide long-term protection of a repaired area.

8. What is the *gain factor* of a transistor?—The fundamental gain factor is a term referred to as *alpha*. It is the ratio (less than unity) of a small change in collector current as caused by a small change in emitter current in a common base configuration:

$$\text{Alpha } (\alpha) = \frac{\Delta I_c}{\Delta I_e} \text{ (with } V_c \text{ held constant)}$$

Equally important and appropriate for the common-emitter type of transistor



(A) Delta-connected secondary. (B) Wye-connected secondary.

Fig. 14-4. Wye and delta secondary transformer connections.

circuit is the factor of *beta*. This represents the current gain of a common-emitter configuration and is the ratio of a small change in collector current to a small change in base current:

$$\text{Beta } (\beta) = \frac{\Delta I_c}{\Delta I_b} \text{ (with } V_c \text{ held constant)}$$

9. What are the main disadvantages of using transistors in a circuit rather than vacuum tubes, assuming the cost is the same for both?—Transistor heating is a significant factor. The operating characteristics of a transistor change significantly with any change in the collector-junction temperature. This effect can be minimized with appropriate circuit design. A transistor is fundamentally a low-impedance device. Input and output impedances, particularly input impedance, are very much lower than those for comparable vacuum tubes used in the same service. There are some power-handling limitations, but this disadvantage in many services is now unimportant because of the development of solid-state devices with substanial power-handling capability.

10. What causes resistance noise in electrical conductors and shot-effect noise in diodes?—Noise in resistance is caused by the random motion of free electrons as a result of thermal agitation. Shot effect is a noise component that results from the random variations in the electron emission from the cathode surface of the diode.

14-2. CALCULATIONS

11. A series-parallel circuit is composed of a 5-ohm resistor in series with the parallel combination of a capacitor having a pure reactance of 20 ohms and an inductance having a pure reactance of 8 ohms. What is the total impedance of the circuit? Is the total reactance capacitive or inductive?—In the parallel circuit of inductor and capacitor the lowest reactance sets the direction of the net current. Inasmuch as this is the inductive reactance, the net reactance is inductive and has a value of:

$$X_N = \frac{-X_C X_L}{-X_C + X_L} = \frac{-20 \times 8}{-20 + 8}$$
$$= 13\tfrac{1}{3} \text{ ohms}$$

The total impedance of the circuit becomes:

$$Z = \sqrt{R^2 + (X_N)^2}$$
$$= \sqrt{(5)^2 + (13\tfrac{1}{3})^2} = 14.26 \text{ ohms}$$

12. A 10-amp alternating current is flowing in a series circuit composed of 5-ohms resistance, 25-ohms capacitive reactance, and 12-ohms inductive reactance. What is the voltage across each component? What is the total voltage? Why is the total voltage not simplv the sum of the individual voltages?—The current magnitude is the same for each component of a series circuit. Therefore, the voltage drops across the capacitor, inductor, and resistor are as follows:

$$E_R = I \times R = 10 \times 5 = 50 \text{ volts}$$
$$E_C = I \times X_C = 10 \times 25 = 250 \text{ volts}$$
$$E_L = I \times L_L = 10 \times 12 = 120 \text{ volts}$$

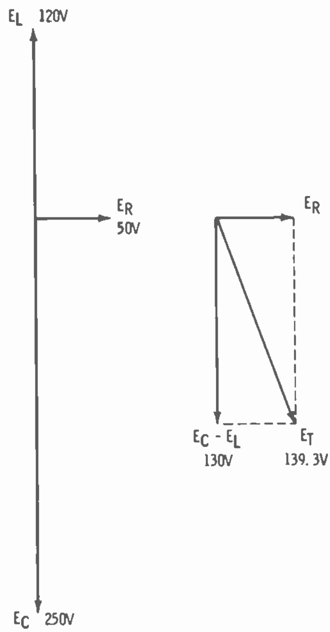


Fig. 14-5. Vector relations for questions.

The total voltage is the vector sum of the individual voltages. This is not a simple arithmetical addition, because the voltages are not in phase. The voltage across the resistor is in phase with the current, the voltage across the capacitor lags the current by 90°, and the voltage across the inductor leads the current by 90°, as in the vector diagram, Fig. 14-5. Note that the inductor and capacitor voltages are out of phase by 180°. They are opposite in polarity, and therefore one subtracts from the other.

Thus the net voltage across the capacitor and inductor in series becomes:

$$E_X = E_C + E_L = -250 + 120$$
$$= -130 \text{ volts}$$

This net voltage lags the voltage across the resistor by 90° and a simple right-triangle solution can be used to determine the total voltage:

$$E_T = \sqrt{(E_R)^2 + (E_X)^2}$$
$$= \sqrt{(50)^2 + (-130)^2} = 139.3 \text{ volts}$$

In summary the total voltage is not the simple sum of the individual voltages, because of the phase relationships among the three voltages.

13. The 10-kilohm cathode resistor of a certain amplifier is bypassed to ground with a capacitor. If it is desired to operate this amplifier at a minimum frequency of 5 kilohertz, what size of capacitor should be used?—In the design of an amplifier the minimum or low-frequency limit is that value at which the low-frequency response drops below some standard level. This standard level is by no means the same throughout the industry. In some cases it represents the frequency at which the response is down 29.3 percent (70.7 percent level or −3 db) relative to the midfrequency gain. In other cases it represents a frequency at which the response is just slightly below its midfrequency value. For some component-value charts for resistance-coupled amplifiers it represents an 80-percent level relative to the midfrequency response.

Quite often it refers to a level at which the low-frequency point is down an insignificant amount. Usually this means the frequency at which the capacitive reactance of the bypass capacitors is 1/5 to 1/10 of the ohmic value of the resistor. In the latter case, the capacitor size would be

$$C = \frac{1}{2\pi f X_C}$$
$$= \frac{1}{2\pi f R/10} \text{ (assumes } X_C = \frac{R}{10}\text{)}$$
$$= \frac{1}{6.28 \times 5000 \times 1000}$$
$$= 0.0318\ \mu F$$

14. Explain the operation of a resistance bridge. If the known resistances in such an instrument are 5 and 10 ohms, and if adjusting the third resistance to 50 ohms produces a perfect balance, what is the unknown resistance?—In a resistance bridge (Fig. 14-6) a source of voltage is connected across two opposite terminals of the bridge while a current meter is connected between the second pair of terminals. Such a bridge is balanced when the voltages at point A and point B are the same. With no difference of potential between points A and B there will be no current in the meter. To obtain the same voltage at points A and B it is necessary that the ratio of R_1/R_2 be the same as R_k/R_x. When so balanced, the voltages across resistor R_1 and R_k are the same, and so are the voltages across R_2 and R_x.

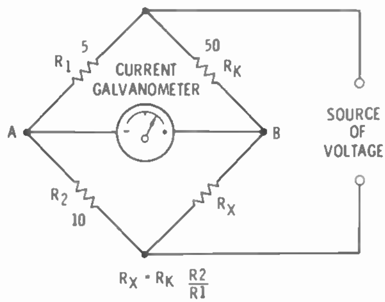


Fig. 14-6. A basic resistance bridge.

In the example of Fig. 14-6 the voltage across R_2 would be twice the voltage across R_1. Therefore, the voltage across R_x must of necessity be two times greater than the voltage across R_k if the bridge is to be balanced. It follows then that resistance R_x is 100 ohms (50 × 2).

The same result can be obtained by rearranging the basic bridge equation as follows:

$$\frac{R_1}{R_2} = \frac{R_k}{R_x}$$
$$R_x = R_k \frac{R_2}{R_1}$$
$$= 50 \times \frac{2}{1} = 100 \text{ ohms}$$

15. Find the gain of a triode amplifier with a plate resistance of 50,000 ohms and a load resistance of 75,000 ohms. The amplification factor is 25.—The basic voltage gain equation of a triode amplifier is

$$A_v = \frac{\mu R_L}{r_p + R_L}$$

By substitution, the voltage gain becomes

$$A_v = \frac{25 \times 75{,}000}{50{,}000 + 75{,}000} = 15$$

14-3. AUDIO COMPONENTS AND AMPLIFIERS

16. What causes sound, and how is sound transmitted in air?—Sound is a vibration in an elastic medium. Air can serve as such a medium. When a person speaks, the mechanical vibration of the vocal cords causes the air particles to compress and rarify, the resultant vibrations expanding outward because of the elasticity of air. When this air-particle motion reaches another person within range it causes his eardrums to vibrate. Here a conversion is made between vibration and nerve stimulation of his sense of hearing.

Such air-particle vibrations of a frequency between 20 Hz and 20,000 Hz which can produce aural stimulation, are known as sound waves, and their frequencies are called audio frequencies.

17. What is an audio frequency? What approximate band of frequencies is normally referred to as the audio frequency range?—An audio frequency is a frequency which can produce an audible sound when it excites the human eardrum. The approximate band of audio frequencies extends between 20-20,000 Hz. In broadcasting we are concerned with the transmission of an acceptable range of audio frequencies.

In a-m broadcasting the audio frequency spectrum of concern falls between 50 and 7500 Hz; in fm broadcasting, between 50 and 15,000 Hz.

18. What is a *decibel?*—The decibel unit is an expression of the magnitude of a change in sound level. The human ear responds logarithmically to an increase in sound level; one decibel being a change in sine-wave sound level that is barely distinguishable by the ear.

The decibel unit is also used to express a change in signal level. In this case it must be based on some reference level. Quite often an audio signal power of 1 milliwatt across a 600-ohm impedance is a standard corresponding to zero decibel (0 dB).

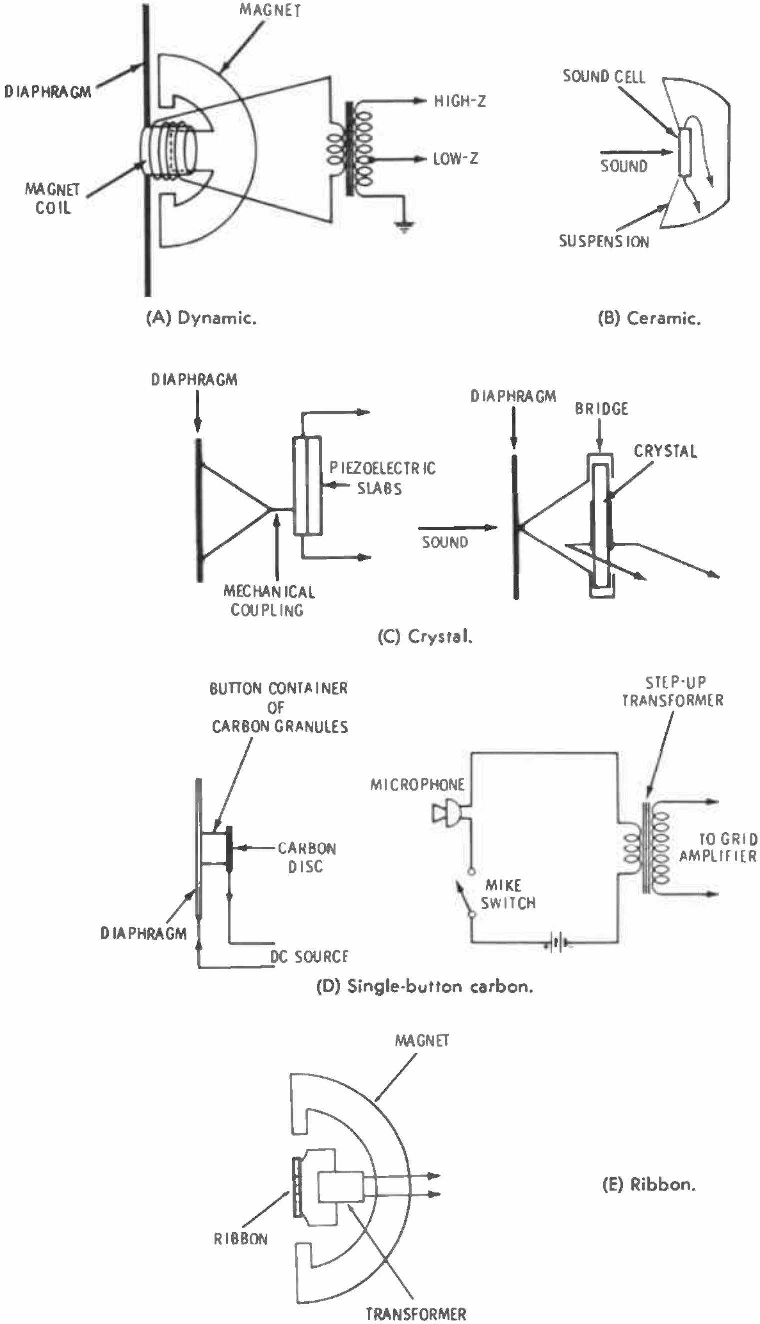
19. Sketch the physical construction of the following types of microphones and list their advantages and/or disadvantages: (a) dynamic, (b) ceramic, (c) crystal, (d) single-button, and (e) ribbon. Which types are normally used in the broadcast studio? Why?—Dynamic and ribbon microphones are used as studio mikes. Each can be designed with a uniform and wideband audio response, and of a low impedance which is a favorable characteristic in terms of long line lengths and minimum hum pickup. They lend themselves to the design of microphones with adjustable patterns.

Sketches of the various types of microphones are given in Fig. 14-7. The single-button carbon microphone (Fig. 14-7D) has a high output and a reasonably low impedance. It has a limited low-frequency response, but its high output and adequate voice response make it an ideal microphone for two-way radio application. It has a limited frequency response, a tendency to carbon hiss, and requires a source of dc current.

The ceramic (Fig. 14-7) and crystal (Fig. 14-7C) microphones are also high-output types. They have a high impedance and therefore are limited as to the length of line that can be used without undue pickup of hum and noise and sacrifice in frequency response. Audio frequency response is better than that of the carbon microphone, but it does not come up to the uniformity and quality of dynamic and ribbon types. The ceramic microphone is more rugged than the crystal type and is able to withstand environmental extremes more readily. Its output is slightly less than a crystal element of like size.

The dynamic (Fig. 14-7A) and ribbon (Fig. 14-7E) microphones are used widely in broadcast studios. The dynamic microphone is versatile because of its light weight, good output, and the ease with which it can be designed with a given impedance and pattern, in both fixed and adjustable types. The ribbon mike is a more fragile type of microphone, has a lower output, and must be handled carefully. However, the ribbon microphone is popular for broadcasting service because of its good frequency response.

20. What is the difference between unidirectional, bidirectional, and omnidirectional microphones?—The various patterns are shown in Fig. 14-8. The omnidirectional or nondirectional microphones pattern is shown in Fig. 14-8A. Thus the omnidirectional microphone can be positioned in the center of a broadcast studio activity and will have uniform sensitivity to sound from all angles. The bidirectional microphone is



(A) Dynamic.

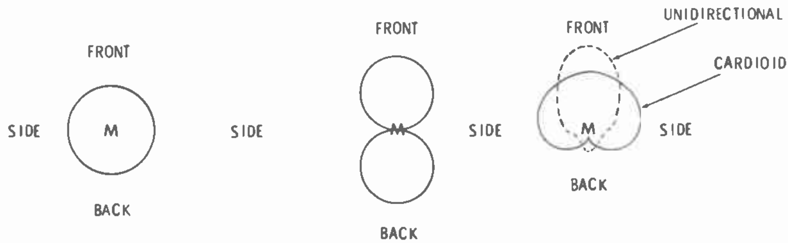
(B) Ceramic.

(C) Crystal.

(D) Single-button carbon.

(E) Ribbon.

Fig. 14-7. Basic microphone types.



(A) Nondirectional. (B) Bidirectional. (C) Cardioid–unidirectional

Fig. 14-8. Basic microphone patterns.

sensitive in two directions and has an approximate figure-8 pattern as shown in Fig. 14-8B. For example, the bidirectional microphone would be good for picking up two people sitting across from each other at an interview table. The unidirectional microphone has a single-direction pattern as shown in Fig. 14-8C. Such a pattern can be quite narrow for picking up one source of signal or it can have a broad unidirection response such as a cardioid pattern for single-direction, large-area pickups.

21. What is meant by the phasing of microphones? When is this necessary? —Microphones must be phased properly when two or more microphones are used rather close together. The microphones must respond to sound waves in a manner so that they deliver similarly phased audio signals to the input of the mixing amplifier. If they are out of phase, there will be a net decrease in signal level and distortion. The microphone wiring and patching arrangement should be such that the microphone signals are additive.

22. What is a preamplifier? Where are they normally used in a broadcast station?—Preamplifiers are often used in association with a studio microphone, particularly when there is a rather long length of line between microphone and the sound console. The preamplifier is usually mounted right in the studio with the microphone. Its function is to provide the correct termination for the microphone and to build up the level of the microphone signal for application to the long audio lines to the studio console. The higher-level signal dominates the hum and noise components that may be induced into the long audio line. Thus, higher signal-to-hum and signal-to-noise ratios are obtained.

Recently solid-state preamplifiers have been built directly into the microphone case. This type of microphone is also used quite frequently for remote pickup and for applications other than strictly studio work.

Preamplifiers also amplify the outputs of phono cartridges, tape heads, and other signal sources.

23. What type of playback stylus is usually used in studio turntables? Why? —The most widely used stylus today is the small-diameter diamond stylus in conjunction with a high-quality cartridge (usually magnetic). A stereo stylus and cartridge are necessary for stereo fm broadcast application. The thin-diameter stylus is needed for microgroove records and long-playing transcriptions. The diamond stylus is long-lasting and durable. Record wear is reduced to a minimum because the stylus and cartridge are designed to apply only a light pressure on the record.

24. How does dirt on the playback head of a tape recorder affect the audio output? How are such heads cleaned? —Dirt reduces output and increases the noise level. Dirt will cause head wear and consequent deterioration of the frequency response and the output level, which reduces the signal-to-noise ratio. Dirt can be removed by cleaning with a soft cloth or a cloth dampened with ethyl alcohol. Various test tapes and cleaner tapes are available too. They can be used to clean and check out tape-head performance.

25. Explain the use of a stroboscope disc in checking turntable speed.—A stroboscopic disc is imprinted with a number of dots or lines the positioning of which is so arranged that when the disc is rotated on the turntable and illuminated by a 60-Hz light source the appropriate dots or lines will remain stationary when the turntable is rotating at the proper speed. If there is a drift in the pattern in one direction or the other, an appropriate adjustment can be made to speed up or slow down the turntable to obtain a stationary pattern. Speed checks should be made with a record on the turntable and stylus in the record grooves.

26. What are wow and rumble as referred to turntables? How can they be prevented?—Wow is a low-frequency flutter that results from an eccentric rotation of the turntable and/or record. This results in the generation of a spurious low-frequency signal which is reproduced in the loudspeaker. Rumble is a low-frequency vibration that is conveyed mechanically to a turntable and introduces a signal that is reproduced in the output. This can be the result of any vibration coupled mechanically to the motorboard. It can also be the result of an unbalanced drive system.

Wow and rumble reduction are to a great extent, a matter of turntable design. In addition, the turntable must be mounted level and all balancing adjustments made carefully so as to result in a smooth rotation and a reduction of any tendency for uneven wear of mechanical components. Electronic filters are available for insertion in the audio system to attenuate the narrow rumble frequency band.

27. What factors can cause a serious loss in high frequencies in tape recordings?—A loss of highs can be the fault of the following: improper azimuthal mounting of the tape head, insufficient pressure-pad tension (which does not hold tape in contact with heads), and unclean heads. Improper bias current or a malfunction in the equalization circuits can also cause a loss of high frequencies.

28. Show how the frequency response of a pickup unit on either a tape recorder or turntable is tested.—There are a variety of test tapes and records that can be used to check out the frequency response of tape playback or phono playback units. Output is measured with an ac voltmeter or a VU meter.

If the pickup cartridge of the turntable can be assumed to be operating correctly, a signal generator can be used as a signal source for checking the frequency response of a phono-preamplifier unit. The input signal level should be adjusted to the approximately normal input level. The preamplifier output can then be checked on an ac voltmeter or VU meter.

The overall performance of a tape recorder and playback system can be checked with the test arrangement of Fig. 12-17. In this arrangement, a calibrated audio oscillator is used as a signal source. The oscillator output is recorded on the tape and then played back and measured at the output of the amplifier with an ac voltmeter or VU meter. When a response fault is located, it is then possible to check the record and playback channels separately to further isolate the point at which the response has been lost.

29. VU meters are normally placed across transmission lines of what characteristic impedance?—A 600-ohm line.

30. Show by a circuit diagram a method of desensitizing a VU meter to cause it to read lower than normal.—Such an arrangement is shown in Fig. 14-9. Its added resistance sets a VU reference at a higher level than the standard 1-milliwatt level. For example, 0 VU can be made to correspond to the standard signal level of +4 dBm (4 dB above 1 milliwatt across 600 ohms) on an incoming phone line.

Adjustable and calibrated pads and attenuators are available. These provide proper matching and when placed ahead of the VU meter they can be used to establish a desired 0 VU reference level.

31. Why is it important to keep clean the contact points on attenuator pads used in a broadcast studio console? How are they cleaned?—Attenuator pads are often varied during the course of a program. If they are dirty, they can introduce scratch noise into the sig-

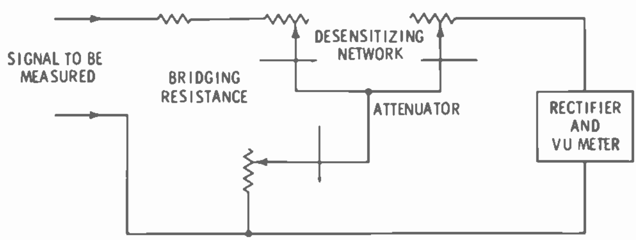


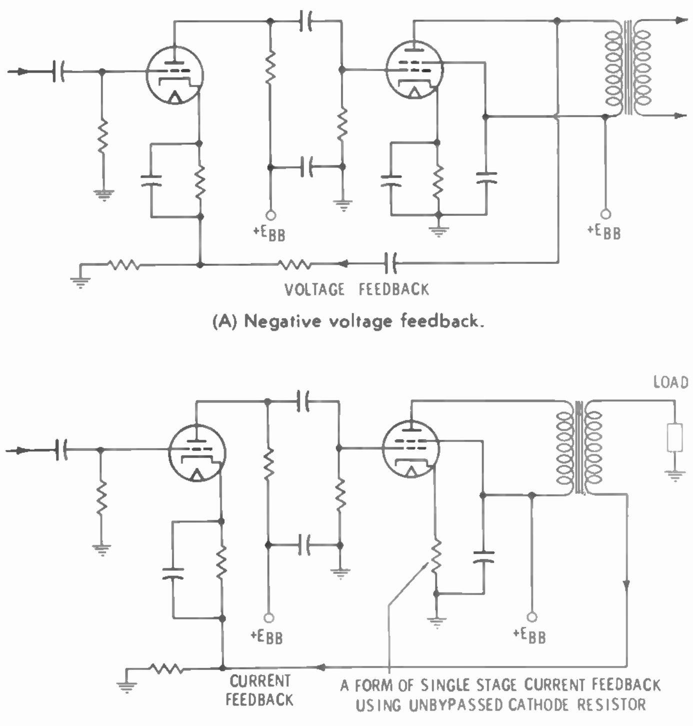
Fig. 14-9. A method of desensitizing a VU meter.

nal and/or cause erratic amplitude variations in the program signal. These pads are kept clean with a soft cloth and a suitable nonabrasive and noncorrosive cleaner.

32. What is meant by the *fidelity* of an audio amplifier? Why is good fidelity an important consideration when replacing amplifiers in a broadcast station?—The fidelity of an amplifier has to do with the faithfulness with which the output signal reproduces the program characteristics of the input signal with a very minimal introduction of spurious components such as noise, hum, harmonic distortion, and intermodulation distortion. For good fidelity, the amplifier must have a uniform overall flat response over the required audio range. Drop-offs at the ends of the bandpass should be such that spurious signal components are not introduced. The amplitude response should be linear, so that the amplifier follows exactly the amplitude variations of the program material. Good fidelity is important in the faithful transmission of the program material. It is particularly important today, with the emphasis on high-fidelity reproduction.

33. What is the technical requirement for negative feedback? Show by circuit diagrams how this is achieved for (1) negative voltage feedback and (2) negative current feedback.—Feedback must be of opposite polarity (180° phase shift). To obtain negative feedback the feedback component derived from the output signal should have a polarity opposite to that of the signal present where the feedback signal is reintroduced into the amplifier. The higher the desired negative feedback, the closer the feedback component must approach the magnitude of the signal at the feedback-injection point. Out-of-phase voltage and current feedback arrangements are shown in Fig. 14-10.

34. Given the gain of an amplifier employing feedback and the overall voltage gain of the circuit, how is it possible to determine the amount of



(A) Negative voltage feedback.

(B) Negative current feedback.

Fig. 14-10. Voltage and current feedback.

feedback used? State the formula used, and solve a sample problem.—The feedback is the fractional part (β) of the output voltage fed back to the input of the amplifier. The greater the negative feedback ($-\beta$) is, the greater is the reduction in the amplifier gain. The basic equation for a feedback amplifier is:

$$A' = \frac{A}{1 - A\beta}$$

This can be rearranged to solve for the negative feedback (—B):

$$-\beta = \frac{A - A'}{AA'}$$

In a typical example if the voltage gain (A) without feedback is 100 and the voltage gain A' with feedback is 10, the feedback β is:

$$-\beta = \frac{100 - 10}{100 \times 10} = 0.09 = 9\%$$

35. What are line equalizers? Why are they used? Where in the transmission line are they normally placed?—A line equalizer is a resistance-reactance network that compensates for the loss of high-frequency response on an audio line. Such an equalizer can be placed across a line without disturbing the impedance match. It has a frequency response which rises in a controllable manner with frequency. Usually it is inserted in an incoming phone line (most often from a remote pickup) ahead of the input to the audio console.

CHAPTER 15

Transmitters and A-M Broadcasting

This chapter covers the FCC Study Guide questions on transmitters, modulators, antennas, transmission lines, and subjects related to these components.

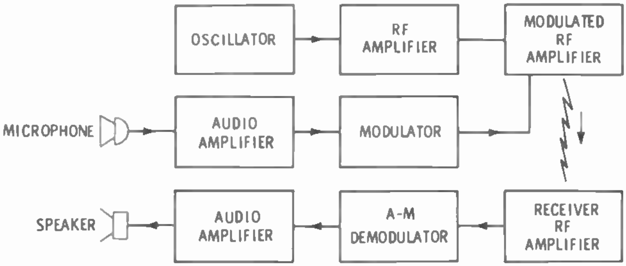
15-1. TRANSMITTERS

1. Explain in a general way how radio signals are transmitted and received through the use of amplitude modulation.—A functional block diagram of an a-m system is given in Fig. 15-1A. In a-m broadcasting, the amplitude of the transmitted rf wave is made to vary with the voice and music components of the modulating signal. The a-m transmitter consists of a carrier generator, or rf exciter, which, in a-m broadcasting, is a crystal-controlled oscillator and a series of succeeding rf amplifiers. The rf amplifiers build up the amplitude of the carrier wave. Prior to their application to the final modulated rf amplifier (Fig. 15-1A), the voice and/or music frequencies (Fig. 15-1B) are increased in level by a series of audio amplifiers. The final high-power stage of the audio chain is called the *modulator*. The audio output of this final stage is used to modulate the rf carrier.

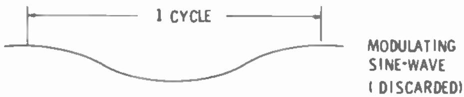
In the modulated amplifier, the rf and audio frequency components mix to produce a resultant rf wave which varies in amplitude in accordance with the modulating wave (voice and/or music). It is said that the amplitude of the rf carrier is varied. Actually, in the modulated amplifier the rf carrier wave and the modulating wave combine to produce three individual rf output waves. They are the carrier, the upper sideband (carrier + modulating-wave frequency) and the lower sideband (carrier − modulating-wave frequency) (Fig. 15-1C). The resultant amplitude-modulated rf wave is the algebraic sum of these three waves; it is this combining that produces the familiar a-m modulation envelope. (Refer to the waveforms of Fig. 15-1C). Note that the variations in the modulation envelope (loosely referred to as a modulated rf carrier) correspond exactly to the variation of the modulating audio wave.

The strength of a modulated rf signal decreases quickly as the signal travels away from the radiating antenna. Thus the receiving antenna picks up a signal that is only a small percent of the signal level at the transmitting antenna. The amplitude-modulated rf signal at receiver antenna terminals is amplified by a number of rf stages before it is applied to a demodulator (a-m detector). The conversion of the rf modulation envelope to the modulating wave (audio) is the function of the a-m demodulator. The conventional a-m demodulator is a combination rectifier and filter. In the rectifier only the positive alternation of each rf cycle causes a flow of demodulator current. The positive alternations at the demodulator output appear as a series of radio-frequency pulses, as shown in Fig. 15-1D. However, the output circuit of the a-m demodulator is a filter network in which the rf cycles are filtered to ground. The reconstructed modulating wave (Fig. 15-1E) is then applied to a following audio amplifier in which the power level of the audio signal is built up to provide adequate drive for the speaker.

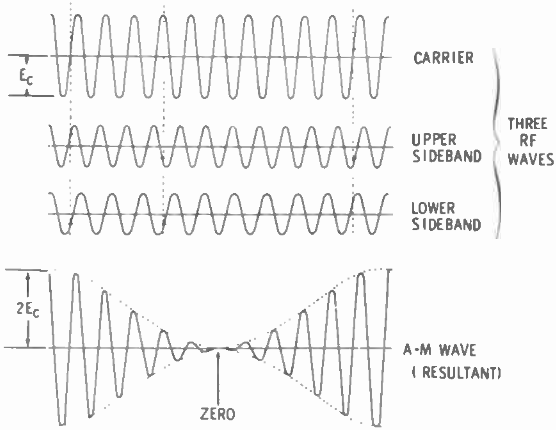
In general it can be stated that an amplitude modulation system provides a means of varying the magnitude of the transmitted rf wave in accordance



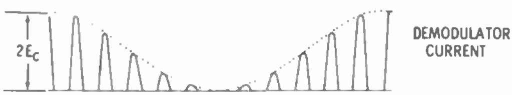
(A) Block diagram of an a-m transmitter.



(B) An audio (program) signal.



(C) An amplitude-modulated signal.



(D) A demodulated a-m signal.

(E) The filtered output (audio) of an a-m demodulator.

Fig. 15-1. A basic a-m modulation system.

with the amplitude changes of the modulating signal. This rf wave provides a means of carrying the desired modulating information between transmitter and receiving sites. The function of the receiver is to first amplify this incoming rf wave and then apply it to an a-m demodulator. The demodulator makes the conversion between the rf modulation envelope and a replica of the original modulating wave.

2. Draw a circuit diagram of a complete radiotelephone transmitter composed of the following stages: (a) microphone input connection, (b) preamplifier, (c) speech amplifier, (d) class-B modulator, (e) crystal oscillator, (f) buffer amplifier, (g) class-C modulated amplifier, and (h) antenna output connection. Insert meters in the circuit where necessary and explain step-by-step how the transmitter is tuned.—The transmitter schematic diagram is given in Fig. 15-2. The essential meters would be located in the grid circuit of the buffer amplifier, grid circuit of the class-C modulated amplifier, plate circuit of the class-C modulated amplifier, plate circuit of the class-B modulator, and in the coupling system to the transmission line of the antenna system.

Often in a-m broadcast practice no frequency control is associated with the transmitter. The crystal is finely ground, mounted in an oven and operates on the precise frequency assigned to the a-m broadcast station by the FCC. In other cases, especially in services other than a-m broadcasting, a fine-frequency adjustment is included. This permits the crystal oscillator to be set to some precise frequency using an appropriate frequency standard. In a-m broadcast practice an accurate frequency monitor is mandatory and, therefore, the frequency of the transmitter can be checked on this meter.

STEP 1. When the crystal oscillator (V1) is functioning and supplying signal to the buffer (V2) there will be a buffer grid-current reading. The oscillator tank (L1-C1) can then be peaked by adjusting the slug in L1 for a maximum buffer-stage grid current (I_{g1}) meter reading.

STEP 2. The adjustments in Step 2 are made without applying dc plate and screen-grid voltages to the final amplifier (V3). However, the filament of V3 is turned on so that grid current can flow. The plate tank (L2-C2) of the buffer amplifier (V2) can be adjusted by C2 for maximum grid-current (I_{g2}) meter reading at the grid circuit of the class-C modulated amplifier (V3). The grid current meter reading will be maximum when there is maximum rf excitation from the buffer stage. In some cases it is necessary that the rf drive to the power amplifier be of some specific value. Often a drive control (R1) in the screen grid circuit of the buffer amplifier permits a precise setting of the power output of this stage. If so, both buffer controls (plate tuning and drive) are adjusted so that the meter reading at the grid of the class-C amplifier is some specific value when the buffer tank is resonated. Usually the tuned circuits are resonated, and then the drive control (R1) is adjusted for a specific grid current.

STEP 3. The adjustment of the modulated amplifier stage can be made with a dummy antenna load connected to the transmitter output instead of the broadcasting antenna. This antenna load has the same characteristics as the broadcasting antenna but it does not radiate any signal.

The initial adjustment of the power amplifier stage is usually made at a low transmitter power output by decreasing the power-amplifier plate and screen grid voltages and with a light load. The plate tank circuit of the modulated power amplifier (C3) can now be adjusted for a dip or minimum plate current meter reading.

STEP 4. The loading on the transmitter can now be increased with C4. In so doing there will be a rise in the plate current meter reading (dip will not be as pronounced). Usually it is necessary to jockey the tank circuit tuning control and the antenna loading control until the plate current reads a specific value when the plate tank circuit is set on resonance. Occasionally a slight detuning of the plate tank circuit is advisable in the transfer of maximum power to the antenna system. The maximum transfer of power will be indicated by a maximum antenna-current meter reading. The two output controls (plate tuning and loading) are optimized when the plate current and antenna-current readings at resonance are in accordance with the manufacturer's recommendations or known desired operating settings for the particular transmitter.

STEP 5. After the output circuit has been tuned it is often advisable to reset the buffer tank circuit and the rf drive from the buffer so that the grid current

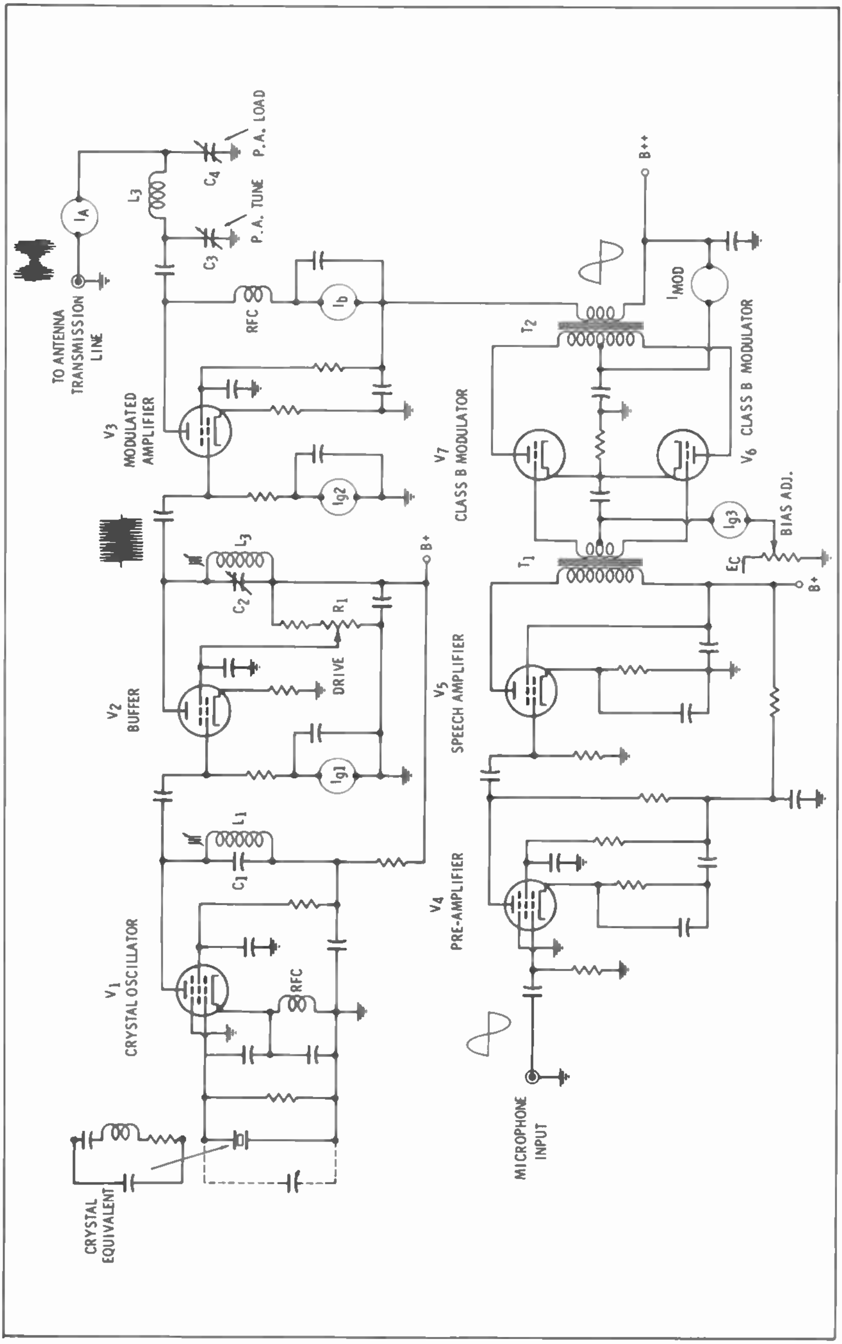


Fig. 15-2. Schematic of a radiotelephone transmitter.

meter reading is of a desired value. In most transmitters there is some interaction between control settings and it is necessary to jockey back and forth until optimum conditions are obtained. Plate tuning and loading can now be readjusted slightly for the most favorable plate current and antenna current readings.

STEP 6. It is now permissible to apply maximum voltage to the modulated rf power amplifier. Input drive and tuning as well as output tuning and loading can now be readjusted ever so slightly for optimum operating conditions. These optimum conditions will be indicated by the three meter readings —modulated rf amplifier grid current, modulated rf amplifier plate current, and rf antenna current.

STEP 7. The performance of the transmitter should be checked with modulation applied. Quite often a tone signal (usually 1000 Hz) of specific amplitude is recommended by the manufacturer for this purpose. The signal is applied to the input of the transmitter. At this level of audio input signal, the transmitter carrier should be modulated 100 percent or some other specific level of modulation in accordance with the transmitter maintenance instructions, and the class-B modulator stage (V6-V7) should also be drawing some specific dc plate current (I_{MOD}). If the modulator stage (V3) does not draw the specified I_{MOD}, the bias voltage to modulator grids, and other possible adjustments should be made in the speech amplifier or modulator sections of the transmitter to obtain the proper drive to the class-B modulator.

In a-m broadcasting, a modulation meter is required by the FCC; the actual percentage of modulation can be read on this meter. An oscilloscope can also be used to check the percentage of modulation. The modulation envelope of the a-m carrier voltage (as displayed on the face of an oscilloscope cathode-ray tube) taken across L3 via a pickup coil gives a good indication of the linearity of the modulation. (See Fig. 15-3.) If it is nonlinear, certain biasing adjustments are recommended to obtain true linear modulation.

STEP 8. Inasmuch as a class-B modulator is employed, the modulator plate-current meter should drop to a very low value when no modulating wave is applied. In many cases the transmitter maintenance manual indicates that a specific value of the plate current (I_b) should be present without a modulating signal on the grid of the modulator. The bias of the modulator is adjusted until this amount of plate current (I_{MOD}) flows in the plate circuits of V7-V8.

With a modulating signal, the plate current (I_{MOD}) meter reading of the class-B modulator will rise. It should kick up to a certain level when a sine wave of specific amplitude is applied to the input of the speech amplifier

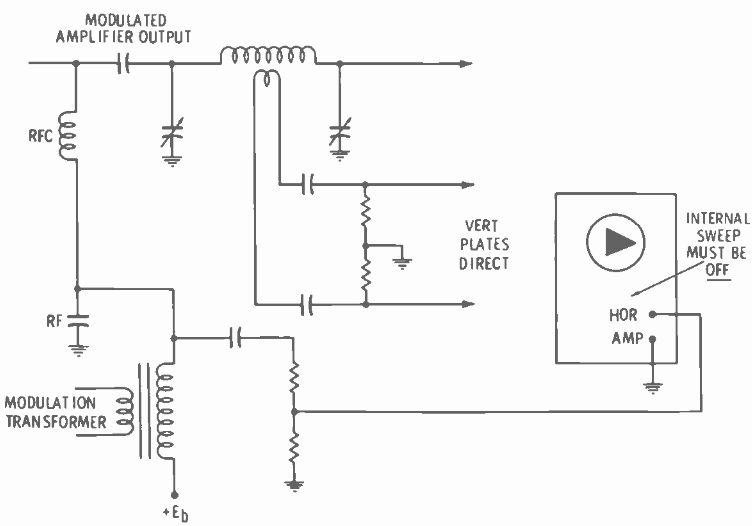


Fig. 15-3. A modulation linearity check.

(V4). At the same time, the antenna (I_A) meter reading should rise. In fact, there should be approximately a 22-percent increase in the antenna current readings from the unmodulated carrier signal to the 100-percent modulated carrier signal.

STEP 9. The application of modulation should not have any adverse influence on the operation of the rf section of the transmitter. Actually, with linear modulation, the plate-current reading (I_b) of the modulated amplifier (V3) should be unchanged. Thus if the plate-current (I_b) meter reading is steady and the antenna-current (I_A) meter reading rises the proper amount with modulation, it is a good indication that the transmitter rf output and the modulation sections of the transmitter are normal. A serious kick in the plate-current (I_b) meter reading of the rf power amplifier with modulation is an indication of a transmitter defect or of an improper transmitter adjustment.

With the application of voice or music frequencies there will be a continuous change in the plate-current (I_{MOD}) meter reading of the modulator. The higher the amplitude of the modulating wave, the higher is the I_{MOD}. Likewise the antenna-current (I_A) meter reading will swing upward with modulation. The higher the amplitude of the modulating wave, the higher is the swing of the antenna-current meter. The plate-current meter reading of V3 and the grid-current (I_{g2}) meter reading of the V3 should remain essentially constant with modulation.

3. Draw the approximate equivalent circuit of a quartz crystal.—Note the equivalent circuit shown above the crystal in Fig. 15-2. The inductor-capacitor equivalent circuit corresponds to the mechanical resonant circuit of the crystal and associated hardware. Since the equivalent resonant circuit of the crystal has a very high Q, an electronic oscillator circuit using a crystal will have exceptional stability.

4. What factors affect the resonant frequency of a crystal? Why are crystal heaters often left on all night even though the broadcast station is not on the air?—The mechanical resonant frequency of a crystal is determined by its physical dimensions and its cut from a block of crystal material. However, the precise resonant frequency of the crystal is also influenced to a limited degree by temperature and the constants of its associated oscillator circuit. In particular, the reactance (usually capacitive across the crystal) of an associated circuit can have some influence on the oscillating frequency. The crystal temperature also influences the oscillating frequency a small but important amount when the transmitter is to be held within the very tight FCC frequency tolerance. For example, in the a-m broadcast band the frequency tolerance is only ±20 Hz relative to the assigned carrier frequency. Therefore, the crystal and often the complete oscillator circuit is mounted in a temperature-controlled oven. This oven holds the crystal at an essentially constant temperature in order to minimize the frequency drift.

Crystal-oscillator frequencies often drift significantly while the crystal and/or its associated circuit are coming up to the normal operating temperature. For this reason, a crystal oven usually operates even when the transmitter is not on the air so that the crystal temperature can be maintained at a constant value. In some transmitters, the power is also applied continuously to the crystal oscillator filaments for the same reason.

5. Explain by the use of simple drawings the principle construction and operation of mercury-thermometer and bimetallic thermal switch types of crystal heater controls.—These two basic methods are shown in Fig. 15-4. A bimetallic element acts as a temperature switch that shuts the heater resistance on and off, maintaining an essentially constant oven temperature. The bimetallic element itself is composed of two dissimilar metal strips. As the internal temperature of the oven is brought up to operating level, the heat causes one of the strips to expand more than the other. Eventually one element bends upward and away from the second element, opening two electrical contacts. The open contacts then switch off the heater until the oven temperature once again falls to a level that will cause the metallic strips to contract and re-establish electrical contact. This closes the electrical circuit to the oven heater and prevents the oven temperature from falling below a specific value. Switching on the heater resistor also applies voltage to a pilot lamp that glows whenever the oven is heating. In normal operation the oven heater switches on and off in a manner that maintains the operating temperature of the oven with reasonable limits.

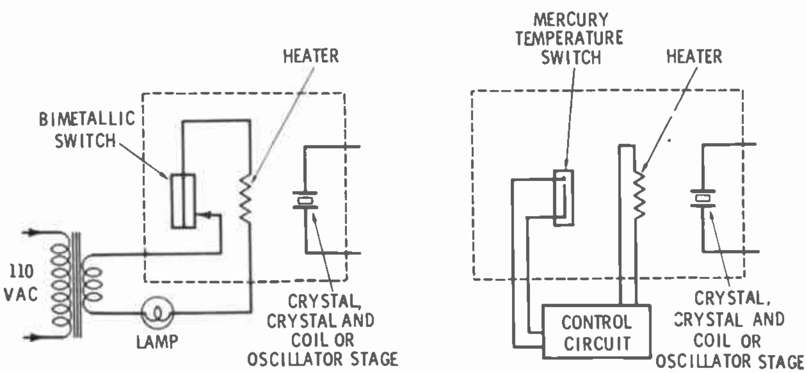
In the mercury thermometer arrangement (Fig. 15-4B) a contact is closed whenever the mercury within the thermometer rises to a specific level. The closing of the contact causes a control unit to shut off the oven heater. When the mercury falls below a certain temperature the mercury switch contact is broken, and the associated circuit once again turns on the oven heater. Again the operation of the mercury temperature switch keeps the oven temperature within narrow limits to maintain crystal frequency stability.

6. Draw circuit diagrams of the following rf amplifiers, and explain their operation—(a) class-C rf power amplifier with battery bias, (b) tetrode rf power amplifier with grid-leak bias, (c) rf power amplifier with two tetrode tubes in parallel, (d) rf power amplifier with two tetrode tubes in push-pull, (e) plate-neutralized triode rf amplifier, (f) grid-neutralized triode rf amplifier, (g) triode frequency-doubler stage, (h) push-push frequency-doubler stage and (i) grounded-grid rf amplifier.— (a) A *class-C rf power amplifier with battery bias* is shown in Fig. 15-5. The class-C stage is the basic rf power amplifier. It operates at a high efficiency since it is biased beyond cutoff, and plate current (i_p) flows for considerably less than half the period of the input rf sine-wave voltage as shown in Fig. 15-5C. The plate current is not continuous and is drawn in bursts. Each burst of plate current shock-excites the tank circuit into oscillation, forming a complete sine-wave cycle. If only a single burst of current were delivered to the tank circuit, damped oscillations would occur in the plate tank, each succeeding cycle being lower in amplitude than the previous one, in accordance with the losses in the tank circuit. However, in a conventional class-C amplifier, a burst of plate current occurs once during each input cycle. Therefore the sine waves developed across the tank circuit are continuous and of constant amplitude. If the tank circuit has an adequate Q, the generated waves are of good sine-wave form and contain a minimum of harmonic components.

The rf power amplifier stage of Fig. 15-5A is biased class-C with a battery. Refer to the transfer characteristic and the waveforms of Fig. 15-5B. Let us assume that the cutoff bias for the tube is −30 volts and the battery bias is −90 volts. Therefore it can be stated that the tube is biased three times beyond cutoff.

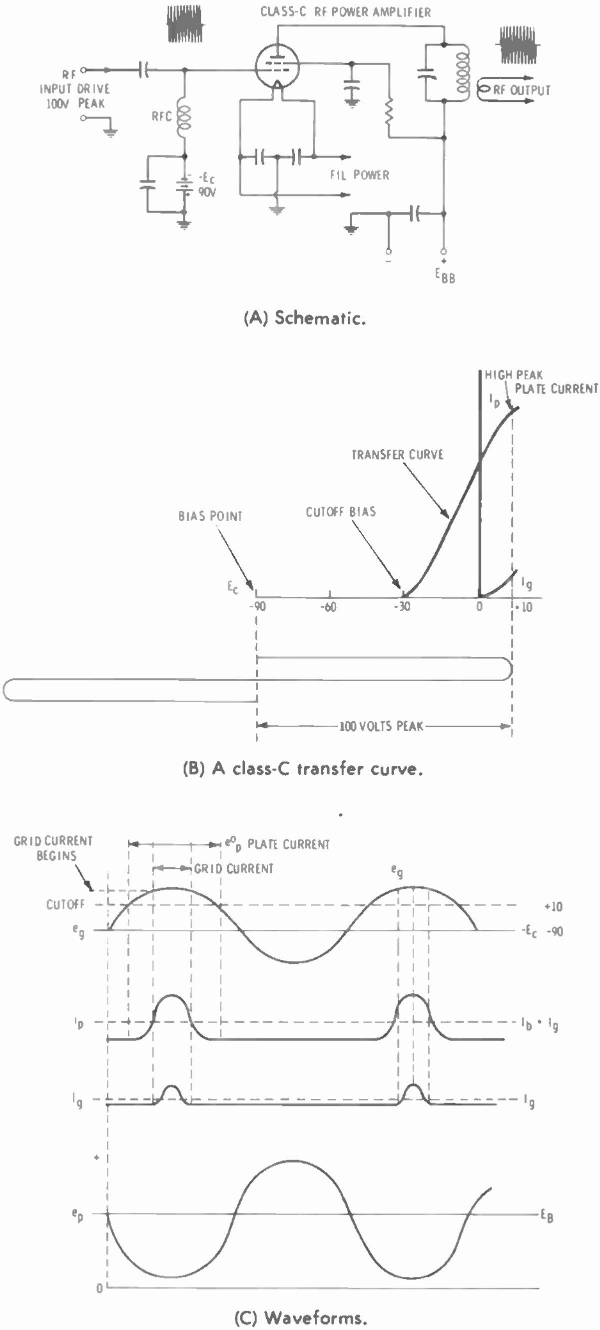
Usually the peak amplitude of the incoming rf wave from the succeeding driver stage is somewhat higher than 90 volts peak. For the efficient operation of most class-C stages, it is necessary to apply enough drive signal to drive the control grid positive, so as to draw a *high peak plate current*. If the amplitude of the rf drive signal is 100 volts peak, the control grid would be driven to 10 volts positive.

From the transfer characteristic shown in Fig. 15-5B, notice that *plate current* occurs only during a portion of the input sine wave (for the time interval that the control grid swings from −30 volts to +10 volts). During the remainder of the input cycle there is no plate current. *Grid current* (in Fig. 15-5C) occurs only during the short



(A) Bimetallic thermal switch. (B) Mercury temperature switch.

Fig. 15-4. Two methods of crystal heater control.



(A) Schematic.

(B) A class-C transfer curve.

(C) Waveforms.

Fig. 15-5. A class-C rf power amplifier with battery bias and its basic operating characteristics.

interval of time that the input wave swings the grid voltage between 0 and +10 volts.

The peak plate current drawn by the class-C amplifier is a function of the screen-grid voltage and how far the control-grid voltage is made to swing positive. The control-grid voltage must not swing too far positive, because many electrons will be attracted to the control grid, resulting in excessive grid current and no further increase in the peak plate current.

The bursts of plate current deliver power to the output tank circuit. The higher the peak plate current, the more energy can be placed in the tank circuit. This energy causes the tank circuit to oscillate and generate a high-amplitude sine wave. The peak plate current, the amplitude of the rf voltage developed across the plate tank, and, therefore, the rf power in the plate tank circuit are a function of the plate supply voltage. In fact, over a very useful range, the rf voltage developed across the tank circuit increases linearily with an increase in plate supply voltage. This factor is taken advantage of in an amplitude-modulation system.

In summary, the class-C amplifier is biased beyond the cutoff point. For efficient operation the input wave (drive signal) should have sufficient peak amplitude to drive the grid positive. Although the class-C amplifier conducts plate current for a small portion of the positive alternation of the input wave, it draws a high peak plate current which delivers an energy pulse to an output tank circuit. The energy-storing ability of the tank circuit develops a high-amplitude rf sine wave in the output circuit. Each succeeding sine wave is initiated by a new burst of plate current during the peak of the positive alternation of the input wave. There are four factors that have a very significant influence on the amount of rf power that can be developed in the output circuit. The peak plate current is influenced by the peak amplitude of the grid drive voltage and the screen-grid supply voltage. The rf voltage developed across the tank circuit is influenced greatly by the dc plate supply voltage and the Q of the resonant tank circuit.

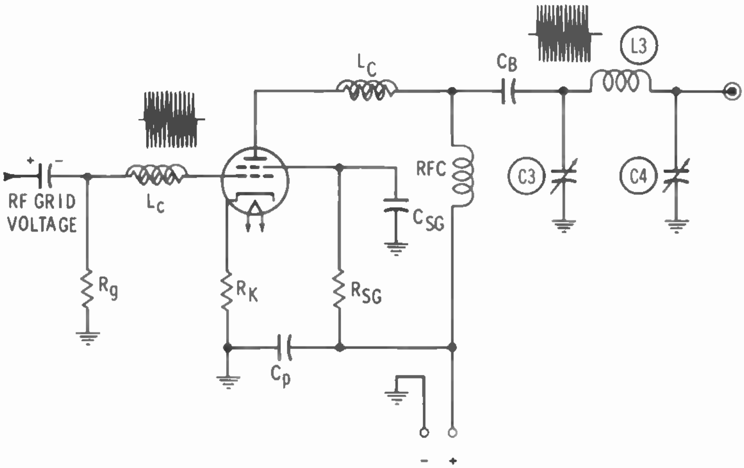
The power developed in the resonant tank circuit can be transferred to a load via a mutually coupled secondary coil. If this coil has a few turns, the coil functions as an impedance-matching transformer to couple the tank circuit to the low-impedance load presented by an antenna system.

(b) A *tetrode rf power amplifier with grid-leak bias* is shown in Fig. 15-6. The fundamental operation of the amplifier is quite similar to the class-C amplifier with battery bias, except for the manner by which it develops the class-C grid bias. The efficient operation of a class-C amplifier requires that the grid be driven positive at the peak of the positive alternation of the input grid voltage. During this short interval, the control grid is positive relative to the cathode, and grid current flows. A grid-leak bias arrangement (C_g-R_g) takes advantage of this grid current to develop the class-C bias. The direction of grid current charges the grid capacitor (C_g) to a potential which makes the grid negative relative to the cathode. Inasmuch as the peak grid current is substantial, the actual negative charge placed on the capacitor is higher than the voltage required for cutoff bias. The charge is held on the capacitor (C_g) during the interval between grid current pulses by the time constant (R_g C_g) which is long in comparison to the time spacing between positive peaks of the rf input wave. During the interval between grid-current pulses, capacitor C_g discharges through resistor R_g (of the grid-leak combination), and a steady class-C dc bias (−90 V) is developed across the grid resistor, R_g. Because the time constant is so long, only a small discharge of capacitor C_g occurs, and the grid bias is held essentially constant between grid-current bursts. Each time a burst of grid current flows, it recharges grid capacitor C_g to the maximum negative value.

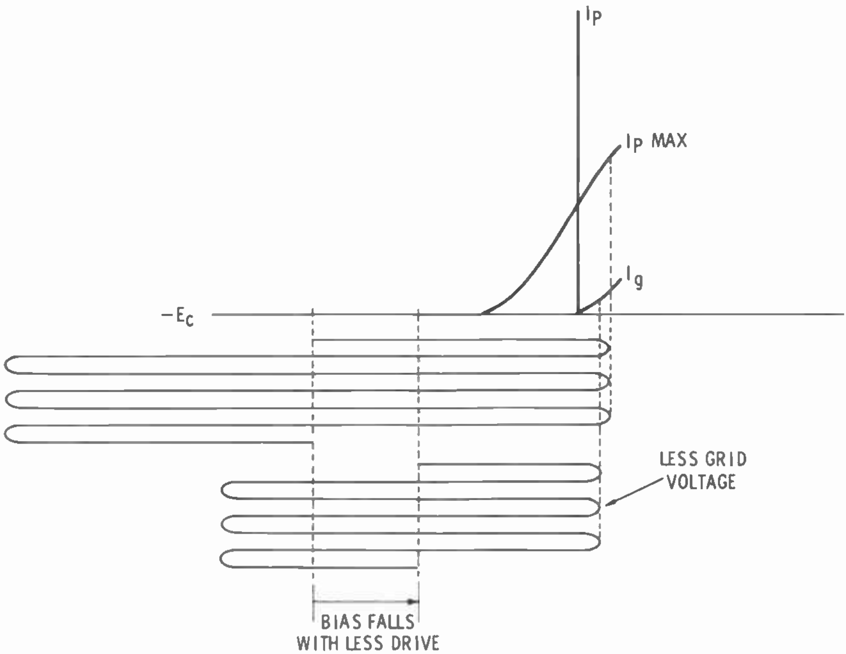
If the power amplifier stages of Fig. 15-5A and Fig. 15-6A have the same operating conditions, the stage waveforms of the battery biased and self-biased power amplifier will be identical.

One significant and very important difference between the battery biasing arrangement and the grid-leak bias arrangement is the fact that the grid-leak self-bias circuit is self-adjusting to the input signal level. In the circuit of Fig. 15-5A a decrease in the input rf drive signal has no influence on the class-C bias, and the peak plate current and rf output voltage will decrease. However, in the circuit of Fig. 15-6A a decrease or an increase in the input signal level has a significant influence on the developed class-C bias. In fact, the resultant change in bias would be such as to maintain an acceptable operating efficiency over a significant range of input signal levels.

The influence of an input signal-level change is shown in the waveforms of Fig. 15-6B. If the input signal level were lower than 100 volts peak, the



(A) Schematic



(B) A class-C transfer curve.

Fig. 15-6. A tetrode rf power amplifier with grid-leak bias.

grid would not be driven as far positive. As a result the peak grid current would be less, and therefore, the class-C bias would decrease. Consequently, the input wave, despite its decrease in level, will still swing into the positive grid region and result in a high peak plate current. Conversely, an increase in the rf drive voltage would result in a higher peak grid current and, therefore, a higher class-C grid bias. The self-regulating action helps to stabilize the operation of the class-C rf power amplifier. It must be pointed out that this self-regulation exists only over a certain range of input signal levels. Too little or too much rf grid drive can still produce improper operation of the stage, but the effect is not quite as pronounced as a similar change at the input of the battery-biased power amplifier of Fig. 15-5A.

Because of the self-regulating action of the grid-leak combination, grid-leak bias is the most widely used method of obtaining class-C bias for an rf power amplifier.

A disadvantage of a grid-leak bias combination is that when the incoming rf drive signal is lost there is *no grid bias* on the stage. Therefore, the tube can draw high currents. Excessive currents can damage or shorten the life of the power amplifier tube and, depending on the circuit arrangement, can damage other stage components. The circuit of Fig. 15-5A is not troubled with this condition because with a loss of rf drive a high "limiting" class-C bias is maintained by a battery.

The limiting bias problem is solved in the grid-leak power amplifier of Fig. 15-6A by the use of a cathode resistor (R_k). Insofar as the normal operation of the stage is concerned, the low ohmic value of resistor R_k is such that it does not influence efficiency and stage operation. However, if the rf drive voltage is lost, there will be a tendency to increase the steady-state tube current. This current rise in the cathode resistor will develop a higher negative bias and will restrain a further increase in the steady-state tube current to a safe value. In effect, the cathode resistor develops a safety bias when the rf drive signal is lost.

Another technique often used is to use a combination of grid-leak (self-bias) and external bias. In this case the class-C bias is a summation of that developed in the grid-leak circuit and the external bias supply. With a loss of the rf drive, the grid-leak bias fails. However, the remaining external bias prevents damaging tube current.

Although not asked for specifically in the FCC study guide question, the component functions of the preceding power amplifier stages will be presented. This knowledge will improve your comprehension of the operation of a class-C amplifier and will be helpful in seeking the answers to some of the Study Guide questions in this chapter and in the following chapters.

Capacitors

C_g—Self-bias capacitor for the grid-leak combination. A peak charge is placed on this capacitor by the grid current drawn at the peak of the positive alternation of the rf drive voltage.

C_p—Supply-voltage filter capacitor. It keeps the rf energy out of the supply voltage lines.

C_{sg}—An rf filter capacitor that keeps the screen-grid voltage constant despite any variation in the screen-grid current.

C_b—A blocking capacitor that keeps the high dc plate voltage out of the resonant tank circuit and antenna system.

Resistors

R_g—The resistor of the grid-leak combination. The discharge of the voltage on capacitor C_g through resistor R_g maintains the class-C bias during the interval between grid-current bursts. The time constant of R_gC_g is long in comparison with the period of the input rf wave. Bias is a dc voltage and requires the joint influence of capacitance and resistance if a steady voltage is to develop.

R_k—A cathode-bias resistor. With the loss of rf excitation the attempted rise in tube current develops a bias across this cathode resistor. This is a safety bias which prevents excessive tube current.

R_{sg}—The screen-voltage dropping resistor. It decreases the supply voltage to the level of dc voltage needed at the screen grid of the tube.

L_r—This component is a resistor on which has been wound several turns of wire. It serves as a parasitic choke and prevents the development of parasitic oscillations. Such oscillations occur outside of the normal frequency range of operation of the stage and cause instability and loss of efficiency.

Pi-Network

Capacitors C3 and C4 plus inductor L3 form the resonant tank circuit for the output of the class-C power amplifier. The pi-network is perhaps the most popular type of resonant circuit because it is capable of serving other functions in addition to that of a resonant load for the amplifier. In addition to providing the proper "Q" and the correct frequency of operation for the stage, the pi-network is also an impedance-matching circuit. It reflects an optimum high impedance to the plate circuit of the tube from the low impedance load to which it delivers rf energy. Thus in most cases the capacitance of C3 is substantially lower than the capacitance of C4. Stated another way, it has a high input impedance (plate side of the pi-network) and a low output impedance (load side.) Off the resonant frequency, a pi-network operates as a low-pass filter. In so doing harmonics of the output wave are suppressed. The network is designed to pass frequencies only up to the fundamental operating frequency of the stage. Higher frequencies, including the harmonic frequencies, are attenuated.

(c) An *rf power amplifier with two tetrode tubes in parallel* is shown in Fig. 15-7. For a given rf drive voltage class-C grid bias, and plate and screen-grid supply voltages, approximately twice as much rf power output can be developed with this circuit. Except for the parallel connection, the stage operates in exactly the same manner as the previous example. Separate parasitic chokes are used for each tube. In suppressing parasitics it is important that the parasitic chokes be placed as near as possible to the electrodes of the individual tubes. This could not be done as readily if only one set of parasitic chokes were used for both tubes. The parallel connection of tubes is quite popular in rf power amplifiers—some few transmitters use as many as five or more tubes connected in parallel. However, such multiple-tube parallel connections are not as common in modern day transmitters as in older broadcast and commercial two-way radio transmitters. The extra rf output of Fig. 15-7 is the result of the approximate doubling of the peak plate current to develop more rf energy in the tank circuit. Of course, the tank-circuit component values of the parallel class-C rf amplifier (Fig. 15-7) differ from the single stage of Fig. 15-6A because of the reduction of the optimum impedance that must be seen by the two parallel connected tubes.

Grid rf driving power and dc plate input power are approximately doubled. The dc plate and screen-grid currents are approximately doubled, control-grid current is also doubled, and the R_gC_g values must be changed to obtain the necessary class-C bias. Likewise the ohmic value of the safety bias resistor R_k must be changed since the current

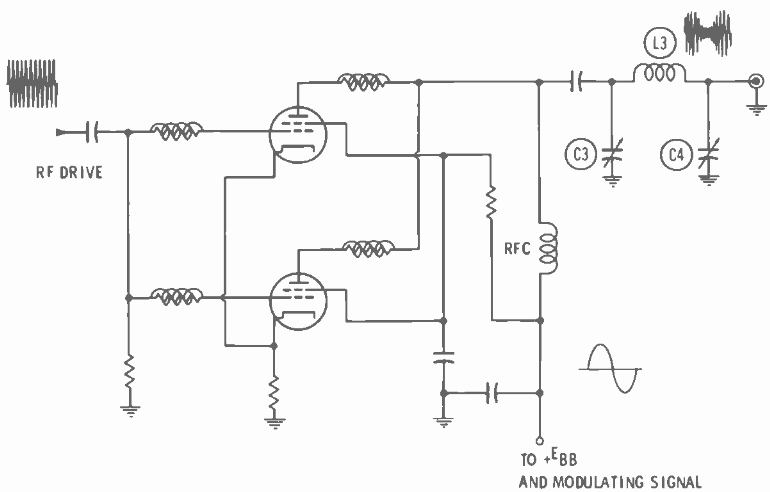


Fig. 15-7. An rf power amplifier with two tetrode tubes in parallel.

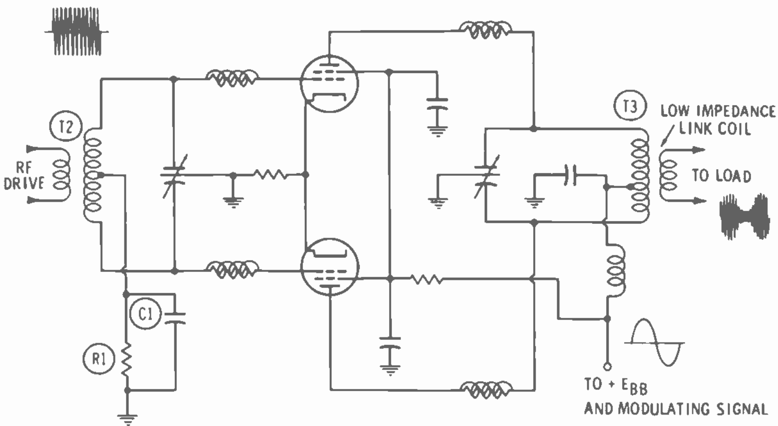


Fig. 15-8. An rf power amplifier with two tetrode tubes in push-pull.

which flows through the resistor has been approximately doubled.

(d) An *rf power amplifier with two tetrode tubes in push-pull* is shown in Fig. 15-8. A push-pull amplifier using two tubes is capable of developing an rf power output that is two or more times higher than that which can be obtained from a single tube. Also, the push-pull power amplifier has an advantage over the parallel connection because it has a low even-harmonic output. This means that the troublesome second harmonic is less than that obtained when the same two tubes are connected in parallel. The grids of the push-pull stage are connected to opposite ends of the grid-tank circuit so that rf drive voltages to the grids are of equal amplitude and opposite polarity. The push-pull stage can be self-biased by connecting a grid-leak network between the center tap of the input coil and ground. Resistor R1 has a resistance value which is one-half of the value for a single tube for a given bias, because the grid current from both tubes is present. A push-pull amplifier can also be supplied with external grid bias. The cathode resistor is also one-half of the value required for a single-tube since both tube plate currents are present in this resistor.

The plates are connected to opposite ends of the output tank circuit, and the plate supply voltage is applied at the center tap of this tank coil. Both ends of the input and output tank coils are at a high rf potential (are said to be "hot") and the center taps of these coils are at rf ground potential.

Efficient operation, minimum trouble with self-oscillation, and good even harmonic suppression are accomplished with the use of balanced or split-stator input and output tank-circuit capacitors. Such capacitors have two sets of stator plates (one set insulated from the other) and a single rotor which is operated at ground potential.

The circuit of Fig. 15-8 shows that the load (antenna) is supplied with signal via the low-impedance link coil. Notice that the link is positioned near the center or ground point of the tank coil.

The push-pull tubes of Fig. 15-8 conduct plate current on opposite alternations of the input wave. Since each alternation of the input wave results in a burst of plate current, a burst of energy is delivered to the plate tank coil for each alternation of the input signal wave. For the same operating conditions, this means that two or more times the rf output voltage is developed across the push-pull tank, as compared with the single-ended tank. In terms of the fundamental frequency the top of the output tank coil is swinging negative when the bottom of the coil is swinging positive, and vice versa. However, in terms of any even harmonic components the two ends vary in phase, and the net even-harmonic rf output is zero.

(e) A *plate-neutralized triode rf amplifier* and its equivalent circuit are shown in Fig. 15-9. Except for the neutralization function, the operation of the triode rf amplifier is similar to the pentode rf power amplifier in Fig. 15-6. The triode rf amplifier is self-biased with grid-leak combination R_gC_g to operate as a class-C amplifier so that its rf plate tank circuit is shock-excited by bursts of plate current.

One of the problems of a triode rf stage, when compared to multigrid tubes, is the fact that a rather low-impedance positive-feedback path exists between the plate and grid via the high interelectrode capacitance (C_{gp}). A triode rf stage with input and output resonant circuits will break into self-oscillation in the mode of a tuned-grid, tuned-plate, self-excited oscillator.

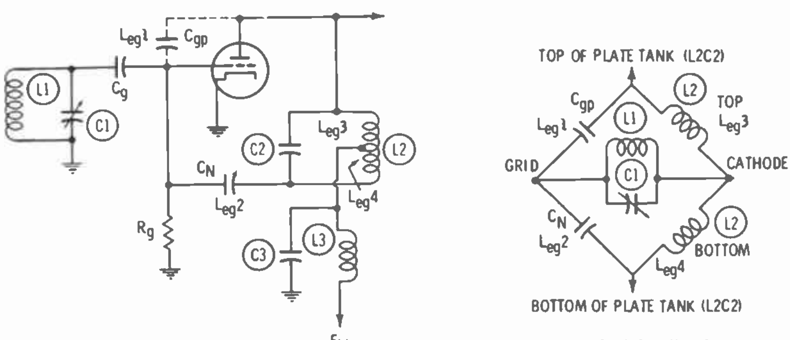
To avoid the possibility of oscillation, a portion of the rf output in the plate circuit is fed back to the input circuit. This feedback has a polarity that is 180° out of phase with the rf component fed back through the plate-to-grid interelectrode capacitance of the tube. The amplitude of this negative feedback is adjusted to obtain exact cancellation of the positive feedback across C_{gp}. In other words, equal negative and positive feedback produces a net feedback of zero and thus removes the tendency of the rf triode amplifier to oscillate.

The negative feedback in a plate-neutralized triode is obtained from the lower end of the tank (opposite from the plate end of the tank) as in Fig. 15-9. The rf ground for the plate tank is a tap located above the bottom end of L2. The phase of the ac voltage between the bottom of the tank coil and ground is opposite to the ac voltage between the plate side of the tank and ground. The voltage at lower end of tank is then fed back through a neutralization capacitor to the grid of the amplifier. The neutralization capacitor can be adjusted to obtain the exact amplitude of inverse or negative feedback needed to cancel the positive feedback at the grid from the plate-to-grid interelectrode capacitance of the tube.

In effect, this operation is comparable to that of a balanced bridge as shown in Fig. 15-9. The plate is connected to the grid via the grid-to-plate capacitance of the tube—this forms leg 1 of the bridge. The bottom of the output tank coil is connected to the same grid via capacitor C_N to form leg 2. The upper half of L2 (above rf ground) is leg 3, and the lower half of L2 is leg 4. When the voltage across C_N (leg 2) equals the voltage across C_{gp} (leg 1), the bridge voltages at grid junction of legs 1-2 and at the junction of legs 3-4 are the same, the positive feedback (of C_{gp}) is cancelled by the negative feedback.

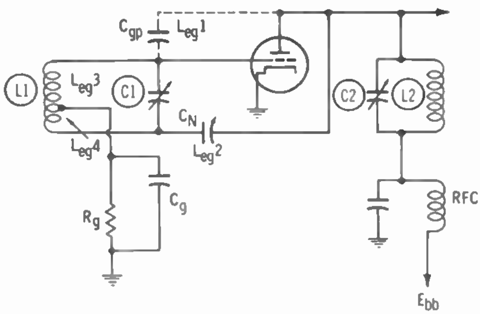
(*f*) *A grid-neutralized triode rf amplifier* with its simplified bridge schematic is shown in Fig. 15-10. Since Study Guide questions (e) and (f) only require the schematics of the rf amplifiers, it is not necessary that you learn the simplified bridge circuit. It is offered here as an explanation of the circuit. In the grid-neutralized system the positive and negative feedback voltages are developed at the grid tank circuit rather than at the plate tank circuit. Otherwise the operation of the grid neutralized triode rf amplifier is similar to the plate-neutralized triode with grid-leak bias.

The tap on coil L1 of the grid tank (Fig. 15-10A) is at rf ground potential. Positive-feedback voltage is developed at the grid, by way of the interelectrode plate-to-grid capacitance. An rf component is also removed from the plate and fed through neutralizing capacitor C_N to the bottom of the grid tank circuit. With

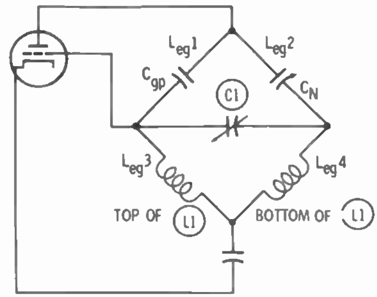


(A) Schematic. (B) Simplified feedback circuit.

Fig. 15-9. A plate-neutralized triode rf amplifier and equivalent feedback circuit.



(A) Schematic.



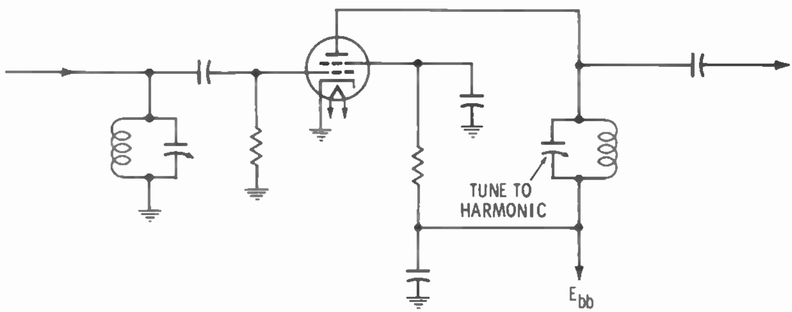
(B) Simplified feedback circuit.

Fig. 15-10. A grid-neutralized triode rf amplifier and equivalent feedback circuit.

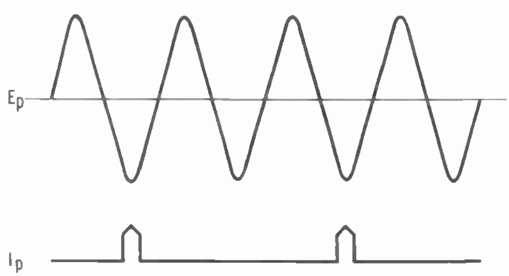
proper choice of C_N reactance, this negative feedback voltage can be made to have the same amplitude as the positive feedback voltage fed through C_{gp}. The net feedback voltage across the grid tank coil will be zero, and the tendency of self oscillation is removed.

The simplified bridge schematic shows the two paths (legs 1-3 and legs 2-4) from the plate to the center tap of the grid tank coil. With the voltages balanced on the legs by the use of the neutralizing capacitor C_N, the net feedback voltage between the top and the bottom of the grid-tank coil is zero.

(g) A *triode frequency-doubler stage* (Fig. 15-11) has the appearance of a conventional class-C rf amplifier. However, it differs in that the plate tank circuit is tuned to the second harmonic of the input rf wave. The input tank circuit, if used, is tuned to the fundamen-



(A) Schematic.



(B) Waveforms.

Fig. 15-11. A triode frequency-doubler stage.

tal frequency of the input wave. Inasmuch as input and output resonant tanks are not tuned to the same frequency, there is little danger of self-oscillation, and neutralization is not required. A frequency multiplier, even though it is a triode, must not be neutralized.

A frequency-doubler stage is also operated class-C. Quite often when there is adequate rf drive available, the doubler stage is operated even further beyond cutoff than is a conventional fundamental-frequency class-C amplifier, and a more pulselike burst of plate current, which is strong in harmonic components, can be drawn. The operation of the frequency doubler is optimized for generating a second-harmonic output component with the proper choice of rf drive amplitude, the proper choice of class-C bias, the angles of grid and plate currents, and the characteristics of the output tank circuit.

The peak of the positive alternation of the input wave draws a burst of plate current that shock-excites the plate tank circuit. However, the resonant frequency of the plate tank circuit is twice the frequency of the input wave, and the rf voltage variation across the tank circuit occurs at the second-harmonic frequency. The constants of the tank circuit are such that two complete cycles are generated. With low tank-circuit losses, the second cycle of oscillation is essentially at the same amplitude as the first cycle. At the conclusion of the second cycle, the input wave will have risen to the positive peak of its next cycle. Therefore a new burst of plate current will be drawn into the tank circuit, and two more cycles will be generated.

The waveforms that accompany Fig. 15-11 show the timing relationship between the burst of plate current and the second-harmonic output wave. Inasmuch as energy is delivered into the plate tank circuit by every other cycle of the output wave, the efficiency of a doubler stage is less than that of a comparable stage being operated as a fundamental-frequency amplifier. However, this is compensated for to a degree with the choice of rf drive, bias, and angle of plate current.

(h) A *push-push frequency-doubler stage* is shown in Fig. 15-12. In the dis-

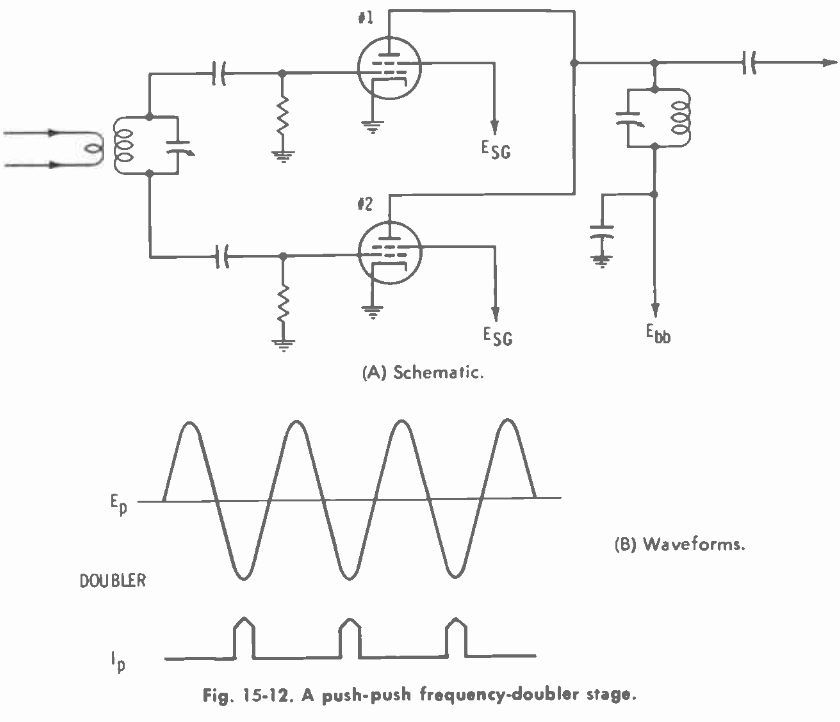


Fig. 15-12. A push-push frequency-doubler stage.

cussion on push-pull power amplifiers a push-pull amplifier was shown to have low even-harmonic output, and consequently the push-pull stage is not a good frequency doubler. However, two tubes can be connected into a very efficient frequency doubler by connecting the grids in push-pull and the plates in parallel. This is referred to as a "push-push" circuit.

In the push-pull stage, the second-harmonic components are in phase at opposite ends of the output tank circuit, and they cancel. However, in the push-push connection, the two plates are connected in parallel, and therefore the second-harmonic components become additive and appear in phase across the output tank circuit.

In the discussion associated with Fig. 15-11, we covered the fact that with a conventional single tube doubler there was a burst of current only during alternate sine waves—this lowers the efficiency. However, in the push-push arrangement (Fig. 15-12) this is not so. During the peak of the positive alternation, tube 1 conducts and draws a burst of current into the plate tank circuit. During the negative alternation of the input wave, tube 2 conducts because its grid is made positive with respect to its cathode. As a result another burst of the plate current is drawn into the tank circuit. Thus, each alternation of the grid signal (two per cycle) results in a plate current burst. Inasmuch as the plate tank circuit is oscillating at twice the frequency of the incoming signal, plate current is drawn into the tank circuit once during each harmonic cycle. Therefore, in the push-push arrangement, a plate-current burst coincides with each negative peak of the rf output, increasing the output and efficiency. Waveforms again demonstrate the operation of the circuit.

(i) A *grounded-grid rf amplifier* is shown in Fig. 15-13. In a grounded-grid amplifier, the rf drive signal is applied between cathode (which is the filament in Fig. 15-13) and ground. Suitable choke and filtering arrangements must be included to permit the application of filament power without placing a short on the incoming rf drive signal. The grid is maintained at rf ground potential by C10. The amplified rf output is developed in the plate circuit in conventional manner.

A grounded-grid rf amplifier operates as a class-C amplifier, and the plate current occurs in bursts that coincide with the most negative portion of the input wave at the cathode. (This is the same as applying a positive alternation to the control grid.) A burst of plate current shock-excites the plate tank circuit just as in the amplifiers described previously. A grounded-grid stage requires no neutralization because the control grid is operated at rf ground potential and acts as a shield between input and output circuits. Consequently

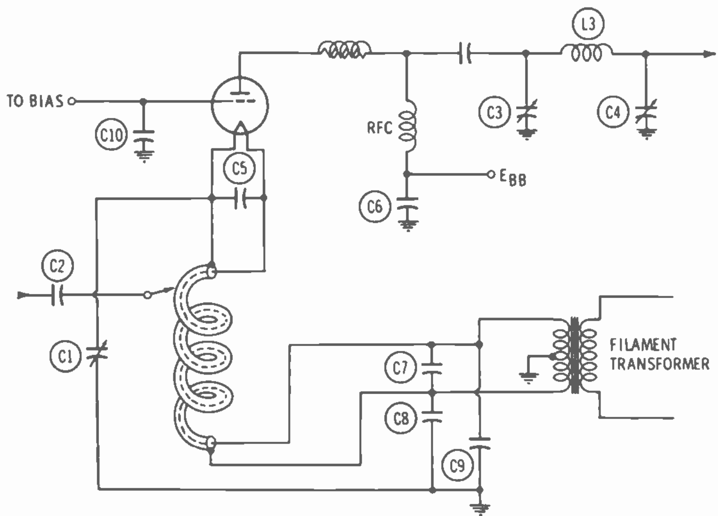


Fig. 15-13. A grounded-grid rf amplifier.

there is no positive feedback from the plate circuit to the input circuit, and there is no tendency to self-oscillation.

It should be noted that in a grounded-grid stage both the input and output rf energies are developed across the plate-cathode circuit. Consequently the total rf power output is the sum of the rf energy developed by the grounded-grid tube, plus the smaller amount of rf energy supplied from the preceding stage. The input impedance to the grounded-grid stage is low, and this fact must be considered in planning the preceding stage or source of the rf drive voltage.

7. Why are tubes used in linear rf amplifiers not normally biased class-A?—Class-AB or class-B operation is preferred, as compared to class-A, because such stages have a higher efficiency and permit a greater rf power output for given dc input and rf driving powers. Many linear rf amplifiers use two tubes in push-pull in a manner similar to class-AB and class-B audio power amplifiers except that resonant circuits are employed instead of audio transformers. However, the energy-storing ability of a resonant tank permits single-tube class-AB and class-B linear rf amplifier operation. The single tube or "single-ended" class-AB linear rf amplifier is very common.

8. In relation to the safety of the radio operator, explain the function of (a) interlocks, (b) circuit breakers, and (c) bleeder resistors.

(a) *Interlock safety switches* are associated with transmitter doors, high-voltage cages, and other hazardous locations. When the door is opened to gain access to circuits that operate at high voltage, the opening of the door turns off the ac power to the high-voltage supplies. Thus the radio operator cannot come in contact with dangerous voltages if he forgets to turn off the high-voltage power supplies before he opens a door or cage.

(b) Various *circuit breakers* are used at strategic points in the power and operating circuits of transmitters. When excessive loads or short circuits are placed on critical stages the excessive current drawn causes the circuit breaker to open the primary ac power lines or high-voltage lines in order to protect the radio operator and/or costly broadcast equipment. By using circuit breakers, the radio operator can switch high voltages on and off without having to come in close proximity to the high-voltage and high-power circuits. Many circuit breakers are designed to respond to a light touch so that high-voltage circuits can be opened quickly in an emergency.

(c) *Bleeder resistors* are connected across important high-voltage and high-power dc supplies to drain off the charge in their filter capacitors. Often high-value filter capacitors are used in the power supplies, and in normal operation these capacitors are charged to a high voltage. When power is removed, the high-voltage charges would remain on the capacitors for a long time and present a shock hazard if they were not drained off by bleeder resistors.

9. Explain the operation of the following relays: (a) overload, (b) time delay, (c) recycle.

(a) The *overload relay* is usually a protective device to prevent damage to electronic equipment from excessive load current. When critical circuits draw a current in excess of an established maximum safe current, the overload relay is energized and opens key power circuits to prevent damage to equipment. Overload relays can be designed to respond quickly to an excessive current demand, while other relays will not respond to a brief transient overload condition but will respond if the overload condition persists for an established interval of time.

(b) A *time-delay relay* is one that does not function until a specific interval of time has elapsed after the relay has been activated. Some time-delay relays will not energize until adequate current has built up for the normal operation of some other transmitter circuit. For example, there is a time delay between the application of filament voltage to a mercury vapor rectifier and the application of high voltage to the plates of the rectifier. This permits the rectifier filament to come up to operating temperature before the high voltage is applied.

(c) A *recycling relay* is one that responds to a temporary overload. It shuts down critical stages for a short interval of time and then turns them back on automatically. If the overload persists it will turn off the critical stages again for a short interval and then recycle them back on. However if the overload persists such a recycling relav will eventually shut down the critical stages permanently until the source of the overload has been removed. Such recycling devices protect the transmitter from brief temporary overloads and quickly restore normal operating conditions after a momentary overload. However, if the overload is of a permanent nature it will shut down key circuits permanently.

10. Explain the method of cleaning relay contacts. Why is it necessary that the original contact shape be maintained?—Although contacts should be kept clean, they should not be misshaped by incorrect burnishing. If the contacts are misshaped, they will not make a firm full-area contact. This will increase the resistance between the contacts and limit its current-carrying capability. The resistance will also introduce heating which will cause further pitting and deterioration of the contacts. A variety of good contact cleaners and burnishing tools are available for cleaning relay contacts in accordance with an established maintenance schedule or when the contacts are damaged by excessive current. Burnishing of contacts should be done carefully and undue pressures should not be applied so as not to disturb the normal spacing and pressures of the contacts. Abrasive cleaners and tools should be avoided.

15-2. MODULATION AND MODULATORS

11. Draw circuit diagrams of (a) triode class-C amplifier properly coupled to a push-pull power amplifier (modulator) and (b) a beam-power tube class-C amplifier coupled to a push-pull class-B power amplifier. For both cases show the modulating signal input, the rf exciting-voltage input, and the modulated output. Include neutralization for the triode case. Explain the operation of both the above types of class-C plate-modulated amplifiers.

(a) A *triode class-C amplifier and push-pull modulator* is shown in Fig. 15-14. These are typical circuits for the modulated amplifier and the modulator in the block diagram of Fig. 15-1. Two signals are applied to the modulated amplifier—an unmodulated rf wave and the modulating audio wave.

The modulated amplifier is basically a class-C amplifier which, in the example of Fig. 15-14, is signal-biased by the incoming rf drive signal. Inasmuch as a triode is employed, the stage must be neutralized. In this case the triode is grid-neutralized. The operation of such a circuit was discussed in question 6(b) and 6(f). A conventional parallel-resonant input tank circuit and a pi-network plate output tank circuit are used.

The modulated class-C amplifier differs from the regular class-C amplifier (one that amplifies an unmodulated rf wave) in that one of its electrode voltages is varied at an audio rate. In Fig. 15-14 it is the plate supply voltage that is varied by the modulating wave. Thus the modulated amplifier is said to be plate modulated or that plate modulation is being used.

Notice that the dc supply voltage for the modulated amplifier is supplied via the secondary of the audio output transformer (usually referred to as a modulation transformer). The modulator, (Fig. 15-14) is fundamentally a push-pull audio-output stage, operating as either a class-A or class-AB_1 push-pull audio amplifier. The preceding stages would be audio voltage amplifiers that build up the audio signal to the level needed to drive the push-pull amplifier.

It is apparent that an ac voltage variation across the secondary of the modulation transformer will cause a like change in the supply voltage to the modulated amplifier. The power output and rf voltage developed across the plate tank circuit of the modulated amplifier depends on the peak plate current and, in turn, the peak plate current is set by the dc plate supply voltage. In fact, over a substantial operating range the rf voltage across the plate tank circuit increases linearity with the plate supply voltage. Therefore the rf voltage developed across the plate tank circuit will increase or decrease linearly with the modulating wave that is varying the plate voltage of the modulated amplifier.

Let us assume that the dc supply voltage for the modulated amplifier is 500 volts and that the peak amplitude of the modulating sine wave developed across the secondary of the modulation transformer is also 500 volts peak. This would mean that the actual supply voltage to the modulated amplifier would vary between 0 and 1000 volts. In the case of the sine-wave modulating wave the average plate-supply voltage remains fixed at 500 volts because there are identical ac variations on each side of the 500-volt dc value (zero axis of ac wave), in Fig. 15-15A.

What will be the influence of the plate voltage change on the modulated amplifier? As you learned in discussing the operation of class-C amplifiers in question 6, the plate voltage determines the peak plate current. Thus as the plate voltage changes so will the peak plate

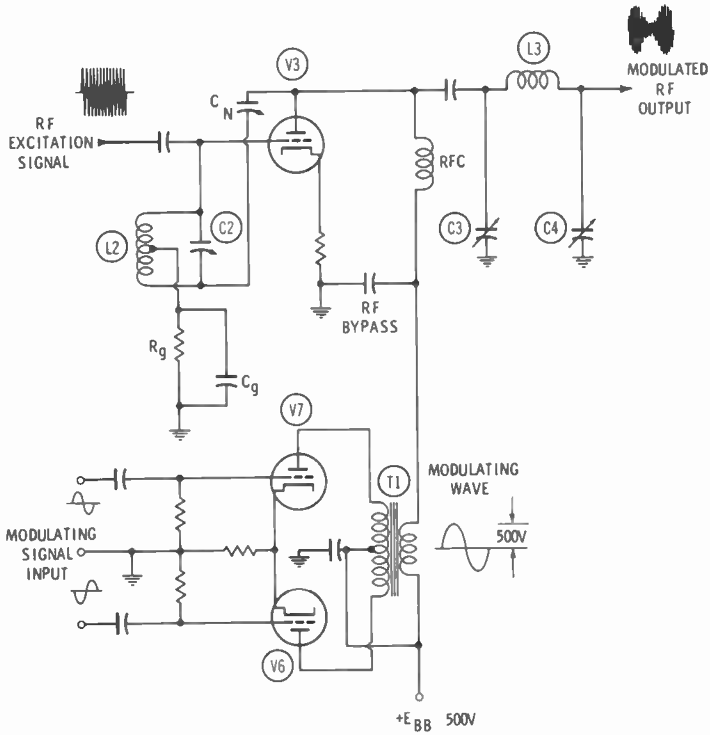
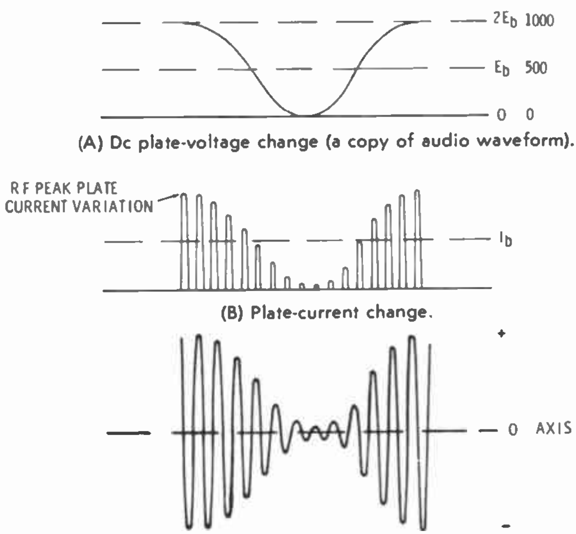


Fig. 15-14. A triode class-C amplifier coupled to a push-pull modulator.



(A) Dc plate-voltage change (a copy of audio waveform).

(B) Plate-current change.

(C) Plate tank-voltage change.

Fig. 15-15. Plate-modulation waveforms.

current. In fact the peak plate-current variation will be a copy of the modulating wave, as shown in Fig. 15-15B. The peak plate current, in turn, determines the magnitude of the rf voltage developed across the plate tank circuit. The higher the peak current, the higher the rf voltage. It follows then that the rf plate-voltage variation will also be a copy of the modulating wave.

Note in Fig. 15-15B that when the plate voltage drops to its lowest value, the peak plate current is minimum as is the rf cycle across the plate tank coil (Fig. 15-15C). During the crest of the positive alternation of the modulating wave, the plate supply voltage rises to a maximum. Consequently, maximum peak plate current is drawn and the peak amplitude of the rf voltage across the tank circuit is also maximum.

The so-called rf modulation envelope is formed in the foregoing manner. Note that the variations of the modulation envelope on both sides of the zero axis conform to the shape of the modulating wave. Just how fully or deeply the envelope is modulated depends upon the amplitude of the modulating wave. The rate at which the envelope varies depends upon the frequency of the modulating wave.

(b) A *beam-power pentode and class-B modulator* are shown schematically in Fig. 15-16. The fundamental operation of the modulated amplifier and modulator are the same as given in part (a). The audio voltage developed across the secondary of the modulation transformer varies the plate and screen-grid supply voltage of the beam-power modulated amplifier. In so doing there is a like change in the peak rf plate current and magnitude of the cycles of the rf voltage developed across the tank circuit of the modulated amplifier. Once again an rf modulation envelope is developed. The variations in the amplitude of this envelope correspond to the modulating wave.

In the case of the beam-power tube there is no necessity for neutralization.

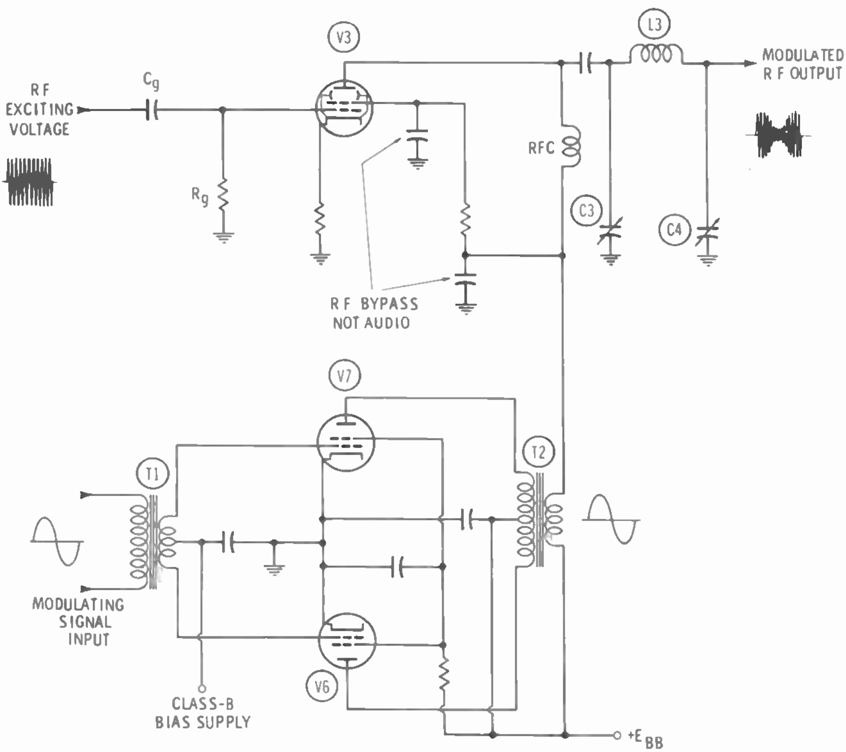


Fig. 15-16. A beam tube class-C amplifier coupled to a class-B push-pull modulator.

In this respect the modulated amplifier differs from the previous triode stage. Also the modulating wave is not only applied to the plate but to the screen grid as well. This is the preferred method of modulating a beam-power tube and it permits the attainment of a more linear modulation characteristic. By this is meant that the change in the amplitude of the rf cycles developed across the tank coil follows exactly the variations of the modulating wave. Even though there is some modulation of the screen grid this type of modulation is fundamentally plate modulation. There is also a form of modulation called screen-grid modulation. In this type of modulation it is only the screen-grid voltage that is modulated by the audio wave; the plate voltage is not modulated and remains constant during the modulating cycle.

Many high-power transmitters use beam-tube modulated amplifiers. They require less rf driving power. The higher the operating power of the modulated amplifier, of course, the higher the required audio power from the modulator. Thus in high-power transmitters it is customary to use class-AB_2 or class-B modulators. The schematic in Fig. 15-16 does not differ greatly from the one in Fig. 15-14. They are both push-pull modulators. However, the modulator of Fig. 15-14 can only be operated class-A or class-AB_1 because of the RC coupled input. A class-AB_2 or class-B modulator draws some grid current. Therefore a certain amount of audio power must be supplied by the driver. Consequently, in the circuit of Fig. 15-16, there is an audio input transformer that provides the optimum method of transferring a certain amount of driving power from the driver stage to the class-B modulator. The bias supplied to the grid circuit must of course be the value required to establish class-B operation.

12. In amplitude modulation, what is the relationship between sideband power, output carrier power, and percent modulation? Give an example of a problem to determine sideband power if other necessary information is given.—In an amplitude-modulation system, an increase in the percentage of modulation of the carrier will increase the total percentage of the rf power output that is vested in the sidebands. Since the actual rf carrier power is a constant in an a-m modulation system, the presence of modulating power contributes to the total rf power output by adding sideband power. For 100-percent sine-wave modulation, one-third of the total power output is vested in the sidebands (one-sixth of the total power in each sideband), while two-thirds of the total power output is vested in the carrier. With a lower percentage of modulation, there is less power in the sidebands, less total rf power output but the same carrier power output. The relationship is given in the following simple equation:

$$P_{SB} = \frac{M^2}{2} P_c$$

where,

P_{SB} is the sideband power,
M is the modulation factor,
P_c is the carrier power.

To determine the sideband power when a transmitter with a carrier output of 600 watts is modulated 50%, the calculation is as follows:

$$P_{SB} = \frac{(0.5)^2}{2} \times 600 = 75 \text{ watts}$$

13. Cathode-ray oscilloscopes are frequently used to register percentage modulation. Sketch the visual displays of (a) 0% modulation, (b) 50% modulation, (c) 100% modulation and (d) 120% modulation.—Waveform and trapezoidal patterns for the 0%, 50%, 100% and 120% modulated rf carrier are shown in Fig. 15-17

14. What is carrier shift? How is it measured? Show by a simple diagram one method of measuring carrier shift.—When an a-m transmitter is properly tuned and is modulated, the plate current (I_b) of the modulated amplifier as read on the dc plate-current meter should remain constant and should not change with modulation. If there is a change in the plate current meter reading with modulation, the plate-current reading change is referred to as "carrier shift." An upward deflection of the meter reading is called positive carrier shift; a downward deflection, a negative carrier shift.

Negative carrier shift causes a flattening of the positive crest of the modulation envelope. Negative carrier shift can be caused by a variety of faults such as inadequate rf drive to the modulated stage, improper transmitter tuning, poor power-supply regulation, nonsymmetrical modulating waveform, etc. Positive carrier shift causes a flattening of the trough of the modulation envelope. Positive carrier shift is most often caused by overmodulation or improper neutralization.

Carrier shift can be measured in percent change of the plate-current reading with modulation. By FCC regulation, it should be no more than 5 percent at full modulation.

When carrier shift occurs, there is a change in the magnitude of the carrier components with modulation. Any such change can be indicated by the simple arrangement of Fig. 15-18. A portion of the modulated rf carrier signal is applied to the linear carrier detector. The dc or average value of the current in such a circuit is a measure of the carrier amplitude. When the modulation is symmetrical the carrier amplitude is unchanged (assuming the transmitter is tuned and adjusted properly) and no carrier shift is indicated on the meter. An upward meter deflection with modulation indicates *positive carrier shift* and a downward meter deflection indicates *negative carrier shift*.

15. Why is plate modulation more desirable than grid modulation for use in standard broadcast transmitters?

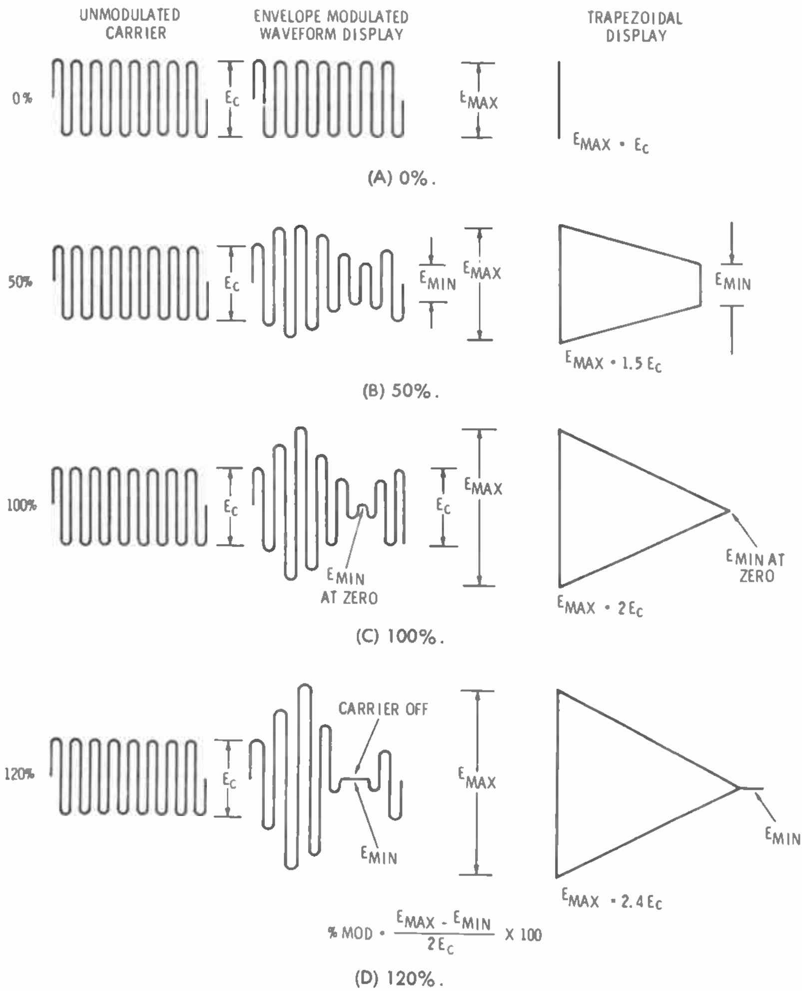


Fig. 15-17. Envelope and trapezoidal oscilloscope displays.

Why is grid modulation desirable in television video transmitters? – The main function of a standard broadcast transmitter is the linear modulation of an rf carrier by an audio signal. Plate modulation provides the most linear and least troublesome form of modulation. Inasmuch as the modulating waves are of low frequency, audio transformers can be used in the driver stages and for the modulation transformer. Transformers can be manufactured to handle considerable audio power and serve as ideal impedance-matching devices.

The composite television signal is a nonsymmetrical waveform and one is concerned mostly with the linearity of the modulation in the segment of the total waveform that carries the video information. In a grid-modulation system this portion of the total waveform can be confined to a region that provides linear modulation. Blanking and sync tips represent fixed voltage levels which can be established at proper relative levels with clamping circuits that operate in conjunction with the grid-modulation process. The video signal also contains very high frequency components, and conventional iron-core transformers can not be employed. The difficulty of building up the voltage and power level of a video signal and in providing a proper impedance match are both difficult and costly. Better performance and fewer troubles are encountered using the grid-modulation process because considerably less modulating power is needed.

16. What are limiting amplifiers? Why are they used in broadcast stations? Where are they normally placed in the program circuit?—Limiting amplifiers permit a broadcast station to use a higher average level of modulation. In so doing the reliable range of transmission can be extended and the performance of the system in the presence of noise and interference can be improved because of the higher level of demodulated signal recovered at the receiver. A limiting amplifier does this by controlling the signal-level range between the lowest-amplitude and the highest-amplitude modulating components. In effect, a limiting amplifier reduces the dynamic range of the transmission without introducing distortion. Therefore, the strongest audio passage does not overmodulate the transmitter, while the weakest audio passage does not reduce the average modulation level to a point where it would become ineffective.

Although the limiter amplifier is particularly advantageous in the transmission of speech, the limiter reduces the dynamic range of high quality musical program material. Most limiting amplifiers include facilities that permit an increase in the dynamic range of transmission when high quality music programs are to be broadcast. Such limiting amplifiers are usually inserted in the audio line ahead of the audio input terminals of the a-m transmitter.

17. What are the uses of peak-limiting amplifiers?—The peak-limiting amplifier, which is similar to the conventional limiting amplifier used in broadcasting, is an amplifier that is most often employed to prevent high-amplitude audio peaks from overmodulating the transmitter. A peak limiter may be used to prevent very high level, fast, transient peaks, which may get by the conventional limiting amplifier, from overmodulating the transmitter.

Some less elaborate peak-limiting amplifiers clip off the very high amplitude audio peaks. However, in the clipping process, harmonic distortion components are introduced. These can be removed with a follow-up low-pass filter. This technique is used widely for voice communication systems which have a confined audio frequency response and appropriate low-pass filters that remove the clipping distortion components. This form of limiter also permits a higher average level of modulation and transmitted range and, at the same time, it does not permit speech peaks to overmodulate the transmitter. Peak limiters of this type are not popular in broadcasting because of the distortion they can introduce.

18. Explain the operation of limiting amplifiers.—A functional plan of a limiting-amplifier is given in Fig. 15-19. Basically it consists of a multiple-stage audio amplifier through which the program signal is conveyed. It includes the necessary circuits for evaluating the

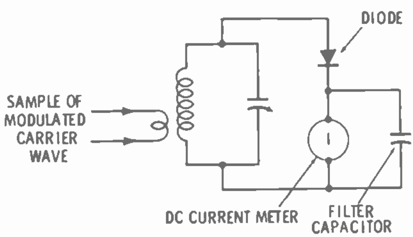


Fig. 15-18. A carrier-shift indicator.

level of the incoming audio signal; usually it can make a separate evaluation of positive and negative amplitude levels because speech and music waveforms are fundamentally nonsymmetrical. Positive and negative audio signal components from the output of the limiter are applied to separate detector circuits. These detector circuits develop a dc output voltage that is a function of the strength of the audio signal passing through the amplifier. This dc component of voltage is then used to bias one of the earlier stages of the limiter amplifier. When a high amplitude passage is going through the amplifier the biasing will increase and the limiter amplifier gain will be reduced just enough to prevent the output signal from overmodulating the transmitter. If the passage through the amplifier is of low level, there is less dc bias developed and the amplifier operates at higher gain. The biasing change that occurs between that for a maximum amplitude signal and that for a usable minimum amplitude signal is such that the net signal output of the amplifier is confined between an established range needed for a reasonably high-average level of transmitter modulation.

It is to be noted that the confining of the dynamic range of the program material is accomplished without peak clipping or the introduction of distortion components. Rather, it is a compression process because it confines the voltage range between signal levels representative of a loud passage and a soft passage.

19. Explain the operation and uses of compression amplifiers.—The fundamental operation of the compression amplifier is the same as that of the limiter amplifier explained in Question 18. Usually the compression amplifier is used in the processing of the program material because the mode of transmission is not able to handle the wide dynamic range of the certain program material. The compression amplifier is used to compress the range of audio levels between the loudest passage and the softest passage of program materials. The weak passages (low-amplitude audio signals) are amplified a certain normal amount by the compression amplifier. When the signal magnitude increases beyond a certain level established by the compression amplifier, the magnitude of the signal is compressed by the automatic decrease in the amplifier gain. Above a certain level of input audio signal (established when 100% modulation of carrier is achieved), all material is reduced to the same output level.

The compression amplifier permits the broadcast station to make more effective use of program material that has a wide dynamic range. A compressor permits a signal to be placed on an audic line (usually a phone line) without exceeding the maximum safe permissible signal level. Too high a signal level on an audio line will cause cross talk (induction of undesired signals into adjacent audio lines).

The compression amplifier fulfills the limited audio range and reliability objectives of a-m broadcasting. In fm broadcasting, particularly in broadcasts of high-fidelity musical programs, the compression of the dynamic range is kept to minimum.

20. What are agc amplifiers and why are they used?—An agc amplifier is one that employs an automatic gain control (agc) facility. These have a variety of uses in a broadcast station. In an agc amplifier the gain of the amplifier is a function of the magnitude of the signal passing through the amplifier. In most applications the agc system lowers the gain of the amplifier in an increasing manner as the strength of the signal rises above a predetermined level It does so by rectifying a bias component that corresponds to the magnitude of the signal. This dc bias component is then used to control the gain of the amplifier.

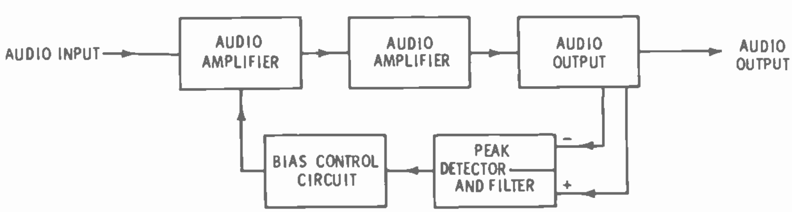


Fig. 15-19. A block diagram of a limiting amplifier.

The various applications of the agc function are in relation to limiter amplifiers, compression amplifiers, constant output amplifiers, and maximum level clamp amplifiers. The fundamental operation of several of these amplifiers was discussed in previous questions. Briefly it can be stated that the limiter amplifier maintains a high average level of modulation at the same time that the very high level passages do not overmodulate the transmitter. The maximum level clamp amplifier is used as a safety unit that can prevent momentary audio peaks from overmodulating the transmitter. This is sometimes a problem in fm broadcasting because of the pre-emphasis given to high-frequency audio peaks. The compression amplifier evaluates the dynamic range of program material and compresses it into a dynamic range that is suitable for broadcast transmission.

The constant-output level amplifier is most often the one referred to as an *agc amplifier*. Such a unit accepts varying input signal levels and holds the output essentially constant. Thus in changing over from one type of program material to another a more constant output level can be maintained. This is important when the program material is to be placed on an audio line with a maximum level restriction. At the same time too low a signal level going into the line makes it vulnerable to the effects of line noises, crosstalk, and other interference.

21. If a standard broadcast station is licensed to operate at a frequency of 1260 kHz, what are the minimum and maximum frequencies at which it may operate and still be within the proper limits established by the Commission's Rules?—The operating frequency must be held within 20 Hz of the assigned 1260-kHz value. Maximum frequency would be 1260.020 kHz, minimum frequency, 1259.980 kHz.

22. Explain the direct and indirect methods of calculating operating power of broadcast station. Give an example of each method.—In the direct method of measuring operating power it is necessary to know the effective antenna resistance (for the operating frequency) at the point where the current is measured. Stated in an equation, it is

$$P_o = (I_a)^2 R_a$$

where,

R_a is the effective antenna resistance,
I_a is the antenna current,
P_o is the operating power of station.

Example—If the antenna resistance of 30 ohms and the antenna current is 6 amperes, what is the operating power?

$$P_o = (6)^2 \times 30 = 180 \text{ watts}$$

In the indirect method of measurement the operating power is determined by using the plate input power of the last radio stage and an FCC-assigned factor, F (based on typical efficiences for various modulation systems). The equation is as follows:

$$P_o = P_{dc\ input} \times F = E_b \times I_b \times F$$

where,

F is the FCC factor (see FCC Sec. 73.52),
E_b is the maximum plate voltage,
I_b is the operating current.

Example—A transmitter with an assigned factor of 0.7 is supplied with a plate voltage of 2000 volts and operates with a total plate current of 750 milliamperes at the last radio stage. Determine the operating power by using the indirect method.

$$P_o = 2000 \times 0.750 \times 0.7$$
$$= 1050 \text{ watts}$$

23. What is a proof-of-performance? How does a proof-of-performance differ from annual equipment-performance measurements required by the Commission's Rules? What must be included in the annual equipment-performance measurements? — Proof-of-performance refers to the station's overall technical performance as related to the technical considerations in the instrument of authorization and the FCC technical standards for the particular class of broadcast station. For example, such a proof-of-performance would include measurements of the radiated field strength and directional radiation pattern of a given broadcast station.

Proof-of-performance tests of a comprehensive and precise nature are made when the station equipment is being installed and prepared for final licensing to make certain it complies with FCC technical standards and rules and regulations.

The annual equipment-performance measurements are less comprehensive than the proof-of-performance. They are largely only the audio and modulation portions of the overall proof-of-performance considerations for a broadcast station.

The annual equipment-performance measurements include a check of frequency response, harmonic content, carrier shift, carrier hum and extraneous noise levels, and any other spurious radiations.

15-3. ANTENNAS AND LINES

24. Show by a circuit diagram two methods of coupling a standard broadcast transmitter output to an antenna. Include a provision for impedance matching, attenuating harmonics and guarding against lightning damage.— The general plan of a broadcast antenna system is shown in Fig. 15-20. The transmitter output must be matched to the transmission line that feeds the signal to the broadcast antenna. The transmitter output system must also include a filter network that attenuates the transmitter harmonics. In some cases these two functions are combined in a single output network. The transmission line terminates in an antenna tuning unit mounted near the base of the antenna. This tuning unit provides optimum matching of the transmission line to the antenna. It also provides a means of tuning out the reactance of the antenna and may also have harmonic suppression capability. It usually includes a metering circuit and facilities for attaching an interconnecting line between the antenna tuning unit and a remote antenna current meter mounted at the transmitter.

Lightning protection is provided by a retarding inductor and a spark gap mounted at the base of the antenna. Lightning sees a low resistance discharge path to ground and a higher impedance looking into the transmitter through the retarding coil.

Two typical circuit arrangements are shown in Fig. 15-21. The output circuit of Fig. 15-21A uses a combination pi- and L- output network. The pi-network serves as the resonant tank circuit and impedance-matching arrangement that matches the transmitter to the transmission line. The L-section aids in impedance matching, tuning out any reactive antenna system component, and provides high harmonic attenuation. It functions as a low-pass filter in conjunction with the output capacitance of the pi-network and the capacitance across the input of the transmission line.

At the antenna end of the transmission line, a matching and tuning arrangement is inserted. This usually is in the form of a T-network. Its function is to provide an impedance match between the low impedance transmission line and the usually higher impedance of the antenna. Most broadcast antennas do not reflect a purely resistive load. Therefore the T-network must also resonate the antenna (tune out its reactance). This is followed by the lightning retard coil.

A push-pull output system is shown in Fig. 15-21B. Energy is transferred to the low-impedance secondary winding of the output tank. A Faraday shield between the two windings provides harmonic and spurious signal rejection. Harmonics are further attenuated by the pi-network positioned in the secondary circuit. This pi-network also provides impedance matching to the low-imped-

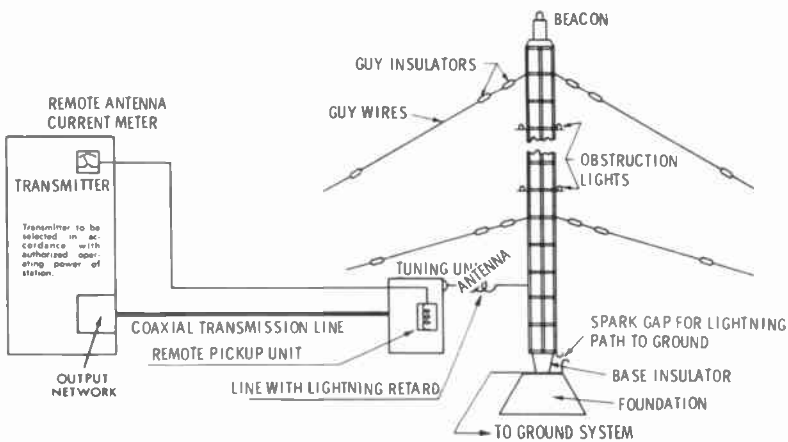


Fig. 15-20. A basic plan for coupling an a-m transmitter to its antennas.

ance transmission line that feeds signal to the antenna tuner and antenna.

25. Explain the method of adjusting a T-network of two tunable coils and a fixed capacitor in order that a standard broadcast station operating on 1340 kilohertz will be properly coupled to its antenna.—Such a T-network is shown in Fig. 15-22A. Proper matching and tuning of the antenna system is a function of the two taps on the inductor and the value of the capacitor.

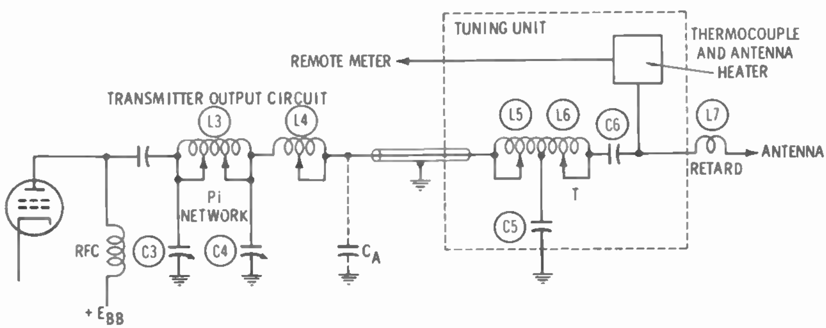
(a) The reactance of C5 at 1340 kHz must be a specific value determined by antenna impedance (measured with impedance bridge) and line impedance. Precise tuning of the network is now done with the inductors L5 and L6.

(b) The impedance bridge is connected across the input of the antenna tuning unit. The tuning procedure now involves making the necessary adjustments to make the input impedance of the tuning unit have a zero reactive component at 1340 kHz and a resistance equal to the characteristic impedance of the transmission line.

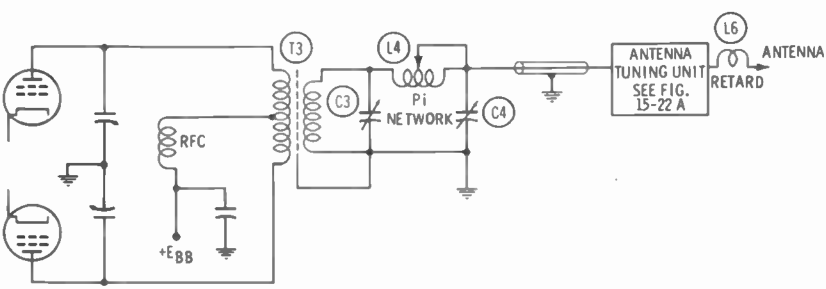
(c) The foregoing is accomplished by adjusting inductor L6 until the resistance at the input of the coupling network equals the characteristic impedance of the line. Now adjust inductor L5 until the input reactance at 1340 kHz falls to zero as recorded by the bridge.

26. Describe how to tune a broadcast antenna by (1) the rf bridge method and (2) the substitution method.—The rf bridge method was covered in the previous question.

In the substitution method, a low-power source of signal at the desired transmit frequency must be made available (generally it can be derived from a low-level rf stage of the transmitter) plus a noninductive resistor with an ohmic value equal to the characteristic impedance of the transmission line. A switching arrangement must be made to change over the signal (1340 kHz in previous example) between the input of the T-network and the substitution resistor. A meter is used to measure the rf current. Proper matching and tuning of

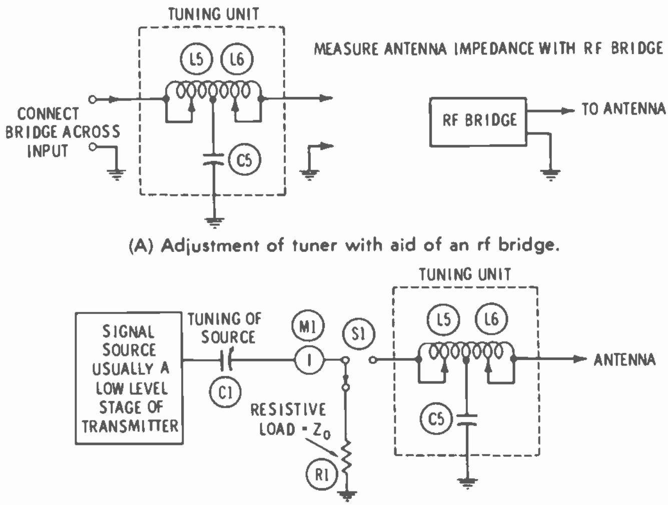


(A) Coupling a single-ended final rf amplifier to an antenna.



(B) Coupling a push-pull rf amplifier to an antenna.

Fig. 15-21. Two methods of coupling an a-m broadcast transmitter output to an antenna.



(B) Substitution method of tuner adjustment.

Fig. 15-22. Two methods of adjusting the antenna tuner (T-network).

the antenna is indicated when it is possible to switch between the two without causing any change in line current.

The capacitor of the coupling network (C1) is first adjusted for maximum meter reading with the substitution resistor in the circuit. This tunes the output circuit to series resonance. Now upon switching over to the input of the T-network it is usually found necessary to retune capacitor C1 to obtain maximum meter reading. This indicates that some reactance is being reflected across the input of the T-network. Suitable adjustment of L5 can then be made until resonance is indicated at the same setting of capacitor C1 when switching between input of the T-network and substitution resistance.

If the resistive component at the input of the network is the same as the ohmic value of the substitution resistor, the absolute value of the current reading at resonance will be the same. If it is not, inductor L6 is adjusted until the meter reads the same current when switching between the input to the T-network and the substitution resistor.

Some jockeying of the adjustments is usually necessary to obtain equal currents for the two positions with the same resonant setting of capacitor C1.

27. Define polarization as it refers to broadcast antennas.—Polarization refers to the direction of the electric vector of the electromagnetic waves (signals) radiated from a broadcast antenna. Horizontally polarized signals have a horizontal electric vector and a vertical magnetic vector. Vertically polarized signals, which are common in radio broadcasting, have a vertical electric vector and a horizontal magnetic vector. The vertical broadcast tower radiates a vertically polarized wave; the tower itself serving as the vertical radiator.

A horizontally polarized wave could be radiated by stretching a length of wire between two vertical towers spaced at the required wave-length. The horizontal wire would be supplied or excited with a signal, producing electromagnetic radiation with horizontal polarization. The supporting vertical towers would not be supplied with rf energy and would be nonradiators.

28. What is the importance of the ground radials associated with standard broadcast antennas? What is likely to be the result of a large number of such radials becoming broken or seriously corroded?—In most a-m broadcast antenna installations, the antenna ground system serves as a mirror reflector for the vertical antenna. The transmission line is connected between the antenna tower base and the ground system. For optimum antenna-radiation performance the ground system should theoretically be a perfect conductor in order to establish the most favorable and constant mirror effect. This ideal antenna system is approached by using many long radials that extend horizontally, like the spokes of a wheel, beneath the tower. Using this method, a more perfect ground—and which is less affected by terrain conditions and changes—is obtained. As a result, the ground losses are minimized, and the antenna characteristics (especially the base impedance, antenna tuning, and radiation pattern characteristics) will remain more nearly constant.

A substantial number of breaks and corrosion in the ground system wiring will influence the efficiency of the ground system and will introduce loss and variables. Consequently, the antenna system characteristics will vary with environmental changes.

29. How does a directional antenna array at an a-m broadcast station reduce radiation in some directions and increase it in other directions?—The directional pattern of a broadcast antenna system is established by two or more vertical radiators positioned so that there is minimum radiation toward the stations with which it must not interfere, and so there is a concentration of radiated energy into its allotted service area. The actual directional pattern is a function of the position, number, and spacing of the vertical radiators of the antenna system, plus the relative phase and magnitude of their antenna currents. The deepness of their nulls (directions of minimum radiation) is determined by the relative magnitudes of the radiator currents.

By controlling the position, number, and spacing of radiators and the relative phase and magnitude of their antenna currents, the radiations from the individual towers in a certain line of direction (compass angle) will cancel to produce minimum field strength. Along another direction line from the antenna system, the radiations from the various towers are essentially additive and maximum signal is sent off in this direction.

30. What factors can cause the directional antenna pattern of an a-m station to change?—The directional pattern depends on the relative antenna currents and their phases. An elaborate directional feed system subdivides the rf energy from the transmitter into the individual currents that feed the directional array. These currents must be of the proper relative magnitude and phase because any change in the amplitude or phase adjustments will cause a change in the directional antenna pattern. Although the spacings among the towers which also influence the pattern are fixed quantities, the presence of other large-area metallic obstacles, deterioration of the ground system, and other terrain variables can influence the directional antenna pattern.

31. What adjustable controls are normally provided at an a-m broadcast station to maintain the directional pattern?—The controls are associated with the two-step process of preparing the transmitter output for proper feeding of the individual towers of a directional antenna system. Controls are included that permit a precise setting of the power division so as to establish precise relative currents. Individual phasing adjustments are also included that establish the precise phase relationships among the individual antenna currents.

32. Define field intensity. Explain how it is measured.—Field intensity refers to the strength of an electromagnetic field at a certain distance from the source of radiation (antenna). It is generally expressed in volts, millivolts, or microvolts per meter. In general, this refers to the voltage that would be induced into an antenna which is one meter in length; this establishes a standard of field-intensity measurement that is independent of frequency. In free space the theoretical field strength of the wave decreases in inverse proportion to the distance. In practice, this relationship varies because of the influence of ground, frequency, and reflections.

More specifically in a-m broadcast practice the effective field intensity is the root-mean-square (rms) value of the inverse-distance (electromagnetic) field at a distance of one mile from the antenna in all directions in the horizontal plane. Field strength is measured by a field-intensity meter that is calibrated to measure field strength in millivolts per meter on the basis of the preceding definition.

Basically, the field-intensity meter consists of a well-shielded receiver that can be tuned precisely to the frequency to be measured. The receiver output supplies signal to an output meter which is calibrated by using a self-contained calibrator consisting of an oscillator with precision output attenuators. By making a comparison between the incoming signal to be measured and the calibration signal of the field-intensity meter, the actual field intensity of the radiated signal can be precisely measured.

33. What type of antenna site is technically best for an a-m broadcast station? For an fm broadcast station? For a vhf television station? For a uhf television station?—The selection of an antenna site for any type of broadcast station is an extremely important consideration. For an a-m broadcast station a site should be selected that is reasonably free of obstructions and will deliver strong signal levels into the populated areas to be served. Quite often a preferred location is a low, flat site in an area of medium to high average terrain height. There should be a minimum of intervening hills between the site and the center of the city or populated area to be served. A site on top of a hill for an a-m broadcast station is often inferior; better ground conditions are usually obtained at a lower site. Clay, marsh, and bog sites usually provide the most favorable ground conditions. Of course the selection of a site also depends on whether an omnidirectional or directional pattern is to be employed.

Fm broadcast and television broadcast antennas provide the greatest coverage when located in positions of high average terrain and high absolute height. Hilltop sites or installations on the top of high-rise buildings are preferred. The site should be more or less central relative to the area to be covered, if a choice of high sites is available. Of course, one should again avoid any site where there are intervening high ridges in the line-of-sight path between the antenna site and the principal high-population area to be served.

In general, the same conditions apply to the uhf broadcast station, namely a very high, centrally located site. However, there is one exception with reference to a uhf transmitter site; one must be careful just how far away the site is located from the principal metropolitan area to be served. The range of transmission is, in general, less for uhf transmission, and dead spots are more prevalent and deep. As a result, better metropolitan area coverage can often be obtained at some sacrifice in low-population fringe area coverage by choosing a high antenna site nearby or in the metropolitan area to be served, rather than a substantially higher antenna site that is some distance from the main area to be served.

CHAPTER 16

FM Broadcasting

The material discussed in the following questions from the FCC Study Guide covers fm broadcasting and the equipment used in conjunction with fm broadcasting.

16-1. FM PRINCIPLES AND EQUIPMENT

1. Explain in a general way how radio signals are transmitted and received through the use of frequency modulation.—A functional block diagram of an fm system is given in Fig. 16-1. In frequency modulation the frequency of the transmitted rf wave is made to vary with the voice and music frequencies. The fm transmitter consists of a carrier generator, or rf exciter, which has either a crystal-controlled oscillator or a highly stable (feedback-controlled), self-excited oscillator and a series of frequency multipliers and rf amplifiers. The frequency of the carrier (center-frequency) oscillator is usually, but not always, lower than the transmitted carrier frequency. A relatively low oscillator frequency helps to obtain good center-frequency stability and to get sufficient deviation (±75 kHz) in the final stages of the fm exciter. The function of the frequency multipliers is to multiply this low oscillator frequency up to the transmit frequency. The multipliers and the succeeding rf power amplifier also aid in building up the strength of the rf wave.

In an fm transmitter the actual modulation takes place in a low signal-level section (exciter) of the transmitter. The direct or indirect frequency-modulation methods may be used in generating an fm wave. In the direct method shown in Fig. 16-1 a reactance modulator is used to deviate the frequency of a stabilized self-excited oscillator. This oscillator may operate on a frequency that is 1/18th of the transmit frequency. For example, if the transmit frequency is to be 90.1 MHz, the center frequency of the oscillator would be 5.005 MHz (90.1 ÷ 18). The oscillator may even operate on the transmit frequency in some transmitter designs.

The center frequency of this oscillator is maintained with high stability using a feedback system. In the feedback system the oscillator frequency is divided down to a very low frequency which is compared in a phase detector circuit with a reference signal from a highly stable crystal-controlled frequency source. If the self-excited oscillator frequency-drifts, a dc error voltage is developed at the output of the phase detector. This error voltage is applied to the reactance modulator to counteract any drift in the oscillator center frequency. The function of the feedback system (afc) is to maintain the stability of the oscillator center frequency, and is completely independent of oscillator frequency deviations caused by the audio signal applied to the reactance modulator.

The program signal is supplied through an audio amplifier and preemphasis network to the input of the reactance modulator. The reactance modulator circuit functions as a variable capacitor, or as a variable inductance across the resonant tank circuit of the oscillator. If the reactance circuit acts as a variable capacitor and the program signal is applied to its input, its effective capacitance will vary with the program signal. This capacitance change will cause a change in the frequency of the self-excited oscillator. If

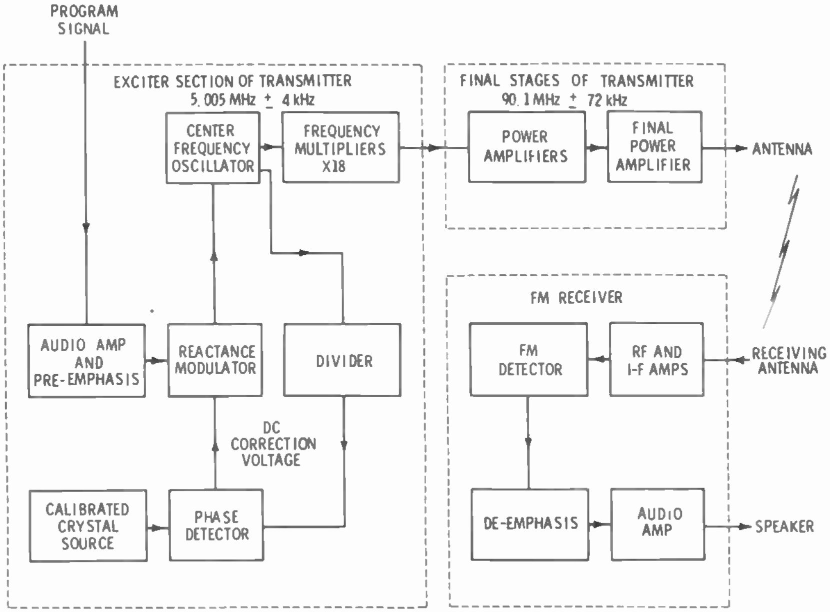


Fig. 16-1. Block diagram of an fm broadcast system.

we assume that an audio sine wave is being applied, the positive alternation of the sine wave will cause the frequency of the oscillator to change or deviate in one direction away from the center frequency of the oscillator. The opposite alternation of the modulating sine wave causes the oscillator to deviate in frequency a like amount on the other side of the center frequency. (See Fig. 16-2A).

In the fm modulation process the *extent* of the deviation of the oscillator frequency is a function of the *amplitude* of the modulating wave. The *rate* at which the frequency deviates on each side of the center frequency is a function of the *frequency* of the modulating wave.

In the fm broadcast system the maximum permissible deviation is ±75 kHz. This figure of ±75 kHz is referred to as 100-percent fm modulation. In other fm systems the maximum permissible deviation (100-percent modulation) is usually less than ±75 kHz. For example the fm sound transmitter associated with a television broadcast station may only be deviated a maximum of ±25 kHz. In the fm two-way radio services maximum deviation is confined to ±15 kHz or ±5 kHz.

The deviation of course refers to the change in frequency relative to the carrier (center) frequency of the fm station. For example, a 90.1-MHz fm station may only deviate ±75 kHz about its assigned carrier frequency.

In a frequency multiplier the center frequency and the deviation frequencies are multiplied. Therefore, the maximum permissible deviation of the 5.005-MHz exciter oscillator may only be ±4.16 kHz, (75 ÷ 18).

The fm signal wave, like the a-m signal wave, is a resultant rf wave. As covered previously, the a-m signal wave is the resultant of a carrier and two sidebands. Similarly, in the fm system, the resultant (or fm signal) consists of a carrier plus one or more pairs of sidebands. The number, frequency position, and relative amplitudes of the sidebands are a function of the frequency and amplitude of the modulating wave. Specifically, the sidebands are a function of a modulation index which is the quotient of the frequency deviation and the modulating frequency as follows:

$$\text{Modulation Index} = \frac{\text{Deviation (kHz)}}{\text{Modulating Frequency (kHz)}}$$

A typical carrier and sideband distribution is shown in Fig. 16-2B. The algebraic sum of the carrier and the sidebands produces a resultant rf signal that deviates ±75 kHz at a rate of 15,000 deviations per second (15-kHz modulating frequency). Note that the frequency of the resultant signal deviates, but the *amplitude* remains *constant*.

Since the strength of the transmitted fm signal decreases quickly as the distance from the radiating antenna increases, the signal level at the receiving antenna is only a very small percent of the signal level at the radiating antenna. The rf signal at the receiver antenna is amplified by a number of rf stages before it is appled to an fm detector (demodulator). Among these is an amplitude limiter which removes amplitude noise and interference components without having any adverse effect on the desired frequency modulation. The fm detector is a circuit that produces an output voltage that corresponds in amplitude to the frequency of the applied input wave. When the incoming fm wave deviates to one side of its center frequency, the polarity of the detector output is opposite to that obtained when the deviation is to the other side of the center frequency. The magnitude of the output voltage depends on just how far the fm signal has deviated from the center frequency. Thus, if the fm wave has been modulated by a sine wave, a frequency excursion to one side of the center frequency will be recovered as a positive alternation of the detector

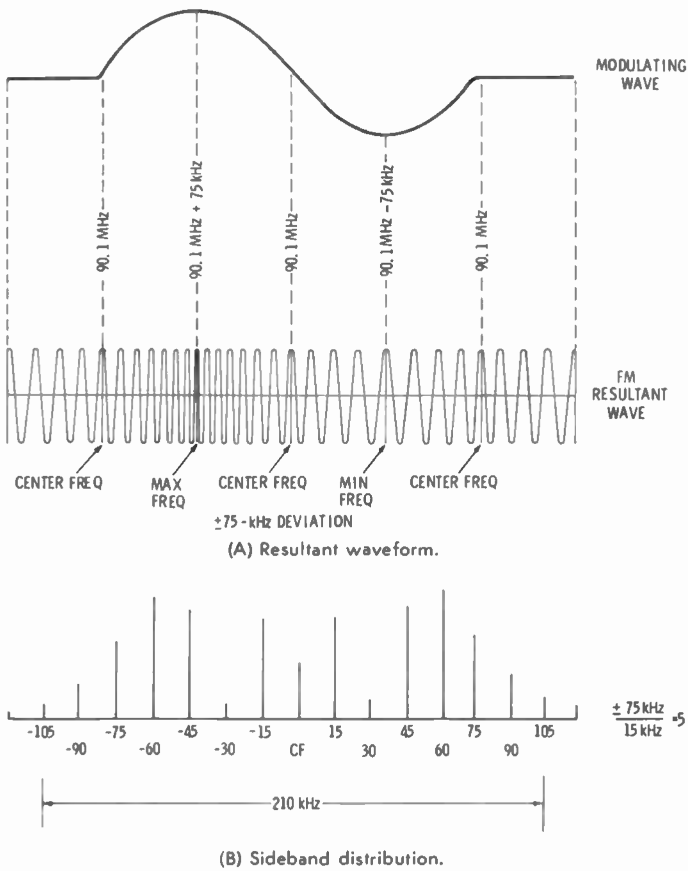


Fig. 16-2. Resultant fm wave and sideband distribution for ± 75-kHz carrier deviation at a 15-kHz rate.

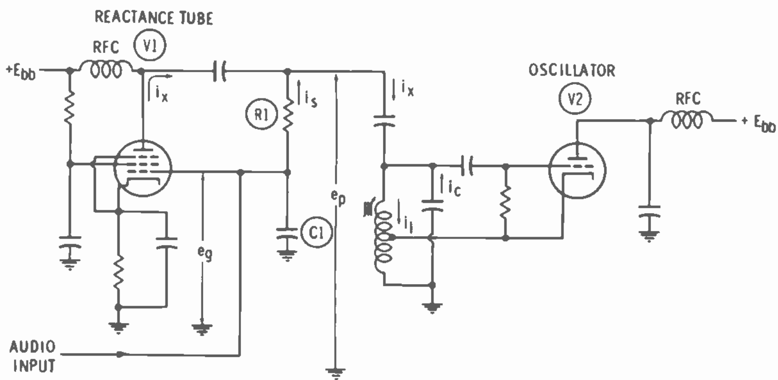
output voltage. Similarly, a frequency excursion to the other side of the center frequency will be recovered as a negative alternation of the demodulator output voltage. In operation, the fm detector functions as a frequency-to-amplitude converter. The recovered modulating wave (voice and music variations) is then applied to the following audio amplifier stages to provide adequate drive for a speaker.

In general it can be stated that a frequency-modulation system provides a means of varying the frequency of the transmitted rf wave in accordance with the amplitude and frequency changes of the modulating signal. This resultant rf wave provides a means of conveying information between transmitter and receivers. The function of the receiver is to amplify this incoming fm wave and then make a conversion between frequency deviation and an amplitude-changing replica of the original modulating wave.

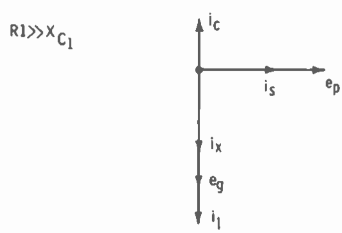
2. Draw a circuit diagram of a reactance-tube modulator, and explain its operation.—Such a diagram is shown in Fig. 16-3. A reactance tube can be made to operate as either a variable inductance or a variable capacitance across the frequency-controlling resonant circuit of an oscillator.

In Fig. 16-3, reactance tube V1 operates as a variable inductor. As the inductance of V1 varies with the modulating wave the oscillator frequency varies. In operation V1 causes an rf current (i_x) in the oscillator tank circuit. This current lags the oscillator rf voltage (e_p) developed across the tank circuit by 90°. I_x introduces an inductive current component which is in phase with the normal inductive current (i_1) circulating in the oscillator tank circuit. When i_1 is made to vary in magnitude, the effect is the same as changing the reactance of the inductive leg of the tank circuit and, in turn, its resonant frequency.

The lagging rf current (i_x) of the reactance tube is formed by applying a part (e_p) of the rf tank voltage of the oscillator to the control grid of the reactance tube through a 90° phase-shifting network R1-C1. The resistance of R1 is many times greater than the reactance of C1 at the oscillator fre-



(A) Schematic.



(B) Vector currents and voltages in the reactance tube and oscillator tank circuits.

Fig. 16-3. A reactance-tube modulator circuit.

quency. The rf series current (i_s) is in phase with the oscillator voltage (e_p) because the R1-C1 network appears as a resistive impedance to the oscillator output. The series current (i_s) flows through C1, and consequently the voltage (e_g) across the grid of reactance tube (V1) lags the oscillator voltage (e_g) by 90°. This network thus provides the phase shift that causes the rf plate current (i_x) of the reactance tube to lag the rf voltage (e_p) across the oscillator tank by 90°.

The next step in understanding the operation of a reactance modulator and oscillator is to understand how the *amplitude* of the rf current is made to vary. The amplitude of the rf current (i_x) at the output of the reactance tube is a function of the mutual conductance ($g_m = \Delta i_p / \Delta e_g$) of the reactance tube. The value of g_m can be varied by changing the reactance-tube control-grid bias. Consequently, the amplitude of the rf current (i_x) in the plate circuit of the reactance tube varies with g_m, and in turn the g_m can be varied with a modulating wave applied to the grid of the reactance tube.

Any change in the amplitude of the rf current (i_x) that is introduced into the tank circuit by the reactance tube causes a change in the inductive current (i_l) in the oscillator tank circuit. This is the same as changing the inductance of the resonant circuit and thus the resonant frequency of the oscillator.

The higher the amplitude of the modulating wave at the input of the reactance tube the greater is the change in amplitude of the rf current supplied to the oscillator tank circuit by the reactance tube. Since the increased rf current will combine with the inductive current in the oscillator tank to produce a greater change (deviation) of the oscillator frequency, the louder program components will cause a greater frequency deviation than softer program components. The higher the frequency of the modulating wave, the faster the rate of rf current change at the output of the reactance tube. Therefore, there will be a faster change in the magnitude of the rf current introduced into the tank circuit, and the rate of change of the oscillator frequency will be increased. Thus, a high-frequency component of the program material will cause the frequency of the oscillator to change at a faster rate than a low-frequency component.

3. What is the difference between frequency- and phase-modulation?—In the fm system of Fig. 16-1 a frequency-modulated rf wave was obtained by changing the effective resonant frequency of an oscillator tank circuit with a modulating wave. This is referred to as direct rf; that is, the frequency deviation was obtained by directly changing the frequency of an oscillator.

In an indirect (phase-modulated) fm system, the phase of an rf wave deviates about the reference zero phase of the center frequency. When the phase of an rf wave is changed, the period of the resultant wave will lengthen or shorten relative to the period of the center-frequency reference wave. Inasmuch as the frequency of a wave varies indirectly with its period, there is also a change in frequency which is the result of the change in phase. Thus phase modulation is referred to as an indirect means of generating a frequency-modulated wave.

The waveforms of Fig. 16-4 demonstrate the influence of phase lead or lag on the resultant wave. A phase lead is indicated in the period set off between the second and fourth cycles. At the third peak, the resultant wave (solid curve) is leading the center-frequency wave. The period of the modulated (resultant) wave is now shorter than the period of the center-frequency wave. This means that the frequency of the resultant wave is higher than the center frequency.

The influence of a phase lag is shown between peaks six and seven. At the peak of the seventh wave the resultant frequency wave lags the center-frequency wave. Since there has been an increase in the resultant wave period, the resultant wave is at a lower frequency. In the actual modulation process the shift phase is designed to gradually follow the excursions of the modulating wave.

In summary, with a phase-modulation process, the phase of the center frequency is deviated and is made to lead and lag its initial phase in accordance with the modulating wave. Indirectly, the frequency of the resultant wave also changes because the phase lead and lag increases and decreases the period of the rf wave, which results in a frequency deviation.

There is another difference too. In the basic phase-modulation process the deviation increases with the modulating

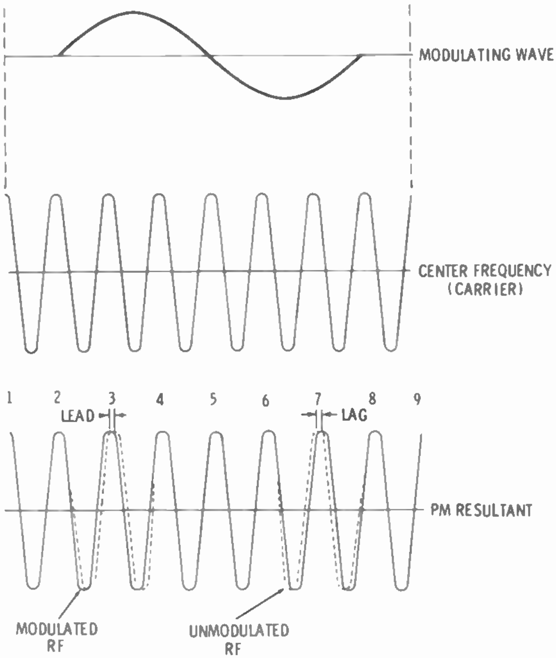


Fig. 16-4. A phase-modulated wave.

frequency assuming a constant audio amplitude. (In direct fm the deviation is the same regardless of the frequency of the audio.) As a result an audio correction network, sometimes called a predistorter, is included. *Such a network makes certain that in a phase-modulation system the deviation is the same for a given audio amplitude regardless of audio frequency.*

4. Describe briefly the operation of the Armstrong and the phasitron methods of obtaining phase modulation.— The fundamental Armstrong and phasitron systems are shown in the functional block diagrams of Fig. 16-5. In the phase-modulation method of generating an fm wave, the center-frequency oscillator can be crystal controlled. In the Armstrong method, the crystal oscillator signal is applied to a center-frequency amplifier and to a balanced modulator. The modulating wave is applied to the balanced modulator. The function of the balanced modulator is to generate two sideband component signals and remove the center-frequency wave at the same time. The sideband components are then applied to a phase shifter and once again recombined with the center-frequency component at the output of the center-frequency amplifier. However at this point the phases of the sideband components have been changed in a manner that will produce a phase-modulated resultant.

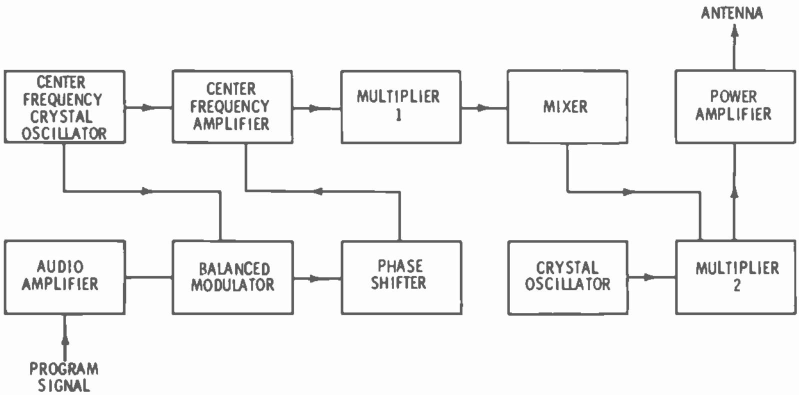
At this stage, an fm wave has already been generated using the indirect-fm (Armstrong) process. However, if the distortion of the resultant wave is to be minimized, the amount of phase deviation may not exceed a certain limit. Only a very small frequency deviation is obtained when the phase deviation is confined to a swing that will not result in distortion. This very small permissible deviation presents a problem in the design of a phase-modulation system.

In the direct fm process, both the center frequency and the deviation frequencies are multiplied an adequate amount to produce a transmit output frequency capable of the maximum permissible deviation. However, if the initial maximum permissible deviation at the modulator is very low (as in the Armstrong circuit), the amount of multiplication required for the center frequency will not be great enough to obtain the required deviation multiplication for the maximum required value of ±75 kHz. Therefore, to obtain the desired transmit frequency as well as the maximum permissible deviation it is necessary to *multiply the frequency deviation more than the center frequency.*

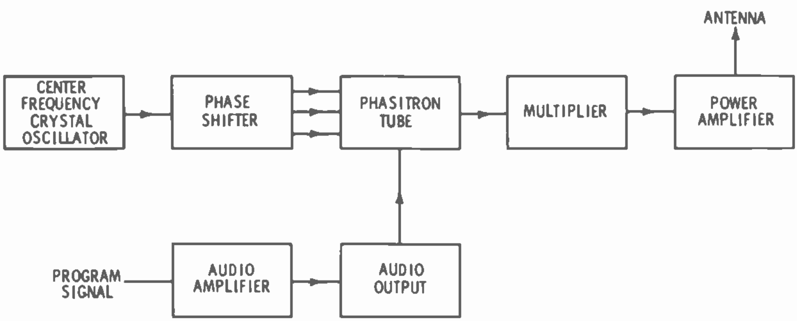
In the Armstrong phase-modulation process (Fig. 16-5A), this unequal multiplication is handled by two separate multipliers and an intervening mixer-oscillator combination. In the first multiplier the frequency and deviation are multiplied the same amount. The output of the first multiplier is then applied to a mixer. The function of the mixer-oscillator combination is to *reduce* the center frequency. In lowering the center frequency by the mixing process the deviation is unchanged. Thus the fm wave applied to the second multiplier is one of a very low center frequency but the deviation frequencies remain the same as at the output of the first multiplier. The second multiplier then multiplies the center frequency and the deviation the same amount. Thus, at the second multiplier output, the required transmit frequency and the capability for maximum permissible deviation (±75 kHz) are obtained.

In summary, in the Armstrong arrangement, the deviation has been multiplied by a greater ratio than the center frequency. This is done to overcome the small deviation limit of the phase-modulation process.

In the phasitron method (Fig. 16-5B) of generating an fm wave by indirect means, a special tube is used to obtain the required phase deviation. This tube, called a *phasitron*, produces an actual phase-modulated wave within itself. The tube develops substantial phase deviation without the introduction of distortion. This overcomes the phase deviation limitation of the Armstrong technique; in fact, the deviation is so



(A) An Armstrong system.



(B) A phasitron system.

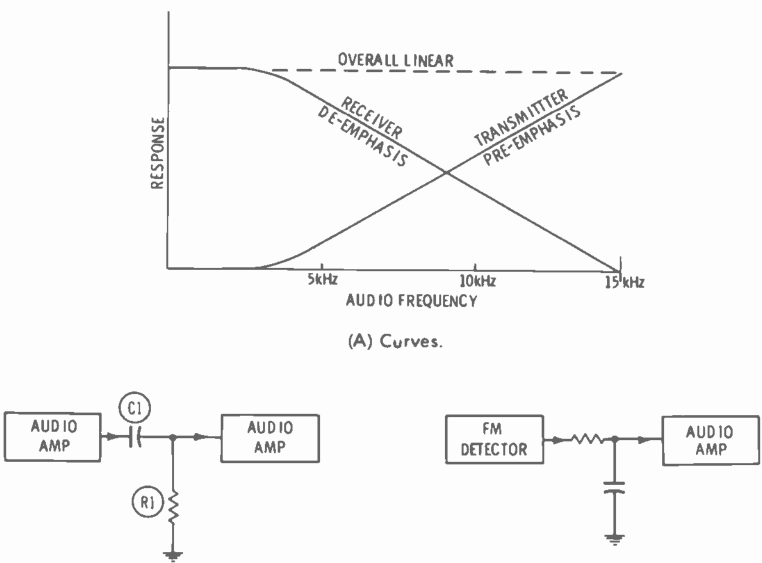
Fig. 16-5. The block diagram of two phase-modulated systems.

high that a dual multiplier system is not required. Notice that the output of the phasitron tube is applied directly to the multiplier. The multiplier provides for the same multiplication of center and deviation frequencies, producing the transmit frequency output and the capability for maximum permissible deviation.

In the phasitron system, the output of a crystal oscillator supplies signal to a phase-shifting circuit which produces three outputs at the same frequency with their phases 120° related. These three components are applied to the deflector-grid assembly of the phasitron producing a rotating electron stream within the tube. The rotation rate of this electron stream is at the center frequency. The phasitron also includes an external modulating coil which generates a magnetic field that can speed up or slow down the internal rotating electron stream. When a modulating signal is applied to the modulating coil, the changing magnetic field accelerates and retards the center frequency variation within the phasitron. Thus, the phase of the resultant rf wave at the output of the phasitron has been deviated over a substantial range. The resultant fm deviation obtained is comparable to that of the direct fm process.

A distinct advantage of the indirect fm system over the direct system is that a stable crystal oscillator can be used for generating the initial carrier or center-frequency wave. Consequently a feedback system is *not* required to maintain the center-frequency stability as in the direct fm oscillator.

5. What is the purpose of pre-emphasis in an fm transmitter? Of de-emphasis in an fm receiver? Draw a circuit diagram of a method of obtaining pre-emphasis.—A diagram and curves showing the influence of pre-emphasis and de-emphasis are given in Fig. 16-6A. A major advantage of f-m transmission is its ability to reject the amplitude-varying noise and interference components. However an fm system is not completely noise-free because there are fm noise components to contend with. The fact that interference has less effect at low modulating frequencies than at higher frequencies is characteristic of an fm system. An improved signal-to-noise ratio is obtained when the fm deviation is greater for a high-frequency modulating wave (audio) as compared with a low-frequency modulating wave (audio) that has the same initial amplitude. The application of this principle is called *pre-emphasis*. A simple series resistor-capacitor com-



(A) Curves.

(B) Pre-emphasis at transmitter.

(C) De-emphasis at receiver.

Fig. 16-6. Fm pre-emphasis and de-emphasis.

bination can be used to obtain pre-emphasis. As shown in Fig. 16-6B, the pre-emphasis network can be inserted between the audio amplifier stages. Since the capacitance of C1 is low, its capacitive reactance is quite high at low and midrange audio frequencies, decreasing to a rather low value at high modulating frequencies. Hence, for a comparable input to the pre-emphasis network, the higher-frequency components will be present at the input of the next stage with approximately the same amplitude as existed at the input to the pre-emphasis network. However, with a decrease in frequency, the reactance of the capacitor increases, and, as a result, the amplitude of the signal delivered to the next stage is decreased. The response of a typical pre-emphasis combination is shown by the pre-emphasis curve (Fig. 16-6A).

Because pre-emphasis is used, the high-frequency components of program material at the receiver output will appear at a greater relative level than the middle- and low-frequency components (as compared to their initial relative magnitudes at the audio input of the transmitter). The audio-frequency components are restored to their initial relative values with the use of a de-emphasis network at the output of the receiver fm detector. The frequency response curve of the de-emphasis network (Fig. 16-6C) is of opposite slope to that of the pre-emphasis network curve (Fig. 16-6A). In the de-emphasis circuit, the high frequencies are attenuated more than the low frequencies, but in exactly the same proportion as the high frequencies were initially pre-emphasized at the transmitter. As a result, the overall frequency response is linear, and the overall signal-to-noise and signal-to-interference ratios of the fm systen have been substantially improved.

6. What is effective radiated power? Given transmitter power output, antenna resistance, antenna transmission-line loss, transmitter efficiency, and power gain, show how effective radiated power is calculated.—By FCC definition, effective radiated power (ERP) is the product of the antenna power (transmitter output power less transmission-line loss) times the antenna power gain, or times the antenna field gain squared. The antenna power gain by definition is the square of the ratio (in decibels) of the rms free-space field strength (in millivolts per meter) produced at one mile in the horizontal plane to that of a standard antenna (137.6MV/m). Therefore, to determine the effective radiated power it is only necessary that one know the transmitter power output, the antenna transmission-line loss, and the antenna power gain.

An example will clarify the procedure. What is the effective radiated power of an fm station that employs a transmitter with a 10-kW rf power output and a transmitting antenna with a gain of 6 dB? Assume that there is a 1000-watt loss in the transmission line. The effective radiated power will be 36 kW. An antenna gain of 6 dB corresponds to an antenna power gain of four.

$$\text{ERP} = (10{,}000 - 1000) \times 4 = 36\text{kW}$$

7. Explain why dry air or inert gases are often used in rf transmission lines which link broadcast transmitter and antennas.—Mismatch, additional line loss, and arcing are prevented. The coaxial line is evacuated and filled with inert gas or dry air under pressure and sealed to prevent moisture from accumulating in the coaxial line. A dehydrator is also inserted in the dry-air coaxial line.

If moisture should accumulate in the coaxial line, the accumulated moisture will increase the dielectric constant of line and may cause arcing in the line. The increased dielectric constant will cause a mismatch resulting in additional line losses.

8. Describe the procedure of installing a transmission line between the broadcast transmitter and the antenna. Include information as to characteristic impedance, bends, kinks, cutting, and connections. Discuss both the solid-dielectric and the gas-filled line.—The transmission line conveys the signal from the transmitter to the antenna system. The transporting of rf power is not accomplished without some loss in the transmission line. However, this loss is minimized by routing the line in as direct as possible a path between the transmitter and the antenna. A low-loss transmission line should be used, and its dimensions should be sufficient to handle the rf power to be conveyed without causing arcing and excessive heat loss. A transmission line operates with minimum loss when its characteristic impedance is matched at both transmitter and antenna ends. Any impedance discontinuity along the line such as might occur at bends, kinks, or connection points can result in additional line loss and is the point where high-voltage arcing can develop. When connections or bends are required, the fittings must be carefully selected, and good workmanship must be employed. Moisture condensation within the line can also cause arcing and impedance discontinuity. Moisture condensation can be avoided by using a dehydrator in the dry-air filled coaxial lines or by using the inert-gas filled coaxial lines. Lines are often laid in metal troughs or under weather shields for protection from the environmental weather conditions.

Although inert-gas coaxial lines are of a rigid or semirigid construction and are more difficult to route and assemble, they have low rf power loss and essentially constant characteristics under environmental extremes. The solid dielectric lines do not require inert gas systems or dehydrators and they are more flexible. Therefore, they can be routed and fitted more conveniently. However, the solid-dielectric lines have limited power-handling capability, and higher rf power losses are encountered, particularly at vhf and uhf frequencies.

Quite often the installation of a line is started at the antenna. If the line is of a rigid type, a suitable mechanical arrangement must be made to permit a firm and rigid attachment to the antenna; usually one or two 90° elbows are used to align the transmission line with the point of antenna attachment. A flange-type of connection is often made between the line and the antenna. A rigid hanger supports the transmission line at the connection to prevent expansion from influencing the connection.

The transmission line can now be run down along the tower using spring-type and sliding hangers. The hangers act as guides for the vertical line and, at the same time, allow for the difference in expansion between the line and tower. Another 90° elbow is required at the base of the tower at the point where the horizontal run to the transmitter building is started. A brace is used to support the line at the point where the changeover from vertical to horizontal is made. Very often the horizontal length of line is placed in a protective trough, or a triangle-type shield is placed over the line. The line must be supported along its entire horizontal length with flexible hangers or rollers to allow for expansion and contraction. A rigid anchor is connected around the line at the wall of the transmitter house. Inside the house, suitable connections must be made for connection of a gas port or an automatic dehydrator.

The flexible and semiflexible transmission lines are easier to install than the rigid type, and their flexibility minimizes the effects of expansion and contraction. Thus the rigid supports, spring hangers, elbows, etc., are not required. Generally the permissible bending of a flexible or semiflexible line is limited to a radius that is approximately ten times the cable diameter. The outer conductor of such lines must be bonded to the metallic tower, at least at the top and the bottom of the tower and also to a ground point where the cable enters the house. The cable must be supported by a messenger wire or adjustable flange in its horizontal run between the tower and transmitter house.

Kinks in transmission lines may introduce impedance discontinuities and possible arcing; therefore, they should be avoided. The flexible or semiflexible lines should be run as a single length from the output of the transmitter to the point of connection at the antenna tower, if at all possible. When lines must be cut, the appropriate connectors and hardware must be used. Even for rigid line the number of connections should be kept to a minimum.

9. What is an stl system?—Stl (studio-transmitter-link) facilities are licensed to broadcast stations and are used to relay programs from the studio to the transmitter. They may also be used for communications between these two points when no programs are being transmitted. If a multiplex arrangement is included, such communications may also be established during actual program transmission. Stl facilities usually operate in the uhf and microwave spectrum, and are licensed for unlimited time operation using directional antennas. Remote control may be employed.

16-2. REVIEW OF A-M AND FM BROADCASTING

The following FCC Study Guide question touches on several phases of broadcasting, which include the standard a-m, fm, fm multiplex, television, and color television broadcasting stations. The portion of this question discussed in this chapter is a review of a-m, fm and fm multiplexer broadcasting. The television part (d) and color television part (e) of this question will be carried over into the next chapter and serve as an introduction to the questions on television broadcasting.

10. Draw block diagrams of the following broadcast transmitter complete from the microphone (and/or camera) inputs to the antenna output. State the purpose of each stage, and explain briefly the overall operation of the transmitter for (a) standard (a-m) broadcast, (b) fm broadcast, (c) multiplex fm broadcast, (d) television broadcast, and (e) color television broadcast.

(a) A functional block diagram of an a-m broadcast facility is given in Fig. 16-7. The five audio-signal or program sources are the microphone, the tape player, the phono player, the remote telephone line, and the network telephone line. All of these program sources terminate in an audio console. The console contains the switching, mixing, and gain-control functions. If two or more microphones are used on a given program, their signals are combined and mixed in the audio console. At the audio console, an announcer can make a spot announcement and then switch from the announce microphone to a record set up on the turntable. In fact the main function of the console is to control the program continuity of the station.

The console includes a VU (volume unit) meter that helps the console operator maintain the program material at the proper absolute and relative levels. The console also includes a monitor so that the operator can hear the program material. Quite often audition monitoring facilities are incorporated. The console permits the operator to check studio, remote, and other audio signal sources for proper operation while other program material passes simultaneously through the amplifier.

The program material at the output of the console is supplied to an audio line that links the console with the transmitter facility. Sometimes an automatic gain control (agc) amplifier is inserted between the console output and the audio line. This amplifier relieves the console operator from some of the tedious work of riding gain and provides a more constant amplitude signal to the audio line from the various program sources. Therefore the signal applied to the line is held at the appropriate level for optimum signal-to-noise ratio without causing crosstalk into other lines. Consequently a more constant signal level is delivered to the input of the transmitter.

Sometimes a compression amplifier, which regulates the dynamic range of the program material, is a part of the studio equipment. This amplifier can be switched into operation when compression control is required.

It may be necessary to employ a line equalizer in the remote and network lines. A line equalizer compensates for the poor frequency response of certain types of audio lines and facilities and can be switched into the line when necessary.

Some of the high-quality microphones may employ preamplifiers. The preamplifier is usually built into the microphone housing or located at the end of the cable where the connection is made to the audio line that runs to the input of the console.

The average broadcast station usually has one or more remote amplifiers, which are very small console units that are used for remote broadcasts. The unit permits the mixing of microphone signals and other program sources and builds them up to the level needed for the remote telephone line that links the source of the remote broadcast with the console at the studio. The remote console usually includes a VU meter so that the operator can observe the signal level being applied to the remote telephone line.

The program signal as it arrives at the transmitter must be amplified (usually by a limiter amplifier to avoid overmodulation) prior to its application to the audio input of the transmitter. Several additional audio amplification stages are included in the transmitter proper to build up the level of the program material for driving the a-m modulator stage.

The rf carrier is generated by the crystal-controlled oscillator and also increased in level by succeeding amplifier stages until the strength of the rf signal is sufficient to drive the modulated amplifier. In the modulated amplifier the program material and the rf carrier are mixed to produce the rf a-m modulation envelope. The modulated rf wave is then applied through an output circuit (coupling system) to a transmission line. At the other end of the transmission line an antenna-tuning unit applies the rf signal to the antenna system.

A frequency monitor and a modulation monitor are required by the FCC

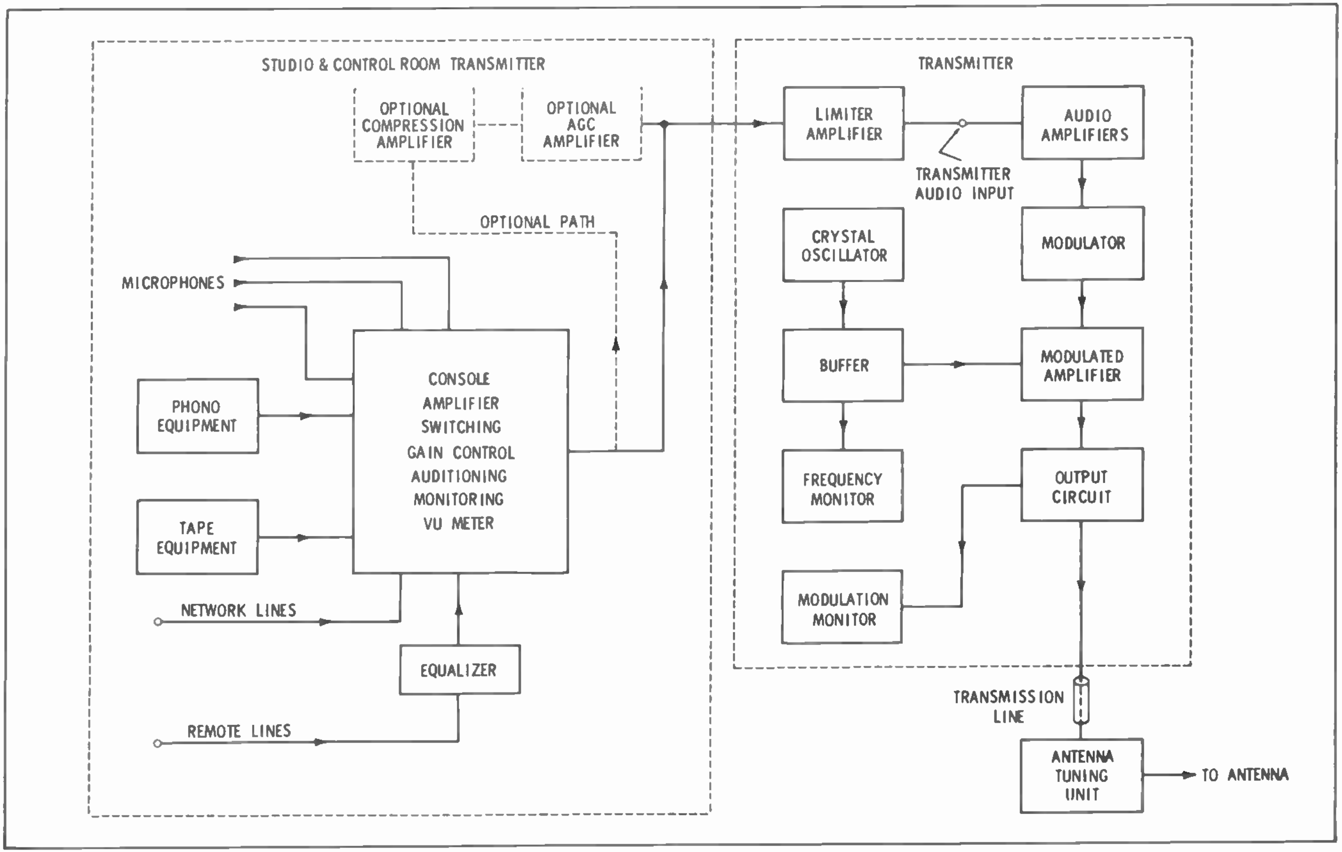


Fig. 16-7. A block diagram of an a-m broadcast station.

as accessory items for the transmitter. If an a-m directional antenna is employed, monitoring equipment must also be included for the directional antenna system.

A general discussion of the a-m system was given in Question 1 of Chapter 15.

(b) A functional block diagram of an fm broadcast transmitter is given in Fig. 16-8. The major units of the studio and control-room equipment are the same as those of the a-m station in Fig. 16-7. Some additional consideration must be given to the frequency response and dynamic range of the program material because of the higher fidelity inherent in an fm system. However, the high-fidelity performance of most modern studio equipment permits the equipment to be used in either a-m or fm services. Many consoles include dual facilities that permit simultaneous handling of different audio signals so that the a-m transmitter and the fm transmitter can be supplied with separate program materials. Of course, compression amplifiers, equalizers, and agc systems are adjusted to operate in accordance with the capabilities of fm broadcasting. The general operation of an fm system was covered in Questions 1 and 2 of this chapter.

Naturally the fm transmitter differs substantially from its a-m counterpart. A limiter amplifier is used ahead of the transmitter, and it establishes the average modulation level relative to a desired dynamic range and, at the same time, prevents overmodulation (excessive deviation of the transmitter). At times a top-level limiter is used between the limiting amplifier and the fm transmitter to prevent transmitter overmodulation at high modulating frequencies. Because of the pre-emphasis employed in fm broadcasting, the high-frequency audio components often cause very high instantaneous modulation peaks. The top-level amplifier is especially effective against these peaks.

A low-level speech amplifier build up the program signal level for application to the reactance (fm) modulator (Fig. 16-8). It is here that the pre-emphasis and the audio correction networks required for the particular type of fm modulation (direct, phase, or serrasoid) are obtained. Audio limiters and filters are also included in this audio amplifier to establish the proper audio response and remove undesired harmonic components.

The carrier is formed by a stable oscillator. In the example of Fig. 16-8, the modulating signal from the audio am-

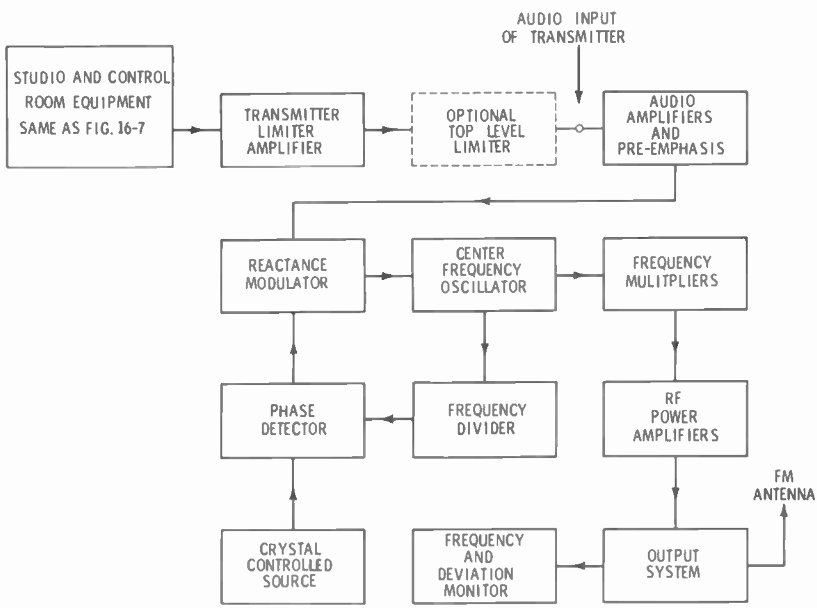


Fig. 16-8. A block diagram of an fm broadcast station.

plier is applied to a reactance modulator which frequency deviates the carrier signal (refer to Question 2 of Chapter 16). An automatic frequency-control (afc) system maintains the center-frequency stability of the oscillator. The fm modulation process begins at a low frequency to establish high center-frequency stability and the required wide-band deviation at the fm broadcast frequency. Therefore, the fm modulated oscillator is followed by a series of frequency multipliers which multiply both the center and the deviation frequencies. The output of the multiplier or so-called rf exciter, is at the transmit frequency (in the frequency range of 88-108 MHz) with a maximum possible deviation of ±75 kHz. A series of following class-C amplifiers now build up the power level of the signal, the final rf power amplifier delivering an rf output power according to the capability of the fm transmitter. An output coupling system then provides a proper match to the fm antenna system. The frequency meter and deviation (modulation) monitor are instruments required by the FCC.

(c) The functional block diagram of a multiplex fm system is shown in Fig. 16-9. In a stereo broadcast system, two separate but related audio signals must be conveyed between transmitter and receiver. Stereo broadcast stations use a form of subcarrier multiplex transmission. One audio signal frequency-modulates the carrier directly (audio channel No. 1 in Fig. 16-9). The second audio signal amplitude-modulates a subcarrier, which in turn frequency-modulates the carrier (audio channel No. 2 in Fig. 16-9).

At the receiver, the regular fm detector demodulates both the channel-1 carrier signal and the channel-2 subcarrier signal. However, the subcarrier signal is supplied to a subcarrier detector—in this case an a-m detector. The output of the subcarrier detector serves at the second audio signal. In this manner, both audio signals have been recovered and applied to a dual-channel audio amplifier.

As shown in the block diagram of Fig. 16-10, the studio and console equipment of an fm multiplex station have the same basic units except that a completely dual arrangement is used for the left (L) and right (R) audio signals. Two completely separate microphone channels are needed for a stereo broadcast. A stereo tape player and phono player supply the two separate audio signals needed for stereo broadcasting. Likewise, two telephone lines would be needed for remote stereo or network stereo program transmission. The audio console will have dual-channel facilities and a separate VU meter for each channel. The dual-type agc amplifier must be employed and, for true fidelity, each channel must be adjusted to have the same performance characteristics. Likewise there should be identical equalization of the two audio channels.

A dual line arrangement carries the two separate left (L) and right (R) audio signals from the console or agc amplifier to the dual limiter amplifier. Both channels are limited a like amount to ensure the proper dynamic range, a high average level of modulation, and no overmodulation.

The two program signals are applied to a stereo generator. Within the stereo generator the two signals are processed

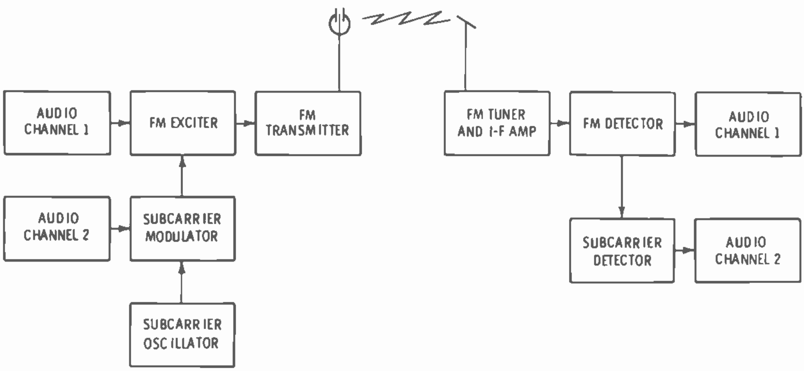


Fig. 16-9. A block diagram of an fm multiplex system.

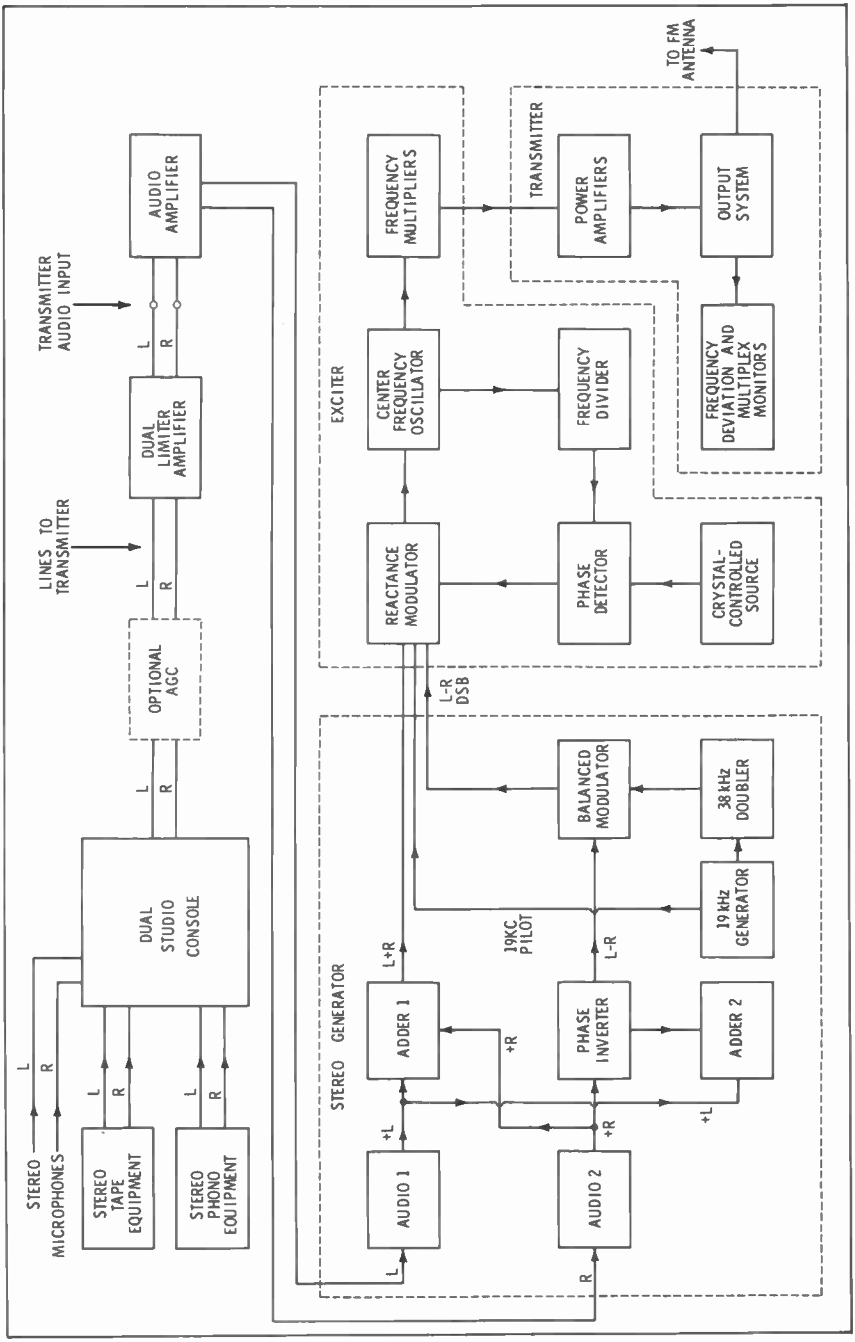


Fig. 16-10. Block diagram of an fm multiplex broadcast station.

in a manner that forms the two audio signals that will modulate the transmitter. These two signals are applied to the fm modulator (a reactance type for the example of Fig. 16-10). One of the audio signals (called the L + R signal) is applied directly as a modulating wave to the reactance tube. The second signal (L — R signal) is applied to the reactance tube as an a-m modulated subcarrier. Its band of frequencies is above that of the L + R signal that has been applied as direct modulation. Both signal components [(L + R) and (L — R) subcarrier] frequency-modulate the rf carrier (center-frequency) signal generated by the stabilized center-frequency oscillator.

As in a conventional fm broadcast transmitter, the center frequency of the oscillator and its deviation are multiplied to obtain the transmit frequency with its maximum ±75 kHz deviation capability.

The functional block diagram, Fig. 16-10 and the spectrum graph of Fig. 16-11 provide the basis for a more detailed coverage of the fm stereo generation process. As in all stereo systems, the left channel (L) and right channel (R) audio signals are required to produce the stereophonic effect at the receiver. In fm broadcasting, the two signals are first applied to a matrix circuit for processing. The two signals are united in the stereo generator to produce sum (L + R) and difference (L — R) components. This technique is necessary in order to transmit a compatible fm signal; that is, one which can be received on a monaural fm receiver and will reproduce as a good-quality monaural signal. It is the L + R signal that represents the monophonic signal and is used by regular monaural receivers. In the stereo process, the L + R signal frequency-modulates the transmitter in conventional manner.

In a stereo broadcast, the L — R signal must also be transmitted to the stereo broadcast receiver. The (L — R) signal at the output of the transmitter matrix is applied to a subcarrier a-m modulator. This is called a *balanced modulator* because in the modulation process the a-m sidebands are generated and the 38-kHz subcarrier is removed. Note in the spectrum graph that the L — R a-m sidebands (23 kHz to 53 kHz) are separated from the

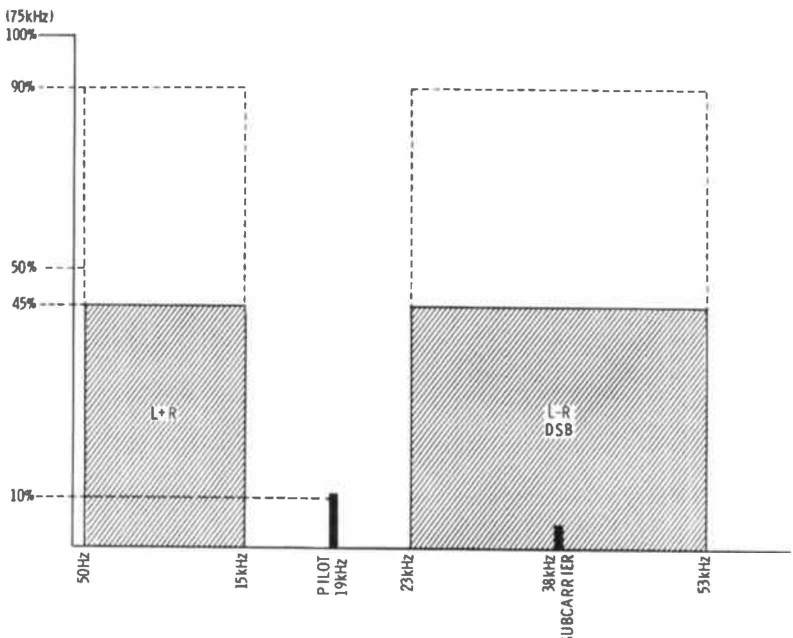


Fig. 16-11. The modulating-frequencies distribution and maximum-deviation limits for an fm system.

L + R signal spectrum, between 50 Hz and 15 kHz.

One other signal component is transmitted as shown in Fig. 16-10; this is the 19-kHz pilot signal developed in the stereo generator. Note its position between the L + R and the L — R subcarrier signals on the spectrum chart of Fig. 16-11. The 19-kHz pilot signal is used to synchronize a 19-kHz oscillator in the stereo receiver. The 19-kHz oscillator signal is doubled in frequency in the fm stereo generator to form the 38-kHz subcarrier. Thus, the 19-kHz pilot-signal oscillator is also the source for the 38-kHz a-m subcarrier. At the receiver the L + R signal is made available directly from the output of the fm demodulator. However, the subcarrier (L — R) signal must first be applied to an a-m demodulator to obtain the resultant signal (L — R). The L + R and L — R audio signals combine in the receiver matrix as follows:

$$(L + R) \pm (L - R)$$
$$L + R + L - R = 2L$$
$$L + R - L + R = 2R$$

Thus the original right-channel (R) and left-channel (L) signals are reconstructed in the receiver.

CHAPTER 17

Television Broadcasting

This chapter covers the FCC Study Guide Questions on monochrome and color television transmitter circuits and on equipment used in conjunction with these transmitters.

17-1. BASIC PRINCIPLES

1. Draw block diagrams of the following broadcast transmitters complete from the microphone (and/or camera) inputs to the antenna output. State the purpose of each stage and explain briefly the overall operation of the transmitter . . . (d) television broadcast, and (e) color-television broadcast. (Note: Parts a, b, and c of this question were answered in Question 10 of the previous chapter.)

(d) A functional block diagram of a television broadcast transmitter is given in Fig. 17-1. The television broadcast station is a two-channel facility (picture and sound). By FCC regulation the picture carrier must be kept within ±1 kHz of assigned frequency. The sound (aural) carrier is transmitted separately from the picture (visual) carrier, on a frequency 4.5 MHz above the picture carrier. The sound carrier is frequency-modulated; from microphone to antenna the sound system is quite similar to that of an fm broadcast station, with the exception that 100-percent modulation constitutes a maximum frequency deviation of ±25 kHz. For this reason this segment of television broadcasting will not be elaborated upon. Many of the television-broadcast microphones are mounted on long booms so that they can be suspended overhead out of view of the camera. The sound system must also include facilities for handling the sound signal derived from motion-picture film and video tape.

The same antenna is used to radiate both the picture and sound carriers and sidebands; a diplexer provides the necessary isolation between sound and picture transmitters. A lock-in system keeps visual and aural carriers on proper relative and absolute frequencies.

In modern television broadcasting, thirty complete pictures are sent out each second. However, each of these pictures is broken down into several hundred thousand elements which are sent in a sequential order. The orderly breakdown of a television scene is accomplished with the cathode-ray electron scanning beam at the camera tube. The scene is then reassembled at the receiver by the scanning beam of a picture tube which is directed onto a fluorescent screen. This technique is shown in Fig. 17-2.

The camera tube contains a photosensitive area or target composed of hundreds of thousands of isolated and light-sensitive elements upon which an optical lens system focuses the scene as an image. A camera-tube scanning beam moves over the surface, in accordance with a standardized motion, releasing a video signal corresponding to the brightness detail of the image. This video signal is released element-by-element and line-by-line as the beam moves across and down the image.

The picture-tube scanning beam at the receiver follows the same motion over the fluorescent screen. As the scanning beam moves across the screen, its electron density is varied by the incoming video signal supplied to the

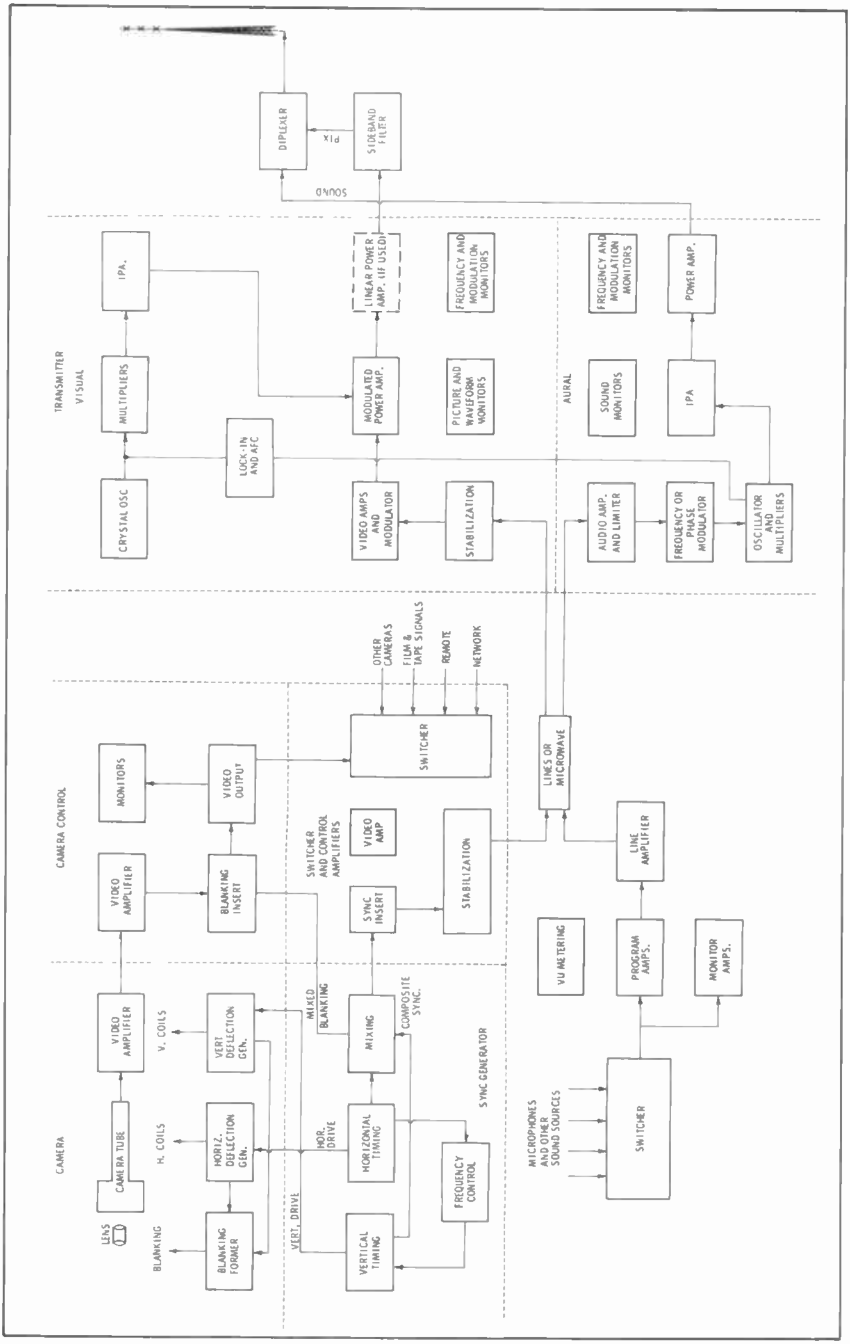
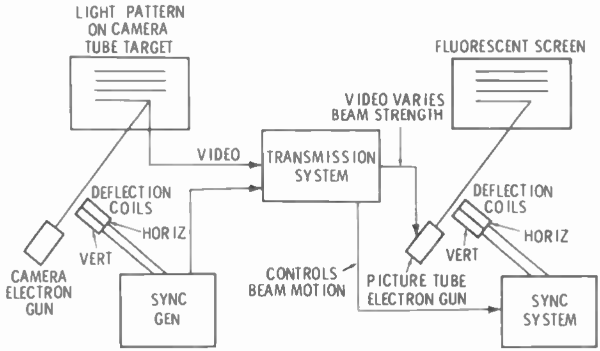
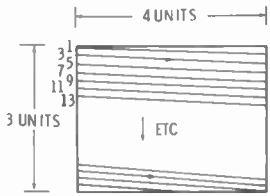


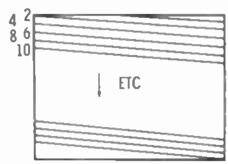
Fig. 17-1. Block diagram of a monochrome television broadcast station.



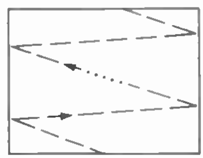
(A) Functional diagram of scanning.



(B) Odd-line scanning.



(C) Even-line scanning.



(D) No blanking, retrace visible.

Fig. 17-2. Scanning at the television camera and picture tube.

control grid of the picture tube. The fluorescent screen of the picture tube glows in accordance with the strength of the scanning beam striking each individual element. Since the strength of the scanning beam is varied as it scans the fluorescent surface, the original brightness detail of the television scene is recovered element-by-element and is then reconstructed on the fluorescent screen.

If a television scene is to be reconstructed exactly, the motion of the picture tube and camera tube scanning beams must be identical—that is, the beams must be *synchronized* with each other. This results in the image being reconstructed at the picture tube at the same rate and in the same order that the video information was released from the image which was focused on the camera tube.

In a television station, a sync generator is used to form the pulses that synchronize the motions of the camera-tube and picture-tube beams. Insofar as the station equipment is concerned, the synchronizing information is sent over cables directly to the camera circuits that control the motion of the camera-tube scanning beam. Similar synchronizing pulses are processed and inserted into the television signal that is transmitted.

In the functional block diagram (Fig. 17-1), the camera tube is shown at the top left. Its output is amplified by a video amplifier. Since the scanning beam must be made to move left to right and slowly down the screen, its motion must be controlled in two dimensions. Therefore, the motion of the scanning beam is controlled by two separate waveforms supplied by a horizontal deflection generator and a vertical deflection generator. In the scanning process, the beam scans one line at a time. After each line the beam must quickly return to the other side of the screen to begin a new line. During this horizontal "retrace" interval, no video signal must be released and the horizontal blanking pulse prevents the release of spurious retrace signals.

After the scanning beam has scanned a complete set of lines it must be returned to the top of the screen quickly to begin a completely new set of lines. Likewise, no video signal must be released during this "retrace" time; hence, it is necessary to generate both horizontal- and vertical-blanking pulses.

The motion of the camera scanning beam and the picture-tube scanning beam must be synchronized. Therefore when the scanning beam at the camera tube is releasing the video information contained in, for example, line No. 3 of the picture, the picture tube scanning beam must be in position and tracing out this information as line No. 3 on the fluorescent screen. The movements of the camera-tube and picture-tube scanning beams are controlled by horizontal- and vertical-sync pulses developed in the sync generator. At the transmitter, these sync pulses synchronize the horizontal and vertical deflection generators controlling the timing of the movement of the camera-tube beam. Similar pulses are transmitted and, at the receiver, these pulses control the operation of the horizontal and vertical deflection generators. Thus, the deflection waveforms that control the movement of the picture tube scanning beam are under control of the pulses that originate at the television broadcast station.

As mentioned, television pulses are formed by a unit called a sync generator which is the master timing center of a television broadcast system. The sync generator develops the timing drive pulses for the generation of horizontal sync, horizontal blanking, vertical sync, vertical blanking, and equalizing pulses. Equalizing pulses are important to establish the relative timing of the horizontal and vertical activities; they permit a system of beam motion referred to as "interlaced scanning."

A camera control unit is associated with each camera. This unit permits each individual studio camera to be regulated from the control room. The camera control unit also includes compensating circuits, additional video amplifiers, and an insert stage to permit the addition of blanking pulses to the signal. These horizontal and vertical blanking pulses are used at the receiver to blank out the screen whenever the picture-tube scanning beam retraces horizontally and vertically.

The camera control unit also contains monitoring circuits and a picture tube that permits the control-room operator to observe the actual picture being picked up by the camera. Waveform cathode-ray tubes are also included which permit the control-room operator to view the actual video signal waveform in the camera circuits. The output of the camera control unit is supplied to a switcher which is a control center for the television system. Other cameras and video-signal sources terminate at the switcher. The switcher is used by the control-room operator to select the particular picture that is to be transmitted. The output of the switcher is supplied to still another video amplifier and then to a sync insert stage. Here, the synchronizing pulses are added to the television signal. Since the blanking pulses were added previously in the camera control unit the composite television signal is present at the output of the sync insert stage.

The composite television signal is now supplied to a line, or stabilization, amplifier which organizes the signal for application to the video line that connects the control room with the television-transmitter proper.

At the transmitter proper, the composite television signal is again passed through another line amplifier and the video amplifiers and modulator of the transmitter. The carrier signal is generated at a low frequency using a crystal oscillator. The crystal oscillator is followed by a series of multipliers and class-C power amplifiers that build up the frequency and power of the rf signal for proper drive of the modulated power amplifier. The rf wave is amplitude-modulated by the video signal. Usually a form of control-grid modulation is employed. The output of the modulated amplifier, in a low-power television transmitter, is often applied directly to the antenna system. In a higher-power television transmitter there are intermediate linear rf power amplifiers between the modulated amplifier and the antenna system.

Frequency and modulation monitors are required for both the picture and the sound transmitters. In addition, picture and waveform monitors are located at the transmitter site.

A vestigial-sideband process is employed in the transmission of the picture. In this mode of transmission, a complete spectrum of side frequencies is transmitted on the upper side of the carrier. However, on the lower side of the carrier only the lower frequencies are transmitted and the higher-frequency components are suppressed. Thus only a vestige, or part, of the frequencies in the sideband below the carrier are transmitted and the system is called vestigial-sideband transmission. This system permits a video signal of a given resolution to be transmitted with less bandwidth. Stated another way, frequency components as high as 4.25 MHz can be transmitted even though the assigned channel bandwidth is only 6 MHz. Were conventional double-side-band amplitude modulation employed, it would normally require an 8.5-MHz bandwidth to transmit a 4.25-MHz modulating wave.

The lower sideband is partly suppressed by the sideband filter. The output of the sideband filter is applied to a diplexer unit. The function of the diplexer is to permit the simultaneous feed of the sound and the picture rf signals to the same antenna. The diplexer permits proper impedance matching of the picture and sound transmitters to the antenna and prevents interaction between the two transmitters.

(e) A functional block diagram of the key circuits necessary for color-picture transmission is given in Fig. 17-3. The sound transmitter is shown as a single block because it is identical to that shown for the television broadcastu transmitter in Fig. 17-1 as discussed in Question 10(b). Likewise, certain of the systems used in color broadcasting are similar to those used in monochrome television broadcasting. Therefore a single block is used to represent basic functions that were shown as a group of blocks in Fig. 17-1. The camera control, switcher, stabilization amplifier, and the transmitter proper (including sideband filter, diplexer, and antenna) are similar in function to those employed in a strictly monochrome television system. In fact these systems are designed to handle either monochrome or color program material. The camera control and monitoring facilities are more elaborate in order to monitor certain color characteristics of the television signal. The sync generator is also similar requiring only certain additional stages for generating the color sync and processing signals.

Color is composed of three basic attributes—brightness detail, hue, and saturation. Brightness detail is the relative brightness among all the elements that make up a scene, regardless of its hue and saturation. It is this brightness detail, between black and white over the gray scale, that makes it possible to transmit a black and white picture. The monochrome picture observed on your television screen or on a magazine page is nothing more than a brightness pattern. The breaking up of a scene into many, many elements of differing brightnesses permits the reconstruction of a scene in detail.

In addition to the brightness detail, the color television system transmits the hue and saturation information. Hue is often referred to loosely as color, because it represents green, yellow, blue, red, etc. but does not include black, white, and values of gray. *Saturation* has to do with how pure a given hue is and how much white light is present. A pure green is a fully saturated hue because no white light is present; whereas a desaturated green would be a paler green because it contained a certain percentage of white light.

Scores of recognizable hues and saturations are transmitted by using only three basic "tristimulus" colors—red, blue, and green. By mixing these three primary colors in proper proportions, an extensive range of hues and saturations is conveyed. This is the basis for our three-color television system. Therefore, in a basic color system (Fig. 17-4), three camera tubes interpret the scene to be conveyed in terms of its blue, red, and green color brightness content. The three camera signals are then processed and transmitted. At the receiver, the three color signals are recovered and supplied to a picture tube that has a separate electron gun for each primary color. The fluorescent screen of the picture tube contains three separate sets of extremely closely spaced color phosphor dots—one set of dots for each primary color. Therefore, the fluorescent screen of the color picture tube is covered by several hundred thousand color-phosphor dots. Those dots are arranged in trios of green, red, and blue are shown in Fig. 17-5 and are individually excited by their respective electron guns. This results in three primary color pictures which, in terms of visual observation, appear superimposed. Thus, three basic primary color pictures are combined by the eye to reconstruct the original color scene.

The scanning activity is the same as that used in monochrome television; therefore, the functions of the horizontal sync, horizontal blanking, vertical blanking, and equalizing pulses are the same. However, it is also necessary to synchronize the color demodulating activities at the receiver so that they take place in step with similar activities at the color television camera. For this

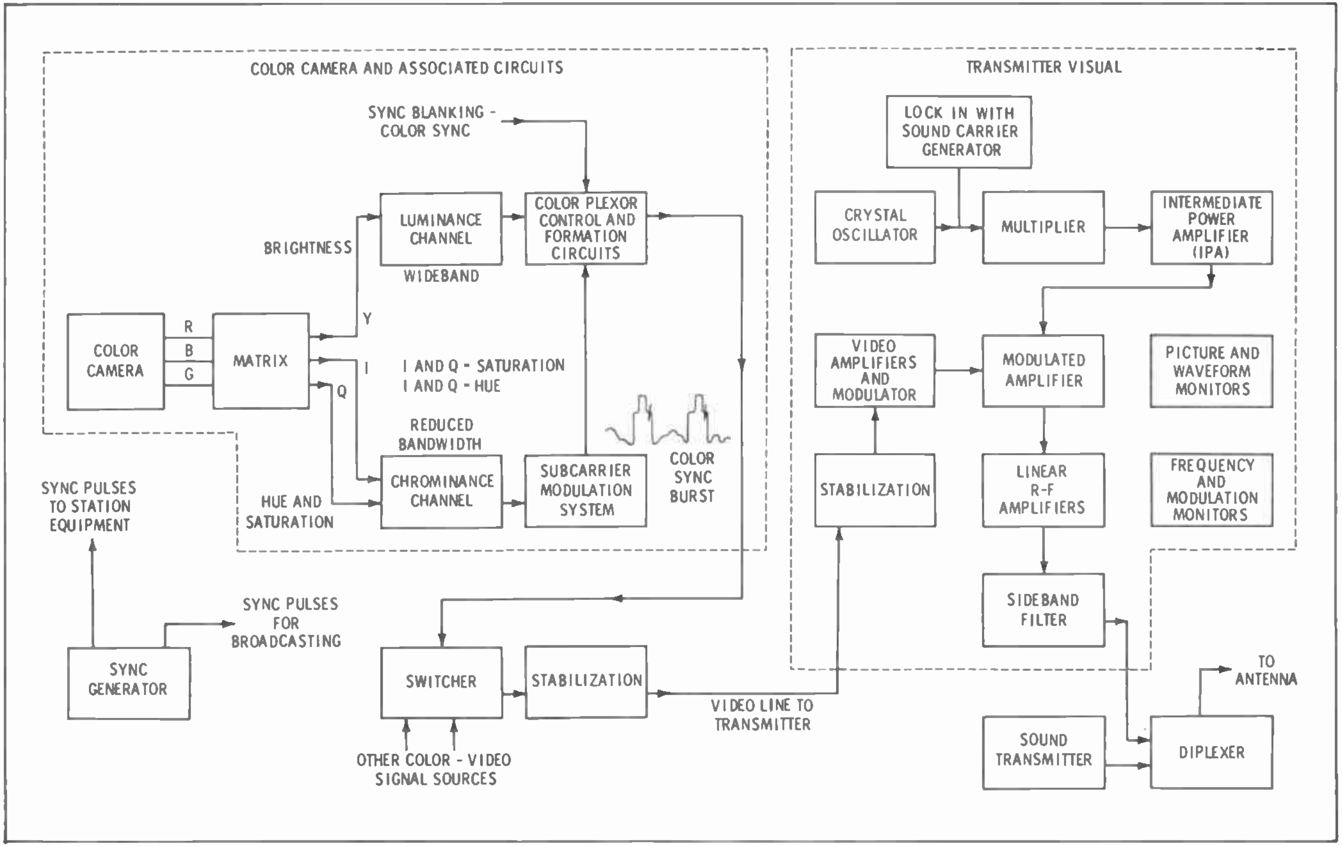


Fig. 17-3. Block diagram of color television broadcast station.

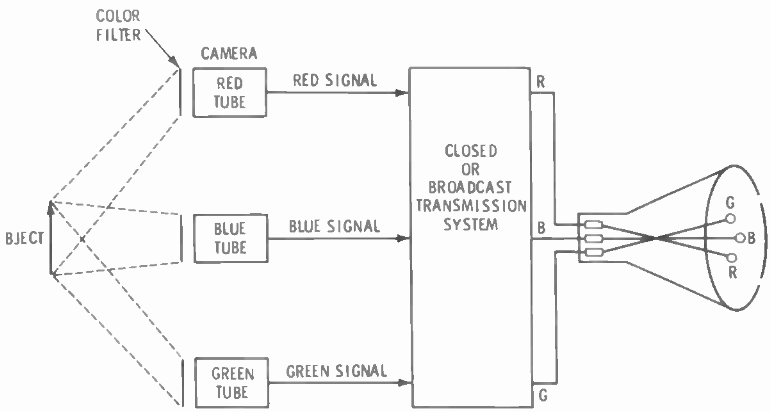


Fig. 17-4. The basics of color television.

reason a color sync burst which is located on the horizontal blanking pulse is also conveyed between the transmitter and the receivers. This color sync pulse controls the operation of the color-receiver circuits so that the individual primary color signals are channeled to their respective guns in the color picture tube.

Refer again to the functional block diagram in Fig. 17-3. To conserve bandwidth and permit the transmission of a high-quality color picture, the three primary color signals are first processed in a so-called matrix. This matrix circuit forms three individual signals—Y, I, and Q. These signals are in the proper proportions to best convey the three attributes of brightness detail, hue, and saturation. The Y signal is fundamentally a brightness detail signal (luminance signal) and it is channeled separately from the I and Q signals. It is this Y signal that, when supplied to a monochrome television receiver, will reproduce a good black and white replica of the color scene being televised. It is passed through a so-called luminance video amplifier and on to control and processing circuits.

The I and Q signal components (chrominance signal) convey the hue and saturation information about the color picture. The relative amplitude of these two signals (I and Q) determines the saturation of the color signal. Their relative phase determines the hue of the transmitted color signal. The combined I and Q signal is used to modulate the color subcarrier. This subcarrier (which has a frequency of ap-

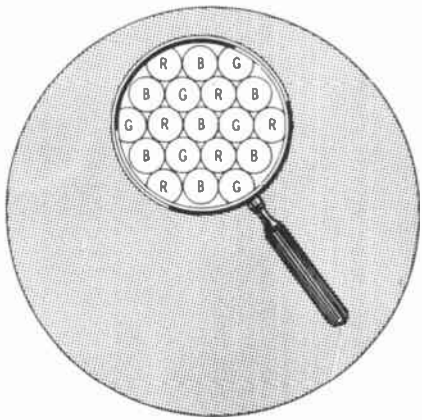


Fig. 17-5. A portion of the picture-tube screen showing the arrangement of dot trios.

proximately 3.58 MHz) frequency was selected so that a minimum of crosstalk is developed between the transmitted sidebands that convey the hue and saturation information and those that convey the brightness detail.

The luminance (Y) signal and the chrominance (I and Q) sideband signals join in the control and formation circuits. Likewise, regular sync and blanking pulses and color sync are also inserted in these stages to form a composite color television signal. The unit in which all of this color processing takes place is often referred to as a *colorplexer*. Then the composite color television signal is passed through the switcher and stabilization amplifier and on to the transmitter proper, as is done in a conventional monochrome television system.

2. Describe the scanning technique used in United States television transmission. Why is interlacing used?—The scanning process (Fig. 17-2) is known technically as a 525-line, 2-to-1 interlace system. The aspect ratio is 4:3 which means that the transmitted picture is four units wide to three units high. In the scanning process, the scanning beam scans the transmitted image from left to right and top to bottom. Thus in the scanning process, a sequence of lines is scanned beginning with line 1 and covering every odd-numbered line from the top of the scan to the bottom. The beam then retraces to the top and scans the even-numbered lines from top to bottom. Then it retraces back to the top again to begin line 1 of the next individual television scene. It is important to recognize that the scanning beam makes two vertical trips (two fields) in conveying one complete picture (frame). Thus each frame consists of two individual fields composed of odd-numbered and even-numbered lines. In one second, the television system transmits 30 individual pictures (frames). This corresponds to 60 (2×30) vertical fields. Hence, the vertical scanning rate or frequency of the television system is 60 Hz. By scanning sixty fields, that is, producing sixty interruptions per second, there is less brightness flicker than there would be with only thirty interruptions.

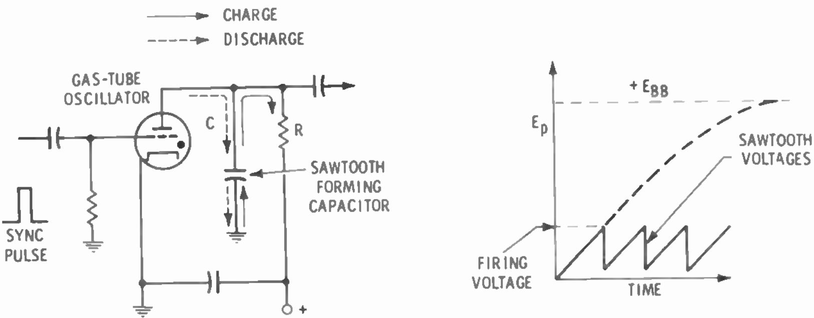
Each television picture (frame) is composed of 525 lines (262½ lines per field). However, there actually are fewer than 525 lines that carry picture information. When the scanning activity is returned from the bottom to the top of the screen (raster), a certain retrace time is required. This occupies a time interval that approximates the time needed to transmit 25 horizontal lines. Since the screen is blacked out or "blanked" during this interval, there are approximately 25 lines lost (inactive lines). Thus the picture information must be carried by approximately 500 lines (active lines).

Inasmuch as each frame is composed of 525 line periods and there are 30 frames transmitted per second, the actual line rate is 15,750 (525×30) lines transmitted per second. This is known as the "line rate" or "horizontal frequency" of the television system.

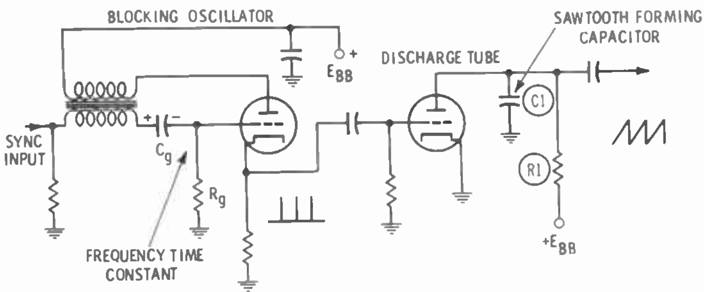
Interlacing is the process of breaking up the picture into two fields composed of even-numbered and odd-numbered lines. This technique reduces flicker and permits the transmission of a picture of a higher resolution (more lines of definition) for a given assigned bandwidth. Good continuity of motion can be obtained with thirty individual pictures per second. However, to reduce annoying brightness flicker, as a result of the blacked out retrace times between the individual thirty pictures, it is better to break up the scanning activity into 60 vertical retrace periods per second. The brightness flicker is reduced by the interlace scanning system because with two fields for each picture there are 60 brightness interruptions per second. Instead of overlapping the lines of the individual fields, the in-between or interlace scanning of the fields permits a total of 525 scanning lines instead of approximately half this number.

3. Show, by simple circuit diagrams, at least two ways of obtaining a sawtooth wave. Explain how the wave shape is formed. Where in television transmitters are sawtooth waves employed? Why?—Two ways of forming a sawtooth wave are shown in Fig. 17-6. In the first example (Fig. 17-6A) a gas discharge tube is used. The anode voltage for the gas-discharge tube is supplied via a resistor-capacitor combination. When the gas tube is nonconducting, the capacitor charges toward the supply voltage through the resistor. The time constant of the combination is such that a significant time is needed to fully charge the capacitor. When the capacitor voltage rises to a certain voltage level, the anode-cathode potential is such that the gas is fired and the tube conducts. The resistance of the conducting gas tube is very low and, consequently, the capacitor discharges through the tube very quickly. With the capacitor discharged, the anode-cathode potential is such that the gas deionizes and the tube becomes nonconducting. The capacitor again begins to charge toward the supply voltage. Again the charge reaches the firing potential of the gas tube, the tube begins to conduct, and discharges the capacitor.

It is apparent that the capacitor charges and discharges at a rate determined by the RC time constant. The discharge period is very short because the RC time constant is made very low



(A) A gas-tube oscillator.



(B) A combination blocking oscillator and discharge tube.

Fig. 17-6. Sawtooth-generating circuits.

by the low resistance of the conducting gas tube. Notice that the charging time constant of the RC combination is so long that the capacitor never fully charges. In fact, it charges only to a small percentage of the total supply voltage before the gas tube fires. This assures that the capacitor charges only over the most linear part of its charge characteristic and a so-called linear sawtooth wave is formed. The charge is linear because the sawtooth voltage rises in a straight line rather than in a exponential (curved) manner. The generated sawtooth wave of course can be amplified by succeeding stages, building it up to the level required in the deflection systems of camera and picture tubes.

The sawtooth-generating circuit can be synchronized (or triggered) by applying a positive pulse to the control grid of the gas tube. This pulse arrives at a critical time and by swinging the grid in a positive direction causes the gas in the tube to ionize. Therefore, the incoming pulse controls the instant at which the gas tube will fire and discharge its associated sawtooth capacitor. Consequently, the frequency and phase of a sawtooth wave can be made to correspond to the frequency and timing of an incoming sync pulse.

The second sawtooth-forming circuit (Fig. 17-6B) is a combination of a vacuum-tube blocking oscillator and discharge tube. In this circuit, a transformer feedback arrangement is used and any small positive swing in the grid voltage will cause an increase in the plate current and drop in plate voltage which is coupled back through the transformer to cause a further amplified rise in grid voltage. Thus the grid is rapidly driven positive until the tube reaches saturation. The grid voltage then begins to fall off and causes a resultant rise in plate voltage which is also coupled to the grid. This feedback is amplified by the tube and transformer activity and rapidly builds up to a level which will drive the control grid far beyond cut off. In so doing, a high negative charge is placed on grid capacitor C_g. The blocking tube then remains cut off until this charge has had time to discharge through the grid resistor. Since the time constant of R_gC_g is long, a significant length of time transpires before the blocking tube will once again go into conduction and initiate a new feedback cycle. The frequency of operation of the blocking tube depends mainly on the time constant of R_gC_g.

The tube conducts only during that short interval existing between the time when the grid is driven positive and when it is driven back to cutoff. During this time interval a positive pulse is developed across the cathode resistor. This positive pulse which coincides with the conducting period of the blocking tube is applied to the control grid of the followup discharge tube. This pulse causes the discharge tube to conduct and discharge any voltage that is across its plate sawtooth-forming capacitor. During the long interval of time that the blocking tube is nonconducting, the discharge tube is also nonconducting. During this relatively long period established by the R_gC_g time constant, plate capacitor C1 of the discharge tube charges toward the supply voltage, E_{bb}. However, after the charge on the grid of the blocking tube has discharged to a certain level, the blocking-tube conducts and the resulting positive cathode pulse also causes the discharge tube to conduct. The conducting discharge tube has a low resistance and the sawtooth forming capacitor C1 is discharged through the tube. The blocking tube now goes into its nonconducting period and once again the discharge tube is cut off and capacitor C1 begins to charge for the next cycle. The next conducting period of the blocking oscillator again causes a discharge of the sawtooth-forming capacitor. In this manner a sawtooth wave is developed in the output of the discharge tube.

The time constant of R1C1 is long in comparison to that of R_gC_g which establishes the blocking-tube frequency; thus, the capacitor again is permitted to charge only over the linear portion of the charging period. This produces the necessary linear rise in the sawtooth wave. The very short time constant that occurs when the discharge tube is conducting permits a very rapid discharge of the output capacitor and, therefore, a short-interval retrace period for the generated sawtooth.

Sawtooth waves are employed in the vertical and horizontal deflection systems of television camera tubes and monitor and receiver tubes. The linear rise portion of the horizontal sweep-generator sawtooth wave (having a fundamental frequency of 15,750 Hz) causes the camera tube scanning beam to move at a constant velocity from left to right across the image of the televised scene. When the beam reaches the right side of the image, the very fast retrace portion of the sawtooth interval permits a very rapid changeover in the deflection system so that very quickly the television system is ready to begin the trace of a new line of picture. Likewise, the linear rise portion of the vertical sweep-generator sawtooth (at the 60-Hz field rate) causes the beam to be moved down the image very slowly as the individual lines are being scanned. When the scanning beam reaches the bottom of the screen, the scanning activity must be returned to the top. This is accomplished during the fast retrace interval of the vertical sawtooth wave.

Similar horizontal and vertical sawtooth waves control the motion of the scanning beam of the television picture tube. The synchronizing pulses of the television system make certain that the frequency and phase of those sawtooth waves generated for the picture tube are the same as those generated to move the electron beam of the camera tube.

4. Make a sketch showing equalizing, blanking, and synchronizing pulses of a standard U.S. television transmitter.—Such a drawing is shown in Fig. 17-7. The top drawing shows two lines of video information and three horizontal sync-blanking intervals. Since the line rate is 15,750 Hz, each line period approximates 63.5 microseconds (1 ÷ 15,750). Approximately 50 microseconds of this period are allocated to the transmission of the video information for a single picture line. The remaining time (approximately ten microseconds) is allocated to the transmission of the horizontal blanking and sync pulses. The horizontal blanking pulse duration is longer than that of the sync pulse. The blanking pulse assures that all trace activities are stopped before the sync pulse comes along. The blanking pulse also permits a period of nonactivity after the sync pulse to make certain that all circuits and the scanning activity are ready for the transmission of the next line of video.

It is to be noted that the lower the amplitude of the signal the brighter is

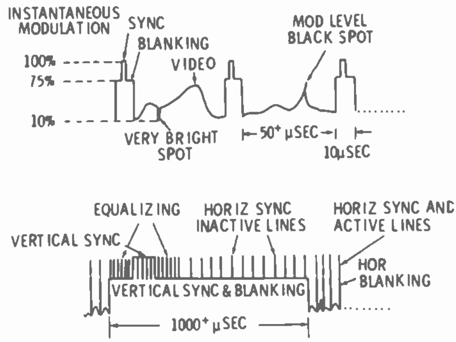


Fig. 17-7. Composite television signal.

the video data it represents. In other words a very bright spot occurs at approximately ten percent of maximum amplitude. The sync tip is referred at 100-percent amplitude. The blanking pulse occurs at about 75 percent of maximum. The blanking pulse coincides as nearly as possible with the so-called black level of the video signal. Thus the video signal information itself is confined between the 10-percent maximum brightness, or white level and the 75-percent black level. Notice that the instantaneous power output of the television transmitter is greater when transmitting black than white—this is known as *negative transmission*. Whenever a blanking pulse arrives the screen swings into darkness because the blanking pulse level is nearly coincident with the black level of the television transmission system.

The vertical blanking and sync pulses are transmitted during the vertical retrace period of the television system. This is, of course, much longer in duration and is between 1000 and 1200 microseconds. However, again before the vertical sync pulses begin, the blanking pulse has been active for an interval of time. Likewise, to provide adequate retrace time, the vertical blanking pulse persists for a substantial period after the vertical sync pulses end. A group of six equalizing pulses occurs before and immediately after the vertical sync pulses. These equalizing pulses maintain a rigid and good interlace, permitting the even-numbered lines to fit exactly between the odd-numbered lines in the interlace scanning pattern. During the vertical blanking and sync period, horizontal sync pulses are also conveyed. Therefore, control of the much faster horizontal timing is not lost during the appreciable length of time which is needed for the completion of the vertical retrace activity.

5. Make a sketch which shows the difference between blanking and synchronizing pulses used for color and those used for monochrome.—The make-up of the sync and blanking pulses is the same for color and monochrome television systems except that an additional synchronizing pulse is required for color television. This additional sync pulse is called a color sync burst (Fig. 17-8), and is added to the back porch which is the portion of the blanking pulse that follows the sync pulse. The color burst consists of at least eight cycles of the

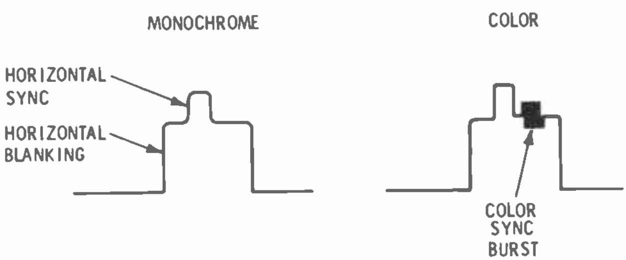


Fig. 17-8. Horizontal blanking and sync pulses for monochrome and color television.

color subcarrier signal (3.58 MHz). This color sync burst is used to synchronize the color demodulation at the receiver.

6. Explain the operation of the image-orthicon camera tube. Include in your explanation a schematic diagram of the tube which shows focusing and scanning details.—The image-orthicon schematic is given in Fig. 17-9. The image orthicon consists of three major sections—image, scanning, and multiplier. Light from the scene is picked up by an optical lens system and focused on the photosensitive photocathode surface directly behind the face of the tube. This surface emits secondary electrons (e_s) in accordance with the strength of the light pattern. These electrons are accelerated to the target surface by the accelerator grid.

The target contains hundreds of thousands of individual elements. Secondary electrons are removed from these elements in accordance with the strength of the arriving primary electrons. The displacement of secondary electrons, according to light intensity, sets up over the surface of the target a varying positive charge that corresponds to the light pattern. The charge distribution on the target is scanned by a scanning beam.

The back of the target is scanned by an electron beam, generated by the electron gun at the camera tube base. This electron beam is moved over the target surface by the horizontal and vertical deflection signals supplied to the respective deflection coils. This motion of the scanning beam is timed by the drive (sync) pulses supplied from the sync generator to the horizontal and vertical sawtooth deflection generators of the camera tube. Hence the scanning beam moves across the target surface in accordance with the standard interlace scanning pattern.

The arrangement of the gun elements and their relative voltages slows down the scanning-beam electrons to nearly zero just short of the target. The electrons return to the base of the tube except when they approach an element which has a positive charge. If an element has a positive charge when the beam is over it, the beam deposits enough electrons on the target to neutralize the positive charge. The remaining electrons return toward the gun. It is important to realize that the beam returning to the gun has been modulated because of the presence of the varying positive charges on the target. These charges have removed electrons from the beam in accordance with their individual potential. Thus as the scanning beam moves across the target element by element, the returning electron beam is modulated in a sequential manner by the light pattern impressed originally on the photo cathode.

The returning electron beam is attracted to the multiplier dynodes which surround the gun at the rear of the tube. The electron multiplier dynodes, because of their secondary emission characteristics and rising potential, amplify the video signal. Consequently, the video-signal variation at the multiplier output is substantially greater than the minute variation in the beam returning from the target surface.

The scanning beam is focused magnetically by an external focusing coil. The magnetic field is such that the scanning beam comes to a sharp focus just at the target surface. The magnetic field of the focusing coil also holds the electrons coming off the photo cathode in a straight-line path from the

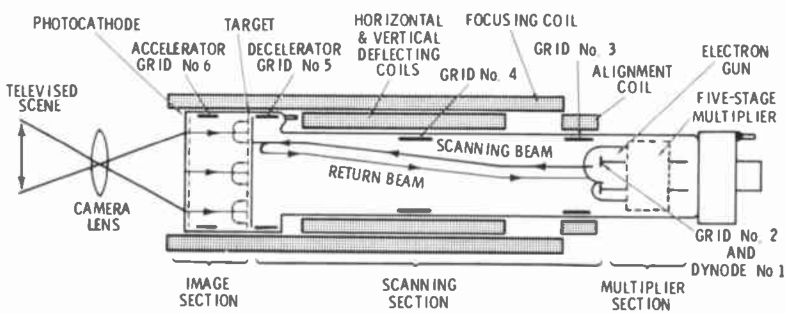


Fig. 17-9. Image-orthicon camera tube.

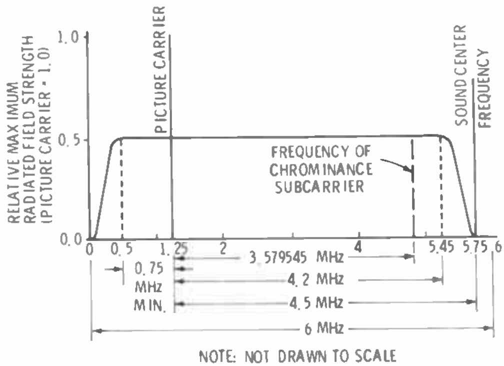


Fig. 17-10. Amplitude characteristics of ideal picture channel.

photocathode to the target surface. An alignment coil helps to maintain uniformity of focus over the entire scanning area.

7. What are the advantages and the disadvantages of the vidicon TV camera tube in comparison to the image-orthicon tube?—The vidicon is a small diameter and short length camera tube, permitting the design of a less bulky camera. In comparison to an image orthicon it has a high sensitivity and, depending upon vidicon type, no more than several hundred volts are needed for operation. Thus, the power source requirements for a vidicon in comparison to an image orthicon are simplified. The resolution capability is not as high as an image orthicon and it has a greater tendency to be sluggish when a fast change is made from one scene to another. This means that occasionally parts of a previous scene will remain on the tube photocathode surface for a short time after the camera has been focused on another scene. The associated circuits for vidicon are not as complex as those for an image orthicon. Although magnetic deflection and focusing are most often employed more recent vidicon types use electrostatic deflection and/or focus.

8. Sketch the amplitude characteristics of an idealized picture transmission of a television sketch in the United States. (See the Commission's Rules.)—Such a characteristic is shown in Fig. 17-10. Note the vestigial sideband arrangement. The picture carrier is 1.25 MHz from band edge. At low frequencies both upper and a vestige or part of the lower sideband are transmitted. However, at higher frequencies only the upper sideband is transmitted. The upper sideband spectrum must drop off very quickly at 4 MHz above the picture carrier; the sound carrier is located at 4.5 MHz above the picture carrier.

9. Explain the operation of a turnstile TV antenna.—The turnstile is the most common television broadcast antenna. Fundamentally each bay (Fig. 17-11) consists of two driven elements mounted normal to each other and driven with rf signals having a phase difference of 90°. This method permits the development of an omnidirectional horizontal radiation pattern, meaning that equal-level signals are radiated in all directions (compass angles) away from the antenna tower.

To obtain a good antenna power gain and a low-angle vertical radiation pattern a number of such bays are stacked one above the other. The vertical arrangement of bays causes the radiated signal to be sent out in the direction of the horizontal (low vertical angle) rather than skyward and directly toward the base of the tower. This means that the radiated rf energy is concentrated at an angle most suitable for tropospheric propagation, skimming over the surface of the earth where it can be intercepted by television receiving antennas.

Instead of a straight simple dipole, the turnstile antenna must be a special shape in order to provide impedance match and uniformly radiate the entire bandwidth of a television station. The bat-wing shape and the slot-type feed method of the bat-wing antenna ensures the constant impedance char-

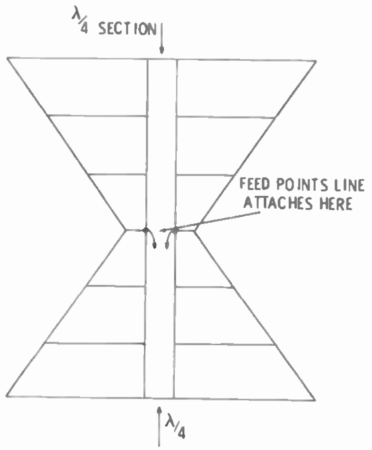


Fig. 17-11. A turnstile television antenna.

acteristic and uniform radiation needed. Each bat wing is approximately one-half wavelength in height.

10. What type of polarization is generally used in the transmission of the aural portion of television signals.—Horizontal polarization is used just as in the transmission of the video portion of the television signal. The same antenna is used to radiate both signals. The bat-wing antenna elements (or other type radiating elements) used for television are positioned and fed to provide horizontal polarization. Likewise the receiving antennas are positioned horizontally to make the best use of the incoming horizontally polarized television signal.

11. Why is a diplexer a necessary stage of most TV transmitters?—Both the sound and picture transmitter outputs are supplied to the diplexer. The output of the diplexer, in turn, feeds a single transmitting antenna. The diplexer unit provides the proper impedance match between the aural and visual transmitters and the antenna, so that a single antenna can be used to radiate both picture and sound signals. The diplexer must be designed so that there is no significant interaction and cross modulation between the picture and sound transmitters.

12. Draw a circuit diagram of a typical bridge-type diplexer used in a television transmitter for the purpose of trans-

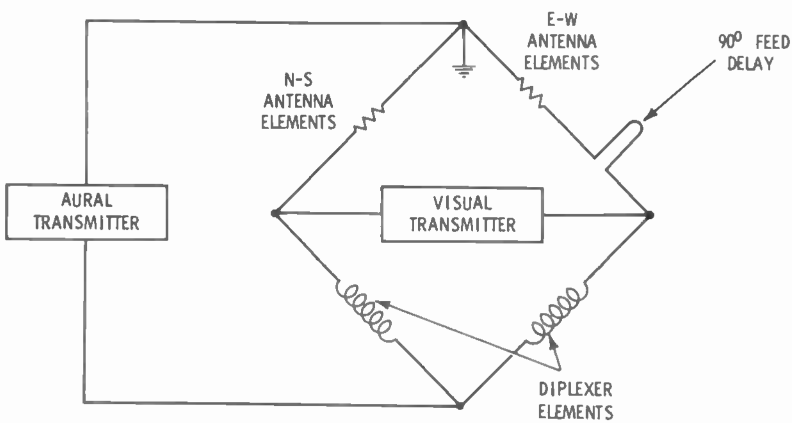


Fig. 17-12. A bridge-type diplexer feed to a television antenna.

mitting both video and audio from a turnstile antenna. — A bridge-diplexer arrangement is shown in Fig. 17-12. The impedances of turnstile elements of the antenna actually become a part of the bridge arrangement. The sound transmitter is connected across the diagonally opposite points (one point is ground) of the bridge; the picture transmitter, across the remaining diagonally opposite points of the bridge.

13. For what purpose are reflectometers or directional couplers used in television transmission systems?—The reflectometer is used to measure direct and reflected power on the transmission line that links the transmitter to the antenna. One reflectometer is positioned near the picture transmitter and another near the sound transmitter. The reflectometer includes a directional coupler which samples the rf energy present on a transmission line in accordance with direction of travel of the rf signal.

A dual-directional coupler or reflectometer arrangement can take a sample of the rf energy that is traveling between the transmitter and the antenna and another sample of any energy that might be reflected back to the transmitter from the antenna. An appropriate comparison between the two samples can be used to determine the actual standing-wave ratio on the transmission line. With suitable calibration, a reflectometer can also be used as a monitor of the rf power output of the transmitter. Reflectometers are sometimes used between the rf stages of a transmitter when there is any significant separation between the site of one unit of a transmitter and the site of a second unit, such as a high-power linear rf amplifier.

CHAPTER 18

Rules and Regulations

This chapter answers the FCC Study Guide Questions on the FCC Rules and Regulations. These questions have been grouped into a-m, fm, television, emergency, special broadcasts, and antenna categories.

18-1. LIST OF ESSENTIAL RULES

First-class radiotelephone operators at broadcast stations should be familiar with Part 73, Part 74, and Part 17 of the Commission's Rules and Regulations —especially those sections of the Rules listed below. If the same regulatory provision basically applies to standard (a-m) and fm and television broadcast stations, only the a-m section will be given.

Standard (A-M) Broadcast Stations

Sec.

73.1-73.15 Definitions
73.39 Indicating instruments; specifications.
73.40 Transmitter; design, construction, and safety-of-life requirements.
73.41 Maximum rated carrier power; tolerances.
73.42 Maximum rated carrier power; how determined.
73.43 Changes in equipment; authority for.
73.44 Other changes in equipment.
73.45 Radiating system.
73.46 Transmitter.
73.47 Equipment performance measurements.
73.51 Operating power; how determined.
73.52 Operating power; maintenance of.
73.54 Antenna resistance and reactance; how determined.

Sec.

73.55 Modulation.
73.56 Modulation monitors.
73.58 Indicating instruments.
73.59 Frequency tolerance.
73.60 Frequency monitor.
73.67 Remote-control operation.
73.72 Operation during experimental period.
73.92 Station and operator licenses; posting of.
73.93 Operator requirements.
73.95 Equipment tests.
73.96 Program tests.
73.97 Station license.
73.98 Operation during emergency.
73.111 General requirements relating to logs.
73.112 Program log.
73.113 Operating log.
73.114 Maintenance lag.
73.115 Retention of logs.
73.116 Availability of logs and records.

FM Broadcast Stations

73.254 Required transmitter performance.
73.257 Changes in equipment and antenna system.
73.261 Time of operation.
73.262 Experimental operation.
73.263 Station inspection.
73.264 Station and operator licenses; posting of.
73.265 Operator requirements.
73.267 Operating power; determination and maintenance of.
73.268 Modulation.
73.269 Frequency tolerance.
73.293 Subsidiary communications authorizations.
73.295 Operation under subsidiary communications authorizations.
73.297 Stereophonic broadcasting.
73.310 Definitions.

Television Broadcast Stations

Emergency Broadcast System

Experimental, Auxiliary, and Special Broadcast Services

Construction, Marking and Lighting of Antenna Structures

18-2. STANDARD (A-M) BROADCASTING

1. Define the following terms as they relate to standard broadcast stations—(a) standard broadcast station, (b) standard broadcast band. (c) standard broadcast channel, (d) daytime, (e) nighttime, (f) sunrise and sunset, (g) broadcast day, (h) experimental period, (i) operating power, (j) plate input power, (k) antenna power, (l) antenna current, (m) antenna resistance, (n) modulator stage, (o) modulated stage, (p) last radio stage, (q) percentage modulation (amplitude), (r) high-level modulation, (s) low-level modulation, (t) plate modulation, and (u) grid modulation.—Refer to Appendix I, Sec. 73.1 through Sec. 73.14.

2. What are the specifications of a plate-current meter in the last radio stage of a transmitter?—The meter specifications are as follows: scale length of not less than 2³⁄₁₀ inches, accuracy at least 2 percent of full-scale reading, a maximum rating such that it will not read off-scale during modulation, a scale of at least forty divisions, and a full-scale reading shall not be greater than five times the minimum normal indication. Refer to Appendix I, Sec. 73.39.

3. Under what conditions may remote reading ammeters be used to indicate antenna current?—Remote-reading antenna ammeter indications may be logged as the antenna current, or (in the case of a directional antenna system)

the common-point current and base currents. Certain specifications must be followed in accordance with the type of remote meter used and for the point of insertion of the remote meter into the antenna circuit. A remote meter must meet the same requirements as the regular antenna ammeter with respect to scale accuracy, etc. It must be inserted at the same location as the regular antenna ammeter but on the transmitter side. Calibration must be checked against the regular antenna current meter at least once a week. The meter system and associated line must be shielded and filtered. Read Sec. 73.39, Appendix I, carefully.

4. What is the maximum temperature variation at the crystal from the normal operating temperature when using X- or Y-cut crystals? When using low temperature-coefficient crystals? – The maximum permissible temperature variation is ±0.1°C when an X- or Y-cut crystal is employed and ±1.0°C for a low temperature-coefficient crystal. Refer to Appendix I, Sec. 73.40.

5. Who keeps the keys to the fence which surrounds the antenna base at a standard broadcast station? Where are the keys usually kept?—The keys must be in the possession of the operator on duty at the transmitter. Refer to Appendix I, Sec. 73.40.

6. What general nature of changes to the broadcast transmitter require Commission approval? What type of changes or alterations do not require approval? —Changes that may *not* be made without authority are the number of vacuum tubes in the last radio stage, a change to a vacuum-tube type of different power rating or class of operation, and any change in the system of modulation. Other changes of a type that do not affect the maximum power rating or operating power of the transmitter or precision of the frequency-control equipment may be made without authority. However, in the next application for renewal of license such changes which affect the information already on file shall be shown in full. Refer to Appendix I, Sec. 73.43 and Sec. 73.44.

7. What are the Commission's requirements regarding maintenance of operating power?—The operating power must be maintained as near as practicable to the licensed power and shall not exceed the limits of 5 percent above and 10 percent below. For a directional system the ratio of the antenna currents in the elements of the system must be kept within 5 percent of that specified by the terms of the license. Refer to Appendix I, Sec. 73.52.

8. What is the frequency tolerance at standard broadcast stations?—The operating frequency must be maintained within 20 Hz of the assigned frequency. Refer to Appendix I, Sec. 73.59.

9. What are the Commission's requirements concerning stations that operate their transmitters by remote controls?—Equipment must be made inaccessible to nonauthorized persons; circuits must include positive on and off control and be designed so that open circuits, short circuits, grounds, and other line faults will not actuate the transmitter; that is, any fault causing loss of such control should automatically place the transmitter in an inoperative position. A malfunction of any part of the remote-control equipment and associated line circuits which causes improper control or inaccurate meter readings shall be cause for the immediate discontinuance of remote operation. Control and monitoring equipment shall permit the licensed operator at the remote-control point to perform all the functions required by the Commission's rules. The indications of the antenna current meter and the directional-antenna current readings shall be read and entered in the operating log each half hour. Directional-antenna readings must be made at the transmitter at least once each day, and such readings must be made within two hours after the commencement of operation for each directional pattern. Study Sec. 73.67, Appendix I.

10. At what place must the station license be posted? Where must the licenses of the station operators be posted?—Such station license must be posted in a conspicuous place at the place the licensee considers to be the principal control point of the transmitter. The original license of each station operator or FCC form 759 shall be posted at the place where he is on duty as an operator. Refer to Appendix I, Sec. 73.92.

11. What are the operator's requirements at a nondirectional 10-kW standard broadcast station? At a directional 10-kW standard broadcast station? At a nondirectional 20-kW standard broadcast station?—For a directional 10-kW and a nondirectional 20-kW standard broadcast station, one or more radio operators holding a valid first-class radiotelephone operator's license shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote-control point. For a nondirectional 10-kW standard broadcast station, the routine operation of the transmitter may be performed by an operator holding a valid first-class or second-class radiotelephone or radiotelegraph operator's license or a third-class radiotelephone operator's permit which has been endorsed for broadcast station operation. Study Sec. 73.93 in Appendix I.

12. What specific equipment-performance measurements must be made on an annual basis at all standard broadcast stations? During what period of time preceding the date of filing for a renewal of the station license should such measurements be made?—These measurements are overall audio-frequency response, audio-frequency harmonic content, percentage of carrier shift, carrier hum and extraneous noises, and measurement of spurious radiation, including radio-frequency harmonics. A set of measurements must be made during a four-month period preceding the date of filing an application for renewal of station license. Study Sec. 73.47, Appendix I.

13. Explain how operating power is computed using direct measurement. Using indirect measurement. Under what conditions at a standard broadcast station may the indirect method be used?—In using the direct method, the power at the operating frequency is equal to the square of the antenna current times the antenna resistance at the point where the current is measured. Thus,

$$P = I_a^2 R_a$$

When an indirect measurement procedure is permissible, the operating power is equal to the plate input power of the last radio stage times a proper efficiency factor, F.

$$P = E_p \times I_p \times F$$

The indirect method can be employed in case of an emergency in which the licensed antenna system has been damaged, when authorized changes are being made in the antenna system, or when any change which can affect the antenna system is being made. Study Sections 73.51, 73.52, and 73.54 of Appendix I.

14. What are the Commission's requirements as to maintenance of percentage of modulation?—Percentage of modulation must be maintained as high as possible (consistent with good quality of transmission) but not more than 100 percent on negative peaks of frequent recurrence. Refer to Appendix I, Sec. 73.55. Usually, recurrent peaks should not be less than 85 percent but may be cut back to avoid objectionable loudness.

15. What should be done if the station modulation monitor becomes defective? If the frequency monitor becomes defective?—The station may be operated without the modulation monitor, pending repair for a period not in excess of 60 days provided the degree of modulation of the station shall be monitored with a cathode-ray oscilloscope or other acceptable means. Appropriate entries shall be made in the maintenance log regarding time and date of removal and restoration. The FCC engineer in charge of the radio district in which the station is located shall be notified both immediately after the modulation monitor is found to be defective and immediately after it has been repaired and placed in operation.

The same conditions apply to the loss of the frequency monitor. As a substitute for the frequency monitor, the frequency of the station shall be measured by an external source at least once each seven days and the results entered in the station's log. Study Sec. 73.56 and Sec. 73.60 of Appendix I.

16. Under what conditions may a standard broadcast station use its facilities for communication directly with individuals or other stations? What notice shall be given when a station is operating during a local emergency?—Such a station may communicate with individuals or other radio stations during a local emergency or imminent emergency. As soon as possible after the beginning of such emergency use, notice must be sent to the Commission at Washington, D.C., and to the engineer in charge of the FCC district in which the station is located. The Commission and the FCC district office must be notified immediately on cessation of such emergency operation. Complete emergency information and logs must be kept and submitted to the Commission and the district office. Read Sec. 73.98 of Appendix I.

17. How many times and when must the station's operating log be signed by an operator who goes on duty at 10 a.m. and off duty at 6 p.m.?—It must be signed twice; at 10 a.m. and at 6 p.m. Refer to Appendix I, Sec. 73.111.

18. What entries shall be made in the station's operating log? In the station's maintenance log?—Entries must include the time the station begins to supply power to the antenna, of each interruption of the carrier where restoration is not automatic, appropriate meter readings each half hour (including operating constants of the last radio stage antenna current and frequency monitor readings), and applicable entries as required for directional antenna systems, remote-control systems and automatic logging devices, plus any other entries required by the instruments of authorization. Study Sec. 73.113 of Appendix I carefully.

Weekly entries must be made in the maintenance log concerning inspection by a first-class radiotelephone operator; comparison of regular and remote-antenna current metering; and test of auxiliary transmitter. Entries must be made concerning frequency checks made independently of the station frequency-monitor, calibration check of automatic recording devices, date and time of removal and restoration of key equipment (including modulation monitor, frequency monitor, final-stage plate voltmeter, final-stage plate ammeter, base-current ammeters, and common-point ammeters), power and light inspections, and details on experimental operation, plus any other entries required by the instrument of authorization. Study Sec. 73.114 of Appendix I carefully.

19. How long must the station's operating log be kept?—For a period of two years and perhaps longer when such logs contain information concerning a disaster, investigation by the commission, and are incident to or involved in any claim or complaint. Refer to Appendix I, Sec. 73.115.

20. What information (logs and records) must be made available to an authorized Commission employee?—Program, operating and maintenance logs, required equipment-performance measurements, copy of most recent antenna resistance or common point impedance measurements, and copy of most recent field-intensity measurements to establish performance of a directional antenna. Refer to Appendix I, Sec. 73.116.

18-3. FM BROADCASTING

21. What specific equipment-performance measurements must be made on an annual basis at all fm broadcast stations?—These are audio-frequency response, audio-frequency harmonic distortion, output noise level (fm) output noise level (a-m), plus data concerning the instruments and procedures followed by the engineer making the measurements. Refer to Appendix I, Sec. 73.254.

22. During what time periods may an fm broadcast station transmit signals for testing and maintenance purposes?—Between midnight and 6:00 a.m. local standard time. Refer to Appendix I, Sec. 73.262.

23. What are the operator license requirements for fm broadcast stations?—When a station is authorized to operate with a transmitter power output in excess of 25 kW, one or more radio operators holding a valid first-class operator's license shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote-control point. When the station authorization is not in excess of 25 kW, the routine operation of the transmitter may be performed by an operator holding a valid first-class or second-class radiotelephone or radiotelegraph operator's license or a third-class radiotelephone operator's permit which has been endorsed for broadcast station operation. Only certain operations are permissible except when the station is under the immediate supervision of a first-class radiotelephone operator. Read Sec. 73.265 of Appendix I.

24. By what methods may operating power at fm broadcast stations be computed?—Direct and indirect methods can be employed. In the direct method the power output is that of the transmitter while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission-line characteristic impedance. The transmitter shall be unmodulated during this method. Using the indirect method, the operating power is the product of the final radio-stage plate voltage and plate current times an efficiency factor, F:

$$P = E_p \times I_p \times F$$

Study Sec. 73.267 of Appendix II carefully.

25. What is the allowable frequency tolerance at fm broadcast stations?—The frequency shall be maintained within 2000 Hz of the assigned center frequency. Refer to Appendix I, Sec. 73.269.

26. What is SCA? What are some possible uses of SCA?—SCA refers to Subsidiary Communications Authorization. Such a service provides a limited type of subsidiary service on a multiplex basis. Primarily the programs are of a broadcast nature but of an interest to limited portions of the public wishing to subscribe. Examples are background music, storecasting, detailed weather forecasting, and special time signals, plus material to special groups engaged in any lawful activity such as educational, professional, religious, etc. Such facilities may also be used in applications directly related to fm broadcast stations such as for relaying of broadcast material to other stations, cuing and order circuits, remote-control telemetering, and similar uses. Read Sec. 73.293 of Appendix I.

27. What items must be included in an SCA operating log?—These items are on and off times of subcarrier generator and modulation of subcarrier. Refer to Appendix II, Sec. 73.295.

28. Define the following terms as they apply to fm broadcast stations: (a) antenna power gain, (b) center frequency, (c) effective radiated power, (d) fm broadcast band, (e) fm broadcast channel, (f) fm broadcast station, (g) field strength, (h) frequency modulation, (i) frequency swing, (j) multiplex transmission, (k) percentage modulation, (l) crosstalk, (m) left signal, (n) left stereophonic channel, (o) main channel, (p) pilot subcarrier, (q) stereophonic separation, (r) stereophonic subcarrier, (s) sterephonic subchannel.—Study Sec. 73.310 of Appendix I.

29. What are the transmission standards of subsidiary communications multiplex operation?—These are that the SCA subcarrier shall be frequency-modulated. The instantaneous frequency of the subcarrier shall be held within the range of 20 to 75 kHz. The algebraic sum of the modulation of the main carrier by SCA subcarrier shall not exceed 30 percent. The total modulation of the main carrier including SCA carrier shall not exceed the limits established for fm broadcasting (Sec. 73.268). Frequency modulation of the main carrier caused by the SCA subcarrier operation in the range of 50 to 15,000 Hz shall be at least 60 dB below 100 percent modulation.

When the station is also engaged in stereophonic broadcasting, some of the above limits are scaled downward. Study Secs. 73.319 and 73.268 of Appendix I carefully.

30. What are the stereophonic transmission standards provided by the Commission's rules?—The modulating signal for the main channel shall be the sum of the left and right signals. There shall be a pilot subcarrier at 19 kHz that shall frequency-modulate the main carrier between the limits of 8 percent and 10 percent. The stereophonic subcarrier shall be the second harmonic of the pilot subcarrier and shall be amplitude-modulated. The stereophonic subcarrier itself shall be suppressed to a level less than 1-percent modulation of the main carrier. The stereophonic subcarrier shall be capable of accepting audio frequencies from 50 to 15,000 Hz, and its modulating signal shall be equal to the difference of its left and right signals. Its preemphasis characteristics should be the same as those of the main channel. Specific deviation, phase relations, and crosstalk limits must be maintained. Total modulation of the main carrier must be in compliance with Sec. 73.268. Study Sec. 73.322 of Appendix I carefully.

18-4. TELEVISION BROADCASTING

31. What are the operator requirements for television stations?—One or more operators holding a valid first-class radiotelephone operator's license shall be on duty at the place where the transmitting apparatus is located or at a remote-control point. Refer to Appendix I, Sec. 73.661.

32. What is the frequency tolerance for television stations?—The carrier frequency of the visual transmitter must be within ±1 kHz of the authorized frequency; the center frequency of the sound transmitter shall be maintained 4.5 MHz ±1 kHz above the picture carrier frequency. Refer to Appendix I, Sec. 73.668.

33. What items must be included in a television station's operating log? In its maintenance log?—Entries must be made at the time that the station begins to supply power to the antenna and the time it stops, plus an entry of each interruption of the carrier where restoration is not automatic. Appropriate meter readings must be taken at the beginning of operation and at intervals not exceeding one-half hour; these include the operating constant of the last radio stage of the sound transmitter and the transmission-line meter readings for both transmitters. Also necessary are any other entries required by the instrument of authorization with regard to indicating equipment and automatic logging equipment.

An entry must be made each week in the maintenance log regarding the frequency-measuring method (and its results) and the calibration of the automatic recording devices. Also, entries are required concerning auxiliary transmitter checks, experimental operation, and tower-light inspection. Information is required regarding the date and time of removal and restoration of certain key equipment including visual modulation monitor, aural modulation monitor, visual and aural frequency monitor, final-stage plate voltmeters of sound and picture transmitters, final plate ammeters of sound and picture transmitters, and picture and sound transmission line rf voltage, current, or power meter. Read Sec. 73.671 and Sec. 73.672 of Appendix I carefully.

34. Define the following terms as they apply to television broadcast stations: (a) aspect ratio (b) aural transmitter (c) aural center-frequency, (d) blanking level, (e) chrominance, (f) chrominance subcarrier, (g) color transmission, (h) effective radiated power, (i) field, (j) frame, (k) free-space field intensity, (l) frequency swing, (m) interlace scanning, (n) luminance, (o) monochrome transmission, (p) negative transmission, (q) peak power, (r) reference black level, (s) reference white level, (t) scanning, (u) scanning line, (v) standard television signal, (w) synchronization, (x) television broadcast band, (y) television channel, (z) television transmission standards, (aa) vestigial sideband transmission, (bb) visual transmitter power.—Study Sec. 73.681 of Appendix I.

35. How is operating power determined for the visual transmitter at a television broadcast station? For the aural transmitter?—The visual transmitter power is measured at the output terminals of the transmitter (including any vestigial sideband and harmonic filters which may be used during normal operation). The average power output is measured while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. During the measurement, the transmitter shall be modulated by only a standard synchronizing signal with blanking level set at 75 percent of peak amplitude as observed in an output monitor. The peak power output shall be the power so measured in the dummy load multiplied by the factor of 1.68.

The aural transmitter power can be measured by either the direct or the indirect method. In the direct method the power is measured at the output terminal of an unmodulated transmitter while operating into a dummy load of substantially zero reactance and resistance equal to the transmission line characteristic impedance. For the indirect method the operating power is the product of the final radio-stage plate voltage and plate current times an efficiency factor, F. Study Sec. 73.689 of Appendix I carefully.

36. Sketch the amplitude characteristics of an idealized picture transmission.—Refer to Fig. 5 of Sec. 73.399, Appendix I.

37. Draw the synchronizing waveform for television transmissions (monochrome). Be certain to show the white level, black level, blanking level, and line writing and vertical blanking interval. Where on the synchronizing waveform would the color bursts for color transmission appear?—Refer to Fig. 18-1. The color burst is mounted on the back porch of the horizontal blanking pulse as shown in Fig. 18-1. Complete standards are given in Sec. 73.682, Appendix I and Figs. 6 and 7 of Sec. 73.699, Appendix I.

18-5. EMERGENCY BROADCAST SERVICE

38. Define the following terms, which apply to the Emergency Broadcast System: (a) Emergency Broadcast System (EBS), (b) National Defense Emergency Authorization (NDEA), (c) Emergency Action Notification, (d) Emergency Action Termination, (e) Emergency Action Condition, and (f) Emergency Broadcast System Plan.—Refer to Sections 73.906 through 73.911 of Appendix I.

39. Describe the Emergency Action Notification attention signal. — The Emergency Action signal consists of cutting the transmitter carrier for five seconds, return carrier to the air for five seconds, cut the transmitter carrier for five seconds, and return the carrier to the air and broadcast a 1000-Hz steady-state tone for 15 seconds. Refer to Sec. 73.906 of Appendix I.

40. Under normal conditions all standard, fm, and television broadcast stations must make what provisions for

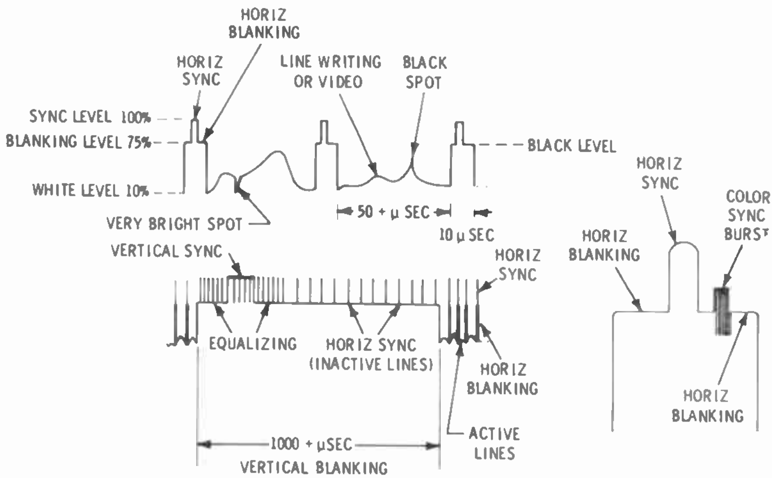


Fig. 18-1. Television waveforms.

receiving Emergency Action Notification and Terminations? — Receiving equipment must be installed to permit reception of radio broadcast messages. This equipment must be maintained in a state of readiness for reception, including arrangement for a human listening-watch (an operator assigned to this duty) or automatic alarm devices. Such equipment shall have its termination at the transmitter control point. Refer to Appendix I, Sec. 73.933.

41. What type of station identification shall be given during an emergency condition?—No broadcast of the call letters of the station shall be made during an emergency action condition. Area identification shall be given. Refer to Appendix I, Sec. 73.934.

42. Must stations operate in accordance with Section 73.57 of the Commission's rules during an Emergency Action Condition?—No, they are specifically exempt from compliance. Refer to Appendix I, Sec. 73.942.

43. How often and at what times must EBS tests be sent?—Tests are made according to the method of notification. Method 1 is twice a week; method 2 is once a week; method 3 is once a week on a random basis between 8:30 a.m. and local sunset. Refer to 73.961.

18-6. SPECIAL BROADCAST SERVICES

44. What is the uppermost power limitation imposed on remote-pickup broadcast stations? Stl stations? Intercity relay broadcast stations? — A remote-pickup broadcast station is licensed with a power output not in excess of that necessary to render satisfactory service. The license will specify this power, and in no event may it rise more than 5 percent above this specified value. The same power limitations apply to aural broadcast stl and intercity relay stations. Refer to Appendix II, Sec. 74.435 and Sec. 74.534.

45. What records of operation must be maintained for each licensed remote-pickup broadcast station? — These include hours of operation, program transmitted, frequency check, pertinent remarks concerning transmission, point of program origination, and receiver location, plus, when required, antenna structure information and illumination. Refer to Appendix II, Sec. 74.481.

46. What is the basic difference between stl and intercity relay broadcast stations?—An stl is a fixed station utilizing telephony for the transmission of all program material between a studio and the transmitter of a broadcasting station. An aural-broadcast intercity relay station is a fixed station utilizing telephony for the transmission of aural material between broadcast stations. Refer to Appendix II, Sec. 74.501.

47. What type of antenna must be used with stl and intercity broadcast stations?—Such stations must use directional antennas with a radiation pattern that is in compliance with specified

FCC limits. Refer to Appendix II, Sec. 74.536.

48. What is the frequency tolerance provided by the Commission's rules for an intercity relay broadcast station?—The frequency tolerance is ±0.005 percent of the assigned frequency. Refer to Appendix II, Sec. 74.561.

18-7. ANTENNAS

49. Under what two general conditions must antenna structures be painted and lighted?—When they require special aeronautical consideration or when they exceed 200 feet in height above the ground. Refer to Appendix III, Sec. 17.21.

50. What colors should antenna structures be painted? Where can paint samples be obtained?—They shall be painted with alternate bands of aviation-service orange and white, terminating with aviation-service orange bands at both top and bottom. Information and samples can be obtained from the General Services Administration (Washington, D.C.). Refer to Appendix III, Sec. 17.23.

51. If a tower is required to be lighted and the lights are controlled by a light-sensitive device, and the device malfunctions, when should the power lights be on?—They shall be left on continuously. Refer to Appendix III, Sec. 17.25.

52. As a general rule, a light-sensitive device used to control tower lights should face which direction? — The north sky. Refer to Appendix III, Sec. 17.25.

53. If the operation of a station's tower lights is not continuously monitored by an alarm device, how often should the lights be visually checked?—At least once every 24 hours. Refer to Appendix III, Sec. 17.47.

54. How often should automatic control devices and alarm circuits associated with antenna tower lights be checked for proper operation?—At least each three months. Refer to Appendix III, Sec. 17.47.

55. What items regarding the operation of antenna-tower lighting should be included in station maintenance logs?—These items should be the times when the tower lights are on and off each day if they are manually controlled, time of the daily check if an automatic alarm system is not provided, information about any observed or otherwise known failure of a tower light, and the date and condition of lights at the completion of each quarterly inspection. Read Sec. 17.49 of Appendix III.

56. Generally speaking, how often should the antenna tower be painted?—It should be cleaned or repainted as often as necessary to maintain good visibility. Refer to Appendix III, Sec. 17.50.

57. Is it necessary to have available replacement lamps for the station's antenna-tower lights?—Yes. Refer to Appendix III, Sec. 17.52.

58. Generally speaking, how soon after a defect in the antenna-tower lights is noted should the defect be corrected?—Replacement and repair shall be accomplished as soon as practicable. Refer to Appendix III, Sec. 17.44.

59. What action should be taken if the tower lights at a station malfunction and cannot be immediately repaired?—In case any observed or otherwise known failure of a coded rotating beacon-light or top light is not corrected within 30 minutes, it is necessary to telephone or telegraph the nearest Flight Service Station or office of the Federal Aviation Agency. Further notification shall be given immediately on resumption of the required illumination. Refer to Appendix III, Sec. 17.48.

CHAPTER 19

Experience Tests

The FCC Study Guide questions are quite diversified and many of them are very general in nature. This should be anticipated because they are planned in such a manner that they encourage the would-be licensee to attain a broad understanding of radio broadcasting. There are other factors that he should know specifically and there are a number of very direct questions in the study guide too.

The FCC examination is a multiple-choice type with the questions being very specific instead of general. Sample tests are a definite help and the licensee can gain experience with this sort of examination. At the same time they test his general knowledge and help him learn what subjects require some additional study.

The three Experience Tests (50 questions each) have been designed for this purpose. Answers are given at the end of each test. In some cases additional explanations are included. By learning what subjects give you the greatest difficulty you are guided back to review and study certain sections of the license handbook.

Space is allocated for you to choose what you consider to be the correct answer to each question. However, it is advisable that for the first or second time through each test you mark down your answers on a separate sheet. Thus in going over the test again you will not be influenced by the previous markings you may have made in the book itself.

If after the third time through the tests you can grade yourself better than 90 percent for each test, you will have come a long way in preparing yourself for the FCC license examination. Do not be discouraged if you have graded yourself very low the first time through the tests. Consider it only as necessary experience in preparing for the examination and in becoming a better-informed license holder.

19-1. EXPERIENCE TEST 1

1. What is the frequency tolerance of an fm broadcast station?
   A. ± 20 Hz. C. ± 100 Hz.
   B. ± 1 kHz. D. ± 2 kHz.

2. What is the frequency tolerance of an a-m broadcast station?
   A. ± 20 Hz. C. ± 100 Hz.
   B. ± 1 kHz. D. ± 2 kHz.

3. What is the frequency tolerance of the picture carrier of a television broadcast station?
   A. ± 20 Hz. C. ± 100 Hz.
   B. ± 1 kHz. D. ± 2 kHz.

4. The sound carrier of a television broadcast station must be kept within how many hertz of the 4.5 MHz separation from the picture carrier?
   A. ± 20 Hz. C. ± 100 Hz.
   B. ± 1 kHz. D. ± 2 kHz.

5. The frequency tolerance of an intercity relay broadcast station is
   A. 0.01%. C. 0.005%.
   B. 0.003%. D. 0.001%.

6. Nondirectional a-m stations above what minimum power level require that a first-class radiotelephone licensee be on duty?
   A. 5 kW. C. 25 kW.
   B. 10 kW. D. 50 kW.

7. The full-scale accuracy and scale length of the final plate current meter must be at least
   A. 2% and 2 3/10 inches. C. 1% and 2 1/10 inches.
   B. 2.5% and 2 inches. D. 3% and 3 3/10 inches.

8. What is maximum permissible temperature variation at the crystal for a low temperature coefficient crystal?
   A. ± 0.1°C. C. ± 1.0°C.
   B. ± 0.2°C. D. ± 0.5°C.

9. An a-m station has an assigned power of 10 kW. It can be operating on one of the following powers and not be in violation.
   A. 8.8kW. C. 11kW.
   B. 10.2kW. D. 8.95kW.

10. SCA transmission may be used to transmit
    A. political speeches to the public. C. network shows.
    B. cue signals. D. video signals.

11. In soldering a transistor into a circuit use
    A. a heat sink. C. acid-core solder.
    B. a very hot iron. D. plenty of muscle to make a good connection.

12. The current always leads in
    A. a capacitive circuit. C. a resistive circuit.
    B. an inductive circuit. D. a delta-wye circuit.

13. The peak value of a 20-volt rms sine wave is
    A. 14.14 volts. C. 40 volts.
    B. 34.64 volts. D. 28.28 volts.

14. Thermal agitation in conductors which increases with temperature produces
    A. shot-effect noise. C. resistance noise.
    B. alpha runaway. D. white noise.

15. The decibel is an expression of the magnitude of a change in sound level. What is the zero dB reference standard often used in sound broadcasting?
    A. 1 watt across 200 ohms. C. 1 watt across 600 ohms.
    B. 1 milliwatt across 600 ohms. D. 10 milliwatts across 200 ohms.

16. A cardioid unidirectional microphone pattern is useful for
    A. round-table interviews. C. sporting event commentary.
    B. stage pick-up. D. taped show announcements.

17. In a three-microphone pick-up a factor of concern is
A. overmodulation.
B. ERP.
C. phasing.
D. dynamic range.

18. An improperly positioned and dirty tape head causes
A. poor high frequency response.
B. overmodulation.
C. improper limiting.
D. wow.

19. What causes noise when an attenuator is adjusted?
A. Too fast a change in setting.
B. Agc action.
C. Sound compression.
D. Dirt.

20. Amplitude noises in an fm receiver are not suppressed by
A. an i-f limiter.
B. ratio detector.
C. Foster-Seeley discriminator.
D. proper tuning.

21. What is the modulation index when the carrier frequency is 89.1 MHz, the audio frequency is 5000 Hz, and the deviation 25.5 kHz?
A. 3.5.
B. 196.
C. ±75.
D. 5.1.

22. What factor does not influence the performance of a transmission line?
A. Condensation.
B. Dehydrator malfunction.
C. Drop in deviation.
D. Bad kink in line.

23. Determine the ERP of an fm station with a 12 kW power output, a transmission line efficiency of 90 percent and an antenna gain of 9 dB.
A. 97.2 kW.
B. 86.4 kW.
C. 9.6 kW.
D. 43.2 kW.

24. The modulation limiter of an fm transmitter does not cause
A. overmodulation.
B. peak suppression.
C. high average modulation.
D. some compression of dynamic range.

25. The vertical sweep waveform
A. is applied to the camera sync circuits.
B. moves the beam from left to right across the screen.
C. is transmitted for use at the receiver.
D. has a 60-Hz repetition rate.

26. The color sync burst
A. locks in the horizontal deflection circuits of a color receiver.
B. rides the back porch of the horizontal blanking pulse.
C. has a frequency of 67 kHz.
D. interferes with monochrome synchronization.

27. Frequency separation between the transmitted picture and sound carriers is
A. 5.75 MHz.
B. 4.5 MHz.
C. 3.58 MHz.
D. 4.2 MHz.

28. The diplexer does not
A. suppress unwanted sidebands.
B. match sound transmitter to antenna system.
C. reduce cross modulation.
D. permit use of same antenna for sound and picture.

29. The transmitted picture signal is polarized horizontally; the sound signal is polarized
A. horizontally.
B. vertically.
C. circularly.
D. for high-angle radiation.

30. What type of class-C amplifier trouble is indicated when grid current is zero and plate current is high?
A. Open filament.
B. Plate tank out of resonance.
C. Loss of screen grid voltage.
D. Loss of excitation.

31. Even though a class-C amplifier is properly tuned and excitation is normal, the plate current has been rising over a period of time. What is the possible trouble?
A. Grid-bias increase.
B. Rise in gas content.
C. Loss of emission.
D. Screen-grid voltage falling off.

32. A pi network does not
A. match impedances.
B. suppress harmonics.
C. tune to resonance.
D. require that the stage be neutralized.

33. A push-push doubler
A. requires plate neutralization.
B. has a strong third-harmonic output.
C. cannot be overmodulated.
D. has its outputs connected in parallel.

34. How would you service relay contacts?
A. File away.
B. Use an abrasive cleaner.
C. Use a burnishing tool.
D. Increase coil current of relay.

35. You are a first-class operator on duty and your frequency monitor suddenly reads off scale. What do you do?
A. Shut down transmitter.
B. Repair frequency monitor.
C. Switch over to spare crystal oscillator.
D. Notify FCC and let them know you're operating off frequency.

36. What condition indicates a fault in the operation of a class-B modulator?
A. Modulator-plate meter reading kicks up with modulation.
B. Antenna meter reading kicks up with modulation.
C. Modulator cathode-current meter reading is steady with modulation.
D. Modulated amplifier plate current is steady with modulation.

37. Plate current meter of a-m modulated amplifier kicks downward with modulation (negative carrier shift). What is most likely at fault?
A. Insufficient rf excitation.
B. Decrease in amplitude of modulating wave.
C. Crystal oscillator has drifted off frequency.
D. Parasitic oscillation.

38. What is the most likely cause of positive carrier shift?
A. Insufficient rf drive.
B. Weak modulator tube.
C. Overmodulation.
D. Oscillator drift.

39. Sustained overmodulation of an a-m transmitter is avoided with a
A. modulation monitor.
B. frequency monitor.
C. trapezoidal pattern.
D. modulation limiter.

40. What is the sideband power with 80 percent a-m modulation if carrier power is 10 kW?
A. 8 kW.
B. 3.2 kW.
C. 6.4 kW.
D. 5 kW.

41. A change occurs in your antenna system that alters antenna resistance. What steps should be taken immediately with regard to operating power?
A. Shut down station.
B. Obtain FCC approval to use indirect method of power measurement.
C. Operate for 30 days to see how things work out.
D. Notify nearest FAA office.

42. What is most likely to happen to directional antenna performance when antenna current ratio changes seriously?
A. Sky wave will depart at a higher angle.
B. Ground wave won't travel as far.
It will cause more interference in a protected city.
D. Antenna line will arc.

43. What is most likely to happen to directional antenna performance if antenna current phasing changes seriously?
A. Signal will decline in desired coverage area.
B. Antenna line will arc.
C. Ground wave won't travel as far.
D. Transmitter will overmodulate.

44. The coil on the antenna side of a T-network antenna tuner has a dominant influence
A. in reflecting a correct matching impedance to the input side.
B. tuning out the reactance of the antenna system.
C. on setting the null position of the directional pattern.
D. on obtaining a proper reading on a remote antenna meter.

45. A broadcast station operates on 610 kHz and uses a low-pass filter in the antenna line. On what frequency would this filter reduce possible interference in the a-m broadcast service?
A. 600.
B. 620.
C. 610.
D. 1220.

46. Two series-opposing coils have a total inductance of 10 mH. If their individual inductances are 8 mH and 12 mH, what is the mutual inductance?
A. 3 mH.
B. 4 mH.
C. 30 mH.
D. 15 mH.

47. What is the gain of a feedback amplifier if its gain without feedback is 200 and the *negative* feedback factor is 10 percent?
A. −10.5.
B. 9.52.
C. 20.
D. 180.

48. An audio amplifier employs a 680-ohm cathode resistor. What is the typical value of cathode capacitor needed to minimize attenuation down to 100 Hz?
A. 2.5 μF.
B. 25 μF.
C. 8 μF.
D. 300 μF.

49. A series-parallel circuit consists of a 5-ohm resistor in series with a parallel combination of a capacitor having a pure reactance of 8 ohms and an inductance with a pure reactance of 20 ohms. What is the impedance of the circuit?
A. 14.26 ohms capacitive.
B. 14.26 ohms inductive.
C. 13 ohms inductive.
D. 13 ohms capacitive.

50. A series circuit consists of a 20-ohm resistance and a 20-ohm capacitive reactance. What is total voltage if current is 1 ampere?
A. 40.
B. Infinite.
C. Zero.
D. 28.3.

19-2. ANSWERS, EXPERIENCE TEST 1

1. D.
2. A.
3. B.
4. B.
5. C. Answer is 0.005%. That of an international broadcast station is 0.003%.
6. B.
7. A.
8. C.
9. B. Output power may not be more than 5 percent higher than the assigned power.
10. B.
11. A.
12. A.
13. D.
14. C.
15. B.
16. B.

17. C.
18. A.
19. D.
20. C.
21. D. 25.5/5. Carrier frequency does not enter into the calculation.
22. C.
23. B. The input to the antenna is 90 percent of the transmitter power output, or 10.8 kW (12 × 0.9). An antenna gain of 9 dB is equivalent to an 8-fold power gain. Therefore the effective radiated power (ERP) is 86.4 kW (10.8 × 8).
24. A.
25. D.
26. B.
27. B.
28. A.
29. A.
30. D.
31. B.
32. D.
33. D.
34. C.
35. C. This is a good choice if the transmitter has a spare crystal or crystal oscillator. The sudden reading off-scale might well be a frequency monitor defect but one cannot be absolutely certain. If the new reading is the same with the new crystal in operation the trouble lies in the frequency monitor and one should look for the defect there. If the monitor must be taken out of service for a period of time, it is necessary that you notify the FCC field office.
36. C.
37. A.
38. C.
39. D.
40. B. Using the sideband power equation:

$$\text{Sideband Power} = \frac{(M)^2}{2} \times \text{Carrier Power}$$

$$\text{Sideband Power} = \frac{(0.8)^2}{2} \times 10 = 3.2 \text{ kW}$$

41. B.
42. C.
43. A.
44. A.
45. D. This is the second harmonic of the assigned station frequency.
46. A. The coils are connected series opposing. As a result the basic equation is:

$$L = L1 + L2 - 2M$$

By substitution:

$$M = \frac{8 + 12 - 10}{2} = 5$$

47. B. Use the feedback equation:

$$\text{Gain} = \frac{A}{1 - (-\beta A)}$$

By substitution:

$$\text{Gain} = \frac{200}{1 + (0.1 \times 200)} = 9.52$$

48. B. Assume that the capacitive reactance at the lower frequency must be 1/10 of the ohmic value of the cathode's resistor. As a result:

$$C = \frac{1}{2\pi f(R/10)}$$

$$C = \frac{1}{6.28 \times 100 \times 680/10} = 23.4\ \mu F$$

49. A. The circuit is capacitive because in a parallel combination of inductance and capacitance the lowest reactance has the dominant influence on the current. The net reactance of the circuit is:

$$X = \frac{-X_C \times X_L}{-X_C + X_L} = \frac{-8 \times 20}{-8 + 20} = -13\tfrac{1}{3}$$

The impedance becomes:

$$Z = \sqrt{R^2 + (-X)^2} = \sqrt{5^2 + (-13\tfrac{1}{3})^2} = 14.26 \text{ ohms}$$

50. D. The impedance of the circuit is:

$$Z = \sqrt{(20)^2 + (20)^2} = 28.3 \text{ ohms}$$

The equation for voltage is:

$$E = IZ = 1 \times 28.3 = 28.3 \text{ volts.}$$

Experience Test 1 was a very general one and drew heavily from the Study Guide Questions of a rather specific nature. If you had trouble with the first ten questions, spend considerable time going over Chapters 1 and 18 plus the Appendices. Questions 10 to 15 dealt with fundamentals and are related closely to questions covered in the early part of Chapter 14. Questions 16 to 20 dealt with audio circuits and components as covered in Chapter 14.

Questions 20 to 24 related to frequency modulation. If you had trouble concentrate on Chapters 10, 11 and 16. Television was the subject matter of Questions 25 through 29. Work a bit more with Chapters 13 and 17. Questions 30 through 45 dealt with a-m broadcasting and basic rf amplifier fundamentals. This subject matter is covered in the major subdivisions of Chapter 15. Review also Chapters 8, 9, and 12. The final group of questions are basically calculations. Comparable examples can be found in the early portion of Chapter 14.

After you have reviewed the above material and improved some of your weak subjects go on to Experience Test 2.

19-3. EXPERIENCE TEST 2

1. What amount of deviation corresponds to 100 percent modulation in the fm broadcast service?
   A. ±25 kHz.
   B. ±15 kHz.
   C. ±5 kHz.
   D. ±75 kHz.

2. What amount of deviation corresponds to 100 percent modulation in the aural transmission of a television broadcast station?
   A. ±25 kHz.
   B. ±15 kHz.
   C. ±5 kHz.
   D. ±75 kHz.

3. What type of modulation of the subcarrier is required for SCA transmissions?
   A. Regular a-m.
   B. Ssb.
   C. Fm.
   D. Dsb.

4. What type of modulation of the subcarrier is required for stereo-fm broadcasting?
   A. Regular a-m.
   B. Ssb.
   C. Fm.
   D. Dsb.

5. In the FCC-required vestigial sideband transmission for television broadcast stations
   A. The lower sideband is removed.
   B. Sidebands are passed but the carrier is removed.
   C. A part of the lower sideband is removed.
   D. The sidebands are frequency-modulated.

6. What is the time period of a broadcast day?
   A. Local sunrise to 12 midnight local time.
   B. 7:00 a.m. to 5:00 p.m.
   C. Twelve hours.
   D. Sunrise to sunset based on Greenwich Mean Time.

7. Which entry is *not* always made in the *operating* log?
   A. Final plate current.
   B. Final plate voltage.
   C. Antenna current.
   D. Every carrier interruption.

8. Which entry must *not* be made in the *maintenance* log when equipment is removed from service?
   A. Final plate current meter.
   B. Base current ammeter.
   C. Modulation limiter.
   D. Frequency monitor.

9. Tests must be made on the a-m broadcast transmitter. When can this be done?
   A. Local sunset to sunrise.
   B. Local sunrise to 9:00 a.m.
   C. Midnight to local sunrise.
   D. 4:00 a.m. to 6:00 a.m.

10. Which of the following equipment performance measurements must not be made on a yearly basis?
    A. Audio frequency response.
    B. Contour coverage.
    C. Percentage carrier shift.
    D. Audio harmonic content.

11. What is the lowest class of licensee who can make entries in the operating log of an a-m station with a nondirectional antenna and an authorized power of 5 kW?
    A. First-class radiotelephone.
    B. Second-class radiotelephone.
    C. Third-class radiotelephone.
    D. Third-class radiotelephone with broadcast endorsement.

12. How does modulation affect the reading of the antenna ammeter in fm broadcasting?
    A. Swings upward.
    B. Steady.
    C. Swing downward.
    D. Swings up and down.

13. Tones of equal amplitude but frequencies of 1000 and 5000 Hz are applied to the input of an fm transmitter. If the deviation caused by the 1000-Hz tone is ±20 kHz, what will be the deviation caused by the 5000-Hz tone?
    A. Same.
    B. Higher.
    C. Lower.
    D. An illegal amount.

14. An fm transmitter has an output efficiency of 80 percent and operates with a dc input to the final of 15 kW. What is the ERP if the antenna power gain is 8 and the transmission line loss is 3 dB?
    A. 48 kW.
    B. 60 kW.
    C. 75 kW.
    D. 30 kW.

15. What is the most the pilot frequency can deviate the output of a stereo-fm broadcast station?
    A. ±75 kHz.
    B. ±6 kHz.
    C. ±7.5 kHz.
    D. ±25 kHz.

16. How many complete pictures or frames are transmitted by a television broadcast station?
    A. 30.
    B. 60.
    C. 24.
    D. 48.

17. What is the horizontal line rate for monochrome (black-white) television broadcasting?
    A. 30.
    B. 60.
    C. 15,750.
    D. 31,500.

18. What is the line or field rate for monochrome (black-white) television broadcasting?
    A. 30.
    B. 60.
    C. 15,750.
    D. 31,500.

19. What happens during the linear rise of the television horizontal sweep sawtooth?
    A. Scanning beam is retraced.
    B. Horizontal blanking pulses are sent.
    C. A line of picture is scanned.
    D. Positive transmission occurs.

20. Give the number of scanning lines in the television broadcast system.
    A. 262½.
    B. 525.
    C. 500.
    D. 15,750.

21. What characteristic *is not* appropriate to a dynamic microphone?
    A. High and low impedance.
    B. Moving coil in magnetic field.
    C. Good output.
    D. Limited frequency response.

22. What is the gain of a triode amplifier stage when μ, r_p and R_L are 20, 75,000 and 50,000 ohms respectively?
A. 12.
B. 8.
C. 37.5.
D. 18.75.

23. Three cascade audio stages have voltage gains of 20, 10 and 5. What is the overall gain in dB?
A. 1000.
B. 10.
C. 60.
D. 40.

24. Audio output stage has a power gain of 10 dB. What is required power input to obtain 20 watts out?
A. 1.
B. 2.
C. 0.632.
D. 1.55.

25. What is an advantage of degenerative feedback?
A. More gain.
B. Higher output impedance.
C. Better frequency response.
D. Greater stability.

26. The output voltage of an amplifier increases from 4 to 8 volts. What is the dB rise?
A. 2.
B. 3.
C. 6.
D. 9.

27. The output power of an amplifier increases from 4 to 8 watts. What is the dB rise?
A. 2.
B. 3.
C. 6.
D. 9.

28. Your VU meter is set for a 0 dB reference level (1 milliwatt across 600 ohms). What would be the most likely change required to set the level for +4 dBm zero reference?
A. Insert amplifier.
B. Use attenuator pad.
C. Shunt resistor across the meter.
D. Reset needle of meter.

29. The VU meter of Question 28 is now being used at the output of an amplifier feeding the phone line. Audio signal is driving output up to +3 dB. What defect could arise?
A. Amplifier burn-out.
B. Crosstalk.
C. Distortion.
D. Meter burn-out.

30. What would you do in the situation of Question 29?
A. Reset an earlier gain control.
B. Readjust desensitizing pad of VU meter.
C. Patch around VU meter.
D. Use more amplifier compression.

31. What fault does a carrier-shift indicator disclose?
A. Shift in carrier frequency with modulation.
B. Undermodulation.
C. Shift in power output with modulation.
D. Asymmetrical modulation.

32. Your a-m transmitter develops negative carrier shift. Which of the following should you be certain to check?
A. Grid current of modulated amplifier.
B. Modulation limiter.
C. Crystal-oven temperature.
D. Frequency monitor.

33. You are switching from daytime nondirectional pattern to nighttime directional pattern. One of the remote antenna tower current meters reads zero. What should you do?
A. Operate nondirectional.
B. Wait for one-half hour to see what develops.
C. Shut station down.
D. Check phase monitor.

34. The normal without modulation dc plate current to the modulated amplifier of an a-m transmitter is 420 milliamperes. What would be the reading with modulation indicating maximum permissible positive carrier shift?
   A. 441.
   B. 400.
   C. 425.
   D. 415.

35. What does loop-current ratio reading of a phase monitor indicate?
   A. SWR.
   B. Ratio of tower current to reference tower current.
   C. Phase angle.
   D. Total current to all towers.

36. What does phase angle reading of phase monitor indicate?
   A. Angle between tower current and reference tower current.
   B. Ratio of tower current to reference tower current.
   C. Angle between tower current and tower voltage.
   D. Ratio of tower current to total current.

37. The deviation reading on the monitor of your fm transmitter installation climbs toward 1000 Hz. What would be a logical step to take?
   A. Wait and see what develops.
   B. Don't be concerned because maximum permissible deviation is ±75 kHz.
   C. Check reference and modulator oscillator currents.
   D. None, a normal condition.

38. The modulation reading on the monitor of your fm transmitter installation begins to read considerably lower than normal. Transmitter operating constants are normal. What would be a logical first step?
   A. Check fm exciter constants.
   B. Check audio level at convenient point ahead of the transmitter.
   C. Check deviation meter.
   D. Check transmitter reflectometer.

39. The dc plate current of the a-m modulated amplifier has been falling off slowly with grid current normal. With modulation there is a slight negative carrier shift. What is the likely trouble?
   A. Weak drive from exciter.
   B. Poor power supply regulation.
   C. Weak modulator tube.
   D. Weak modulated amplifier tube.

40. The SWR on the reflectometer at the output of a TV transmitter suddenly reads high. What is the first action that should be taken?
   A. Shut down transmitter.
   B. Run out and look for a line or antenna fault.
   C. Wait a half hour to see what develops.
   D. None, a normal condition with modulation.

41. The plate current of the final amplifier of an fm transmitter does not change with modulation. What action should be taken?
   A. None, a normal condition.
   B. Check for presence of modulating wave at input of transmitter.
   C. Check modulation monitor.
   D. Check rf exciter operating constants.

42. The dc plate current of the modulated amplifier of a TV transmitter changes with modulation. What is the possible fault?
   A. No fault.
   B. Lack of rf excitation.
   C. Asymmetrical modulation.
   D. Loss of dc level in modulator.

43. How does a decline in rf excitation affect the grid-current reading of the usual tube class-C amplifier?
   A. Stays same.
   B. Drops.
   C. Rises.
   D. Fluctuates.

44. How does a decline in rf excitation affect the base current of a common-emitter class-C amplifier?
A. Stays same.
B. Drops.
C. Rises.
D. Fluctuates.

45. How does a decline in rf excitation affect the plate current reading of a class-C amplifier?
A. Stays same.
B. Drops.
C. Rises.
D. Fluctuates.

46. How does a decline in rf excitation affect the collector current of a common-emitter class-C amplifier?
A. Stays same.
B. Drops.
C. Rises.
D. Fluctuates.

47. How does an increase in modulation affect the resting dc plate or cathode currents of a class-B modulator?
A. Stays same.
B. Decreases.
C. Increases.
D. One up and the other down.

48. The rf power amplifiers of an fm transmitter are operated
A. Class-C.
B. Class-B.
C. Class-AB.
D. Class-A.

49. An alarm sounds telling you the lights have gone off on the station's 300-foot tower. What do you do?
A. Wait until daylight.
B. Call nearest flight service office or FAA immediately.
C. Give yourself one-half hour to find trouble and then call FAA.
D. Turn on your building spot lights and swing them upward.

50. What would you use to check the frequency response of a tape player?
A. Stroboscopic disc.
B. Audio oscillator.
C. Test tape.
D. Bias oscillator and VU meter.

19-4. ANSWERS, EXPERIENCE TEST 2

1. D.
2. A.
3. C.
4. D. Double-sideband transmission with carrier suppressed.
5. C.
6. A.
7. D. At times the carrier may be interrupted briefly because of an overload and the transmitter recycled back on the air automatically. Such an interruption need not be entered.
8. C.
9. C.
10. B.
11. D.
12. B.
13. B. Pre-emphasis is used in commercial fm broadcasting. As a result, a higher frequency audio component of the same magnitude produces a greater deviation.
14. A. A 3-dB transmission line loss reduces the 12 kW output of the transmitter to 6 kW (the power is halved). However, the antenna power gain is 8 and, as a result, the effective radiated power is stepped up to 48 kW (8×6 kW).
ERP = (Transmitter Output Power − Power Loss in Transmission Line System) × Antenna Power Gain
15. C. The magnitude of the pilot frequency must be such that it does not result in more than a 10 percent deviation of the fm wave. Therefore,
Maximum Permissible Pilot Deviation $= 0.1 \times \pm 75\text{kHz} = \pm 7.5\text{kHz}$
16. A.
17. C.
18. B.
19. C.
20. B.
21. D.
22. B.

$$\text{Gain} = \frac{\mu R_L}{R_P + R_L} = \frac{20 \times 50K}{75K + 50K} = 8$$

23. C. The total voltage gain is 1000 ($20 \times 10 \times 5$). This corresponds to a voltage gain of 60 dB.
It is important to memorize certain dB, voltage, and power relationships. The values given in the following chart are of help. The relationships can be memorized with little difficulty. Any 10-dB rise means a 100-fold increase in power. A 20-dB rise means a 100-fold increase in voltage.

dB Gain	*Power Gain*	*Voltage Gain*
3	2	1.414
6	4	2
10	10	3.16
20	10^2 (100)	10
30	10^3 (1000)	31.6
40	10^4 (10000)	100
50	10^5 (100000)	316
60	10^6 (1000000)	1000

24. B. A 10-dB gain means the power is amplified by a factor of ten. Refer to the preceding chart. If the output watts is 20, the input required is 2 watts.
25. D.
26. C.
27. B.
28. B.
29. B.
30. A.
31. D.
32. A.
33. D. Here is a problem of determining whether the trouble is really the antenna or the remote metering installation. A quick check of the reading of the phase monitor isolates the problem. If the phase monitor is normal, the defect is in the metering system. If however, the phase monitor shows a serious fault the transmitter should be shut down and the divider and feed system to the particular tower investigated.
34. A. The FCC tolerance for carrier shift is 5 percent. A 5 percent change in the plate current meter reading would be 21 milliamperes (420×0.05). Added to the normal plate current of 420 milliamperes this becomes 441 milliamperes ($420 + 21$).
35. B. The modern phase monitor for a directional antenna system indicates the ratio of a particular tower current to a reference tower current. For a station that operates omnidirectional during daytime hours, the reference tower is quite often the daytime omni tower.
The phase angle meter of the modern phase monitor also indicates relative phase angle of a given tower current relative to the phase of the reference tower current. If more than two towers are employed, a switching arrangement permits the same measurements to be made for each of the directional towers.
36. A.
37. C. The term deviation reading can be confusing because one thinks of modulation in terms of an fm transmission system. However, the deviation as indicated by the frequency and modulation monitor represents the deviation of the center frequency from the assigned value. Thus our meter is indicating that the center frequency of the fm transmitter has risen 1000 Hz. Therefore a sensible step to take is to take a look at the reference oscillator and modulated oscillator currents. Modern fm exciters permit you to make this observation with the meter switching arrangement. Improper reading indicates a possible fault with the oscillators or the automatic frequency control system.
38. B. This type of trouble is indicating a drop in the amplitude of the modulating wave applied to the input of the transmitter. The logical step to take is to find out just where the signal level is declining or whether the signal on the incoming phone line has decreased. If the latter is the case, check with the studio to find out its output level. If that is normal, the signal decline has occurred somewhere in the common carrier lines and you will have to make a check with the phone company facility.
39. D. The nature of this fault seems to indicate a loss of emission in the tube of the modulated amplifier. A reasonably normal grid current indicates that there is proper drive to the stage. The slight negative carrier shift also indicates that the tube seems incapable of supplying the necessary peak current at the crest of a strong modulating wave.
40. A. Such a defect requires drastic action and the transmitter should be shut down. A very high SWR is

present on the line and there can be improper loading of the transmitter which could damage components. Also there is a possibility of damage to the transmission line system and associated tuners.

41. A. In an fm system the various rf amplifiers that build up the fm signal can be operated class-C. Recall that the desired information is on the fm carrier in the form of a frequency change and not an amplitude change. As a result the plate current readings will be steady whether modulation is present or not. A steady plate current reading with modulation is normal.
42. A. There may not be a fault. The modulating wave of the television signal is an asymmetrical one, and changes in dc current components occur. Therefore it is normal to observe current changes with modulation.
43. B. The grid current drawn by the class-C stage is a function of the magnitude of the exciting rf wave. If it declines, so will the grid current meter reading.
44. B. It is also true in the operation of the common-emitter rf stage. Base current is a function of the magnitude of the incoming rf wave.
45. C. The plate current rises because of the loss of the class-C bias. The exciting rf wave draws grid current which in turn develops a dc component of negative bias for the grid. If this bias declines there will be an increase in the dc component of the plate current.
46. B. In the case of a common-emitter class-C amplifier, the emitter junction must be forward biased to turn on collector current. The higher the base current, the higher is the collector current. Inasmuch as the base current depends upon the magnitude of the rf exciting wave, any such decline in rf excitation results in a drop in the collector current.
47. A. The resting dc plate and cathode current of a class-B modulator is a dc component. The dc bias is set slightly above cutoff to avoid crossover distortion. This dc resting current is drawn whether modulation is present or not. It is also independent of the strength of the normal modulating wave. During any interval of time when there is no modulation present the reading will fall back to this resting value.

    The peak plate and cathode currents are very much a function of the magnitude of the modulating wave. They increase with the strength of the modulating wave.
48. A.
49. C. According to FCC regulations a time interval of 30 minutes is alloted for repairing a defective lighting system or switching over to a spare facility. However, if the lighting is not restored in the half-hour interval it is necessary to inform the FAA.
50. C.

Experience Test 2 included many questions related to FCC Rules and Regulations and to some specific-answer questions of the Study Guide. About half of the examination was very practical, concerned with possible defects in circuits and systems of a broadcast station. They have helped to orient your thinking with regard to procedures that should be followed when faults arise. In most cases it is not a matter of digging immediately into the equipment to find a bad part but rather a logical procedure for operating the equipment when a fault is indicated with a view of continuing station operation in a legal manner while the actual fault is located and repaired or patched around.

The first eleven questions had to do with rules and regulations. If you had trouble, review Chapter 18 and the Appendices, as well as Chapters 8 through 13 which cover the various types of broadcast transmitter equipment. Questions 12 through 15 dealt mainly with fm broadcasting. If you had problems refer to Chapters 10, 11, 16, and 18. Television questions are covered in questions 16 to 20. If you did not do well, refer to Chapters 13 and 17. Questions 21 through 30 emphasized audio systems. If they were troublesome for you, review Chapters 4, 6, and 14.

The remaining questions of the test emphasized transmitters and the practical aspects of operation and localizing faults. In responding to a defect the operator must also consider legalities and they must guide him in determination of his initial steps. If you had trouble with these questions plan an extensive review of Chapters 15, 16, and 18. Do some further studying of the material covered in Chapters 8, 9, 10, 11, and 12.

19-5. EXPERIENCE TEST 3

1. What is the bandwidth separating a-m channels?
A. 5 kHz.
B. 10 kHz.
C. 15 kHz.
D. 20 kHz.

2. What is the bandwidth of an fm channel?
A. 75 kHz.
B. 100 kHz.
C. 150 kHz.
D. 200 kHz.

3. What is the bandwidth of a TV channel?
A. 4.2 MHz.
B. 6 MHz.
C. 10 MHz.
D. 12 MHz.

4. Give the designation for the type of emission used by a-m broadcast stations.
A. A1.
B. A2.
C. A3.
D. F3.

5. Give the designation for the type of emission used by fm broadcast stations.
A. A1.
B. A3.
C. F3.
D. F5.

6. Give the designation for the type of emission used by the sound transmitter of a TV station.
A. A1.
B. A3.
C. F3.
D. F5.

7. Give the designation for the type of emission used by the picture transmitter of a TV station.
A. A1.
B. A5.
C. F3.
D. F5.

8. What is the emergency action condition?
A. Time between emergency notification and emergency termination.
B. A special identification signal.
C. A grave national crisis.
D. NDEA.

9. What is the purpose of the Emergency Broadcast System?
A. Pick up marine distress signals.
B. Send out attention signals.
C. Dissemination of emergency information.
D. Monitor emergency stations.

10. Which frequency is not produced in the output when 1.53 MHz is mixed with 5.2 MHz?
A. 5.2 MHz.
B. 2.67 MHz.
C. 6.73 MHz.
D. 1.53 MHz.

11. What is the wavelength in meters of a 100-MHz frequency?
A. 3.
B. 30.
C. 3.33.
D. 0.333.

12. A 500,000-ohm resistor combined with what size capacitor results in a 75 microsecond time constant?
A. 150 pF.
B. 1.5 μF.
C. 375 pF.
D. 3.75 μF.

13. What is the resonant frequency of a 100-pF capacitor and a 1.44-microhenry inductor?
A. 13.2 MHz.
B. 14.4 MHz.
C. 66 MHz.
D. 1.33 MHz.

14. When two parallel resonant circuits such as that of Question 13 are connected in parallel what happens to the resonant frequency?
A. Doubles.
B. Halves.
C. Stays same.
D. Decreases by 50%.

15. What happens to the Q and impedance of a parallel resonant circuit when the resistance across it is decreased?
A. Rises.
B. Falls.
C. Stays same.
D. One up and one down.

16. What happens to the Q and impedance of a series resonant circuit when the series resistance is increased?
A. Rises.
B. Fall.
C. Stays same.
D. One up and one down.

17. Give the rms value of a 10-volt peak sine wave.
A. 7.07.
B. 5.
C. 6.32.
D. 14.4.

18. An a-m transmitter with a carrier power output of 10 kW is modulated 100 percent. What is the power in each sideband?
A. 1.25 kW.
B. 2.5 kW.
C. 5 kW.
D. 7.5 kW.

19. State the advantage of a VTVM in measuring voltage in critical circuits.
A. Minimum loading.
B. Ac rectification.
C. Low ohms loading.
D. High input capacity.

20. What is the advantage of a bridge circuit in measuring electronic components.
A. High impedance.
B. High accuracy.
C. Large meter face.
D. Light loading.

21. What is the power supply regulation in percent when no-load voltage is 1000 and full-load voltage is 960?
A. 4.16.
B. 9.6.
C. 4.
D. 1.04.

22. Which statement applies to power supply ripple?
A. Increases with resistive loading.
B. Is always a 60-Hz component.
C. Decreases with current demand.
D. Increases with filter capacitance.

23. What is the coefficient of coupling when the mutual inductance between two 50 μH coils is 10 μH?
A. 60.
B. 1.
C. 0.5.
D. 0.2.

24. Which statement is not true of power factor?
A. True power/apparent power.
B. Resistance/impedance.
C. Is not related to phase angle.
D. Is not relative to a dc circuit.

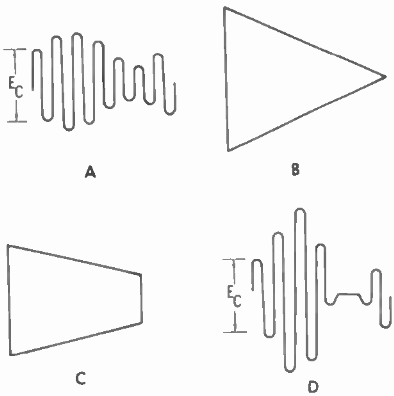
25. Determine transformer efficiency for primary voltage and current of 110 volts and 2 amperes, and secondary voltage and current of 2200 volts and 120 milliamperes.
A. 83%.
B. 17%.
C. Impossible situation.
D. 22%.

26. What is the percentage level of the blanking pulse of the composite television signal?
A. 100%.
B. 85%.
C. 75%.
D. 60%.

27. How many single-phase outputs can be derived from a three-phase wye secondary?
A. None.
B. 1.
C. 2.
D. 3.

28. A form of single-stage negative-current feedback uses
A. an unbypassed cathode resistor.
B. a series resistor and capacitor connected from plate to grid.
C. an unbypassed grid resistor.
D. Not possible.

29. Which oscilloscope pattern shows overmodulation?
A.
B.
C.
D.



30. What type of circuit is shown in Fig. 19-1?
A. Cascade voltage amplifier.
B. Sawtooth generator.
C. Multivibrator.
D. Fm limiter.

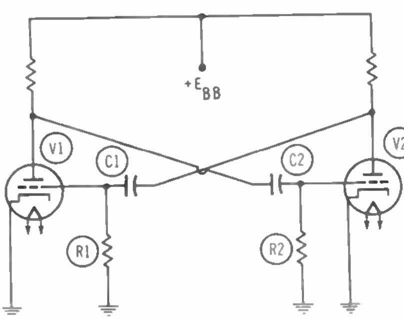


Fig. 19-1.

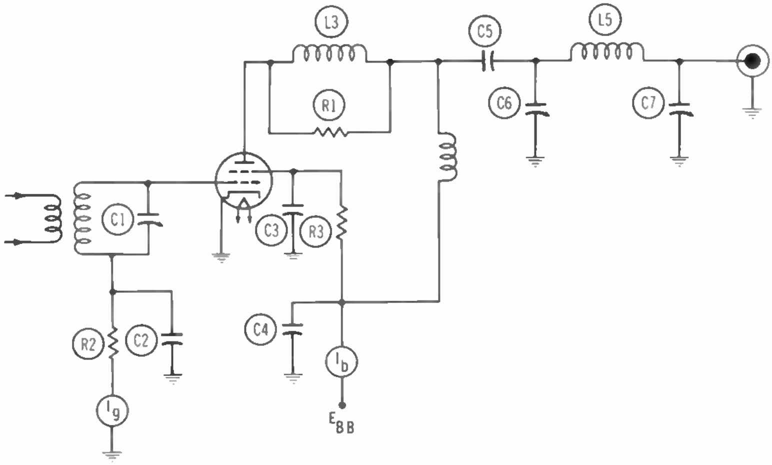


Fig. 19-2.

31. What is the purpose of R2-C2 in the circuit of Fig. 19-2?
A. Raises Q of grid resonant circuit.
B. Protects grid current meter.
C. Sets class-C bias.
D. Keeps grid circuit impedance high.

32. What is the purpose of inductor L3 in circuit of Fig. 19-2?
A. Neutralization.
B. Parasitic suppression.
C. Radio-frequency choke.
D. High-frequency peaking.

33. What is the purpose of inductor L4 in Fig. 19-2?
A. Coil of plate resonant circuit.
B. Parasitic suppression.
C. Radio-frequency choke.
D. Neutralization.

34. What is the C6, C7, and L5 combination in Fig. 19-2?
A. Modulation filter.
B. T-network.
C. Plate resonant circuit.
D. High-pass filter.

35. Capacitor C3 of Fig. 19-2 develops a short. What happens to I_b reading?
A. Rises slightly.
B. Falls.
C. Does not change.
D. Goes off scale.

36. What happens to the I_g and I_b readings in Fig. 19-2 when the rf excitation is lost?
A. Rise.
B. Fall.
C. I_g up and I_b down.
D. I_b up and I_g down.

37. What is lacking in the circuit of Fig. 19-3 for use as a fundamental class-C amplifier?
A. Bias circuit.
B. Neutralization circuit.
C. Radio-frequency choke.
D. Screen-grid capacitor.

38. If the circui of Fig. 19-3 is normal it could be used as a
A. doubler.
B. linear amplifier.
C. modulated amplifier.
D. buffer.

39. What is the type of circuit shown in Fig. 19-4?
A. Common base.
B. Common-emitter amplifier.
C. Transistor class-C amplifier.
D. Emitter-follower.

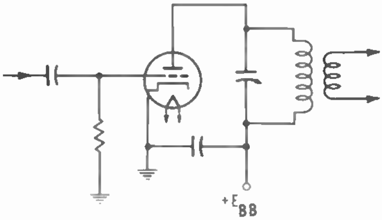


Fig. 19-3.

40. What happens to collector current when resistor R2 in Fig. 19-4 opens?
   A. Goes to zero.
   B. Falls a bit.
   C. Rises.
   D. Does not change.

41. Which of the following statements is true about Fig. 19-4?
   A. Input impedance is less than output impedance.
   B. No current gain is possible.
   C. No voltage gain is possible.
   D. Will not amplify audio frequencies.

42. The circuit of Fig. 19-5 is
   A. not used as a fundamental frequency amplifier.
   B. not practical.
   C. a frequency tripler.
   D. class-B linear amplifier.

43. What is the circuit of Fig. 19-6?
   A. Cathode follower.
   B. Grounded-grid amplifier.
   C. Phase inverter.
   D. Common-plate amplifier.

44. What fault can you find in the circuit arrangement of Fig. 19-6?
   A. There is no fault.
   B. No grid bias circuit.
   C. Forgot neutralization.
   D. Circuit has no gain.

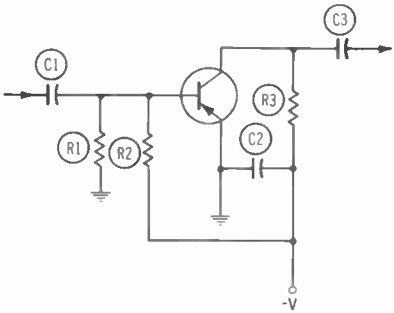


Fig. 19-4.

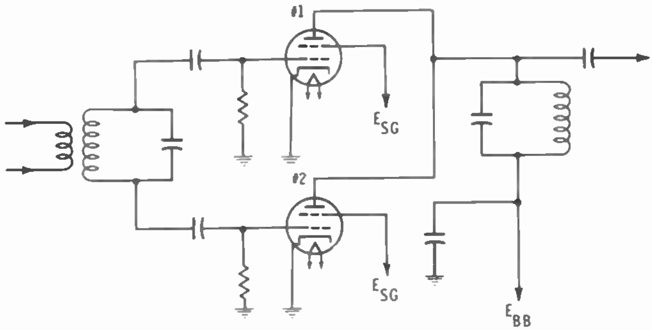


Fig. 19-5.

45. What type of circuit is shown in Fig. 19-7?
   A. Class-B linear amplifier and class-B modulator.
   B. Push-pull rf amplifier and class-B modulator.
   C. Push-push rf amplifier and class-B modulator.
   D. Single sideband modulator.

46. What is the purpose of capacitor C6 in Fig. 19-7?
   A. Rf bypass.
   B. Audio bypass.
   C. Neutralization.
   D. Negative feedback.

47. What happens to the modulated-amplifier plate voltage on a positive crest of 100% maximum modulating wave across the secondary of the modulation transformer?
   A. Rises no more than 5%.
   B. Rises near to twice the supply voltage.
   C. Falls.
   D. Holds steady.

48. What resistive load in Fig. 9-17 must the secondary of the modulation transformer work into?
   A. 300.
   B. 83⅓.
   C. 12,000.
   D. 30.

49. If amplifier efficiency is 85 percent, what is the total sideband power for 100 percent modulation?
   A. 750.
   B. 1500.
   C. 1275.
   D. 2550.

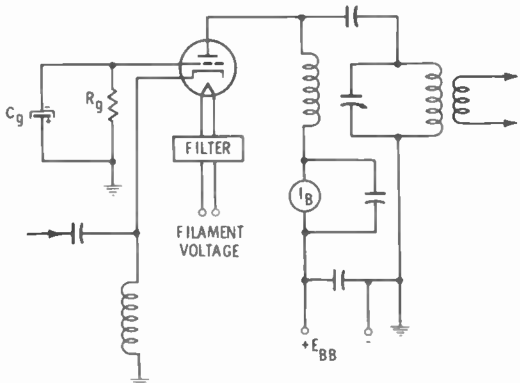


Fig. 19-6.

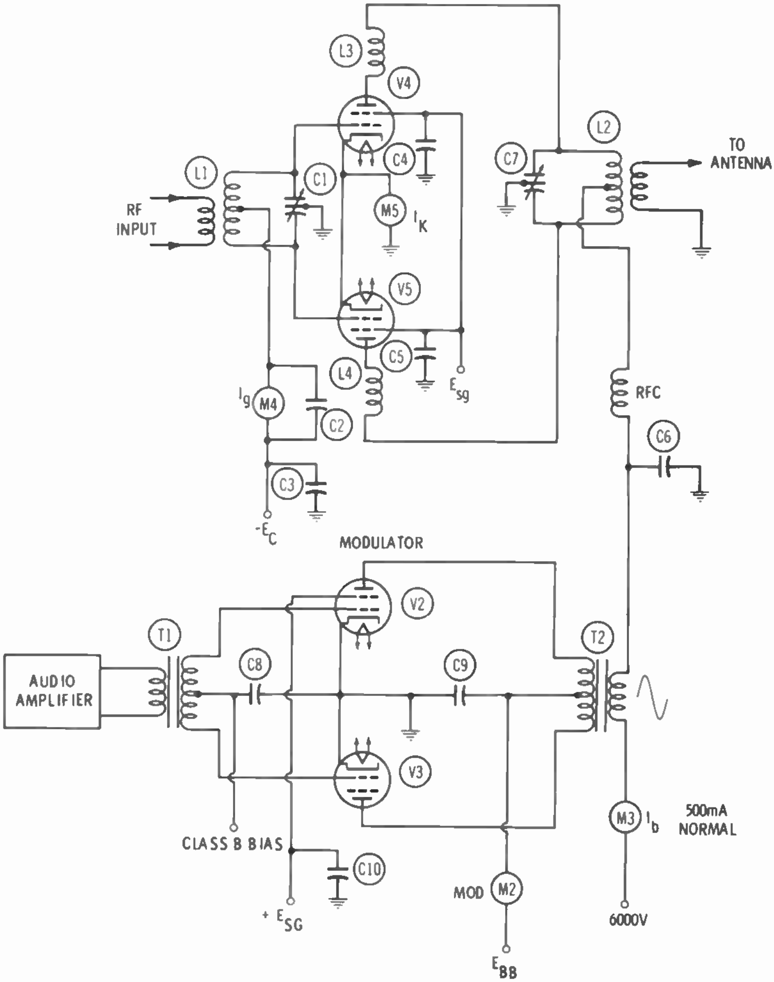


Fig. 19-7.

50. How much power is needed across the secondary of the modulation transformer to attain 100 percent modulation?
A. 1500.
B. 750.
C. 3000.
D. 1000.

19-6. ANSWERS, EXPERIENCE TEST 3

1. B.
2. D.
3. B.
4. C.
5. C.
6. C.
7. B.
8. A.
9. C.
10. B. The major frequencies produced are the two fundamental frequencies, a sum frequency and the dif-

ference frequency. The difference frequency is 3.67 MHz.

11. A.

$$\lambda \text{ in Meters} = \frac{300}{f \text{ in MHz}} = \frac{300}{100} = 3 \text{ meters}$$

12. A.

Time constant in microseconds = $R_{MEG} \times C_{pF}$

$$C_{pF} = \frac{\text{Time constant in microseconds}}{R_{MEG}} = \frac{75}{0.5} = 150 \text{ pF}$$

13. A.

$$f_o = \frac{1}{2\pi \sqrt{LC}}$$

$$f_o = \frac{1}{6.28 \sqrt{(1.44 \times 10^{-6})(100 \times 10^{-12})}} = 13.2 \text{ MHz}$$

14. C. When two parallel circuits of the same frequency are placed in parallel, the resonant frequency remains the same because inductance is halved and the capacitance is doubled.
15. B.
16. D.
17. A.
18. B. With 100 percent modulation one-fourth of the carrier power is vested in each sideband. By classic equation:

$$\text{Sideband Power} = \frac{(M)^2}{2} \times \text{Carrier Power}$$

$$\text{Sideband Power} = \frac{(1)^2}{2} \times 10 = 5 \text{ kW (both sidebands)}$$

Each sideband is one-half of the value or 2.5 kW.

19. A.
20. B.
21. A. The equation is:

$$\% \text{ Regulation} = \frac{E_{NO\ LOAD} - E_{FULL\ LOAD}}{E_{FULL\ LOAD}} = \frac{1000 - 960}{960} = 4.16\%$$

22. A.
23. D. The equation is:

$$k = \frac{M}{\sqrt{L_1 L_2}} = \frac{10}{\sqrt{50 \times 50}} = 0.2$$

24. D.
25. C. An impossible situation because you cannot derive more power output from the secondary than you apply to the primary.
26. C.
27. D.
28. A.
29. D.
30. C.
31. C.
32. B.
33. C.
34. C. Pi-network resonant circuit.
35. B. There will be no screen grid voltage which in the case of a beam tetrode or pentode controls the plate current.
36. D.
37. B.
38. A.
39. B.
40. A. This removes the base current bias and the collector current falls to zero.
41. A.
42. A.
43. B.
44. A.
45. B.
46. A. The capacitor must filter the radio-frequency only. If it were too high in value and filtered audio frequencies, the audio variations would be removed from the transmitted wave.
47. B.
48. C. The transmitter is operating with a supply voltage of 6000 volts and a plate current of 500 milliamperes. The impedance is:

$$Z = \frac{6000}{0.5} = 12{,}000 \text{ ohms}$$

49. C. The power input to the transmitter is 3000 watts (6000×0.5). The sideband input power would be one-half of this value or 1.5 kW. However, amplifier efficiency is only 85 percent and the actual transmitted sideband power is 1275 watts (0.85×1500).
50. A. The sideband power must be supplied by the modulator. This is 1500 watts. The required sideband power for 100 percent modulation is one-half of the carrier power.

Subject matter of Experience Test 3 divides between fundamentals and schematic diagrams. FCC tests include some schematics and associated questions. Pay particular attention to the schematic diagrams of Chapter 15 in the Study Guide Questions. Some diagrams are also found in Chapters 14 and 16.

The first ten questions have to do with rules and regulations. If you had trouble refer again to Chapter 18 and also to the FCC Appendices. Questions 11 through 25 are concerned mainly with electronic fundamentals. These are not all covered in Chapter 14 or the FCC Study Guide Questions for Element 4. However the FCC in preparing their tests may also draw from some of the subject matter that is a part of Element 3. Therefore, it is useful to review Element 3 although at this time you may already possess a second-class radiotelephone license. Pay particular attention to fundamentals in this review. If you possess a copy of the *Second-Class Radiotelephone License Handbook* review Chapters 7 through 10 in particular.

The remaining questions had to do with schematics and other drawings. Fundamental questions were asked with relation to these schematics. If you had trouble, pay particular attention to Chapter 15. A thorough review of class-C amplifier operation and the simple mathematics associated with amplitude modulation are helpful.

After a review period, go through the three experience tests again in exactly the same manner. As a last step of preparation sit down and take all three examinations in sequence. Use no reference materials at all. Consider yourself as being in the FCC office actually taking the tests. Aspire to a 90 percent grade on each test.

The FCC Element IV examination will consist of 50 questions; to pass you must have a grade of at least 75 percent.

APPENDIX I

Extracts From Part 73 FCC Rules and Regulations

STANDARD BROADCAST STATIONS

Definitions

SEC. 73.1 *Standard broadcast station.* The term "standard broadcast station" means a broadcasting station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 535-1605 kilohertz (kHz).

SEC. 73.2 *Standard broadcast band.* The term "standard broadcast band" means the band of frequencies extending from 535 to 1605 kHz.

SEC. 73.3 *Standard broadcast channel.* The term "standard broadcast channel" means the band of frequencies occupied by the carrier and two side bands of a broadcast signal with the carrier frequency at the center. Channels shall be designated by their assigned carrier frequencies. The 107 carrier frequencies assigned to standard broadcast stations shall begin at 540 kHz and be in successive steps of 10 kHz.

SEC. 73.4 *Dominant station.* The term "dominant station" means a Class I station, as defined in Sec. 73.21, operating on a clear channel.

SEC. 73.5 *Secondary station.* The term "secondary station" means any station except a Class I station operating on a clear channel.

SEC. 73.6 *Daytime.* The term "daytime" means that period of time between local sunrise and local sunset.

SEC. 73.7 *Nighttime.* The term "nighttime" means that period of time between local sunset and local sunrise.

SEC. 73.8 *Sunrise and sunset.* The terms "sunrise and sunset" mean, for each particular location and during any particular month, the time of sunrise and sunset as specified in the instrument of authorization.

SEC. 73.9 *Broadcast day.* The term "broadcast day" means that period of time between local sunrise and 12 midnight local time.

SEC. 73.10 *Experimental period.* The term "experimental period" means that time between 12 midnight local time and local sunrise. This period may be used for experimental purposes in testing and maintaining apparatus by the licensee of any standard broadcast station on its assigned frequency and with its authorized power, provided no interference is caused to other stations maintaining a regular operating schedule within such period. No station licensed for "daytime" or "specified hours" of operation may broadcast any regular or scheduled program during this period.

SEC. 73.11 *Service areas* (a) The term "primary service area" of a broadcast station means the area in which the groundwave is not subject to objectionable interference or objectionable fading.

(b) The term "secondary service area" of a broadcast station means the area served by the skywave and not subject to objectionable interference. The signal is subject to intermittent variations in intensity.

(c) The term "intermittent service area" of a broadcast station means the area receiving service from the groundwave but beyond the primary service area and subject to some interference and fading.

SEC. 73.12 *Portable transmitter.* The term "portable transmitter" means a transmitter so constructed that it may be moved about conveniently from place to place, and is in fact so moved about from time to time, but not ordinarily used while in motion. In the standard broadcast band, such a transmitter is used in making field intensity measurements for locating a transmitter site for a standard broadcast station. A portable broadcast station will not be licensed in the standard broadcast band for regular transmission of programs intended to be received by the public.

SEC. 73.14 *Technical definitions.* (a) *Combined audio harmonics.* The term "combined audio harmonics" means the arithmetical sum of the amplitudes of all the separate harmonic components. Root sum square harmonic readings may be accepted under conditions prescribed by the Commission.

(b) *Effective field.* The term "effective field" or "effective field intensity" is the root-mean-square (RMS) value of the inverse distance fields at a distance of 1 mile from the antenna in all directions in the horizontal plane.

(c) *Operating power.* "Operating power" is the power that is actually supplied to the radio station antenna.

(d) *Maximum rated carrier power.* "Maximum rated carrier power" is the maximum power at which the transmitter can be operated satisfactorily and is determined by the design of the transmitter and the type and number of vacuum tubes used in the last radio stage.

(e) *Plate input power.* "Plate input power" means the product of the direct plate voltage applied to the tubes in the last radio stage and the total direct current flowing to the plates of these tubes, measured without modulation.

(f) *Antenna power.* "Antenna input power" or "antenna power" means the product of the square of the antenna current and the antenna resistance at the point where the current is measured.

(g) *Antenna current.* "Antenna current" means the radio-frequency current in the antenna with no modulation.

(h) *Antenna resistance.* "Antenna resistance" means the total resistance of the transmitting antenna system at the operating frequency and at the point at which the antenna current is measured.

(i) *Modulator stage.* "Modulator stage" means the last amplifier stage of the modulating wave which modulates a radio-frequency stage.

(j) *Modulated stage.* "Modulated stage" means the radio-frequency stage to which the modulator is coupled and in which the continuous wave (carrier wave) is modulated in accordance with the system of modulation and the characteristics of the modulating wave.

(k) *Last radio stage.* "Last radio stage" means the oscillator or radio-frequency power-amplifier stage which supplies power to the antenna.

(l) *Percentage modulation (amplitude).* "Percentage modulation" with respect to an amplitude modulated wave means the ratio of half the difference between the maximum and minimum amplitudes of the amplitude-modulated wave to the average amplitude expressed in percentage.

(m) *Maximum percentage of modulation.* "Maximum percentage of modulation" means the greatest percentage of modulation that may be obtained by a transmitter without producing in its output harmonics of the modulating frequency in excess of those permitted by these regulations.

(n) *High level modulation.* "High level modulation" is modulation produced in the plate circuit of the last radio stage of the system.

(o) *Low level modulation.* "Low level modulation" is modulation produced in an earlier stage than the final.

(p) *Plate modulation.* "Plate modulation" is modulation produced by introduction of the modulating wave into the plate circuit of any tube in which the carrier frequency wave is present.

(q) *Grid modulation.* "Grid modulation" is modulation produced by introduction of the modulating wave into any of the grid circuits of any tube in which the carrier frequency wave is present.

(r) *Blanketing.* Blanketing is that form of interference which is caused by the presence of a broadcast signal of one volt per meter (v/m) or greater intensity in the area adjacent to the antenna of the transmitting station. The 1 v/m contour is referred to as the blanket contour and the area within this contour is referred to as the blanket area.

SEC. 73.15 *NARBA and the U.S./Mexican Agreement.* The term "NARBA" where used in this part means the North American Regional Broadcasting Agreement signed at Washington, D.C., November 15, 1950, which entered into force April 19, 1960, and to which the signatory countries are the Bahama Islands and Jamaica, Canada, Cuba, the Dominican Republic, and the United States of America. The term "U.S./Mexican Agreement" where used in this part means the Agreement between the United States of America and the United Mexican States concerning Radio Broadcasting in the Standard Broadcast Band, signed at Mexico, D.F., January 29, 1957, which entered into force June 9, 1961.

Equipment

SEC. 73.39 *Indicating instruments—specifications.* (a) Instruments indicating the plate current or plate voltage of the last radio stage (linear scale instruments) shall meet the following specifications:

(1) Length of scale shall be not less than 2³⁄₁₀ inches.

(2) Accuracy shall be at least 2 percent of the full scale reading.

(3) The maximum rating of the meter shall be such that it does not read off scale during modulation.

(4) Scale shall have at least 40 divisions.

(5) Full scale reading shall not be greater than five times the minimum normal indication.

(b) Instruments indicating antenna current, common point current, and base currents shall meet the following specifications:

(1) Instruments having logarithmic or square law scales.

(i) Shall meet same requirements as paragraph (a) (1), (2), (3) of this section for linear scale instruments.

(ii) Full scale reading shall not be greater than three times the minimum normal indication.

(iii) No scale division above one-third full scale reading (in amperes) shall be greater than one-thirtieth of the full scale reading. (Example: An ammeter meeting requirement (i) having full scale reading of 6 amperes is acceptable for reading currents from 2 to 6 amperes, provided no scale division between 2 and 6 amperes is greater than one-thirtieth of 6 amperes, 0.2 ampere.)

(2) Radio frequency instruments having expanded scales.

(i) These instruments shall meet same requirements as paragraph (a) (1), (2), and (3) of this section for linear scale instruments.

(ii) Full scale reading shall not be greater than five times the minimum normal indication.

(iii) No scale division above one-fifth full scale reading (in amperes) shall be greater than one-fiftieth of the full scale reading. (Example: An ammeter meeting the requirement (i is acceptable for indicating currents from 1 to 5 amperes, provided no division between 1 and 5 amperes is greater than one-fiftieth of 5 amperes, 0.1 ampere.)

(iv) Manufacturers of instruments of the expanded scale type must submit data to the Commission showing that these instruments have acceptable expanded scales, and the type number of these instruments must include suitable designation.

(c) A thermocouple type ammeter meeting the requirements of paragraph (b) of this section shall be permanently installed in the antenna circuit or a suitable jack and plug arrangement may be made to permit removal of the meter from the antenna circuit so as to protect it from damage by lighting. Where a jack and plug arrangement is used, contacts shall be made of silver and capable of operating without arcing or heating, and shall be protected against corrosion. Insertion and removal of the meter shall not interrupt the transmissions of the station. When removed from the antenna circuit, the meter shall be stored in a suitable housing at the base of the tower in which it is used. Care must be exercised in handling the meter to prevent damage which would impair its accuracy. Where the meter is permanently connected in the antenna circuit, provision may be made to short or open the meter circuit when it is not being used to measure antenna current. Such switching shall be accomplished without interrupting the transmissions of the station.

(d) Remote reading antenna ammeter(s) may be employed and the indications logged as the antenna current, or in the case of directional antenna, the common point current and base currents, in accordance with the following:

(1) Remote reading antenna, common point or base ammeters may be provided by:

(i) Inserting second thermocouple directly in the antenna circuit with remote leads to the indicating instrument.

(ii) Inductive coupling to thermocouple or other device for providing direct current to indicating instrument.

(iii) Capacity coupling to thermocouple or other device for providing direct current to indicating instrument.

(iv) Current transformer connected to second thermocouple or other device for providing direct current to indicating instrument.

(v) Using transmission line current meter at transmitter as remote reading ammeter. See subparagraph (7) of this paragraph.

(vi) Using indications of phase monitor for determining the antenna base currents or their ratio in the case of directional antennas, provided that the base current readings are read and logged in accordance with the provision of the station license, and provided further that the indicating instruments in the unit are connected directly in the current sampling circuits with no other shunt circuits of any nature. The meters in the phase monitor may utilize arbitrary scale divisions provided a calibration curve showing the relationship between the arbitrary scale and the scale of the base meters is maintained at the transmitter location.

(vii) Using indications of remote control equipment provided that the indicating instruments are capable of being connected directly into the antenna circuit at the same point at, but below (transmitter side) the antenna ammeter. The meter(s) in the remote control equipment may utilize an arbitrary scale division provided a calibration curve showing the relationship between the arbitrary scale and the scale of the antenna ammeter is maintained at the remote control point. The meter(s) in the remote control equipment must be calibrated once a week against the regular meter and the results thereof entered in the operating log.

(2) Remote ammeters shall be connected into the antenna circuit at the same point as, but below (transmitter side) the antenna ammeter(s), and shall be calibrated to indicate within 2 percent of the regular meter over the entire range above one-third or one-fifth full scale. See paragraphs (b) (1), (i), (iii) and (b) (2) (i), (iii) of this section.

(3) The regular antenna ammeter, common point ammeter, or base current ammeters shall be above (antenna side) the coupling to the remote meters in the antenna circuit so they do not read the current to ground through the remote meter(s).

(4) All remote meters shall meet the same requirements as the regular antenna ammeter with respect to scale accuracy, etc.

(5) Calibration shall be checked against the regular meter at least once a week.

(6) All remote meters shall be provided with shielding or filters as necessary to prevent any feed-back from the antenna to the transmitter.

(7) In the case of shunt excited antennas, the transmission line current meter at the transmitter may be considered as the remote antenna ammeter provided the transmission line is terminated directly into the excitation circuit feed line, which shall employ series tuning only (no shunt circuits of any type shall be employed) and insofar as practicable the type and scale of the transmission line meter should be the same as those of the excitation circuit feed line meter (meter in slant wire feed line or equivalent).

(8) Remote reading antenna ammeters employing vacuum tube rectifiers or semiconductor devices are acceptable, provided:

(i) The indicating instruments shall meet all the above requirements for linear scale instruments.

(ii) Data are submitted under oath showing the unit has an overall accuracy of at least 2 percent of the full scale reading.

(iii) The installation, calibration, and checking are in accordance with the requirements of this paragraph.

(9) In the event there is any question as to the method of providing the remote indication, or the accuracy of the remote meter, the burden of proof of satisfactory performance shall be upon the licensee and the manufacturer of the equipment.

(e) [Reserved]

(f) No instrument, the seal of which has been broken, or the accuracy of which is questionable, shall be employed. Any instrument which was not originally sealed by the manufacturer that has been opened shall not be used until it has been recalibrated and sealed in accordance with the following: Repairs and recalibration of instruments shall be made by the manufacturer by an authorized instrument repair service of the manufacturer or by some other properly qualified and equipped instrument repair service. In either case the instrument must be resealed with the symbol or trade-mark of the repair service and a certificate of calibration supplied therewith.

(g) Since it is usually impractical to measure the actual antenna circuit of a shunt excited antenna system, the current measured at the input of the excitation circuit feed line is accepted as the antenna current.

(h) [Reserved]

(i) The function of each instrument shall be clearly and permanently shown on the instrument itself or on the panel immediately adjacent thereto.

(j) Digital meters, printers, or other numerical readout devices may be used in addition to or in lieu of indicating instruments meeting the specifications of paragraphs (a) and (b) of this section. If a single digital device is used at the transmitter for reading and logging of operating parameters, either (1) indicating instruments meeting the above-mentioned specifications shall be installed in the transmitter and antenna circuit, or (2) a spare digital device shall be maintained at the transmitter with provision for its rapid substitution for the main device should that device malfunction. The readout of the device shall include at least three digits and shall indicate the value or a decimal multiple of the value of the parameter being read to an accuracy of at least 2 percent. The multiplier to be applied to the reading of each parameter shall be indicated at the operating position of a switch used to select the parameter for display, or on the face of an automatically printed log at least once for each calendar day.

SEC. 73.40 *Transmitter; design. construction, and safety of life requirements.* (a) *Design.* The general design of standard broadcast transmitting equipment (main studio microphone [including telephone lines, if used, as to performance only] to antenna output) shall be in accordance with the following specifications. (In cases where telephone lines are not available to give the performance as required in these specifications a relay transmitter may be authorized to supersede the lines.) For the points not specifically covered in this paragraph, the principles set out shall be followed. The equipment shall be so designed that:

(1) The maximum rated carrier power (determined by Sec. 73.42) is in accordance with the requirements of Sec. 73.41.

(2) The equipment is capable of satisfactory operation at the authorized operating power or the proposed operating power with the modulation of at least 85 to 95 percent with no more distortion than given in subparagraph (3) of this paragraph.

(3) The total audio frequency distortion from microphone terminals, including microphone amplifier, to antenna output does not exceed 5 percent harmonics (voltage measurements of arithmetical sum or r. s. s.) when modulated from 0 to 84 percent, and not over 7.5 percent harmonics (voltage measurements of arithmetical sum or r. s. s.) when modulating 85 percent to 95 percent (distortion shall be measured with modulating frequencies of 50, 100, 400, 1000, 5000 and 7500 hertz up to tenth harmonic or 16,000 Hz or any intermediate frequency that readings on these frequencies indicate as desirable).

(4) The audio frequency transmitting characteristics of the equipment from the microphone terminals (including microphone amplifier unless microphone frequency correction is included in which event proper allowance shall be made accordingly) to the antenna output does not depart more than 2 decibels (dB) from that at 1000 hertz between 100 and 5000 Hz.

(5) The carrier shift (current) at any percentage of modulation does not exceed 5 percent.

(6) The carrier hum and extraneous noise level, unweighted r. s. s. (exclusive of microphone and studio noises) over the frequency band 30 to 20,000 Hz is at least 45 dB below the level of a sinusoidal tone of 400 Hz, producing 100 percent modulation of the carrier.

(7) The transmitter shall be equipped with suitable indicating instruments in accordance with the requirements of Sec. 73.58 and any other instruments necessary for the proper adjustment and operation of the equipment.

(8) Adequate provision is made for varying the transmitter power output between sufficient limits to compensate for excessive variations in line voltage, or other factors which may affect the power output.

(9) The transmitter is equipped with automatic frequency control equipment capable of maintaining the operating frequency within the limit specified by Sec. 73.59.

(i) The maximum temperature variation at the crystal from the normal operating temperature shall not be greater than:

Plus or minus 0.1° C. when an *X* or *Y* cut crystal is employed, or

Plus or minus 1.0°C. whena low temperature coefficient crystal is employed.

(ii) Unless otherwise authorized, a thermometer shall be installed in such manner that the temperature at the crystal can be accurately measured within 0.05° C. for *X* or *Y* cut crystal or 0.5° for low temperature coefficient crystal.

(iii) It is preferable that the tank circuit of the oscillator tube be installed in the temperature controlled chamber.

NOTE: Explanations of excessive frequency deviations will not be accepted when temperature variations are in excess of the values specified.

(10) Means are provided for connection and continuous operation of approved modulation monitor and approved frequency monitor. The radio frequency energy for operation of the approved frequency monitor shall be obtained from a radio-frequency stage prior to the modulated stage unless the monitor is of such design as to permit satisfactory operation when otherwise connected and the monitor circuits shall be such that the carrier is not heterodyned thereby.

(11) Adequate margin is provided in all component parts to avoid overheating at the maximum rated power output.

(12) Any emission appearing on a frequency removed from the carrier by between 15 kHz and 30 kHz, inclusive, shall be attenuated at least 25 kHz below the level of the unmodulated carrier. Compliance with the specification will be deemed to show the occupied bandwidth to be 30 kHz or less.

(13) Any emission appearing on a frequency removed from the carrier by more than 30 kHz and up to and including 75 kHz, inclusive, shall be attenuated at least 35 dB below the level of the unmodulated carrier.

(14) Any emission appearing on a frequency removed from the carrier by more than 75 kHz shall be attenuated at least 43+ 10 Log_{10} (Power, in watts) decibels below the level of the unmodulated carrier, or 80 decibels whichever is the lesser attenuation.

(b) *Construction.* In general, the transmitter shall be constructed either on racks and panels or in totally enclosed frames protected as required by the provisions of the National Electrical Code concerning transmitting equipment at radio and television stations.

NOTE: The final stages of high power transmitters may be assembled in open frames provided the equipment is enclosed by a protective fence.

(1) Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

(2) Proper bleeder resistors or other automatic means shall be installed across all the condenser banks to remove any charge which may remain after the high voltage circuit is opened (in certain instances the plate circuit of the tubes may provide such protection; however, individual approval of such shall be obtained by the manufacturer in case of standard equipment, and the licensee in case of composite equipment).

(3) All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

(i) Commutator guards shall be provided on all high voltage rotating machinery (coupling guards on motor generators, although desirable, are not required).

(ii) Power equipment and control panels of the transmitter shall meet the above requirements (exposed 220 volt ac switching equipment on the front of the power control panels is not recommended; however, it is not prohibited).

(iii) Power equipment located at a broadcast station but not directly associated with the transmitter (not purchased as part of same), such as power distribution panels, control equipment on indoor or outdoor stations and the substations associated therewith, are not under the jurisdiction of the Commission; therefore, Sec. 73.46 does not apply.

(iv) It is not necessary to protect the equipment in the antenna tuning house and the base of the antenna with screens and interlocks, provided the doors to the tuning house and antenna base are fenced and locked at all times, with the keys in the possession of the operator on duty at the transmitter. Ungrounded fencing or wires should be effectively grounded, either directly or through proper static leaks. Lighting protection for antenna system is not specifically required but should be installed.

(v) The antenna, antenna lead-in, counterpoise (if used), etc., shall be installed so as not to present a hazard. The antenna may be located close by or at a distance from the transmitter building. A properly designed and terminated transmission line should be used between the transmitter and the antenna when located at a distance.

(4) Metering equipment. (In addition to the following requirements, instruments shall meet the requirements of sections 73.39 and 73.58.)

(i) All instruments having more than 1000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturer to operate safely with voltages in excess of 1000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

(ii) In case the plate voltmeter is located on the low potential side of the multiplier resistor with one terminal of the instrument at or less than 1000 volts above ground, no protective case is required. However, it is good practice to protect volmeters subject to more than 5000 volts with suitable over-voltage protective devices across the instrument terminals in case the winding opens.

(iii) The antenna ammeters (both regular and remote) and any other radic frequency instrument which it is necessary for the operator to read shall be so installed as to be easily and accurately read without the operator having to risk contact with circuits carrying high potential radio frequency energy.

(c) *Wiring and shielding.* (1) The transmitter panels or units shall be wired in accordance with standard switchboard practice, either with insulated leads properly cabled and supported or with rigid bus bar properly insulated and protected.

(2) Wiring between units of the transmitter, with the exception of circuits carrying radio frequency energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.

(3) Circuits carrying low level radio frequency energy between units shall be either concentric tube, two wire balanced lines, or properly shielded to prevent the pickup of modulated radio frequency energy from the output circuits.

(4) Each stage (including the oscillator) preceding the modulated stage shall be properly shielded and filtered to prevent unintentional feedback from any circuit following the modulated stage (an exception to this requirement may be made in the case of high level modulated transmitters of approved manufacture which have been properly engineered to prevent reaction).

(5) The crystal chamber, together with the conductor or conductors to the oscillator circuit, shall be totally shielded.

(6) The monitors and the radio frequency lines to the transmitter shall be thoroughly shielded.

(d) *Installation.* (1) The installation shall be made in suitable quarters.

(2) Since an operator must be on duty at the transmitter control point during operation, suitable facilities for his welfare and comfort shall be provided at the control point.

(e)[Reserved]

(f) *Studio equipment.* (1) The studio equipment shall be subject to all the above requirements where applicable except as follows:

(i) If it is properly covered by an underwriter's certificate, it will be considered as satisfying the safety requirements.

(ii) The pertinent provisions of the National Electrical Code concerning transmitting equipment at radio and television stations shall apply for voltages only when in excess of 500 volts.

(2) No specific requirements are made relative to the design and acoustical treatment. However, the studios and particularly the main studio should be in accordance with the standard practice for the class of station concerned, keeping the noise level as low as reasonably possible.

SEC. 73.41 *Maximum rated carrier power; tolerances.* The maximum rated carrier power of a transmitter shall be an even power step as recognized by the Commission's plan of allocation (250 watts, 500 watts, 1 kW, 5 kW, 10 kW, 25 25 kW, 50 kW) and shall not be less than the authorized power nor shall it be greater than the value specified in the following table:

Class of station	Maximum power authorized to station	Maximum rated carrier power permitted to be installed
Class IV	250, 500 or 1000 watts	1,000
Class III	500 or 1000 watts	1,000
	5000 watts	5,000
Class II	250, 500 or 1000 watts	1,000
	5000 or 10,000 watts	10,000
	25,000 or 50,000 watts	50,000
Class I	10,000 watts	10,000
	25,000 or 50,000 watts	50,000

SEC. 73.42 *Maximum rated carrier power, how determined.* The maximum rated carrier power of a standard broadcast transmitter shall be determined as the sum of the applicable power ratings of the vacuum tubes employed in the last radio stage.

SEC. 73.43 *Changes in equipment, authority for.* No licensee or permittee shall change, in the last radio stage, the number of vacuum tubes, nor change to vacuum tubes of different power rating or class of operation, nor shall it change the system of modulation, without authority of the Commission.

SEC. 73.44 *Other changes in equipment.* Other changes except as provided for in this subpart which do not affect the maximum power rating or operating power of the transmitter or the operation or precision of the frequency control equipment may be made at any time without authority of the Commission, but in the next succeeding application for renewal of license such changes which affect the information already on file shall be shown in full.

SEC. 73.45 *Radiating system.* (a) All applicants for new, additional, or different broadcast facilities and all licensees requesting authority to change the transmitter site of an existing station shall specify a radiating system the efficiency of which complies with the requirements of good engineering practice for the class and power of the station. (See Sections 73.186 and 73.189.)

(b) No broadcast station licensee or permittee shall change the physical height of the transmitting antenna or supporting structures, or make any changes in the radiating system which will measurably alter the radiation patterns, except upon application to and authority from the Commission.

(c) Should any changes occur which would alter the resistance of the antenna system, the licensee shall immediately make a new determination of the antenna resistance (see Sec. 73.54) and shall submit application for authority to determine power by the direct method on the basis of the new measurements. In this connection, see Sections 73.316(g) and 73.685(h).

(d) The antenna and/or supporting structure shall be painted and illuminated in accordance with the specifications supplied by the Commission pursuant to section 303 (q) of the Communications Act of 1934 as amended. (See Part 17 of this chapter, Construction, Marking, and Lighting of Antenna Structures.)

(e) The simultaneous use of a common antenna or antenna structure by more than one standard broadcast station, or by one or more standard broadcast stations and one or more stations of any other class or service may be authorized provided:

(1) Complete verified engineering data are submitted showing that satisfactory operation of each station will be obtained without adversely affecting the operation of the other station.

(2) The minimum antenna height or field intensity for each standard broadcast station concerned complies with paragraph (a) of this section.

(f) If a common tower is used for antenna and/or antenna supporting purposes by two or more licensees or permittees of standard broadcast stations or by one or more such licensees or permittees and one or more licensees or permittees of any other class or service, each permittee or licensee shall be responsible for painting and illuminating the structure when obstruction marking and lighting are required by the Commission.

SEC. 73.46 *Transmitter.* (a)The transmitter proper and associated transmitting equipment of each broadcast station shall be designed, constructed, and operated in accordance with good engineering practice in all phases not otherwise specifically included in the regulations in this subpart.

(b) The transmitter shall be wired and shielded in accordance with good engineering practice and shall be provided with safety features in accordance with the specifications concerning transmitting equipment at radio and television stations contained in the current National Electrical Code as approved by the American Standards Association.

(c) The station equipment shall be so operated, tuned, and adjusted that emissions outside of the authorized channel do not cause harmful interference to the reception of other radio stations. Standard broadcast stations employing radio transmitter type accepted after January 1, 1960 shall maintain the bandwidth occupied by their emissions in accordance with the specifications set forth in Sec. 73.40(a). Stations employing transmitters installed or type accepted prior to January 1, 1960, shall achieve the highest degree of compliance practicable with their existing equipment. In either case, should harmful interference to the reception of other radio stations occur, the licensee may be required to take such further steps as may be necessary to eliminate the interference.

(d) The audio distortion, audio frequency response, carrier hum, noise level, and other essential phases of the operation which control the external effects shall at all times conform to the requirements of good engineering practice.

SEC. 73.47 *Equipment performance measurements* (a) The licensee of each standard broadcast station shall make equipment performance measurements of authorized main and alternate main transmitters at least once each calendar year: *Provided, however,* That the dates of completion of successive sets of measurements shall be no more than fourteen months apart. One set of equipment performance measurements shall be made during the four month period preceding the filing date of the application for renewal of station license. If the same transmitter is authorized for more than one mode of operation, equipment performance measurements of this transmitter need be made only at the highest authorized power level. Equipment performance measurements for auxiliary transmitters are not required. Equipment performance measurements shall be made with equipment adjusted for normal program operation, and shall include all circuits between the main studio amplifier input and antenna output, including equalizer or correction circuits normally employed, but without compression if such amplifier is employed. The measurement program shall yield the following information:

(1) Data and curves showing overall audio frequency response from 50 to 7500 hertz (Hz) for approximately 25, 50, 85, and 100 (if obtainable) percent modulation. Family of curves should be plotted (one for each percentage above) with dB above and below a reference frequency of 1000 Hz as ordinate and audio frequency as abscissa.

(2) Data and curves showing audio frequency harmonic content for 25, 50, 85, and 100 (if obtainable) percent modulation for fundamental frequencies of 50, 100, 400, 1000, 5000, 7500 Hz (either arithmetical or root sum square values up to the tenth harmonic or 16000 Hz). Plot family of curves (one for each percentage above) with percent distortion as ordinate and audio frequency as abscissa.

(3) Data showing percentage carrier shift for 25, 50, 85, 100 percent modulation with 400 Hz tone.

(4) The carrier hum and extraneous noise level generated within the equipment, and measured throughout the audio spectrum, or by bands, referred to the level for 100 percent modulation of the carrier by a sinusoidal tone with a frequency of 400 Hz.

(5) Measurements or evidence showing that spurious radiations including radio frequency harmonics are suppressed or are not present to a degree capable of causing objectionable interference to other radio services. Field intensity measurements are preferred but observations made with a communications type receiver may be accepted. However, in particular cases involving interference or controversy, the Commission may require actual measurements.

(b) The data required by paragraph (a) of this section, together with a description of instruments and procedure, signed by the engineer making the measurements, shall be kept on file at the transmitter and retained for a period of two years, and on request shall be made available during that time to any duly authorized representative of Federal Communications Commission.

Technical Operation

SEC. 73.51 *Operating power, how determined.* (a) Except as provided in paragraph (b) of this section, the operating power shall be determined by the direct method, i.e., as the product of the antenna resistance at the operating frequency (see Sec. 73.54) and the square of the antenna current at this frequency, measured at the point where the antenna resistance has been determined.

(b) The operating power shall be determined on a temporary basis by the indirect method described in paragraphs (c) and (d) of this section, in the following circumstances: (1) In an emergency, where the authorized antenna system has been damaged by causes beyond the control of the licensee or permittee (see Sec. 73.45), or (2) pending completion of authorized changes in the antenna system, or (3) if changes occur in the antenna system or its environment which affect or appear likely to affect the value of antenna resistance or (4) if the antenna current meter becomes defective (see Sec. 73.58). Prior authorization for determination of power by the indirect method is not required. However, an appropriate notation shall be made in the operating log.

(c) (1) Operating power is determined by the indirect method of applying an appropriate factor to the plate input power, in accordance with the following formula:

$$\text{Operating power} = Ep \times Ip \times F$$

where,

Ep is the plate voltage of the final radio stage;

Ip is the total plate current of the final radio stage;

F is the efficiency factor.

(2) The value of F applicable to each mode of operation shall be entered in the operating log for each day of operation, with a notation as to its derivation. This factor shall be established by one of the methods described in paragraph (d) of this section which are listed in order of preference. The product of the plate current and plate voltage, or alternatively, the computed operating power, shall be entered in the operating log under an appropriate heading for each log entry of plate current and plate voltage.

(d) (1) If the transmitter and the power utilized during the period of indirect power determination are the same as have been authorized and utilized for any period of regular operation, the factor F shall be the ratio of such authorized power to the corresponding plate input power of the transmitter for regular conditions of operation, computed with values of plate voltage and plate current obtained from the operating logs of the station for the last week of regular operation. However, if the station has been regularly authorized for operation with directional antenna, and temporary authority has been granted for nondirectional operation with regularly authorized power, during the period that power is being determined indirectly, an adjusted factor F shall be employed, which is derived dividing the factor, as determined above, by a constant (0.925 for authorized powers of 5 kW or less; 0.95 for powers above 5 kW).

(2) If a station has not been previously in regular operation with the power authorized for the period of indirect power determination, if a new transmitter has

been installed, or if, for any other reason, the determination of the factor *F* by the method described in paragraph (d) (1) of this section is impracticable:

(i) The factor *F* shall be obtained from the transmitter manufacturer's letter or test report retained in the station's files, if such a letter or test report specifies a unique value of *F* for the power level and frequency utilized; or

(ii) By reference to the following table:

Factor (*F*)	Method of modulation	Maximum rated carrier power	Class of amplifier
0.70	Plate	0.25—1.0 kW	
.80	Plate	5 kW and over	
.35	Low level	0.25 kW and over	B
.65	Low level	0.25 kW and over	BC[1]
.35	Grid	0.25 kW and over	

[1]All linear amplifier operation where efficiency approaches that of Class-C operation.

(3) When the factor *F* is obtained from the table, this value shall be used even though the operating power may be less than the maximum rated carrier power of the transmitter.

SEC. 73.52 *Operating power; maintenance of.* (a) The operating power of each station shall be maintained as near as practicable to the licensed power and shall not exceed the limits of 5 percent above and 10 percent below the licensed power, except that in an emergency when due to causes beyond the control of the licensee it becomes impossible to operate with full licensed power, the station may be operated with reduced power for a period not to exceed 10 days: *Provided,* That the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified immediately after the emergency develops and also upon resumption of licensed power.

(b) In addition to maintaining the operating power within the above limitations, stations employing directional antenna systems shall maintain the ratio of the antenna currents in the elements of the system within 5 percent of that specified by the terms of the license or other instrument of authorization.

SEC. 73.54 *Antenna resistance and reactance; how determined.* (a) The resistance of an omnidirectional series fed antenna shall be measured at the base of the antenna, without intervening coupling networks or components. For a shunt-excited antenna, the antenna resistance shall be measured at the point when the radio frequency energy is fed to the slant wire or other feed wire circuit without intervening networks or components.

(b) The resistance and reactance of a directional antenna shall be measured at the point of common radio frequency input to the directional antenna system. The following conditions shall obtain:

(1) The antenna shall be finally adjusted for the required radiation pattern.

(2) The reactance at the operating frequency and at the point of measurement shall be adjusted to zero, or as near thereto as practicable.

(c) (1) The resistance of an antenna shall be determined by the following procedure: A series of discrete measurements shall be made over a band of frequencies extending from approximately 25 kHz below the operating frequency to approximately 25 kHz above that frequency, at intervals of approximately 5 kHz. The measured values shall be plotted on a linear graph, with frequency as the abscissa and resistance as the ordinate. A smooth curve shall be drawn through the plotted values. The resistance value corresponding to the point of intersection of the curve and the ordinate representing the operating frequency of the station shall be the resistance of the antenna.

(2) For a directional antenna, the reactance of the antenna shall be determined by a procedure similar to that described in subparagraph (1) of this paragraph.

(d) The license of a station with a directional antenna, and authorized power of 5 kilowatts or less shall specify an antenna resistance 92.5 percent of that determined at the point of common input; for a station with directional antenna and authorized power exceeding 5 kilowatts the license shall specify an antenna resistance 95 percent of that determined at the point of common input.

(e) Applications for authority to determine power by the direct method shall specify the antenna or common point resistance, and shall include the following supporting information.

(1) A full description of the method used to make measurements.

(2) A schematic diagram showing clearly all components of coupling circuits, the point of resistance measurement, location of antenna ammeter, connections to and characteristics of all tower lighting isolation circuits, static drains, and any other fixtures, sample lines, etc., connected to or supported by the antenna, including other antennas and associated circuits.

(3) Make and type of each calibrated instrument employed, manufacturer's rated accuracy, together with the date of last calibration of the instrument, the accuracy of the calibration, and the identity of the person or firm making the calibration.

(4) A tabulation of all measured data.

(5) Graph(s) plotted from this data.

(6) The qualifications of the engineer(s) making the measurements.

SEC. 73.55 *Modulation.* The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice. In no case is it to exceed 100 percent on negative peaks of frequent recurrence. Generally, it should not be less than 85 percent on peaks of frequent recurrence; but where necessary to avoid objectionable loudness modulation may be reduced to whatever level is necessary, even if the resulting modulation is substantially less than 85 percent on peaks of frequent recurrence.

SEC. 73.56 *Modulation monitors.* (a) Each station shall have in operation, either at the transmitter or at the place the transmitter is controlled, a modulation monitor of a type approved by the Commission.

NOTE: Approved modulation monitors are included on the Commission's "Radio Equipment List." Copies of this list are available for inspection at the Commission's office in Washington, D.C. and at each of its field offices.

(b) In the event that the modulation monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided*, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The degree of modulation of the station shall be monitored with a cathode ray oscilloscope or other acceptable means.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with Sec. 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is operating for such additional time as may be required to complete repairs of the defective instrument.

(d) Each station operated by remote control shall continuously, except when other readings are being taken, monitor percent of modulation or shall be equipped with an automatic device to limit percent of modulation on negative peaks to 100.

SEC. 73.58 *Indicating instruments.* (a) Each standard broadcast station shall be equipped with indicating instruments which conform with the specifications set forth in Sec. 73.39 for measuring the dc plate circuit current and voltage of the last radio frequency amplified stage; the radio frequency base current of each antenna element; and, for stations employing directional antenna systems, the radio frequency current at the point of common input to the directional antenna.

(b) In the event that any one of these indicating instruments becomes defective when no substitute which conforms with the required specifications is available, the station may be operated without the defective instrument pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided*, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the meter was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the instrument is found to be defective and immediately after the repaired or replacement instrument has been installed and is functioning properly.

(3) If the defective instrument is the antenna current meter of a nondirectional station which does not employ a remote antenna ammeter, or if the defective instrument is the common point meter of a station which employs a directional antenna, and does not employ a remote common point meter, the operating power shall be determined by the indirect method in accordance with Sec. 73.51 (c) and (d) during the entire time the station is operated without the antenna current meter or common point meter. However, if a remote antenna ammeter or a remote common point meter is employed and the antenna current meter or common point meter becomes defective, the remote meter may be used in determining operating power by the direct method pending the return to service of the regular meter, provided other meters are maintained at the same value previously employed.

(c) If conditions beyond the control of the licensee prevent the restoration of the meter to service within the above allowed period, informal request in accordance with Sec. 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

(d) Remote antenna ammeters and remote common point meters are not required; therefore, authority to operate without them is not necessary. However, if a remote antenna ammeter or common point meter is employed and becomes defective, the antenna base currents may be read and logged once daily for each mode of operation, pending the return to service of the regular remote meter.

SEC. 73.59 *Frequency tolerance.* The operating frequency of each station shall be maintained within 20 hertz of the assigned frequency.

SEC. 73.60 *Frequency monitor.* (a) The licensee of each station shall have in operation, either at the transmitter or at the place where the transmitter is controlled, a frequency monitor of a type approved by the Commission which shall be independent of the frequency control of the transmitter.

(b) In the event that the frequency monitor becomes defective the station may be operated without the monitor pending its repair or replacement for a period not in excess of 60 days without further authority of the Commission: *Provided*, That:

(1) Appropriate entries shall be made in the maintenance log of the station showing the date and time the monitor was removed from and restored to service.

(2) The Engineer in Charge of the radio district in which the station is located shall be notified both immediately after the monitor is found to be defective and immediately after the repaired or replacement monitor has been installed and is functioning properly.

(3) The frequency of the station shall be measured by an external source at least once each 7 days and the results entered in the station log.

(c) If conditions beyond the control of the licensee prevent the restoration of the monitor to service within the above allowed period, informal request in accordance with Sec. 1.549 of this chapter may be filed with the Engineer in Charge of the radio district in which the station is located for such additional time as may be required to complete repairs of the defective instrument.

SEC. 73.63 *Auxiliary transmitter.* Upon showing that a need exists for the use of an auxiliary transmitter in addition to the regular transmitter of a broadcast station, a license therefor may be issued: *Provided*, That:

(a) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(b) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(c) The auxiliary transmitter shall be maintained so that it may be placed in operation at any time for any one of the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of the regular programs during maintenance or modification work on the main transmitter necessitating discontinuance of its operation.

(3) Emergency Broadcast System operation, provided the auxiliary transmitter is used in connection with a National Defense Emergency Authorization.

(4) Upon request of a duly authorized representative of the Commission.

(5) An auxiliary transmitter may be used for the regular transmission of programs during periods of operation included in a Presunrise Service Authority (PSA).

(d) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the licensed frequency: *Provided, however,* That the test in any week may be omitted if the auxiliary transmitter has been operated during the week pursuant to paragraph (c) of this section and such operation was satisfactory. Tests while using the regular antenna shall be conducted only between 12 midnight and 9:00 a.m., local time. Tests with a dummy load may be conducted at any time.

(e) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by the regulations in this subpart.

(f) An auxiliary transmitter which is licensed at a geographical location different from that of the main transmitter shall be equipped with a frequency control which will automatically hold the frequency within the limits prescribed by the regulations in this part without any manual adjustment during operation or when it is being put into operation.

(g) The operating power of an auxiliary transmitter may be less than the authorized power, but in no event shall it be greater than such power.

(h) All regulations as to safety requirements and spurious emissions applying to broadcast transmitting equipment shall apply also to an auxiliary transmitter.

SEC. 73.64 *Alternate main transmitters.* The licensee of a standard broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown (such as licensees maintaining 24-hour schedules and needing alternate operations for maintenance, or where developmental work requires alternate operation) and that the following conditions are met:

(a) Both transmitters are located at the same place.

(b) The transmitters have the same power rating except at stations operating with different daytime and nighttime power, when it shall be permissible to employ transmitters of power ratings appropriate to either the licensed daytime or nighttime power.

(c) The external effects from both transmitters are substantially the same as to frequency stability, reliability of operation, radio harmonics and other spurious emissions, audio frequency range and audio harmonic generation in the transmitter.

SEC. 73.65 *Antenna structure, marking and lighting.* The provisions of Part 17 of this chapter, "Construction, Marking, and Lighting of Antenna Structures," require that certain antenna structures be painted and/or lighted in accordance with the provisions of that part. Where the antenna structure of a facility authoized under this subject is required to be painted or lighted; see Secs. 17.47 through 17.53 of this chapter.

Remote Control

SEC. 73.67 *Remote control operation.* Operation by remote control shall be subject to the following conditions:

(1) The equipment at the operating and transmitting positions shall be so installed and protected that it is not accessible to or capable of operation by persons other than those duly authorized by the licensee.

(2) The control circuits from the operating positions to the transmitter shall provide positive on and off control and shall be such that open circuits, short circuits, grounds or other line faults will not actuate the transmitter and any fault causing loss of such control will automatically place the transmitter in an inoperative position.

(3) A malfunction of any part of the remote control equipment and associated line circuits resulting in improper control or inaccurate meter readings shall be cause for the immediate cessation of operation by remote control.

(4) Control and monitoring equipment shall be installed so as to allow the licensed operator at the remote control point to perform all the functions in a manner required by the Commission's rules.

(5) The indications at the remote control point of the antenna current meter

or, for directional antennas, the common point current meter and remote base current meters, shall be read and entered in the operating log each half hour.

(6) The indications at the transmitter, if a directional antenna station, of the common point current, base currents, phase monitor sample loop currents and phase indications shall be read and entered in the operating log once each day for each pattern. These readings must be made within two hours after the commencement of operation for each pattern.

(b) All stations, whether operating by remote control or direct control, shall be equipped so as to be able to follow the Emergency Action Notification procedures described in Sec. 73.932.

(c) The broadcast transmitter carrier may be amplitude-modulated with a tone for the purpose of transmitting to the remote control point essential meter indications and other data on the operational condition of the broadcast transmitter and associated devices, subject to the following conditions:

(1) The tone shall have a frequency no higher than 30 hertz.

(2) The amplitude of modulation of the carrier by the tone shall not be higher than necessary to effect reliable and accurate data transmission, and shall not, in any case, exceed 6 percent.

(3) The tone shall be transmitted only at such times and during such intervals that the transmitted information is actually being observed or logged.

(4) Measures shall be employed to insure that during the periods the tone is being transmitted the total modulation of the carrier does not exceed 100 percent on negative peaks.

(5) Such tone transmissions shall not significantly degrade the quality of program transmission or produce audible effects resulting in public annoyance.

(6) Such tone transmissions shall not result in emissions of such a nature as to result in greater interference to other stations than is produced by normal program modulation.

Operation

SEC. 73.72 *Operation during experimental period.* The licensee of each standard broadcast station shall operate or refrain from operating its station during the experimental period as directed by the Commission in order to facilitate frequency measurement or for the determination of interference.

SEC. 73.92 *Station and operator licenses; posting of.* (a) The station license and any other instrument of station authorization shall be posted in a conspicuous place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

SEC. 73.93 *Operator requirements.* (a) One or more radio operators holding a valid radiotelephone first-class operator license, except as provided in paragraph (b) of this section, shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote control point. If operation by remote control has not been authorized, the transmitter shall be readily accessible and clearly visible to the operator at his normal operating position. If operation by remote control is authorized, the control and monitoring equipment shall be readily accessible and clearly visible to the operator at his normal operating position.

(b) In cases where a station is authorized for nondirectional operation with power not in excess of 10 kilowatts, the routine operation of the transmitter may be performed by an operator holding a valid first-class or second-class radiotelephone or radiotelegraph operator license or a radiotelephone third-class operator permit which has been endorsed for broadcast station operation. The operator shall be on duty at the transmitter or authorized remote control point and in actual charge thereof. Except at times when the operation of the station is under the immediate supervision of an operator holding a valid radiotelephone first-class operator license, adjustments of the transmitting equipment shall be limited to the following:

(1) Those necessary to turn the transmitter on and off.

(2) Adjustments of external controls as may be required to compensate for voltage fluctuations in the power supply.

(3) Adjustments of external controls to maintain modulation of the transmitter within the prescribed limits.

(4) Adjustments of external controls necessary to effect routine changes in operating power which are required by the station's instrument of authorization.

(5) Adjustments of external controls necessary to offset operation in accordance with a National Defense Emergency Authorization during an Emergency Action Condition.

It shall be the responsibility of the licensee to insure that the person who may be required to perform these tasks as well as to perform other duties (such as reading meters and making log entries) is properly instructed so as to be capable of performing the duties required of him at times when not under the immediate supervision of a radiotelephone first-class operator. Where necessary, printed step-by-step instructions shall be posted for those transmitter adjustments which the lesser grade operator is authorized to make. Should the transmitting apparatus be observed to be operating in any manner inconsistent with this subpart or the current instrument of authorization for the station at any time when an operator holding a valid radiotelephone first-class operator license is not immediately available, and none of the above adjustments is effective in correcting the condition of improper operation, the emissions of the station shall be immediately terminated.

(c) If the routine operation of the transmitting apparatus at a standard broadcast station with power of 10 kW or less and nondirectional antenna is performed by an operator other than a radiotelephone first-class operator pursuant to the provisions of paragraph (b) of this section, the licensee shall either employ one or more operators holding a valid radiotelephone first-class operator license as a full-time member of the station staff or, in the alternative, contract in writing for the services on a part-time basis of one or more such operators. The radiotelephone first-class operator or operators shall perform transmitter maintenance and shall be promptly available at all times to correct conditions of improper operation beyond the scope of authority of the lesser grade operator on duty. If such services are on a contract part-time basis, a signed copy of the agreement shall be kept in the files of the station and at the transmitter or control point and shall be made available for inspection upon request by any authorized representative of the Commission. A signed copy of the agreement shall also be forwarded to the Commission and to the Engineer in Charge of the radio district in which the station is located within 3 days after the agreement is signed.

(d) The licensed operator on duty and in charge of a standard broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such other stations: *Provided, however,* That such duties shall in no way interfere with the proper operation of the standard broadcast transmitter.

(e) At all standard broadcast stations, a complete inspection of all transmitting equipment in use shall be made by an operator holding a valid radiotelephone first-class operator license at least once each day, 5 days each week, with an interval of no less than 12 hours between successive inspections. This inspection shall include such tests, adjustments, and repairs as may be necessary to insure operation in conformance with the provisions of this subpart and the current instrument of authorization for the station.

SEC. 73.95 *Equipment tests.* (a) During the process of construction of a standard broadcast station the permittee, after notifying the Commission and Engineer in Charge of the radio district in which the station is located, may without further authority of the Commission, conduct equipment tests during the experimental period for the purpose of such adjustments and measurements as may be necessary to assure compliance with the terms of the construction permit, the technical provisions of the application thereof, the rules and regulations, and the applicable engineering standards. In addition the Commission may authorize equipment tests other than during the experimental period if such operation is shown to be desirable to the proper completion of construction and adjustment of the transmitting equipment and antenna system. An informal application for such authority, giving full details regarding the need for such tests, shall be filed with the Commission at least two (2) days (not including Sundays and Saturdays and legal holidays when the offices of the Commission are not open) prior to the date on which it is desired to begin such operation.

(b) The Commission may notify the permittee to conduct no tests or may cancel, suspend, or change the date for the beginning of equipment tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Equipment tests may be continued so long as the construction permit shall remain valid and shall be conducted only during the experimental period (12 midnight to local sunrise) unless otherwise specifically authorized.

(d) Inspection of a station will ordinarily be required during the equipment test period and before the commencement of program tests. After construction and after adjustments and measurements have been completed to show compliance with the terms of the construction permit, the technical provisions of the application therefor, the rules and regulations and the applicable engineering standards, the permittee should notify the Engineer in Charge of the radio district in which the station is located that it is ready for inspection.

(e) The authorization for tests embodied in this section shall not be constructed as constituting a license to operate but as a necessary part of construction.

SEC. 73.96 *Program tests.* (a) Upon completion of construction of a standard broadcast station in accordance with the terms of the construction permit, the technical provisions of the application therefor, and the rules and regulations and applicable engineering standards and when an application for station license has been filed showing the station to be in satisfactory operating condition, the permittee may request authority to conduct program tests: *Provided*, That such request shall be filed with the Commission at least ten (10) days prior to the date on which it is desired to begin such operation and that the Engineer in Charge of the radio district in which the station is located is notified. All data necessary to show compliance with the terms and conditions of the construction permit must be filed with the license application. If the station is using a directional antenna, a proof of performance must also be filed as required by Sec. 73.33(b).

(b) Program tests shall not commence until specific Commission authority is received. The Commission reserves the right to change the date of the beginning of such tests or to suspend or revoke the authority for program tests as and when such action may appear to be in the public interest, convenience, and necessity.

(c) Unless sooner suspended or revoked program test authority continues valid during Commission consideration of the application for license and during this period further extension of the construction permit is not required. Program test authority shall be automatically terminated by final determination upon the application for station license.

(d) All operation on program test authority shall be in strict compliance with the rules governing standard broadcast stations and in strict accordance with representations made in the application for license pursuant to which the tests were authorized.

(e) The granting of program test authority shall not be construed as approval by the Commission of the application for station license.

SEC. 73.97 *Station inspection.* The license of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

SEC. 73.98 *Operation during emergency.* (a) When necessary to the safety of life and property and in response to dangerous conditions of a general nature, standard broadcast stations may, at the discretion of the licensee and without further Commission authority, transmit emergency weather warnings and other emergency information. Examples of emergency situations which may warrant either an immediate or delayed response by the licensee are: Tornadoes, hurricanes, floods, tidal waves, earthquakes, icing conditions, heavy snows, widespread fires, discharge of toxic gases, widespread power failures, industrial explosions, and civil disorders. Transmission of information concerning school closings and changes in schoolbus schedules resulting from any of these conditions, is appropriate. In addition, and if requested by responsible public officials, emergency point-to-point messages may be transmitted for the purpose of requesting or dispatching aid and assisting in rescue operations.

(b) When emergency operation is conducted utilizing the facilities, systems, and procedures of a Detailed State EBS Operational Plan as provided in Sec. 73.971, the attention signal described in Sec. 73.906 may be employed.

(c) Except as provided in paragraph (d) of this section, emergency operation shall be confined to the hours, frequencies, powers, and modes of operation specified in the license documents of the stations concerned.

(d) When adequate advance warning cannot be given with the facilities or hours authorized, stations may employ their full daytime facilities during nighttime hours to carry weather warnings and other types of emergency information connected with the examples listed in paragraph (a) of this section. Because of skywave interference impact on other stations assigned to the same channel, such operation may be undertaken only if regular, unlimited-time service is nonexistent, inadequate from the standpoint of coverage, or not serving public need. All operation under this paragraph must be conducted on a noncommercial basis. Recorded music may be used to the extent necessary to provide program continuity.

(e) Any emergency operation undertaken in accordance with this section may be terminated by the Commission, if required in the public interest.

(f) Immediately upon cessation of an emergency during which broadcast facilities were used for the transmission of point-to-point messages under paragraph (a) of this section, or when daytime facilities were used during nighttime hours in accordance with paragraph (d) of this section, a report in letter form shall be forwarded to the Commission and the Engineer in Charge of the radio district in which the station is located, setting forth the nature of the emergency, the dates and hours of emergency operation, and a brief description of the material carried during the emergency period. A certification of compliance with the noncommercialization provision of paragraph (d) of this section must accompany the report where daytime facilities are used during nighttime hours, together with a detailed showing concerning the alternate service provisions of that paragraph.

(g) If an Emergency Action Condition is declared while emergency operation under this section is in progress, the Emergency Action Notification shall take precedence.

Other Operating Requirements

SEC. 73.111 *General requirements relating to logs.* (a) The licensee or permittee of each standard broadcast station shall maintain program, operating, and maintenance logs as set forth in Sections 73.112, 73.113, and 73.114. Each log shall be kept by the station employee or employees (or contract operator) competent to do so, having actual knowledge of the facts required, who in the case of program and operating logs shall sign the appropriate log when starting duty, and again when going off duty.

(b) The logs shall be kept in an orderly and legible manner, in suitable form, and in such detail that the data required for the particular class of station concerned is readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log. Each sheet shall be numbered and dated. Time entries shall be made in local time. For the period from the last Sunday in April until the last Sunday in October of each year, the program and operating log entries showing times of sign-on, sign-off, and change in the station's mode of operation shall specifically be indicated as advanced or nonadvanced time.

(c) No log or preprinted log or schedule which becomes a log, or portion thereof, shall be erased, obliterated, or willfully destroyed within the period of retention provided by the provisions of this part. Any necessary correction shall be made only pursuant to Sections 73.112, 73.113, and 73.114, and only by striking out the erroneous portion, or by making a corrective explanation on the log or attachment to it as provided in those sections.

(d) Entries shall be made in the logs as required by Sections 73.112, 73.113, and 73.114. Additional information such as that needed for billing purposes or for the cuing of automatic equipment may be entered on the logs. Such additional information, so entered, shall not be subject to the restrictions and limitations in the Commission's rules on the making of corrections and changes in logs.

SEC. 73.112 *Program log.* (a) The following entries shall be made in the program log:

(1) *For each program.* (i) An entry identifying the program by name or title.

(ii) An entry of the time each program begins and ends. If programs are broadcast during which separately identifiable program units of a different type or source are presented, and if the licensee wishes to count such units separately, the beginning and ending time for the longer program need be entered only once for the entire program. The program units which the licensee wishes to count separately shall then be entered underneath the entry for a longer program, with the beginning and ending time of each such unit, and with the entry indented or otherwise distinguished so as to make it clear that the program unit referred to was broadcast within the longer program.

(iii) An entry classifying each program as to type, using the definitions set forth in Note 1 at the end of this section.

(iv) An entry classifying each program as to source, using the definitions set forth in Note 2 at the end of this section. (For network programs, also give name or initials of network, e.g., ABC, CBS, NBC, Mutual.)

(v) An entry for each program presenting a political candidate, showing the name and political affiliation of such candidate.

(2) *For commercial matter.* (i) An entry identifying (a) the sponsor(s) of the program, (b) the person(s) who paid for the announcement, or (c) the person(s) who furnished materials or services referred to in Sec 73.119(d). If the title of a sponsored program includes the name of the sponsor, e.g., XYZ News, a separate entry for the sponsor is not required.

(ii) An entry or entries showing the total duration of commercial matter in each hourly time segment (beginning on the hour) or the duration of each commercial message (commercial continuity in sponsored programs or commercial announcements) in each hour. See Note 5 at the end of this section for statement as to computation of commercial time.

(iii) An entry showing that the appropriate announcement(s) (sponsorship, furnishing material or services, etc.) have been made as required by Section 317 of the Communications Act and Sec 73.119. A checkmark (✓) will suffice but shall be made in such a way as to indicate the matter to which it relates.

(3) *For public service announcements.* (i) An entry showing that a public service announcement (PSA) has been broadcast together with the name of the organization or interest on whose behalf it is made. See Note 4 following this section for definition of a public service announcement.

(4) *For other announcements.* (i) An entry of the time that each required station identification announcement is made (call letters and licensed location; see Sec. 73.117).

(ii) An entry for each announcement presenting a political candidate showing the name and political affiliation of such candidate.

(iii) An entry for each announcement made pursuant to the local notice requirements of Sections 1.580 (pregrant) and 1.594 (designation for hearing) of this chapter, showing the time it was broadcast.

(iv) An entry showing that a mechanical reproduction announcement has been made in accordance with the provisions of Sec. 73.118.

(b) Program log entries may be made either at the time of or prior to broadcast. A station broadcasting the programs of a national network which will supply it with all information as to such programs, commercial matter and other announcements for the composite week need not log such data but shall record in its log the time when it joined the network, the name of each network program broadcast, the time it leaves the network, and any nonnetwork matter broadcast required to be logged. The information supplied by the network, for the composite week which the station will use in its renewal application, shall be retained with the program logs and associated with the log pages to which it relates.

(c) No provision of this section shall be construed as prohibiting the recording or other automatic maintenance of data required for program logs. However, where such automatic logging is used, the licensee must comply with the following requirements:

(1) The licensee, whether employing manual or automatic logging or a combination thereof, must be able accurately to furnish the Commission with all information required to be logged;

(2) Each recording, tape, or other means employed shall be accompanied by a certificate of the operator or other responsible person on duty at the time or other duly authorized agent of the licensee, to the effect that it accurately reflects what was actually broadcast. Any information required to be logged which cannot be incorporated in the automatic process shall be similarly authenticated;

(3) The licensee shall extract any required information from the recording for the days specified by the Commission or its duly authorized representative and sub-

mit it in written log form, together with the underlying recording, tape, or other means employed.

(d) Program logs shall be changed or corrected only in the manner prescribed in Sec. 73.111(c) and only in accordance with the following:

(1) *Manually kept log.* Where, in any program log, or preprinted program log, or program schedule which upon completion is used as a program log, a correction is made before the person keeping the log has signed the log upon going off duty, such correction, no matter by whom made, shall be initialed by the person keeping the log prior to his signing of the log when going off duty, as attesting to the fact that the log as corrected is an accurate representation of what was broadcast. If corrections or additions are made on the log after it has been so signed, explanation must be made on the log or on an attachment to it, dated and signed by either the person who kept the log, the station program director or manager, or an officer of the licensee.

NOTE 1. *Program type definitions.* The definitions of the first eight types of programs (a) through (h) are intended not to overlap each other and will normally include all the various programs broadcast. Definitions (i) through (k) are subcategories and the programs classified thereunder will also be classified under one of the appropriate first eight types. There may be further duplication within types (i) through (k); e. g., a program presenting a candidate for public office, prepared by an educational institution, would be classified as Public Affairs (PA), Political (POL), and Educational Institutions (ED).

(a) Agricultural programs (A) include market reports, farming, or other information specifically addressed, or primarily of interest, to the agricultural population.

(b) Entertainment programs (E) include all programs intended primarily as entertainment, such as music, drama, variety, comedy, quiz, etc.

(c) News programs (N) include reports dealing with current local, national, and international events, including weather and stock market reports and when an nitegral part of a news program, commentary, analysis, and sports news.

(d) Public affairs programs (PA) include talks, commentaries, discussions, speeches, editorials, political programs, documentaries, forums, panels, roundtables, and similar programs primarily concerning local, national and international public affairs.

(e) Religious programs (R) including sermons or devotionals, religious news, and music, drama, and other types of programs designed primarily for religious purposes.

(f) Instructional programs (I) include programs (other than those classified under Agricultural, News, Public Affairs, Religious or Sports) involving the discussion of, or primarily designed to further an appreciation or understanding of, literature, music, fine arts, history, geography, and the natural and social sciences; and programs devoted to occupational and vocational instruction, instruction with respect to hobbies, and similar programs intended primarily to instruct.

(g) Sports programs (S) include play-by-play and pre- or post-game related activities and separate programs of sports instruction, news or information (e.g., fishing opportunities, golfing instruction, etc).

(h) Other programs (O) include all programs not falling within definitions (a) through (g).

(i) Editorials (EDIT) include programs presented for the purpose of stating opinions of the licensee.

(j) Political programs (POL) include those which present candidates for public office or which give expressions (other than in station editorials) to views on such candidates or on issues subject to public ballot.

(k) Educational Institution programs (ED) include any program prepared by, in behalf of, or in cooperation with, educational institutions, educational organizations, libraries, museums, PTAs, or similar organizations. Sports programs shall not be included.

NOTE 2. *Program source definitions.*—(a) A local program (L) is any program originated or produced by the station, or for the production of which the station is primarily responsible, employing live talent more than 50 percent of the time. Such a program, taped or recorded for later broadcast, shall be classified as local. A local program fed to a network shall be classified by the originating station as local. All non-network news programs may be classified as local. Programs primarily featuring records or transcriptions shall be classifield as recorded (REC) even though a station announcer appears in connection with such material. However, identifiable units of such programs which are live and separately logged as such may be classified as local. (E.g., if during the course of a program featuring records or transcriptions a nonnetwork 2-minute news report is given and logged as a news program, the report may be classified as local.)

(b) A network program (NET) is any program furnished to the station by a network (national, regional or special). Delayed broadcasts of programs originated by networks are classified as network.

(c) A recorded program (REC) is any program not otherwise definded in this Note including, without limitation, those using recordings, transcriptions or tapes.

NOTE 3. *Definition of commercial matter* (CM) includes commercial continuity (network and nonnetwork) and commercial announcements (network and nonnetwork) as follows: (Distinction between continuity and announcements is made only for definition purposes. There is no need to distinguish between the two types of commercial matters when logging.)

(a) Commercial continuity (CC) is the advertising message of a program sponsor.

(b) A commercial announcement (CA) is any other advertising message for which a charge is made, or other consideration is received.

(1) Included are (i) "bonus spots"; (ii) trade-out spots, and (iii) promotional announcements of a future program where consideration is received for such an announcement or where such announcement identifies the sponsor of a future program beyond mention of the sponsor's name as an integral part of the title of the program. (E.g., where the agreement for the sale of time provides that the sponsor will receive promotional announcements, or when the promotional announcements contain a statement such as "Listen tomorrow for the—[name of program]—brought to you by—[sponsor's name]—.")

(2) Other announcements, including but not limited to the following, are not commercial announcements:

(i) Promotional announcements, except as heretofore defined in paragraph (b).

(ii) Station identification announcements for which no charge is made.

(iii) Mechanical reproductional announcements.

(iv) Public service announcements.

(v) Announcements made pursuant to Sec. 73.119(d) that materials or services have been furnished as an inducement to broadcast a political program or a program involving the discussion of controversial public issues.

(vi) Announcements made pursuant to the local notice requirements of Sec. 1.580 (pregrant) and 1.594 (designation for hearing) of this chapter.

NOTE 4. *Definition of a public service announcement.* A public service announcement is an announcement for which no charge is made and which promotes programs, activities, or services of Federal, State, or local governments (e.g., recruiting, sales of bonds, etc.) or the programs, activities or services of nonprofit organizations (e.g., UGF, Red Cross Blood Donations, etc.). and other announcements regarded as serving community interests, excluding time signals, routine weather announcements, and promotional announcements.

NOTE 5. *Computation of commercial time.* Duration of commercial matter shall be as close an approximation to the time consumed as possible. The amount of commercial time scheduled will usually be sufficient. It is not necessary, for example, to correct an entry of a 1-minute commercial to accommodate varying reading speeds even though the actual time consumed might be a few seconds more or less than the scheduled time. However, it is incumbent upon the licensee to ensure that the entry represents as close an approximation of the time actually consumed as possible.

SEC. 73.113 *Operating log.* (a) The following entries shall be made in the operating log by the properly licensed operator in actual charge of the transmitting apparatus only:

(1) An entry of the time the station begins to supply power to the antenna and the time it stops.

(2) An entry of each interruption of the carrier wave, where restoration is not automatic, its cause and duration, followed by the signature of the person restoring operation (if licensed operator other than the licensed operator on duty).

(3) An entry, at the beginning of operation and at intervals not exceeding one-half hour, of the following (actual readings observed prior to making any adjustments to the equipment) and, when appropriate, an indication of corrections made to restore parameters to normal operating values:

(i) Operating constants of last radio stage (total plate voltage and plate current).

(ii) Antenna current or common point current (if directional) without modulation if the meter reading is not affected by modulation.

(iii) Frequency monitor reading.

(4) An entry each day of the following where applicable:

(i) Antenna base current(s) without modulation, or with modulation if the meter reading is not affected by modulation, for each mode of operation:

(a) Where remote antenna meters or a remote common point meter are normally employed but are defective.

(b) Where required by the station license for directional antenna operation.

(ii) Where there is remote control operation of a directional antenna station, readings for each pattern taken at the transmitter (within 2 hours of commencement of operation with each pattern) of:

(a) Common point current without modulation, or with modulation if the meter reading is not affected by modulation.

(b) Base current(s) without modulation, or with modulation, if the meter reading is not affected by modulation.

(c) Phase monitor sample loop current(s) without modulation or with modulation if the meter reading is not affected by modulation.

(d) Phase indications.

(5) Any other entries required by the instrument of authorization or the provisions of this part. See particularly, the additional entries required by Sec. 73.51(c) (2) when power is being determined by the indirect method.

(6) The entries required by Sec. 17.49(a), (b), and (c) of this chapter concerning daily observations of tower lights.

(b) Automatic devices accurately calibrated and with appropriate time, date and circuit functions may be utilized to record the entries in the operating log: *Provided*, That:

(1) They do not affect the operation of circuits or accuracy of indicating instruments of the equipment being recorded;

(2) The recording devices have an accuracy equivalent to the accuracy of the indicating instruments;

(3) The calibration is checked against the original indicators at least once a week and the results noted in the maintenance log;

(4) Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerances or other requirements specified in the rules or instrument of authorization;

(5) Unless the alarm circuit operates continuously, devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded;

(6) The automatic logging equipment is located at the remote control point if the transmitter is remotely controlled, or at the transmitter location if the transmitter is directly controlled;

(7) The automatic logging equipment is located in the near vicinity of the operator on duty and is inspected by him periodically during the broadcast day;

(8) The indicating equipment conforms with the requirements of Sec 73.39 except that the scales need not exceed 2 inches in length. Arbitrary scales may not be used.

(c) In preparing the operating log, original data may be recorded in rough form and later transcribed into the log, but in such a case all portions of the original memoranda shall be preserved as a part of the complete log.

(d) Operating logs shall be changed or corrected only in the manner prescribed in Sec. 73.111(c) and only in accordance with the following:

(1) *Manually kept log.* Any necessary corrections in a manually kept operating log shall be made only by the person making the original entry who shall make and initial each correction prior to signing the log when going off duty in accordance with Sec. 73.111(a). If corrections or additions are made on the log after it has been so signed, explanation must be made on the log or on an attachment to it, dated and signed by either the operator who kept the log, the station technical supervisor or an officer of the licensee.

(2) *Automatic logging.* No automatically kept operating log shall be altered in any way after entries have been recorded. Any errors or omissions found in an automatically kept operating log shall be noted and explained in a memorandum signed by the operator on duty (who, under the provisions of paragraph (b)(7) of this section, is required to inspect the automatic equipment), or by the station

technical supervisor or an officer of the licensee. Such memorandum shall be affixed to the original log in question.

SEC. 73.114 *Maintenance log.* (a) The following entries shall be made in the maintenance log:

(1) An entry each week of the following were applicable:

(i) A notation indicating the readings of the tower base current ammeter(s) and the associated remote antenna ammeter(s) (actual readings observed prior to remote antenna ammeter recalibration) and indicating calibration of the remote ammeter(s) against the tower base ammeter(s).

(ii) Time and result of test of auxiliary transmitter.

(iii) A notation of all frequency checks and measurements made independently of the frequency monitor and of the correlation of these measurements with frequency monitor indications.

(iv) A notation of the calibration check of automatic recording devices as required by Sec. 73.113(b)(3).

(2) An entry of the data and time of removal from and restoration to service of any of the following equipment in the event it becomes defective:

(i) Modulation monitor.

(ii) Frequency monitor.

(iii) Final stage plate voltmeter.

(iv) Final state plate ammeter.

(v) Base current ammeter(s).

(vi) Common point ammeter.

(3) The entries required by Sec. 17.49(d) of this chapter concerning quarterly inspections of the condition of tower lights and associated control equipment and an entry when towers are cleaned or repainted as required by Sec. 17.50 of this chapter.

(4) Entries made so as to describe fully any experimental operation pursuant to Sec. 73.10.

(5) Any other entries required by the current instrument of authorization of the station and the provisions of this subpart.

(b) Upon completion of the inspection required by Sec. 73.93(e), the inspecting operator shall enter a signed statement that the required inspection has been made, noting in detail the tests, adjustments and repairs which were accomplished in order to insure operation in accordance with the provisions of this subpart and the current instrument of authorization of the station.

The statement shall also specify the amount of time, exclusive of travel time to and from the transmitter, which was devoted to such inspection duties. If complete repair could not be effected, the statement shall set forth in detail the items of equipment concerned, the manner and degree in which they are defective, and the reason for failure to make satisfactory repairs.

(c) The inspecting operator shall sign and date the maintenance log at the conclusion of each inspection. In preparing the maintenance log, original data may be recorded in rough form and later transcribed into the log, but in such cases all portions of the original memorandum shall be preserved as a part of the complete log.

(d) Any necessary corrections in the maintenance log shall be made by the inspecting operator who shall initial and date all changes prior to signing the log. If corrections or additions are made on the log after it has been so signed, explanation must be made the subject of a separate memorandum, dated and signed by the operator who made the entry in question, or the station's technical supervisor or by an officer of the licensee. Such memorandum shall explain fully the circumstances surrounding the errors or ambiguities, and shall be affixed to the original log in question. If written and signed by other than the inspecting operator who made the entry, the memorandum shall contain a satisfactory explanation of why such signature is lacking.

SEC. 73.115 *Retention of logs.* Logs of standard broadcast stations shall be retained by the licensee or permittee for a period of 2 years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee or permitee has been notified, shall be retained by the licensee or permittee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee or permittee has notice shall be retained by the licensee or permittee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

NOTE: Application forms for licenses and other authorizations require that certain operating and program data be supplied. It is suggested that these application forms be kept in mind in connection with maintenance of station program and operating records.

SEC. 73.116 *Availability of logs and records.* The following shall be made available upon request by an authorized representative of the Commission:

(a) Program, operating and maintenance logs.

(b) Equipment performance measurements required by Sec. 73.47.

(c) Copy of the most recent antenna resistance or common-point impedance measurements submitted to the Commission.

(d) Copy of the most recent field intensity measurements to establish performance of directional antennas required by Sec. 73.151.

FM BROADCAST STATIONS

Equipment

SEC. 73.254 *Required transmitter performance.* (a) The construction, installation, operation and performance of the broadcast transmitting system shall be in accordance with Sec. 73.317.

(b) The licensee of each broadcast station shall make equipment performance measurements at least once each calendar year: *Provided, however,* That the dates of completion of successive sets of measurements shall be no more than fourteen months apart. One set of measurements shall be made during the 4 month period preceding the filing date of the application for renewal of station license. Equipment performance measurements for auxiliary transmitters are not required. Equipment performance measurements shall be made with equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna circuit, including telephone lines, preemphasis circuits and any equalizers employed, except for microphones, and without compression if a compression amplifier is installed. The measurement program shall yield the following information:

(1) Audio frequency response from 50 to 15,000 hertz(Hz) for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000 and 15,000 Hz. The frequency response measurements should normally be made without deemphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

(2) Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000, and 5000 Hz. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 Hz. Measurements shall normally include harmonics to 30,00 Hz. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(3) Output noise level (frequency modulation) in the band of 50 to 15,000 Hz in decibels (dB) below the audio frequency level representing a frequency swing of 75 kHz. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(4) Output noise level (amplitude modulation) in the band of 50 to 15,000 Hz in dB below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(c) The data required by paragraph (b) of this section together with a description of instruments and procedure signed by the engineer making the measurements shall be kept on file at the transmitter and retained for a period of two years and shall be made available during that time upon request to any duly authorized representative of the Federal Communications Commission.

SEC. 73.257 *Changes in equipment and antenna system.* Licensees of fm broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(a) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with that prescribed in Sec. 73.317.

(b) Specific authority, upon filing formal application (FCC Form 301) therefor, is required for a change in service area or for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitter.

(2) A replacement of the transmitter as a whole, unless such transmitter is one which may be installed and utilized in accordance with the provisions of Sec. 73.250(a)(5).

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(6) Change in power delivered to the antenna.

(7) Change in frequency control and/or modulation system.

(8) Change in the authorized transmitter remote control point(s).

(c) Other changes, except as above provided for in this section or in the Technical Standards of this subpart, may be made at any time without the authority of the Commission: *Provided*, That the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

Technical Operation and Operators

SEC. 73.261 *Time of operation.* (a) All fm broadcast stations will be licensed for unlimited time operation. A minimum of 36 hours per week during the hours of 6:00 a.m. to midnight, consisting of not less than 5 hours in any one day, except Sunday, must be devoted to the fm broadcast operation.

(b) In the event that causes beyond a licensee's control make it impossible to adhere to the operating schedule in paragraph (a) of this section or to continue operating, the station may limit or discontinue operation for a period of not more than 10 days, without further authority of the Commission. However, the Commission and the Engineer in Charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule and shall be subsequently notified when the station resumes regular operation.

SEC. 73.262 *Experimental operation.* (a) The period between midnight and 6:00 a.m., local standard time, may be used for experimental purposes in testing and maintaining apparatus by the licensee of any fm broadcast station on its assigned frequency and not in excess of its authorized power, without specific authorization by the Commission.

(b) Fm Broadcast stations may (with prior notification to the Commission and the Engineer in Charge of the radio district in which the station is located) test, maintain, and adjust the apparatus at the station during other time periods; and may (upon informal application) conduct technical experimentation directed to the improvement of technical phases of operation during other time periods, and for such purposes may utilize a signal other than the standard fm signal, subject to the following conditions:

(1) That the licensee complies with the provisions of Sec. 73.261 with regard to the minimum number of hours of operation.

(2) That emissions outside the authorized bandwidth shall comply with Sec. 73.317(a) and that no interference is caused to the transmissions of other fm broadcast stations.

(3) No charges either direct or indirect shall be made by the licensee of an fm broadcast station for the production or transmission of programs when conducting technical experimentation.

SEC. 73.263 *Station inspection.* The licensee of any fm broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

SEC. 73.264 *Station and operator licenses; posting of.* (a) The station license and any other instrument of station authorization shall be posted in a conspicuous place and in such manner that all terms are visible, at the place the licensee considers to be the principal control point of the transmitter. At all other control points listed on the station authorization, a photocopy of the station license and other instruments of station authorization shall be posted.

(b) The original operator license, or FCC Form 759, of each station operator shall be posted at the place where he is on duty as an operator.

SEC. 73.265 *Operator requirements.* (a) One or more radio operators holding a valid radiotelephone first-class operator license, except as provided in paragraph (b) of this section, shall be in actual charge of the transmitting apparatus and shall be on duty either at the transmitter location or remote control point. If operation by remote control has not been authorized, the transmitter shall be readily accessible and clearly visible to the operator at his normal operating position. If operation by remote control is authorized, the control and monitoring equipment shall be readily accessible and clearly visible to the operator at his normal operating position.

(b) In cases where a station is authorized to operate with a transmitter power output not in excess of 25 kilowatts, the routine operation of the transmitter may be performed by an operator holding a valid first-class or second-class radiotelephone or radiotelegraph operator license or a radiotelephone third-class operator permit which has been endorsed for broadcast station operation. The operator shall be on duty at the transmitter or authorized remote control point and in actual charge thereof. Except at times when the operation of the station is under the immediate supervision of an operator holding a valid radiotelephone first-class operator license, adjustments of the transmitter shall be limited to the following:

(1) Those necessary to turn the transmitter on and off.

(2) Adjustments of external controls as may be necessary to compensate for voltage fluctuations in the power supply.

(3) Adjustments of external controls to maintain modulation of the transmitter within prescribed limits. It shall be the responsibility of the licensee to insure that the person who may be required to perform these tasks as well as to perform other duties (such as reading meters and making log entries), is properly instructed so as to be capable of performing the duties required of him at times when not under the immediate supervision of a radiotelephone first-class operator. Where necessary, printed step-by-step instructions shall be posted for those transmitter adjustments which the lesser-grade operator is authorized to make. Should the transmitting apparatus be observed to be operating in any manner inconsistent with this subpart or the station's instrument of authorization at any time when an operator holding a valid radiotelephone first-class operator license is not immediately available, and none of the above adjustments is effective in correcting the condition of improper operation, the emissions of the station shall be immediately terminated.

(c) If the routine operation of the transmitting apparatus at a fm broadcast station is performed by an operator other than a radiotelephone first-class operator pursuant to the provisions of paragraph (b) of this section, the licensee shall either employ one or more operators holding a valid radiotelephone first-class operator license as a full-time member of the station staff or, in the alternative, contract in writing for the service on a part-time basis of one or more such operators. The radiotelephone first-class operator or operators shall perform transmitter maintenance and shall be promptly available at all times to correct conditions of improper operation beyond the scope of authority of the lesser-grade operator on duty. If such services are on a contract part-time basis, a signed copy of the agreement shall be kept in the files of the station and at the transmitter or control point and shall be made available for inspection upon request by any authorized representative of the Commission. A signed copy of the agreement shall also be forwarded to the Commission and to the Engineer in Charge of the radio district in which the station is located within 3 days after the agreement is signed.

(d) The licensed operator on duty and in charge of a fm broadcast transmitter may at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and the rules and regulations governing such other stations: *Provided, however*, That such duties shall in nowise interfere with the proper operation of the fm broadcast transmitter.

(e) At all fm broadcast stations, a complete inspection of all transmitting equipment in use shall be made by an operator holding a valid radiotelephone first-class operator license at least once each day, 5 days each week, with an interval of no less than 12 hours between successive inspections. This inspection shall include such tests, adjustments, and repairs as may be necessary to insure operation in conformance with the provisions of this subpart and the current instrument of authorization for the station.

SEC. 73.267 *Operating power; determination and maintenance of.* (a) *Determination.* The operating power of each station shall be determined by either the direct or indirect method.

(1) Using the direct method, the power shall be measured at the output terminals of the transmitter while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. The transmitter shall be unmodulated during this measurement. If electrical devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of ±5 percent of the power indicated by the full scale reading of the electrical indicating instrument of the device. If temperature and coolant flow indicating devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of 4 percent of measured average power output. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement.

(2) Using the indirect method, the operating power is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F, as follows:

$$\text{Operating power} = E_p \times I_p \times F$$

(3) The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which he submits data to the Commission, over the entire operating range of powers for which the transmitter is designed, and shall be shown in the instruction books supplied to the customer with each transmitter. In the case of composite equipment, the factor F shall be furnished to the Commission with a statement of the basis used in determining such factor.

(b) *Maintenance.* (1) The operating power shall be maintained as near as practicable to the authorized power and shall not be less than 90 percent nor greater than 105 percent of authorized power except as indicated paragraph (c) of this section.

(2) When determined by the direct method, the operating power of the transmitter shall be monitored by a transmission line meter which reads proportional to the voltage, current, or power at the output terminals of the transmitter, the meter to be calibrated at intervals not exceeding 6 months. The calibration shall cover, as a minimum, the range from 90 to 105 percent of authorized power and the meter shall provide clear indications which will permit maintaining the operating power within the prescribed tolerance or the meter shall be calibrated to read directly in power units.

(c) *Reduced power.* In the event it becomes technically impossible to operate with authorized power, the station may be operated with reduced power for a period of 10 days or less without further authority of the Commission: *Provided,* That the Commission and the Engineer in Charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule (specified in Sec. 73.261) with authorized power and shall be subsequently notified upon resumption of operation with authorized power.

SEC. 73.268 *Modulation.* The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice. In no case is it to exceed 100 percent on peaks of frequent recurrence Generally, it should not be less than 85 percent on peaks of frequent recurrence; but where necessary to avoid objectionable loudness modulation may be reduced to whatever level is necessary, even if the resulting modulation is substantially less than 85 percent on peaks of frequent recurrence.

SEC. 73.269 *Frequency tolerance.* The center frequency of each fm broadcast station shall be maintained within 2000 cycles of the assigned center frequency.

Other Operating Requirements

SEC. 73.293 *Subsidiary Communications Authorizations.* (a) An fm broadcast licensee or permittee may apply for a Subsidiary Communications Authorization (SCA) to provide limited types of subsidiary services on a multiplex basis. Permissible uses must fall within one or both of the following categories:

(1) Transmission of programs which are of a broadcast nature, but which are of interest primarily to limited segments of the public wishing to subscribe thereto. Illustrative services include: background music; storecasting; detailed weather forecasting; special time signals; and other materials of a broadcast nature expressly designed and intended for business, professional, educational, religious, trade, labor, agricultural or other groups engaged in any lawful activity.

(2) Transmission of signals which are directly related to the operation of fm broadcast stations; for example: relaying of broadcast material to other fm and standard broadcast stations; remote cuing and order circuits; remote control telemetering functions associated with authorized STL operation, and similar uses.

(b) Applications for Subsidiary Communications Authorizations shall be submitted on FCC Form 318. An applicant for SCA shall specify the particular nature or purpose of the proposed use.

(c) SCA operations may be conducted without restriction as to time so long as the main channel is programmed simultaneously.

SEC. 73.295 *Operation under Subsidiary Communications Authorizations.* (a) Operations conducted under a Subsidiary Communications Authorization (SCA) shall conform to the uses and purposes authorized by the Commission in granting the SCA application. Prior permission to engage in any new or additional activity must be obtained from the Commission pursuant to application therefor.

(b) Superaudible and subaudible tones and pulses may, when authorized by the Commission, be employed by SCA holders to activate and deactivate subscribers' multiplex receivers. The use of these or any other control techniques to delete main channel material is specifically forbidden.

(c) In all arrangements entered into with outside parties affecting SCA operation, the licensee or permittee must retain control over all material transmitted over the station's facilities, with the right to reject any material which it deems inappropriate or undesirable. Subchannel leasing agreements shall be reduced to writing and filed with the Commission pursuant to Sec. 1.613(d) of this chapter.

(d) The logging, announcement, and other requirements imposed by Sections 73.282, 73.283, 73.284, 73.287, 73.288, and 73.289 are not applicable to material transmitted on authorized subcarrier frequencies.

(e) To the extent that SCA circuits are used for transmission of program material, each licensee or permittee shall maintain a daily program log in which a general description of the material transmitted shall be entered once during each broadcast day: *Provided, however,* That in the event of a change in the general description of the material transmitted, an entry shall be made in the SCA program log indicating the time of each such change and a description thereof.

(f) Each licensee or permittee shall maintain a daily operating log of SCA operation in which the following entries shall be made (excluding subcarrier interruptions of five minutes or less):

(1) Time subcarrier generator is turned on.

(2) Time modulation is applied to subcarrier.

(3) Time modulation is removed from subcarrier.

(4) Time subcarrier generator is turned off.

(g) Program and operating logs for SCA operation may be kept on special columns provided on the station's regular program and operating log sheets.

(h) Technical standards governing SCA operation (Sec. 73.319) shall be observed by all fm broadcast stations engaging in such operation.

(i) The subcarrier frequency of each SCA subcarrier shall be checked as often as necessary to insure that it is kept at all times within 500 hertz of the authorized frequency. At least one check shall be made each day. The choice of method of performing the daily frequency check is left to the discretion of the licensee. However, whatever method is used shall be capable of sufficient accuracy to reveal deviations of the operating frequency in excess of the 500 hertz tolerance.

SEC. 73.297 *Stereophonic broadcasting.* (a) Fm broadcast stations may, without further authority, transmit stereophonic programs in accordance with the technical standards set forth in Sec. 73.322: *Provided, however,* That the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified within 10 days of the installation of type-accepted stereophonic transmission equipment or any change therein, and of the commencement of stereophonic programing.

(b) The pilot subcarrier frequency shall be checked as often as necessary to insure that it is kept at all times within the prescribed tolerance. At least one check shall be made each day. The choice of method of performing the daily frequency check is left to the discretion of the licensee. However, whatever method is used shall be capable of sufficient accuracy to reveal deviations of the pilot subcarrier frequency in excess of the prescribed 2 hertz tolerance.

FM Technical Standards

SEC. 73.310 *Definitions.* (a) *Frequency modulation. Antenna height above average terrain.* The average of the antenna heights above the terrain from 2 to 10 miles from the antenna for the eight directions spaced evenly for each 45 degrees of azimuth starting with True North. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than eight directions may be used. See Sec. 73.313 (d). Where circular or elliptical polarization is employed, the antenna height above average terrain shall be based upon the height of the radiation center of the antenna which transmits the horizontal component of radiation.

Antenna power gain. The square of the ratio of the root-mean-square free space field strength produced at 1 mile in the horizontal plane, in millivolts per meter for 1 kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (dB). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

Center frequency. The term "center frequency" means:

(1) The average frequency of the emitted wave when modulated by a sinusoidal signal.

(2) The frequency of the emitted wave without modulation.

Effective radiated power. The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain, or (2) the antenna field gain squared. Where circular or elliptical polarization is employed, the term effective radiated power is applied separately to the horizontal and vertical components of radiation. For allocation purposes, the effective radiated power authorized is the horizontally polarized component of radiation only.

Fm broadcast band. The band of frequencies extending from 88 to 108 megahertz, which includes those assigned to noncommercial educational broadcasting.

Fm broadcast channel. A band of frequencies 200 kHz wide and designated by its center frequency. Channels for fm broadcast stations begin at 88.1 MHz and continue in successive steps of 200 kHz to and including 107.9 MHz.

Fm broadcast station. A station employing frequency modulation in the fm broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

Field strength. The electric field strength in the horizontal plane.

Free space field strength. The field strength that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

Frequency modulation. A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

Frequency swing. The instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

Multiplex transmission. The term "multiplex transmission" means the simultaneous transmission of two or more signals within a single channel. Multiplex transmission as applied to fm broadcast stations means the transmission of facsimile or other signals in addition to the regular broadcast signals.

Percentage modulation. The ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For fm broadcast stations, a frequency swing of ±75 kHz is defined as 100 percent modulation.

(b) *Stereophonic broadcasting.*

Crosstalk. An undesired signal occurring in one channel caused by an electrical signal in another channel.

Fm stereophonic broadcast. The transmission of a stereophonic program by a single fm broadcast station utilizing the main channel and a stereophonic subchannel.

Left (or right) signal. The electrical output of a microphone or combination of microphones placed so as to convey the intensity, time, and location of sounds originating predominately to the listener's left (or right) of the center of the performing area.

Left (or right) stereophonic channel. The left (or right) signal as electrically reproduced in reception of fm stereophonic broadcasts.

Main channel. The band of frequencies from 50 to 15,000 Hz which frequency-modulate the main carrier.

Pilot subcarrier. A subcarrier serving as a control signal for use in the reception of fm stereophonic broadcasts.

Stereophonic separation. The ratio of the electrical signal caused in the right (or left) stereophonic channel to the electrical signal caused in the left (or right) stereophonic channel by the transmission of only a right (or left) signal.

Stereophonic subcarrier. A subcarrier having a frequency which is the second harmonic of the pilot subcarrier frequency and which is employed in fm stereophonic broadcasting.

Stereophonic subchannel. The band of frequencies from 23 to 53 kHz containing the stereophonic subcarrier and its associated sidebands.

(c) *Facsimile.*

Available line. The portion of the total length of scanning line that can be used specifically for picture signals.

Index of cooperation. The product of the number of lines per inch, the available line length in inches, and the reciprocal of the line-use ratio (e.g., $105 \times 8.2 \times 8/7 = 984$).

Line-use ratio. The ratio of the available line to the total length of scanning line.

Optical density. The logarithm (to the base 10) of the ratio of incident to transmitted or reflected light.

Rectilinear scanning. The process of scanning an area in a predetermined sequence of narrow straight parallel strips.

SEC. 73.319 *Subsidiary communications multiplex operations: engineering standards.* (a) Frequency modulation of SCA subcarriers shall be used.

(b) The instantaneous frequency of SCA subcarriers shall at all times be within the range 20 to 75 kHz: *Provided, however,* That when the station is engaged in stereophonic broadcasting pursuant to Sec. 73.297, the instantaneous frequency of SCA subcarriers shall at all times be within the range 53 to 75 kHz.

(c) The arithmetic sum of the modulation of the main carrier by SCA subcarriers shall not exceed 30 percent: *Provided, however,* That when the station is engaged in stereophonic broadcasting pursuant to Sec. 73.297, the arithmetic sum of the modulation of the main carrier by the SCA subcarriers shall not exceed 10 percent.

(d) The total modulation of the main carrier, including SCA subcarriers, shall meet the requirements of Sec. 73.268.

(e) Frequency modulation of the main carrier caused by the SCA subcarrier operation shall, in the frequency range 50 to 15,000 Hz, be at least 60 dB below 100 percent modulation: *Provided, however,* That when the station is engaged in stereophonic broadcasting pursuant to Sec. 73.297, frequency modulation of the main carrier by the SCA subcarrier operation shall, in the frequency range 50 to 53,000 Hz, be at least 60 dB below 100 percent modulation.

SEC. 73.322 *Stereophonic transmission standards.* (a) The modulating signal for the main channel shall consist of the sum of the left and right signals.

(b) A pilot subcarrier at 19,000 Hz plus or minus 2 Hz shall be transmitted that shall frequency modulate the main carrier between the limits of 8 and 10 percent.

(c) The stereophonic subcarrier shall be the second harmonic of the pilot subcarrier and shall cross the time axis with a positive slope simultaneously with each crossing of the time axis by the pilot subcarrier.
(d) Amplitude modulation of the stereophonic subcarrier shall be used.
(e) The stereophonic subcarrier shall be suppressed to a level less than one percent modulation of the main carrier.
(f) The stereophonic subcarrier shall be capable of accepting audio frequencies from 50 to 15,000 Hz.
(g) The modulating signal for the stereophonic subcarrier shall be equal to the difference of the left and right signals.
(h) The pre-emphasis characteristics of the stereophonic subchannel shall be identical with those of the main channel with respect to phase and amplitude at all frequencies.
(i) The sum of the side bands resulting from amplitude modulation of the stereophonic subcarrier shall not cause a peak deviation of the main carrier in excess of 45 percent of total modulating (excluding SCA subcarriers) when only a left (or right) signal exists; simultaneously in the main channel, the deviation when only a left (or right) signal exists shall not exceed 45 percent of total modulation (excluding SCA subcarriers).
(j) Total modulation of the main carrier including pilot subcarrier and SCA subscribers shall meet the requirements of Sec. 73.268 with maximum modulation of the main carrier by all SCA subcarriers limited to 10 percent.
(k) At the instant when only a positive left signal is applied, the main channel modulation shall cause an upward deviation of the main carrier frequency; and the stereophonic subcarrier and its sidebands signal shall cross the time axis simultaneously and in the same direction.
(l) The ratio of peak main channel deviation to peak stereophonic subchannel deviation when only a steady state left (or right) signal exists shall be within plus or minus 3.5 percent of unity for all levels of this signal and all frequencies from 50 to 15,000 Hz.
(m) The phase difference between the zero points of the main channel signal and the stereophonic subcarrier sidebands envelope, when only a steady state left (or right) signal exists, shall not exceed plus or minus 3 degrees for audio modulating frequencies from 50 to 15,000 Hz.

N°95: If the stereophonic separation between left and right stereophonic channels is better than 29.7 decibels at audio modulating frequencies between 50 and 15 000 Hz, it will be assumed that paragraphs (l) and (m) of this section have been complied with.

(n) Crosstalk into the main channel caused by a signal in the stereophonic subchannel shall be attenuated at least 40 decibels below 90 percent modulation.
(o) Crosstalk into the stereophonic subchannel caused by a signal in the main channel shall be attenuated at least 40 decibels below 90 percent modulation.
(p) For required transmitter performance, all of the requirements of Sec. 73.254 shall apply with the exception that the maximum modulation to be employed if 90 percent (excluding pilot subcarrier) rather than 100 percent.
(q) For electrical performance standards of the transmitter and associated equipment, the requirements of Sec. 73:317(a) (2), (3), (4), and (5) shall apply to the main channel and stereophonic subchannel alike, except that where 100 percent modulation is referred to, this figure shall include the pilot subcarrier.

TELEVISION BROADCAST STATIONS

General Operating Requirements

SEC. 73.651 *Time of operation.* All television broadcast stations will be licensed for unlimited time operation. Each such station shall maintain a regular program operating schedule as follows: Not less than 2 hours daily in any 5 broadcast days per week and not less than a total of 12 hours per week during the first 18 months of the station's operation; not less than 2 hours daily in any 5 broadcast days per week and not less than a total of 16 hours, 20 hours and 24 hours per week for each successive 6-month period of operation, respectively; and not less than 2 hours in each of the 7 days of the week and not less than a total of 28 hours per week thereafter.

(2) "Operation" includes the period during which a station is operated pursuant to temporary authorization or during program tests, as well as during the license period. Time devoted to test patterns, or to aural presentations accompanied by the incidental use of fixed visual images which have no substantial relationship to the subject matter of such aural presentations, shall not be considered in computing periods of program service.

(3) In the event that causes beyond a licensee's control make it impossible to adhere to the operating schedule in subparagraph (1) of this paragraph or to continue operating, the station may limit or discontinue operation for a period of not more than 10 days without further authority of the Commission. However, the Commission and the Engineer in Charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule and shall be subsequently notified when the station resumes regular operation.

(b) Noncommercial educational television broadcast stations are not required to operate on a regular schedule and no minimum number of hours of operation is specified; but the hours of actual operation during a license period shall be taken into consideration in considering the renewal of noncommercial educational television broadcast licenses.

(c)(1) The aural transmitter of a television station shall not be operated separately from the visual transmitter except for the following purposes:

(i) For actual tests of station equipment or actual experimentation in accordance with Sec. 73.666; and

(ii) For emergency "fills" in case of visual equipment failure or unscheduled and unavoidable delays in presenting visual programs. In such situations the aural transmitter may be used to advise the audience of difficulties and to transmit for a short period program material of such nature that the audience will be enabled to remain tuned to the station; for example, music or news accompanying a test pattern or other visual presentation.

(2) During periods of transmission of a test pattern on the visual transmitter of a television station, aural transmission shall consist only of a single tone or series of variable tones. During periods when still pictures or slides are employed to produce visual transmissions which are accompanied by aural transmissions, the aural and visual transmissions shall be integral parts of a program or announcement and shall have a substantial relationship to each other: *Provided*, That nothing herein shall preclude the transmission of a test pattern, still pictures or slides for the following purposes and periods:

(i) To accompany aural announcements of the station's program schedule and aural news broadcasts or news commentaries, for a total period not to exceed one hour in any broadcast day.

(ii) To accompany aural transmissions for a period of time not to exceed fifteen minutes immediately prior to the commencement of a programming schedule.

SEC. 73.661 *Operator requirements.* One or more operators holding a valid radiotelephone first-class operator license shall be on duty at the place where the transmitting apparatus is located or at a remote control point established pursuant to the provisions of Sec. 73.677, and in actual charge thereof whenever the transmitter is delivering power to the transmitting antenna. The original license (or FCC Form 759) of each station operator shall be posted at the place where he is on duty. The licensed operator on duty and in charge of the television broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of license which he holds and the rules and regulations governing such other stations. However, such other duties shall in nowise impair or impede the required supervision of the television broadcast transmitter. If operation by remote control has not been authorized, the transmitter shall be readily accessible and clearly visible to the operator at his normal operating position. If operation by remote control is authorized, the control and monitoring equipment shall be readily accessible and clearly visible to the operator at his normal operating position.

SEC. 73.668 *Frequency tolerance.* (a) The carrier frequency of the visual transmitter shall be maintained within ±1000 hertz (Hz) of the authorized carrier frequency.

(b) The center frequency of the aural transmitter shall be maintained 4.5 megahertz (MHz), ±1000 Hz, above the visual carrier frequency.

SEC. 73.671 *Operating log.* (a) The following entries shall be made in the operating log by the properly licensed operator in actual charge of the transmitting apparatus only.

(1) An entry of the time the station begins to supply power to the antenna and the time it stops.

(2) An entry of each interruption of the carrier wave, where restoration is not automatic, its cause and duration followed by the signature of the person restoring operation (if licensed operator other than the licensed operator on duty).

(3) An entry, at the beginning of operation and at intervals not exceeding one-half hour, of the following (actual readings observed prior to making any adjustments to the equipment) and, when appropriate, an indication of corrections made to restore parameters to normal operating values:

(i) Operating constants of last radio stage of aural transmitter (total plate voltage and plate current).

(ii) Transmission line meter readings for both transmitters.

(4) Any other entries required by the instrument of authorization or the provisions of this part.

(5) The entries required by Sec. 17.49 (a), (b), and (c) of this chapter concerning daily observations of tower lights.

(b) Automatic devices accurately calibrated and with appropriate time, date and circuit functions may be utilized to record the entries in the operating log: *Provided*, That:

(1) They do not affect the operation of circuits or accuracy of indicating instruments of the equipment being recorded;

(2) The recording devices have an accuracy equivalent to the accuracy of the indicating instruments;

(3) The calibration is checked against the original indicators at least once a week and the results noted in the maintenance log;

(4) Provision is made to actuate automatically an aural alarm circuit located near the operator on duty if any of the automatic log readings are not within the tolerances or other requirements specified in the rules or instrument of authorization;

(5)Unless the alarm circuit operates continuously, devices which record each parameter in sequence must read each parameter at least once during each 10-minute period and clearly indicate the parameter being recorded;

(6) The automatic logging equipment is located in the near vicinity of the operator on duty and is inspected by him periodically during the broadcast day;

(7) The indicating equipment conforms to the requirements of Sec. 73.688 except that the scales need not exceed 2 inches in length. Arbitrary scales may not be used.

(c) In preparing the operating log, original data may be recorded in rough form and later transcribed into the log, but in such a case all portions of the original memoranda shall be preserved as a part of the complete log.

(d) Operating logs shall be changed or corrected only in the manner prescribed in Sec. 73.669(c) and only in accordance with the following:

(1) *Manually kept log.* Any necessary corrections in a manually kept operating log shall be made only by the person making the original entry who shall make and initial each correction prior to signing the log when going off duty in accordance with Sec. 73.669(a). If corrections or additions are made in the operating log after it has been so signed, explanation must be made on the log or on an attachment to it, dated and signed by either the person who kept the log or the station technical supervisor or an officer of the licensee.

(2) *Automatic logging.* No automatically kept operating log shall be altered in any way after entries have been recorded. Any errors or omissions found in an automatically kept operating log shall be noted and explained in a memorandum signed by the operator on duty (who, under the provisions of paragraph (b (7) of this section, is required to inspect the automatic equipment) or, by the station technical supervisor or an officer of the licensee. Such memorandum shall be affixed to the original log in question.

SEC. 73.672 *Maintenance log.* (a) The following entries shall be made in the maintenance log:

(1) An entry each week of the time and result of test of auxiliary transmitters.

(2) A notation each week of the calibration check of automatic recording devices as required by Sec. 73.671(b)(3).

(3) An entry describing the method used and the results obtained in determining the operating frequency of the transmitter:

(i) Whenever the frequency check required by Sec. 73.690(a) is made.

(ii) Whenever the frequency measurement required by Sec. 73690(c) is made. made.

(4)An entry of the date and time of removal from and restoration to service of any of the following equipment in the event it becomes defective:

(i) Visual modulation monitoring equipment or aural modulation monitor.

(ii) Final stage plate voltmeters of aural and visual transmitters.

(iii) Final stage plate ammeters of aural and visual transmitters.

(iv) Visual and aural transmitter transmission line radio frequency voltage, current, or power meter.

(5) The entries required by Sec. 17.49(d) of this chapter concerning quarterly inspections of the condition of tower lights and associated control equipment and an entry when towers are cleaned or repainted as required by Sec. 17.50 of this chapter.

(6) Entries shall be made so as to describe fully any operation for testing and maintenance purposes.

(7) Whenever the calibration of the output power meter is made as required by Sec. 73.689(b)(1) and (2) with a brief description of the method and results.

(8) Any other entries required by the instrument of authorization or the provisions of this part.

(b) The inspecting operator shall sign and date the maintenance log at the conclusion of each inspection. In preparing the maintenance log, original data may be recorded in rough form and later transcribed into the log, but in such cases all portions of the original memorandum shall be preserved as a part of the complete log.

(c) Any necessary corrections in the maintenance log shall be made only by the inspecting operator who shall initial and date all changes prior to signing the log. If corrections or additions are made on the maintenance log after the log has been so signed, explanation must be made the subject of a separate memorandum, dated and signed by the operator who made the entry in question or the station technical supervisor or by an officer of the licensee. Such memorandum shall explain fully the circumstances surrounding the errors or ambiguities, and shall be affixed to the original log in question. If written and signed by other than the inspecting operator who made the entry the memorandum shall contain a satisfactory explanation of why such signature is lacking.

SEC. 73.676 *Remote control operation.* (a) Television broadcast stations operating on Channels 14-83 may be authorized to operate by remote control upon a satisfactory showing as to the manner of compliance with the following requirements:

(1) Suitable control circuits shall be installed to:

(i) Turn the transmitter on and off at will.

(ii) Determine the power output of the visual and aural final radio frequency amplifiers or the power delivered to the antenna.

(iii) Adjust the power output of the final radio frequency amplifier to compensate for variations in line voltage.

(iv) Make such adjustments as may be necessary to insure that the characteristics of the transmitted signal comply in all respects with the technical requirements of the rules.

(2) The control point shall be equipped with apparatus suitable for observing the waveform and other pertinent characteristics of the transmitted visual signal and the percent of modulation of the transmitted aural signal.

(3) The control circuits from the control point to the transmitter shall be so designed and installed that open circuits, short circuits, accidental grounding, or other line faults will not activate the transmitting apparatus and any fault which results in loss of control of the transmitting apparatus will automatically remove power from the transmitting antenna.

(4) The transmitting equipment and control equipment shall be adequately protected against tampering or activation by unauthorized persons.

(b) Where a transmitter is operated by remote control the transmitting apparatus and associated controls shall be checked as often as is necessary to insure proper operation and confirm the accuracy of the transmitter data sent to the control point over the control circuits and in all cases at least once each week until it can be demonstrated to the Commission that checks at less frequent intervals are satisfactory.

TV Technical Standards

SEC. 73.681 *Definitions.*

Amplitude modulation (a-m). A system of modulation in which the envelope of the transmitted wave contains a component similar to the wave form of the signal to be transmitted.

Antenna electrical beam tilt. The shaping of the radiation pattern in the vertical plane of a transmitting antenna by electrical means so that maximum radiation occurs at an angle below the horizontal plane.

Antenna height above average terrain. The average of the antenna heights above the terrain from two to ten miles from the antenna for the eight directions spaced evenly for each 45 degrees of azimuth starting with True North. (In general, a different antenna height will be determined in each direction from the antenna. The average of these various heights is considered the antenna height above the average terrain. In some cases less than 8 directions may be used. See Sec. 73.684(d).)

Antenna mechanical beam tilt. The intentional installation of a transmitting antenna so that its axis is not vertical, in order to change the normal angle of maximum radiation in the vertical plane.

Antenna power gain. The square of the ratio of the root-mean-square free space field intensity produced at one mile in the horizontal plane, in millivolts per meter for one kilowatt antenna input power to 137.6 mv/m. This ratio should be expressed in decibels (dB). (If specified for a particular direction, antenna power gain is based on the field strength in that direction only.)

Aspect ratio. The ratio of picture width to picture height as transmitted.

Aural transmitter. The radio equipment for the transmission of the aural signal only.

Aural center frequency. (1) The average frequency of the emitted wave when modulated by a sinusoidal signal; (2) the frequency of the emitted wave without modulation.

Blanking level. The level of the signal during the blanking interval, except the interval during the scanning synchronizing pulse and the chrominance subcarrier synchronizing burst.

Chrominance. The colorimetric difference between any color and a reference color of equal luminance, the reference color having a specific chromaticity.

Chrominance subcarrier. The carrier which is modulated by the chrominance information.

Color transmission. The transmission of color television signals which can be reproduced with different values of hue, saturation, and luminance.

Effective radiated power, The product of the antenna input power and the antenna power gain. This product should be expressed in kilowatts and in decibels above 1 kilowatt (dBk). (If specified for a particular direction, effective radiated power is based on the antenna power gain in that direction only. The licensed effective radiated power is based on the average antenna power gain for each horizontal plane direction. When a station is authorized to use a directional antenna or an antenna beam tilt, the direction and amount of maximum effective radiated power will also be specified.)

Field. Scanning through the picture area once in the chosen scanning pattern. In the line interlaced scanning pattern of two to one, the scanning of the alternate lines of the picture area once.

Frame. Scanning all of the picture area once. In the line interlaced scanning pattern of two to one, a frame consists of two fields.

Free space field intensity. The field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

Frequency modulation (fm). A system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous amplitude of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the frequency of the modulating signal.

Interlaced scanning. A scanning process in which successively scanned lines are spaced an integral number of line widths, and in which the adjacent lines are scanned during successive cycles of the field frequency.

Luminance. Luminous flux emitted, reflected, or transmitted per unit solid angle per unit projected area of the source.

Monochrome transmission. The transmission of television signals which can be reproduced in gradations of a single color only.

Negative transmission. Where a decrease in initial light intensity causes an increase in the transmitted power.

Peak power. The power over a radio frequency cycle corresponding in amplitude to synchronizing peaks.

Percentage modulation. For the aural transmitter of television broadcast stations, a frequency swing of ±25 kHz is defined as 100 percent modulation.

Polarization. The direction of the electric field as radiated from the transmitting antenna.

Reference black level. The level corresponding to the specified maximum excursion of the luminance signal in the black direction.

Reference white level of the luminance signal. The level corresponding to the specified maximum excursion of the luminance signal in the white direction.

Scanning. The process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

Scanning line. A single continuous narrow strip of the picture area containing highlights, shadows, and half-tones, determined by the process of scanning.

Standard television signal. A signal which conforms to the television transmission standards.

Television broadcast band. The frequencies in the band extending from 54 to 890 MHz which are assignable to television broadcast stations. These frequencies are 54 to 72 MHz (channels 2 through 4), 76 to 88 MHz (channels 5 and 6), 174 to 216 MHz (channels 7 through 13), and 470 to 890 MHz (channels 14 through 83).

Television broadcast station. A station in the television broadcast band transmitting simultaneous visual and aural signals intended to be received by the general public.

Television channel. A band of frequencies 6 MHz wide in the television broadcast band and designated either by number or by the extreme lower and upper frequencies.

Television transmission standards. The standards which determine the characteristics of a television signal as radiated by a television broadcast station.

Television transmitter. The radio transmitter or transmitters for the transmission of both visual and aural signals.

Vestigial sideband transmission. A system of transmission wherein one of the generated sidebands is partially attenuated at the transmitter and radiated only in part.

Visual carrier frequency. The frequency of the carrier which is modulated by the picture information.

Visual transmitter. The radio equipment for the transmission of the visual signal only.

Visual transmitter power. The peak power output when transmitting a standard television signal.

SEC. 73.682 *Transmission standards and changes.* (a) *Transmission standards.* (1) The width of the television broadcast channel shall be 6 MHz.

(2) The visual carrier frequency shall be nominally 1.25 MHz above the lower boundary of the channel.

(3) The aural center frequency shall be 4.5 MHz higher than the visual carrier frequency.

(4) The visual transmission amplitude characteristic shall be in accordance with the chart designated as Figure 5 of Sec 73.699: *Provided, however,* That for stations operating on Channel 15-83 and employing a transmitter with maximum peak visual power output of 1 kilowatt or less the visual transmission amplitude characteristic may be in accordance with the chart designated as Figure 5A of Sec. 73.699.

(5) The chrominance subcarrier frequency shall be 3,579545 MHz ±10 Hz with a maximum rate of change not to exceed one-tenth hertz per second.

(6) For monochrome and color transmissions the number of scanning lines per frame shall be 525, interlaced two to one in successive fields. The horizontal scanning frequency shall be $\frac{2}{455}$ times the chrominance subcarrier frequency; this corresponds nominally to 15,750 Hz (with an actual value of 15,734.264 ± 0.044 Hz). The vertical scanning frequency is $\frac{2}{525}$ times the horizontal scanning frequency; this corresponds nominally to 60 Hz (the actual value is 59.94 Hz). For monochrome transmissions only, the nominal values of line and field frequencies may be used.

(7) The aspect ratio of the transmitted television picture shall be 4 units horizontally to 3 units vertically.

(8) During active scanning intervals, the scene shall be scanned from left to right horizontally and from top to bottom vertically, at uniform velocities.

(9) A carrier shall be modulated within a single television channel for both picture and synchronizing signals. For monochrome transmission, the two signals comprise different modulation ranges in amplitude, in accordance with the charts designated as Figures 5 and 7 of Sec. 73.699 for stations operating on Channels 2–14 or Figures 5A and 7 for stations operating on Channels 15–83 and employing a transmitter with maximum peak visual power output of 1 kilowatt or less. For color transmission, the two signals comprise different modulation ranges in amplitude except where the chrominance penetrates the picture region, in accordance with the charts designated as Figures 5 and 6 of Sec. 73.699 for stations operating on Channels 2–14 or Figures 5A and 6 for stations operating on Channels 15–83 and employing a transmitter with maximum peak visual power output of 1 kilowatt or less.

(10) A decrease in initial light intensity shall cause an increase in radiated power (negative transmission).

(11) The reference black level shall be represented by a definite carrier level, independent of light and shade in the picture.

(12) The blanking level shall be transmitted at 75 ± 2.5 percent of the peak carrier level.

(13) The reference white level of the luminance signal shall be 12.5±2.5 percent of the peak carrier level.

(14) The signals radiated shall have horizontal polarization.

(15) The effective radiated power of the aural transmitter shall not be less than 10 percent nor more than 20 percent of the peak radiated power of the visual transmitter.

NOTE: Existing licensees presently authorized an aural effective radiated power greater than 20 percent of the peak visual effective radiated power may continue to so operate until March 1, 1966.

(16) The peak-to-peak variation of transmitter output within one frame of video signal due to all causes, including hum, noise, and low-frequency response, measured at both scanning synchronizing peak and blanking level, shall not exceed 5 percent of the average scanning synchronizing peak signal amplitude. This provision is subject to change but is considered the best practice under the present state of the art. It will not be enforced pending a further determination thereof.

(17) The reference black level shall be separated from the blanking level by the setup interval, which shall be 7.5±2.5 percent of the video range from blanking level to the reference white level.

(18) For monochrome transmission, the transmitter output shall vary in substantially inverse logarithmic relation to the brightness of the subject. No tolerances are set at this time. This provision is subject to change but is considered the best practice under the present state of the art. It will not be enforced pending a further determination thereof.

(19) The color picture signal shall correspond to a luminance component transmitted as amplitude modulation of the picture carrier and a simultaneous pair or chrominance components transmitted as the amplitude modulation sidebands of a pair of suppressed subcarriers in quadrature.

(20) Equation of complete color signal.

(i) The color picture signal has the following composition:

$$E_M = E_Y' + [E_Q' \sin(\omega t + 33°) + E_I' \cos(\omega t + 33°)]$$

where,

E_Q' is the $0.41(E_B' - E_Y') + 0.48(E_R' - E_Y')$.
E_I' is the $-0.27(E_B' - E_Y') + 0.74(E_R' - E_Y')$.
E_Y' is the $0.30E_R' + 0.59E_G' + 0.11E_B'$.

For color-difference frequencies below 500 kHz (see (iii) below), the signal can be represented by:

$$E_M = E_Y' + \left\{\frac{1}{1.14}\left[\frac{1}{1.78}(E_B' - E_Y') \sin \omega t + (E_R' - E_Y') \cos \omega t\right]\right\}$$

(ii) The symbols in subdivision (i) of this subparagraph have the following significance:

E_M is the total video voltage, corresponding to the scanning of a particular picture element, applied to the modulator of the picture transmitter.

E_Y' is the gamma-corrected voltage of the monochrome (black-and-white) portion of the color picture signal, corresponding to the given picture element.

NOTE: Forming of the high frequency portion of the monochrome signal in a different manner is permissible and may in fact be desirable in order to improve the sharpness on saturated colors.

E_Q' and E_I' are the amplitudes of two orthogonal components of the chrominance signal corresponding respectively to narrow-band and wide-band axes.

E_R', E_G', and E_B' are the gamma-corrected voltages corresponding to red, green, and blue signals during the scanning of the given picture element.

ω is the angular frequency and is 2π times the frequency of the chrominance subcarrier.

The portion of each expression between brackets in (i) represents the chrominance subcarrier signal which carries the chrominance information.

The phase reference in the E_M equation in (i) is the phase of the burst +180°, as shown in Figure 8 of Sec. 73.699. The burst corresponds to amplitude modulation of a continuous sine wave.

(iii) The equivalent bandwidth assigned prior to modulation to the color difference signals E_Q' and E_I' are as follows:

Q-channel bandwidth:
- At 400 kHz less than 2dB down.
- At 500 kHz less than 6 dB down.
- At 600 kHz at least 6 dB down.

I-channel bandwidth:
- At 1.3 MHz less than 2 dB down.
- At 3.6 MHz at least 20 dB down.

(iv) The gamma corrected voltages E_R', E_G', and E_B' are suitable for a color picture tube having primary colors with the following chromaticities in the CIE system of specification:

	X	Y
Red (R)	0.67	0.33
Green (G)	0.21	0.71
Blue (B)	0.14	0.08

and having a transfer gradient (gamma exponent) of 2.2 associated with each primary color. The voltages E_R', E_G', and E_B' may be respectively of the form $E_R^{1/T}$, $E_G^{1/T}$,, and $E_B^{1/T}$ although other forms may be used with advances in the state of art.

NOTE: At the present state of the art it is considered inadvisable to set a tolerance on the value of gamma and correspondingly this portion of the specification will not be enforced.

(v) The radiated chrominance subcarrier shall vanish on the reference white of the scene.

NOTE: The numerical values of the signal specification assume that this condition will be reproduced as CIE Illuminant C ($x = 0.310$, $y = 0.316$).

(vi) E_Y', E_Q', E_I', and the components of these signals shall match each other in time to 0.05 μsecs.

(vii) The angle of the subcarrier measured with respect to the burst phase, when reproducing saturated primaries and their complements at 75 percent of full amplitude, shall be within ±10° and their amplitudes shall be within ±20 percent of the values specified above. The ratios of the measured amplitudes of the subcarrier to the luminance signal for the same saturated primaries and their complements shall fall between the limits of 0.8 and 1.2 of the values specified for their ratios. Close tolerances may prove to be practicable and desirable with advances in the art.

(21) The interval beginning with the last 12 microseconds of line 17 and continuing through line 20 of the vertical blanking interval of each field may be used for the transmission of test signals subject to the conditions set forth below. Test signals may be used to supply reference modulation levels so that variations in light intensity of the scene viewed by the camera will be faithfully transmitted; signals designed to check the performance of the overall transmission system or its individual components; and cue and control signals related to the operation of the television broadcast station. Figures 6 and 7 of Sec. 73.699 identify the numbered lines referred to in this subparagraph.

(i) Modulation of the television transmitter by such test signals shall be confined to the area between the reference white level and the blanking level except where such test signals are composed of chrominance subcarrier frequencies, in which case their negative excursions may extend into the synchronizing peak amplitude. In no case may the modulation excursions produced by test signals extend beyond peak-of-sync-level.

(ii) The use of test signals shall not result in significant degradation of the program transmissions of the television broadcast station nor create emission components in excess of those permitted for normal program transmissions.

(iii) Test signals may not be transmitted during that portion of each line devoted to horizontal blanking.

(iv) A guard interval of no less than one-half line shall be maintained at all times between the last test signal and the beginning of the first picture scanning line.

(22) The intervals within the first and last 10 microseconds of lines 21 through 23 and 260 through 262 (on a "field" basis) may contain coded patterns for the purpose of electronic identification of television broadcast programs and spot announcements. No single transmission of such coded patterns shall exceed one second in duration. The transmission of these patterns shall not result in significant degradation of broadcast transmission.

(b) *Changes in transmission standards.* The Commission will consider the question whether a proposed change or modification of transmission standards adopted for television would be in the public interest, convenience and necessity, upon petition being filed by the person proposing such change or modification, setting forth the following:

(1) The exact character of the change or modification proposed;

(2) The effect of the proposed change or modification upon all other transmission standards that have been adopted by the Commission for television broadcast stations;

(3) The experimentation and field tests that have been made to show that the proposed change or modification accomplishes an improvement and is technically feasible;

(4) The effect of the proposed change or modification in the adopted standards upon operation and obsolescence of receivers;

(5) The change in equipment required in existing television broadcast stations for incorporating the proposed change or modification in the adopted standards;

(6) The facts and reasons upon which the petitioner bases his conclusion that the proposed change or modification would be in the public interest, convenience, and necessity.

(c) *Subscription television technical systems.* The Commission may specify deviation from the transmission standards set forth in paragraph (a) of this section to the extent it deems necessary to permit proper operation of an approved subscription television technical system. Any decision to specify such deviation shall be solely at the discretion of the Commission.

SEC. 73.687 *Transmitters and associated equipment.* (a) *Visual transmitter.* (1) For monochrome transmission only, the overall attenuation characteristics of the transmitter, measured in the antenna transmission line after the vestigial sideband filter (if used), shall not be greater than the following amounts below the ideal demodulated curve. (See Figure 11 of Sec. 73.699.)

2 dB at 0.5MHz
2 dB at 1.25 MHz
3 dB at 2.0 MHz
6 dB at 3.0 MHz
12 dB at 3.5 MHz

The curve shall be substantially smooth between these specified points, exclusive of the region from 0.75 to 1.25 MHz. Output measurement shall be made with the transmitter operating into a dummy load of pure resistance and the demodulated voltage measured across this load. The ideal demodulated curve is that shown in Figure 11 of Sec. 73.699. Stations operating on Channels 15-83 and employing a transmitter delivering maximum peak visual power output of 1 kilowatt or less will not be required to comply with the provisions of this subparagraph.

(2) For color transmission, the standard given by subparagraph (1) of this paragraph applies except as modified by the following: A sine wave of 3.58 MHz introduced at those terminals of the transmitter which are normally fed the composite color picture signal, shall produce a radiated signal having an amplitude (as measured with a diode on the rf transmission line supplying power to the antenna) which is down 6 ±2 dB with respect to a signal produced by a sine wave of 200 kHz. In addition, between the modulating frequencies of 2.1 and 4.1 MHz the amplitude of the radiated signal shall not vary by more than ±2 dB from its value at 3.58 MHz. At the modulating frequency of 4.18 MHz, the amplitude of the radiated signal shall not be down more than 4 dB below its value of 3.58 MHz. Stations operating on Channels 15—83 and employing a transmitter delivering maximum peak visual power output of 1 kilowatt or less are not required to comply with the provisions of this subparagraph.

(3) The field strength or voltage of the lower sideband, as radiated or dissipated and measured as described in subparagraph (4) of this paragraph, shall not be greater than —20 dB for a modulating frequency of 1.25 MHz or greater and in addition, for color, shall not be greater than –42 dB for a modulating frequency of 3.579545 MHz (the color subcarrier frequency). For both monochrome and color, the field strength or voltage of the upper sideband as radiated or dissipated and measured as described in subparagraph (4) of this paragraph, shall not be greater than –20 dB for a modulating frequency of 4.75 MHz or greater. For stations operating on Channels 15—83 and employing a transmitter delivering maximum peak visual power output of 1 kilowatt or less, the field strength or voltage of the upper and lower sidebands, as radiated or dissipated and measured as described in subparagraph (4) of this paragraph, shall depart from the visual amplitude characteristic (Figure 5A of Sec. 73.699) by no more than the following amounts:

—2 dB at 0.5 MHz below visual carrier frequency;
—2 dB at 0.5 MHz above visual carrier frequency;
—2 dB at 1.25 MHz above visual carrier frequency;
—3 dB at 2.0 MHz above visual carrier frequency;
—6 dB at 3.0 MHz above visual carrier frequency;
—12 dB at 3.5 MHz above visual carrier frequency;
—8 dB at 3.58 MHz above visual carrier frequency (for color transmission only).

The field strength or voltage of the upper and lower sidebands, as radiated or dissipated and measured as described in subparagraph (4) of this paragraph, shall not exceed a level of –20 dB for a modulating frequency of 4.75 MHz or greater. If interference to the reception of other stations is caused by out-of-channel lower sideband emission, the technical requirements applicable to stations operating on Channels 2—13 shall be met.

(4) The attenuation characteristics of a visual transmitter shall be measured by application of a modulating signal to the transmitter input terminals in place of the normal composite television video signal. The signal applied shall be a composite signal composed of synchronizing signal to establish peak output voltage plus a

variable frequency sine wave voltage occupying the interval between synchronizing pulses. (The "synchronizing signal" referred to in this section means either a standard synchronizing wave form or any pulse that will properly set the peak.) The axis of the sine wave in the composite signal observed in the output monitor shall be maintained at an amplitude 0.5 of the voltage at synchronizing peaks. The amplitude of the sine wave input shall be held at a constant value. This constant value should be such that at no modulating frequency does the maximum excursion of the sine wave, observed in the composite output signal monitor, exceed the value 0.75 of peak output voltage. The amplitude of the 200 kHz sideband shall be measured and designated zero dB as a basis for comparison. The modulation signal frequency shall then be varied over the desired range and the field strength or signal voltage of the corresponding sidebands measured. As an alternate method of measuring, in those cases in which the automatic dc insertion can be replaced by manual control, the above characteristic may be taken by the use of a video sweep generator and without the use of pedestal synchronizing pulses. The dc level shall be set for midcharacteristic operation.

(5) A sine wave, introduced at those terminals of the transmitter which are normally fed the composite color picture signal, shall produce a radiated signal having an envelope delay, relative to the average envelope delay between 0.05 and 0.20 MHz, of zero microseconds up to a frequency of 3.0 MHz; and then linearly decreasing to 4.18 MHz so as to be equal to -0.17 μsecs at 3.58 MHz. The tolerance on the envelope delay shall be ± 0.05 μsecs at 3.58 MHz. The tolerance shall increase linearly to ± 0.1 μsec down to 2.1 MHz, and remain at ± 0.1 μsec down to 0.2 MHz. (Tolerances for the interval of 0.0 to 0.2 MHz are not specified at the present time.) The tolerance shall also increase linearly to ± 0.1 μsec at 4.18 MHz.

(6) The radio frequency signal, as radiated, shall have an envelope as would be produced by a modulating signal in conformity with Sec. 73.682 and Figure 6 or 7 of Sec. 73.699, as modified by vestigial sideband operation specified in Figure 5 of Sec. 73.699. For stations operating on Channels 15—83 the radio frequency signal as radiated, shall have an envelope as would be produced by a modulating signal in conformity with Sec. 73.682 and Figures 6 or 7 of Sec. 73.699.

(7) The time interval between the leading edges of successive horizontal pulses shall vary less than one-half of one percent of the average interval. However, for color transmissions, Sec. 73.682(a) (5) and (6) shall be controlling.

(8) The rate of change of the frequency of recurrence of the leading edges of the horizontal synchronizing signals shall be not greater than 0.15 percent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20, nor more than 100 lines, such lines not to include any portion of the blanking interval. However, for color transmissions, Sections 73.682 (a) (5) and (6) shall be controlling.

(9) For color transmission the transfer characteristic (that is, the relationship between the transmitter rf output and video signal input) shall be substantially linear between the reference black and reference white levels.

(b) *Aural transmitter.* (1) The transmitter shall operate satisfactorily with a frequency swing of ± 25 kHz, which is considered 100 percent modulation. It is recommended, however, that the transmitter be designed to operate satisfactorily with a frequency swing of at least ± 40 kHz.

(2) The transmitting system (from input terminals of microphone pre-amplifier, through audio facilities at the studio, through telephone lines or other circuits between studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be capable of transmitting a band of frequencies from 50 to 15,000 Hz. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Figure 12 of Sec. 73.699.) The deviation of the system response from the standard pre-emphasis curve shall lie between two limits as shown by Figure 12 of Sec. 73.699. The upper of these limits shall be uniform (no deviation) from 50 to 15,000 Hz. The lower limit shall be uniform from 100 to 7500 Hz, and three dB below the upper limit; from 100 to 50 Hz the lower limit shall fall from three dB limit at a uniform rate of one dB per octave (4 dB at 50 Hz); from 7500 to 15,000 Hz the lower limit shall fall from three dB limit at a uniform rate of two dB per octave (5 dB at 15,000 Hz).

(3) At any modulating frequency between 50 and 15,000 Hz and at modulation percentages of 25 percent, 50 percent, and 100 percent, the combined audio frequency harmonics measured in the output of the system shall not exceed the root-mean-square values given in the following table:

Modulation frequency	*Distortion (percent)*
50 to 100 Hz	3.5
100 to 7500 Hz	2.5
7500 to 15,000 Hz	3.0

(ii)Measurement shall be made employing 75 microsecond de-emphasis in the measuring equipment and 75 microsecond pre-emphasis in the transmitting equipment, and without compression if a compression amplifier is employed. Harmonics shall be included to 30 kHz.

NOTE: Measurements of distortion using de-emphasis in the measuring equipment are not practical at the present time for the range 7500 to 15,000 Hz for 25 and 50 percent modulation. Therefore, measurements should be made at 100 percent modulation and on at least the following modulating frequencies: 50, 100, 400, 1000, 5000, 10,000, and 15,000 Hz. At 25 and 50 percent modulation, measurements should be made on at least the following modulating frequencies: 50, 100, 400, 1000 and 5000 Hz.

(ii) It is recommended that none of the three main divisions of the system (transmitter, studio to transmitter circuit, and audio facilities) contribute over one-half of these percentages, since at some frequencies the total distortion may become the arithmetic sum of the distortions of the divisions.

(4) The transmitting system output noise level (frequency modulation) in the band of 50 to 15,000 Hz shall be at least 55 dB below the audio frequency level representing a frequency swing of ±25 kHz.

NOTE: For the purpose of these measurements, the visual transmitter should be inoperative since the exact amount of noise permissible from that source is not known at this time.

(5) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15,000 Hz shall be at least 50 dB below the level representing 100 percent amplitude modulation.

NOTE: For the purpose of these measurements, the visual transmitter should be inoperative since the exact amount of noise permissible from that source is not known at this time.

(6) If a limiting or compression amplifier is employed, precaution should be maintained in its connection in the circuit due to the use of pre-emphasis in the transmitting system.

(7) The percentage of modulation shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice. In no case is it to exceed 100 percent on peaks of frequent recurrence. Generally, it should not be less than 85 percent on peaks of frequent recurrence; but where necessary to avoid objectionable loudness modulation may be reduced to whatever level is necessary, even if the resulting modulation is substantially less than 85 percent on peaks of frequent recurrence.

(c) *Requirements applicable to both visual and aural transmitters.* (1) Automatic means shall be provided in the visual transmitter to maintain the carrier frequency within ±one kilohertz of the authorized frequency; automatic means shall be provided in the aural transmitter maintain the carrier frequency 4.5 MHz above the actual visual carrier frequency within ±one kilohertz.

(2) The transmitters shall be equipped with suitable indicating instruments for the determination of operating power and with other instruments necessary for proper adjustment, operation, and maintenance of the equipment.

(3) Adequate provision shall be made for varying the output power of the transmitters to compensate for excessive variations in line voltage or for other factors affecting the output power.

(4) Adequate provisions shall be provided in all component parts to avoid overheating at the rated maximum output powers.

(d) *Construction.* In general, the transmitters shall be mounted either on racks and panels or in totally enclosed frames protected as required by the provisions of the National Electrical Code concerning transmitting equipment at radio and television stations, and as set forth below:

(1) Means shall be provided for making all tuning adjustments, requiring voltages in excess of 350 volts to be applied to the circuit, from the front of the panels with all access doors closed.

(2) Proper bleeder resistors or other automatic means shall be installed across all the capacitor banks to lower any voltage which may remain accessible with access door open to less than 350 volts within two seconds after the access door is opened.

(3) All plate supply and other high voltage equipment, including transformers, filters, rectifiers and motor generators, shall be protected so as to prevent injury to operating personnel.

(i) Commutator guards shall be provided on all high voltage rotating machinery. Coupling guards should be provided on motor generators.

(ii) Power equipment and control panels of the transmitters shall meet the above requirements (exposed 220-volt ac switching equipment on the front of the power control panels is not recommended but is not prohibited).

(iii) Power equipment located at a television broadcast station not directly associated with the transmitters (not purchased as part of same), such as power distribution panels, are not subject to the provisions of this subpart.

(4) The following provisions shall be applicable to metering equipment:

(i) All instruments having more than 1000 volts potential to ground on the movement shall be protected by a cage or cover in addition to the regular case. (Some instruments are designed by the manufacturers to operate safely with voltages in excess of 1000 volts on the movement. If it can be shown by the manufacturer's rating that the instrument will operate safely at the applied potential, additional protection is not necessary.)

(ii) In case the plate voltmeters are located on the low potential side of the multiplier resistors with the high potential terminal of the instruments at or less than 1000 volts above ground, no protective case is required. However, it is good practice to protect voltmeters subject to more than 5000 volts with suitable overvoltage protective devices across the instrument terminals in case the winding opens.

(iii) Transmission line meters and any other radio frequency instrument which may be necessary for the operator to read shall be so installed as to be read easily and accurately without the operator having to risk contact with circuits carrying high potential radio frequency energy.

(e) *Wiring and shielding.* (1) The transmitter panels or units shall be wired in accordance with standard practice, such as insulated leads properly cabled and supported, coaxial cables, or rigid bus bar properly insulated and protected.

(2) Wiring between units of the transmitters, with the exception of circuits carrying radio frequency energy or video energy, shall be installed in conduits or approved fiber or metal raceways to protect it from mechanical injury.

(3) Circuits carrying radio frequency or video energy between units shall be coaxial cables, two wire balanced lines, or properly shielded lines.

(4) All stages or units shall be adequately shielded and filtered to prevent interaction and radiation.

(5) The frequency and modulation monitors and associated radio frequency lines to the transmitter shall be thoroughly shielded.

(f) *Auxiliary transmitters.* Auxiliary transmitters may not exceed the power rating of the main transmitters. As a general guide, specifications for auxiliary transmitters should conform as much as possible to those of the main transmitters. No requirements are set forth at this time.

(g) *Installation.* (1) The installation of transmitting equipment shall be made in suitable quarters.

(2) Suitable facilities shall be provided for the welfare and comfort of the operator.

(h) *Other technical data.* An accurate circuit diagram, as furnished by the manufacturer of the equipment, shall be retained at the transmitter location.

(i) *Operation.* (1) Spurious emissions, including radio frequency harmonics, shall be maintained at as low a level as the state of the art permits. As measured at the output terminals of the transmitter (including harmonic filters, if required) all emissions removed in frequency in excess of 3 MHz above or below the respective channel edge shall be attenuated no less than 60 dB below the visual transmitted power. (The 60 dB value for television transmitters specified in this rule should be considered as a temporary requirement which may be increased at a later date, especially when more higher-powered equipment is utilized. Stations should, therefore, give consideration to the installation of equipment with greater attenuation than 60 dB). In the event of interference caused to any service, greater attenuation will be required.

(2) If a limiting or compression amplifier is used in conjunction with the aural transmitter, due operating precautions should be maintained because of pre-emphasis in the transmitting system.

(j) *Studio equipment.* Studio equipment shall be subject to all the above requirements where applicable, except as follows:

(1) If properly covered by an underwriter's certificate, it will be considered as satisfying safety requirements.

(2) The pertinent provisions of the National Electrical Code concerning transmitting equipment at radio and television stations shall apply for voltages only when in excess of 500 volts.

(3) No specific requirements are made relative to the design and acoustical treatment of studios. However, the design of studios, particularly the main studio, shall be compatible with the required performance characteristics of television broadcast stations.

(k) *Subscription television technical systems.* The Commission may specify deviation from the transmitter and associated equipment requirements set forth in this section to the extent it deems necessary to permit proper operation of an approved subscription television technical system. Any decision to specify such deviation shall be solely at the discretion of the Commission.

SEC. 73.689 *Operating power.* (a) *Determination*—(1) *Visual transmitter.* The operating power of the visual transmitter shall be determined at the output terminals of the transmitter, which includes any vestigial sideband and harmonic filters which may be used during normal operation. For this determination the average power output shall be measured while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. During this measurement the transmitter shall be modulated only by a standard synchronizing signal with blanking level set at 75 percent of peak amplitude as observed in an output monitor, and with this blanking level amplitude maintained throughout the time interval between synchronizing pulses. If electrical devices are used to determine the output power, such devices shall permit determination of this power to within an accuracy of ±5 percent of the power indicated by the full scale reading of the electrical indicating instrument of the device. If temperature and coolant flow indicating devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of 4 percent of measured average power output. The peak power output shall be the power so measured in the dummy load multiplied by the factor 1.68. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement.

(2) *Aural transmitter.* The operating power of the aural transmitter shall be determined by either the direct or indirect method.

(i) Using the direct method, the power shall be measured at the output terminals of the transmitter while operating into a dummy load of substantially zero reactance and a resistance equal to the transmission line characteristic impedance. The transmitter shall be unmodulated during this measurement. If electrical devices are used to determine the output power, such devices shall permit determination of this power to within an accuracy of ±5 percent of the power indicated by the full scale reading of the electrical indicating instrument of the device. If temperature and coolant flow indicating devices are used to determine the power output, such devices shall permit determination of this power to within an accuracy of 4 percent of measured average power output. During this measurement the direct plate voltage and current of the last radio stage and the transmission line meter shall be read and compared with similar readings taken with the dummy load replaced by the antenna. These readings shall be in substantial agreement.

(ii) Using the indirect method, the operating power is the product of the plate voltage (E_p) and the plate current (I_p) of the radio stage, and an efficiency factor, F, as follows:

$$\text{Operating power} = E_p \times I_p \times F$$

(iii) The efficiency factor, F, shall originally be established by the transmitter manufacturer for each type of transmitter for which he submits data to the Commission, and shall be shown in the instruction books supplied to the customer with each transmitter. In the case of composite equipment, the factor F shall be furnished to the Commission by the applicant along with a statement of the basis used in determining such factor.

(b) *Maintenance*—(1) *Visual transmitter.* The operating power shall be maintained as near as is practicable to the authorized power and shall not be less than 80 percent nor more than 110 percent of the authorized power at any time, except as provided in subparagraph (3) of this paragraph. The peak power shall be monitored at the output terminals of the transmitter with a peak reading meter whose indications are proportional to peak voltage, current or power. The range and electrical accuracy of the meter and the physical characteristics of the meter scale shall be adequate to permit a determination that the power output does not exceed the prescribed tolerance. The meter shall be calibrated with the transmitter operating at 80, 100, and 110 percent of the authorized power as often as may be necessary to insure compliance with the requirements of this paragraph and in any event at intervals of no more than 6 months. In cases where the transmitter is incapable of operating at 110 percent of the authorized power output, the calibration may be made at a power output between 100 and 110 percent of the authorized power output. However, where this is done, the output meter shall be marked at the point of calibration of maximum power output, and the station will be deemed to be in violation of this rule if that power is exceeded. If any component in the power measuring circuit is replaced, the meter shall be recalibrated upon completion of such repairs. The upper and lower limits of permissible power deviation as determined by the prescribed calibration, shall be shown upon the meter either by means of adjustable red markers incorporated in the meter or by red marks placed upon the meter scale or glass face. These markings shall be checked and changed, if necessary, each time the meter is calibrated.

(2) *Aural transmitter.* (i) The operating power shall be maintained as near as practicable to the authorized power and shall not be less than 80 percent nor greater than 110 percent of authorized power except as indicated in subparagraph (3) of this paragraph.

(ii) When determined by the direct method, the operating power of the transmitter shall be monitored at the output terminals of the transmitter with a transmission line meter whose indications are proportional to voltage, current, or power. The range and electrical accuracy of the meter and the physical characteristics of the meter scale shall be adequate to permit a determination that the power output does not exceed the prescribed tolerance. The meter shall be calibrated with the transmitter operating at 80, 100, and 110 percent of the authorized power as often as may be necessary to insure compliance with the requirements of this paragraph and in all cases at intervals of no more than 6 months. In cases where the transmitter is incapable of operating at 110 percent of the authorized power output, the calibration may be made at a power output between 100 and 110 percent of the authorized power output. However, where this is done, the output meter shall be marked at the point of calibration of maximum power output, and the station will be deemed to be in violation of this rule if that power is exceeded. If any component in the power measuring circuit is replaced, the meter shall be recalibrated upon completion of such repairs. The upper and lower limits of permissible power deviation as determined by the prescribed calibration, shall be shown upon the meter either by means of adjustable red markers incorporated in the meter or by red marks placed upon the meter scale or glass face. These markings shall be checked and changed, if necessary, each time the meter is calibrated.

(3) *Reduced power.* In the event it becomes technically impossible to operate with the authorized power, the station may be operated with reduced power for a period of 10 days or less without further authority of the Commission: *Provided,*

That the Commission and the Engineer in Charge of the radio district in which the station is located shall be immediately notified in writing if the station is unable to maintain the minimum operating schedule (specified in Sec. 73.651) with authorized power and shall be subsequently notified upon resumption of operation with authorized power.

(c) *Subscription television technical systems.* The Commission may specify deviation from the power determination and maintenance methods set forth in this section to the extent it deems necessary to permit proper operation of an approved subscription television technical system. Any decision to specify such deviation shall be solely at the discretion of the Commission.

SEC. 73.699 *Engineering Charts.* (See pages 382 through 392.)

EMERGENCY ACTION NOTIFICATION SYSTEM AND THE EMERGENCY BROADCAST SYSTEM

Scope and Objectives

SEC. 73.901 *Scope of subpart.* This subpart provides for an Emergency Action Notification System for all licensees and regulated services of the Federal Communications Commission and the general public, and for an Emergency Broadcast System (EBS). This subpart applies to all broadcast stations governed by this part within any State, the District of Columbia, the Commonwealth of Puerto Rico, and the possessions of the United States, but not those stations located in the Canal Zone.

SEC. 73.902 *Objectives of subpart.* The objectives of this subpart are to provide an expeditious means for the dissemination of an Emergency Action Notification (with or without an Attack Warning) to licensees and regulated services of the Federal Communications Commission and to the general public during conditions of a grave national crisis or war and to provide for an Emergency Broadcast System (EBS), which would be activated upon release of an Emergency Action Notification by direction of the President of the United States. The Emergency Broadcast System provides for controlled operation of broadcast stations subject to this part, on a voluntary organized basis, to provide the President and the Federal Government, as well as State and local governments, with an expeditious means of communicating with the general public during an Emergency Action Condition.

SEC. 73.906 *Attention Signal.* The signaling arrangement whereby standard, fm, and television broadcast stations can actuate muted receivers for the receipt of emergency cuing announcements and broadcasts, is as follows:

(a) Cut the transmitter carrier for 5 seconds. (Sound carrier only for TV stations.)

(b) Return carrier to the air for 5 seconds.

(c) Cut transmitter carrier for 5 seconds. (Sound carrier only for TV stations.)

(d) Return carrier to the air.

(e) Broadcast 1000 Hz steady-state tone for 15 seconds.

NOTE: Steps (a) through (e) above, constitute the present Attention Signal. Revision of the Attention Signal is under study by a Special National Industry Advisory Committee Working Group.

SEC. 73.907 *Emergency Action Notification.* The Emergency Action Notification is the notice (with or without an Attack Warning) to all licensees and regulated services of the Federal Communications Commission and to the general public of the existence of an Emergency Action Condition. The Emergency Action Notification is released upon direction of the President of the United States and is disseminated only via the Emergency Action Notification System.

SEC. 73.908 *Emergency Action Condition.* The Emergency Action Condition is the period of time between the transmission of an Emergency Action Notification and the transmission of the Emergency Action Condition Termination.

SEC. 73.909 *Emergency Action Condition Termination.* The Emergency Action Condition Termination is the notice to all licensees and regulated services of the Federal Communications Commission and to the general public of the termination of an Emergency Action Condition. The Emergency Action Condition Termination is released upon direction of the President of the United States and is disseminated only via the Emergency Action Notification System.

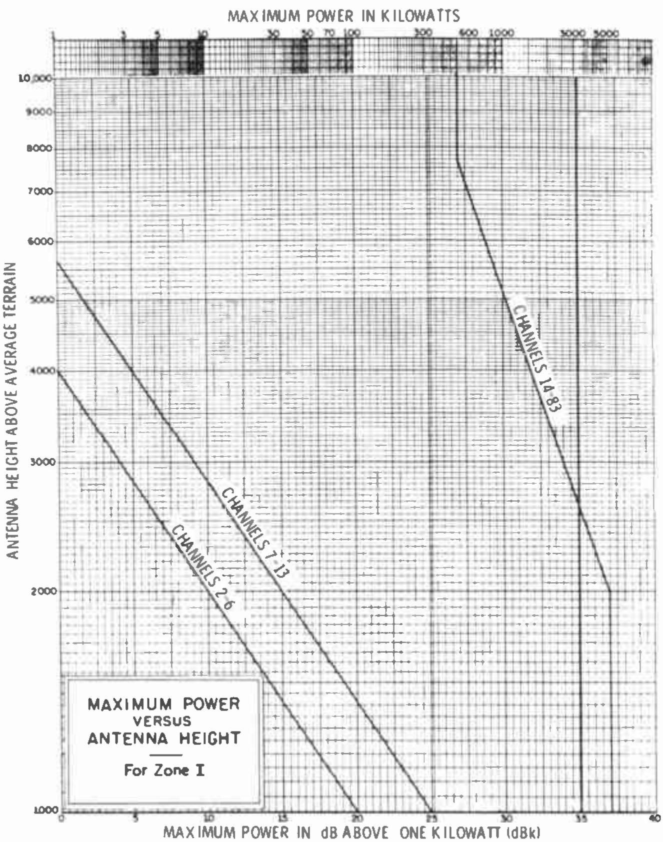

MAXIMUM POWER IN KILOWATTS
ANTENNA HEIGHT ABOVE AVERAGE TERRAIN
MAXIMUM POWER IN dB ABOVE ONE KILOWATT (dBk)
CHANNELS 2-6
CHANNELS 7-13
CHANNELS 14-83
MAXIMUM POWER
VERSUS
ANTENNA HEIGHT
For Zone I

Fig. 3.

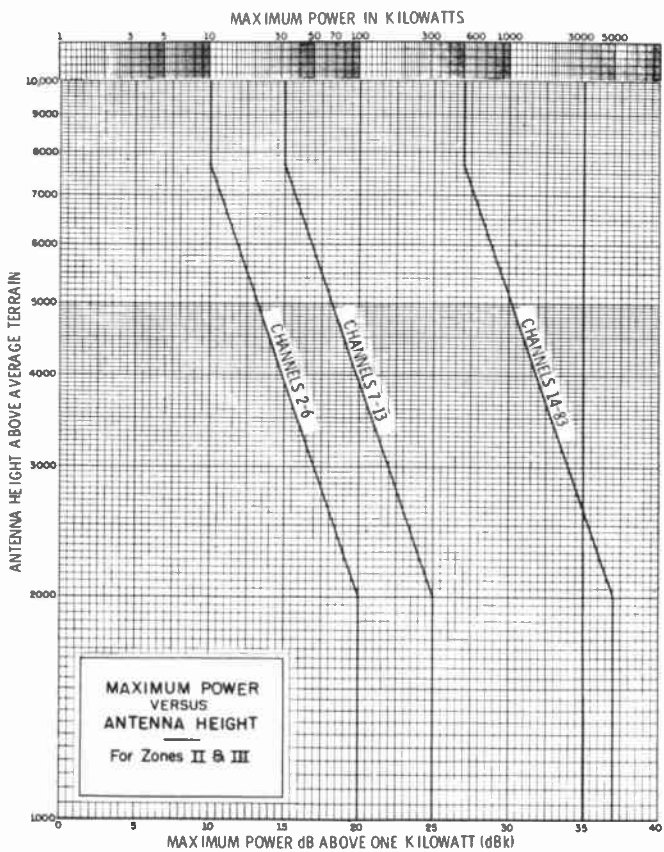

MAXIMUM POWER IN KILOWATTS
1
3
5
10
30
50
70
100
300
600
1000
3000
5000
ANTENNA HEIGHT ABOVE AVERAGE TERRAIN
10,000
9000
8000
7000
6000
5000
4000
3000
2000
1000
CHANNELS 2-6
CHANNELS 7-13
CHANNELS 14-83
MAXIMUM POWER
VERSUS
ANTENNA HEIGHT
For Zones II & III
0
5
10
15
20
25
30
35
40
MAXIMUM POWER dB ABOVE ONE KILOWATT (dBk)

Fig. 4.

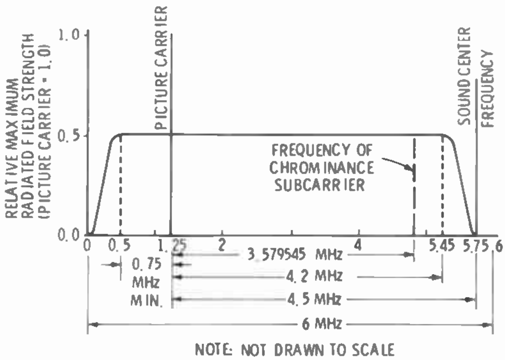

1.0
0.5
0.0
RELATIVE MAXIMUM RADIATED FIELD STRENGTH (PICTURE CARRIER = 1.0)
PICTURE CARRIER
SOUND CENTER FREQUENCY
FREQUENCY OF CHROMINANCE SUBCARRIER
0 0.5 1.25 2 4 5.45 5.75 6
0.75 MHz MIN.
3.579545 MHz
4.2 MHz
4.5 MHz
6 MHz
NOTE: NOT DRAWN TO SCALE

Fig. 5.

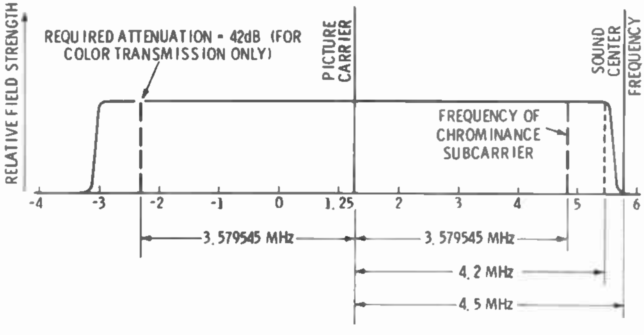

RELATIVE FIELD STRENGTH
REQUIRED ATTENUATION = 42dB (FOR COLOR TRANSMISSION ONLY)
PICTURE CARRIER
SOUND CENTER FREQUENCY
FREQUENCY OF CHROMINANCE SUBCARRIER
-4 -3 -2 -1 0 1.25 2 3 4 5 6
3.579545 MHz
3.579545 MHz
4.2 MHz
4.5 MHz

Fig. 5A.

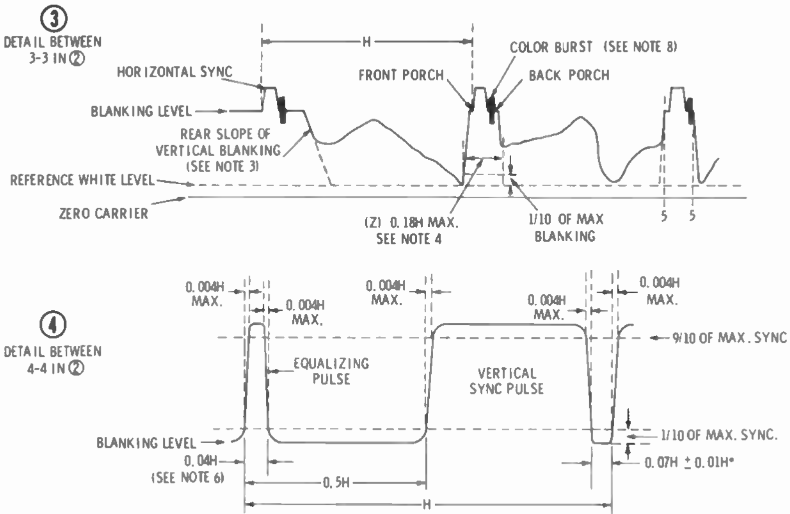


Fig. 6

NOTES

1 H = Time from start of one line to start of next line.
2 V = Time from start of one field to start of next field.
3 Leading and trailing edges of vertical blanking should be complete in less than 0.1H.
4 Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x + y) and (z) under all conditions of picture content.
*5 Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.
6 Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse.
7 Color burst follows each horizontal pulse, but is omitted following the equalizing pulses and during the broad vertical pulses.
8 Color bursts to be omitted during monochrome transmission.
9 The burst frequency shall be 3.579545 MHz. The tolerance on the frequency shall be ± 10 Hz with a maximum rate of change of frequency not to exceed 1/10 Hz per second.
10 The horizontal scanning frequency shall be $\frac{2}{455}$ times the burst frequency.
11 The dimensions specified for the burst determine the times of starting and stopping the burst, but not its phase. The color burst consists of amplitude modulation of a continuous sine wave.
12 Dimension "P" represents the peak excursion of the luminance signal from blanking level, but does not include the chrominance signal. Dimension "S" is the sync amplitude above blanking level. Dimension "C" is the peak carrier amplitude.
13 Start of Field 1 is defined by a whole line between first equalizing pulse and preceding H sync pulses.
14 Start of Field 2 is defined by a half line between first equalizing pulse and preceding H sync pulses.
15 Field 1 line numbers start with first equalizing pulse in Field 1.
16 Field 2 line numbers start with second equalizing pulse in Field 2.
17 Refer to text for further explanations and tolerances.

TELEVISION SYNCHRONIZING WAVE FORM
FOR COLOR TRANSMISSION

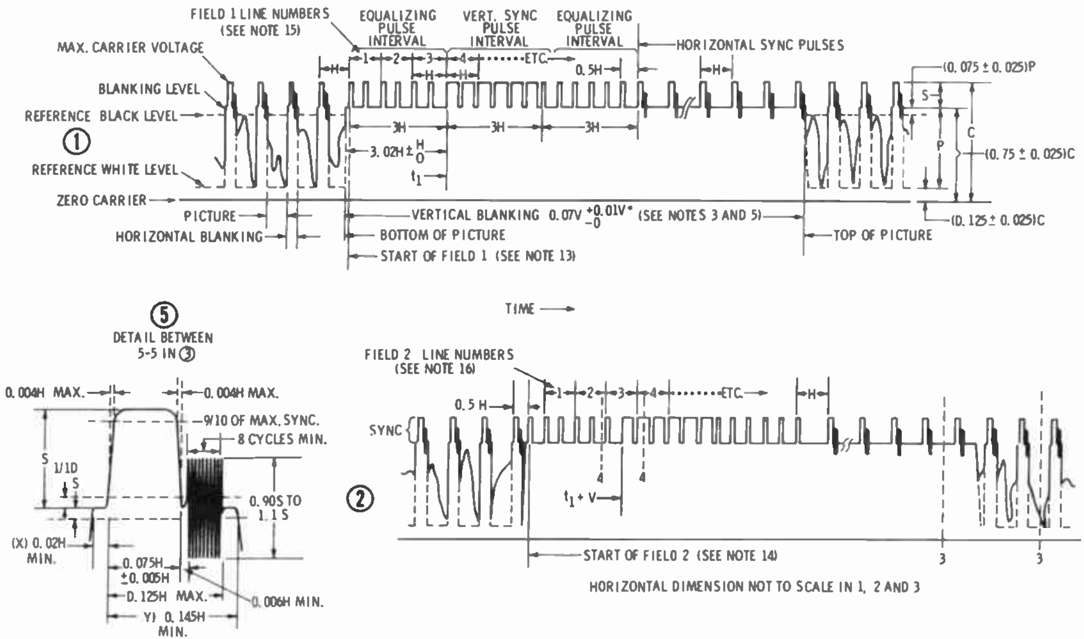
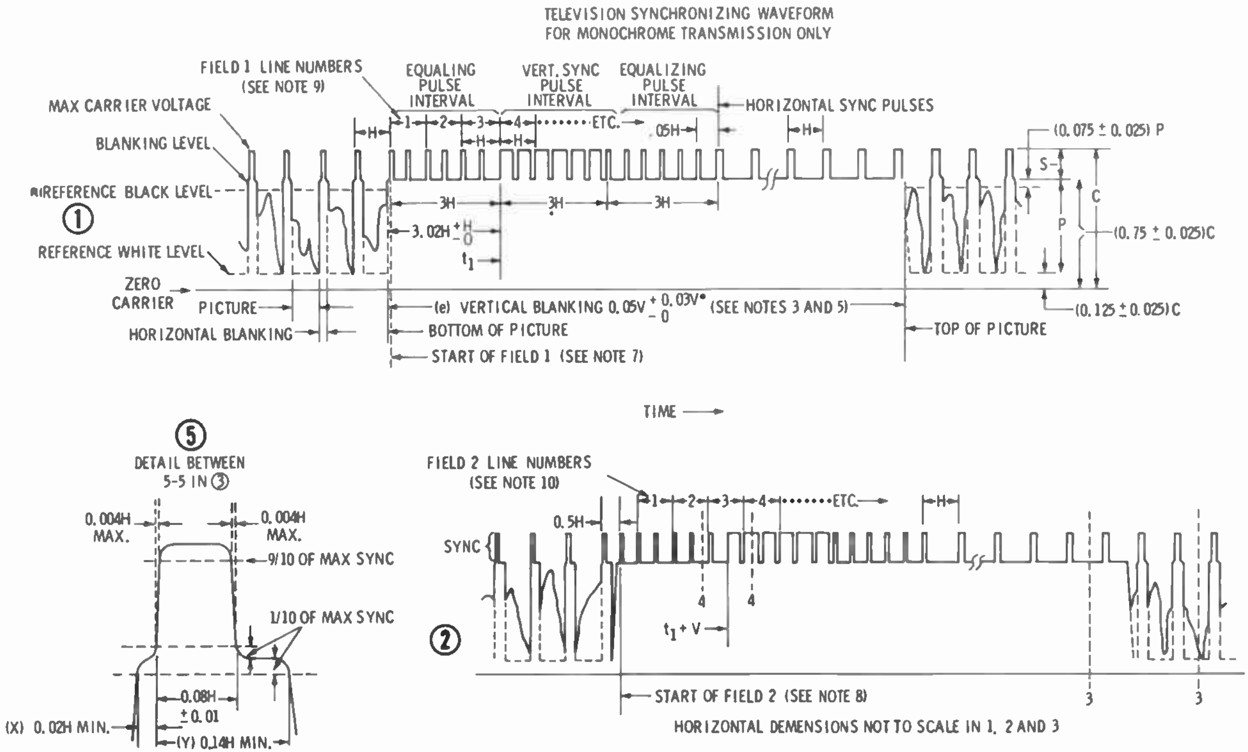


Fig. 6



TELEVISION SYNCHRONIZING WAVEFORM
FOR MONOCHROME TRANSMISSION ONLY
FIELD 1 LINE NUMBERS (SEE NOTE 9)
MAX CARRIER VOLTAGE
BLANKING LEVEL
REFERENCE BLACK LEVEL
REFERENCE WHITE LEVEL
ZERO CARRIER
PICTURE
HORIZONTAL BLANKING
EQUALING PULSE INTERVAL
VERT. SYNC PULSE INTERVAL
EQUALIZING PULSE INTERVAL
HORIZONTAL SYNC PULSES
1 2 3 4 ETC.
H
3H
3.02H
t1
.05H
(0.075 ± 0.025) P
S
P
C
(0.75 ± 0.025)C
(0.125 ± 0.025)C
(e) VERTICAL BLANKING 0.05V + 0.03V* - 0 (SEE NOTES 3 AND 5)
BOTTOM OF PICTURE
START OF FIELD 1 (SEE NOTE 7)
TOP OF PICTURE
TIME
5
DETAIL BETWEEN 5-5 IN 3
0.004H MAX.
0.004H MAX.
9/10 OF MAX SYNC
1/10 OF MAX SYNC
0.08H ± 0.01
(X) 0.02H MIN.
(Y) 0.14H MIN.
FIELD 2 LINE NUMBERS (SEE NOTE 10)
0.5H
SYNC
1 2 3 4 ETC.
4
4
t1 + V
2
START OF FIELD 2 (SEE NOTE 8)
3
3
HORIZONTAL DEMENSIONS NOT TO SCALE IN 1, 2 AND 3

Fig. 7

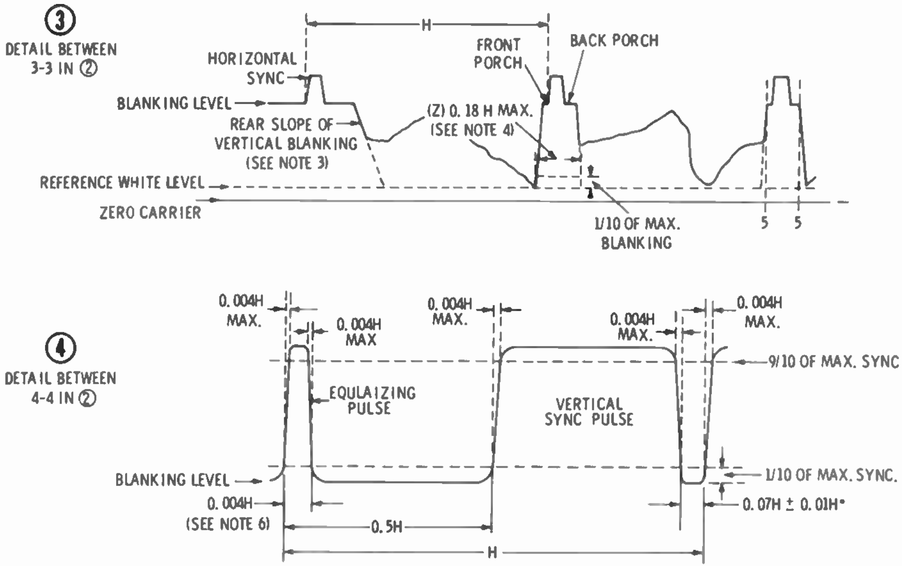


Fig. 7

NOTES

1 H = Time from start of one line to start of next line.

2 V = Time from start of one field to start of next field.

3 Leading and trailing edges of vertical blanking should be complete in less than 0. 1H.

4 Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x + y) and (z) under all conditions of picture content.

*5 Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles.

6 Equalizing pulse area shall be between 0. 45 and 0. 5 of area of a horizontal sync pulse.

7 Start of Field 1 is defined by a whole line between first equalizing pulse and preceding H sync pulses.

8 Start of Field 2 is defined by a half line between first equalizing pulse and preceding H sync pulses.

9 Field 1 line numbers start with first equalizing pulse in Field 1

10 Field 2 line numbers start with second equalizing pulse in Field 2.

11 Refer to text for further explanations and tolerances.

SEC. 73.910 *Emergency Broadcast System (EBS).* The Emergency Broadcast System (EBS) is a system of facilities and personnel of nongovernment broadcast stations and other authorized facilities licensed or regulated by the Federal Communications Commission, including approved and authorized integral facilities or systems, arrangements, procedures, and interconnecting facilities, which have been authorized by the Commission to operate in a controlled manner during a grave national crisis or war.

SEC. 73.911 *Basic Emergency Broadcast System (EBS) Plan.* The Basic Emergency Broadcast System (EBS) Plan is a plan containing, among other things, approved basic concepts and designated national-level systems, arrangements, procedures, and interconnecting facilities to satisfy the White House Statement of Requirements for Presidential Messages and National Programing and News. Provision is made therein for the development, designation, and approval of facilities, mutually compatible operational arrangements, procedures, and interconnecting facilities to satisfy the Department of Defense (Office of Civil Defense) statement of requirements for the dissemination of emergency information and instructions by Regional, State, and Operational Area (Local) authorities in addition to Presidential Messages and National Programing and News, as set forth above.

SEC. 73.913 *National Defense Emergency Authorization (NDEA).* A National Defense Emergency Authorization (NDEA) is an authorization issued by the Federal Communications Commission only to the licensees of broadcast stations subject to the provisions of this part to permit controlled operation of such stations, as well as associated auxiliary broadcast stations subject to Part 74 of this chapter, on a voluntary organized basis during an Emergency Action Condition, consistent with the provisions of this subpart and the Basic Emergency Broadcast System (EBS) Plan, including the annexes and supplements to that plan. A broadcast station licensee will be issued a National Defense Emergency Authorization only in accordance with the Criteria for Eligibility set forth in the Basic Emergency Broadcast System (EBS) Plan, which will remain valid concurrently with the term of the broadcast station license, so long as the station licensee continues to comply with the Criteria for Eligibility.

Emergency Actions

SEC. 73.931 *Notification of Emergency Action Condition.* (a) Authority for release of the Emergency Action Notification rests solely with the President of the United States. This authority has not been delegated, except as set forth in paragraph (b) of this section.

(b) Under the President's responsibility to activate the Emergency Broadcast System (EBS), he has directed that in the event an enemy attack has been detected, the White House Communications Agency shall be authorized to activate the Emergency Broadcast System (EBS) and the Office of Civil Defense shall be authorized to follow with the dissemination of appropriate warning messages.

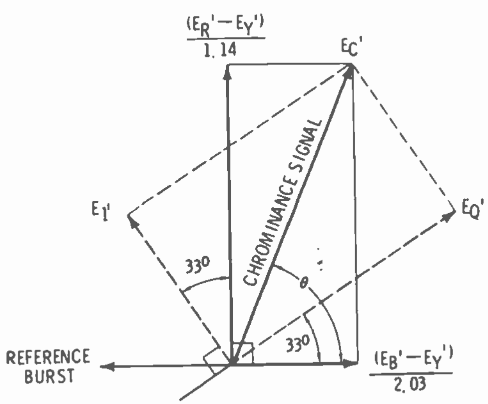
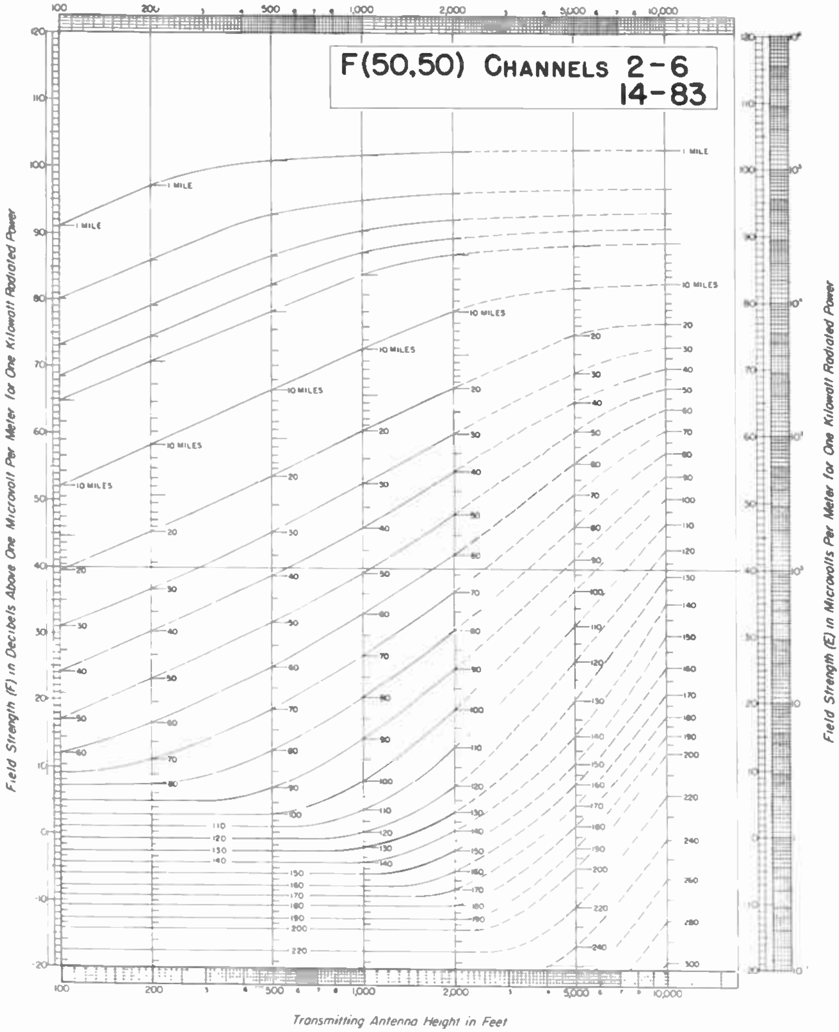
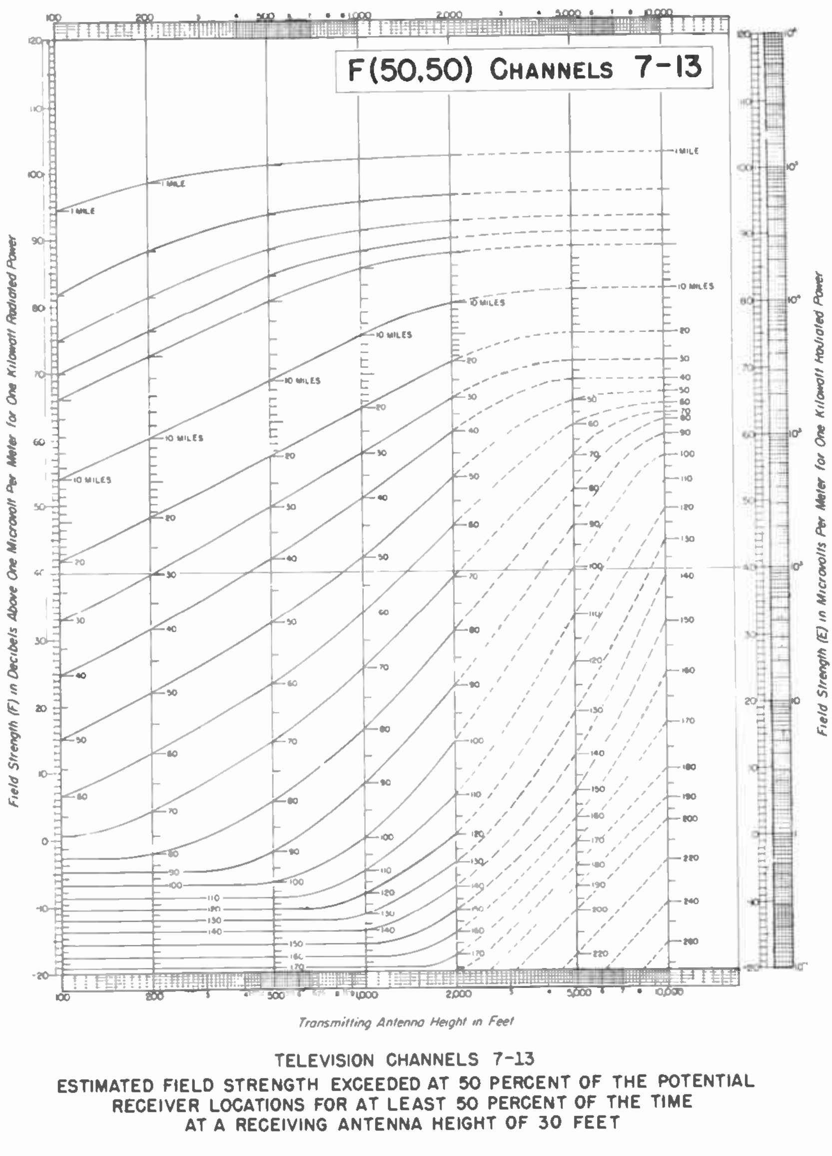


Fig. 8.



TELEVISION CHANNELS 2-6, 14-83
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 9



TELEVISION CHANNELS 7-13
ESTIMATED FIELD STRENGTH EXCEEDED AT 50 PERCENT OF THE POTENTIAL RECEIVER LOCATIONS FOR AT LEAST 50 PERCENT OF THE TIME AT A RECEIVING ANTENNA HEIGHT OF 30 FEET

Fig. 10.

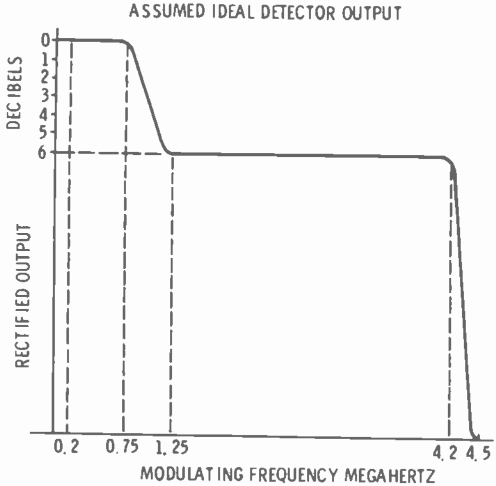


Fig. 11.

(c) The Emergency Action Notification will be released by direction of the President and will be disseminated only via the Four Methods of the Emergency Action Notification System in one of the following two forms:

(1) The Emergency Action Notification only without Attack Warning Message.

(2) The Emergency Action Notification with Attack Warning Message.

SEC. 73.932 *Emergency Action Notification Procedures.* All broadcast stations are to be furnished complete instructions on color coded cards (yellow, white, red, blue). Each card specifies the procedure to be followed (texts of these cards are included in Annex V of the EBS Plan). Immediately upon receipt of an Emergency Action Notification (yellow card), all standard, commercial fm, and noncommercial educational fm broadcast stations with a transmitter output of over 10 watts, and television broadcast stations, including all such stations operating under equipment or program test authority, will proceed as set forth in paragraph (a) or (b) of this section, as applicable:

(a) Receipt of the Emergency Action Notification without Attack Warning:

(1) Discontinue normal program and follow the detailed transmission procedures set forth on the White Card entitled "Broadcast Message" EAN–1. This White Card has been furnished to all licensed broadcast stations for posting in all studios and broadcast operating positions.

(2) Upon completion of these detailed transmission procedures, all licensed broadcast stations which do not hold a National Defense Emergency Authorization (NDEA) shall discontinue operation for the duration of the Emergency Action Condition.

(b) Receipt of the Emergency Action Notification with Attack Warning:

(1) Discontinue normal program and follow the detailed transmission procedures set forth on the Red Card entitled "Broadcast Message" EAN–2. This Red Card has been furnished to all licensed broadcast stations for posting in all studios and broadcast operating positions.

(2) Upon completion of these detailed transmission procedures, all licensed broadcast stations which do not hold a National Defense Emergency Authorization (NDEA) shall discontinue operation for the duration of the Emergency Action Condition.

(c) A station which normally broadcasts a substantial part of its programing in a language other than English may broadcast the required announcements as well as EBS programing, in such foreign language sequentially with the broadcast in English, provided such station has been authorized to do so as part of an approved Detailed State Emergency Broadcast System (EBS) Operational Plan.

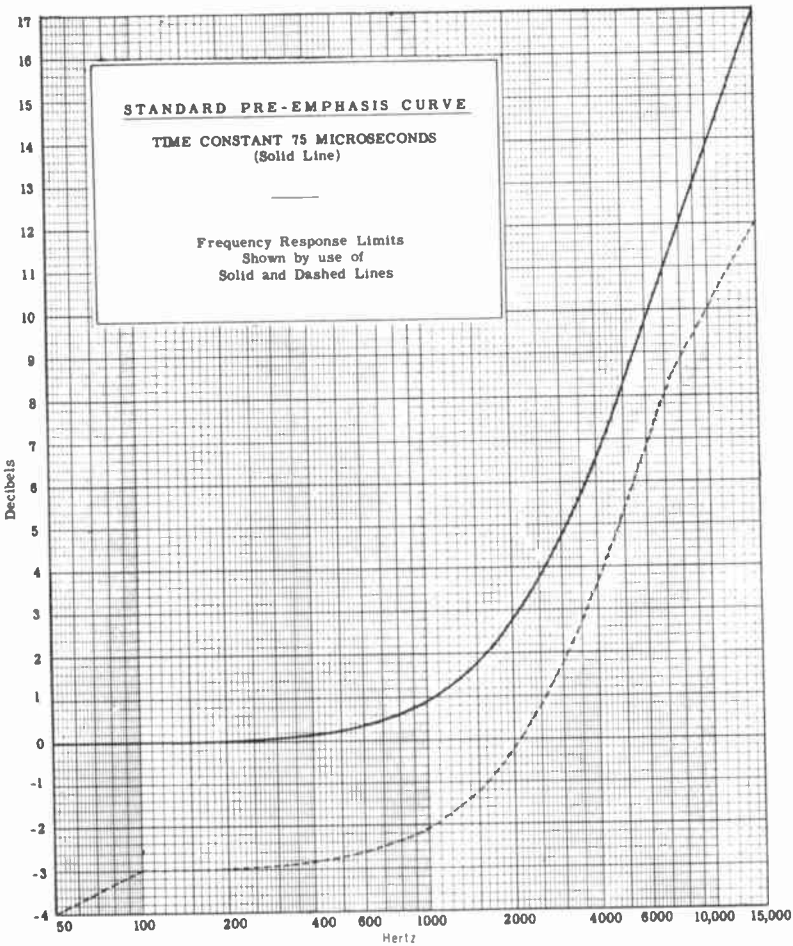

STANDARD PRE-EMPHASIS CURVE
TIME CONSTANT 75 MICROSECONDS
(Solid Line)
Frequency Response Limits
Shown by use of
Solid and Dashed Lines
Decibels
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
50
100
200
400
600
1000
2000
4000
6000
10,000
15,000
Hertz

Fig. 12.

(d) Noncommercial educational fm broadcast stations with a transmitter power output of 10 watts or less will, upon receipt of an Emergency Action Notification, interrupt the program in progress and broadcast the appropriate Emergency Action Notification Message as provided in paragraph (a) of this section, but without the transmission of the Attention Signal. Such stations will then discontinue operation and maintain radio silence in accordance with the Basic Emergency Broadcast System (EBS) Plan.

(e) International broadcast stations will cease broadcasting immediately upon receipt of an Emergency Action Notification and will maintain radio silence in accordance with the basic Emergency Broadcast System (EBS) Plan.

SEC.. 73.933 *Radio Monitoring Requirement.* (a) In order to ensue the effectiveness of the Third Method of the Emergency Action Notification System, all broadcast station licensees must install and operate during their hours of broadcast operation equipment capable of receiving Emergency Action Notifications or Terminations transmitted by other radio broadcast stations. This equipment must be maintained in operative condition, including arrangements for human listening watch or automatic alarm devices, and shall have its termination at each transmitter control point. However, where more than one broadcast transmitter is controlled from a common point by the same operator, only one set of equipment is required at that point.

(b) The off-the-air monitoring assignment of each standard, fm, and television broadcast station is specified in the Detailed State Emergency Broadcast System (EBS) Operational Plan. Particular attention should be paid to avoiding "closed loops" in monitoring assignments.

(c) Prior to commencing routine operation or originating any emissions under program test, equipment test, experimental, or other authorizations or for any other purpose, licensees or permittees shall first ascertain whether an Emergency Action Condition exists and, if so, shall operate only in accordance with the Basic Emergency Broadcast System (EBS) Plan and Detailed State Emergency Broadcast System (EBS) Operational Plan.

SEC. 73.934 *Emergency Broadcast System (EBS) operation during an Emergency Action Condition.* Following completion of the procedures set forth in Sec. 73.932, and upon receipt of emergency programing, authorized participating broadcast stations will immediately begin operations in accordance with the approved Detailed State Emergency Broadcast System (EBS) Operational Plan, as follows:

(a) Primary NDEA stations within an Operational Area will, upon cue from the Common Program Control Broadcast station, begin broadcast of a common program consisting of either Presidential Messages, State programing, Operational Area (local) programing, National programing and news, or Regional programing in the order or priority indicated, consistent with the provisions of the Basic Emergency Broadcast System (EBS) Plan and the Detailed State Emergency Broadcast System (EBS) Operational Plan.

(b) Alternate NDEA Stations within an Operational Area will stand by in a state of operational readiness to begin operation to broadcast a common program upon cue from a Primary or Alternate NDEA station which is discontinuing operation for any reason, or has discontinued operation with no advance notice, consistent with the provisions of the Basic Emergency Broadcast System (EBS) Plan and the Detailed State Emergency Broadcast System (EBS) Operational Plan.

(c) Primary Relay NDEA Stations will begin emergency program relay and distribution service in accordance with the provisions of the Basic Emergency Broadcast System (EBS) Plan and the Detailed Regional and State Emergency Broadcast System (EBS) Operational Plans.

(e) Broadcast stations which do not hold a National Defense Emergency Authorization (NDEA) are not authorized to operate in the Emergency Broadcast System (EBS). Such stations shall discontinue operation and remove their carriers from the air after completion of the Emergency Action Notification Procedures set forth in Sec. 73.932.

(f) Stations in the International Broadcast Service operating under the jurisdiction of the Federal Communications Commission may under certain conditions be issued a NDEA by the Federal Communications Commission with concurrence of the Director, Office of Emergency Planning, and will transmit only Federal Government broadcasts or communications. The station's carrier must be removed from the air during periods of no broadcast or communications transmissions.

(g) No station shall broadcast its call letters during an Emergency Action Condition. Only State and Operational Area identifications shall be given.

(h) All stations operating and identified with a particular Operational Area will broadcast a common program.

(i) Stations are exempted from keeping operating or maintenance logs during an Emergency Action Condition. Program logs should be maintained where possible.

(j) Broadcast stations are specifically exempt from complying with Sec. 73.57 (pertaining to maintenance of operating power) while operating under their National Defense Emergency Authorization.

Sec. 73.935 *Emergency Broadcast System (EBS) Programming Priorities.* (a) Program priorities for the Emergency Broadcast System (EBS) are as follows:

Priority One—Presidential Messages.
Priority Two—State Programing.
Priority Three—Operational Area (Local) Programing.
Priority Four—National Programing and News and Regional Programing.

(b) The Common Program Control Broadcast Station is responsible for coordinating the operations of the participating stations in the Operational Area in the broadcast of a common program for the Operational Area in accordance with the program priorities set forth in paragraph (a) of this section.

(c) All authorized participating stations that remain on the air in accordance with the Basic Emergency Broadcast System (EBS) Plan and the Detailed State Emergency Broadcast System (EBS) Operational Plan must carry Presidential Messages "live" at time of transmission.

(d) The nationwide commercial radio and Television (aural) Broadcast Network program distribution facilities shall be reserved exclusively for the distribution of Presidential Messages (Priority One) and National Programing and News (Priority Four). National Programing and News which is not broadcast at the time of original transmission shall be recorded locally by the Common Program Control Broadcast Station for broadcast at the earliest opportunity consistent with Operational Area requirements.

(e) Regional Programing (Priority Four), which utilizes the approved interconnecting distribution facilities for State Programing, as provided in the Detailed State Emergency Broadcast System (EBS) Operational Plans within the Federal Region, is an integrated and coordinated Regional/State operation. If not broadcast at the time of original transmission, Regional/State Programing shall be recorded at the Common Program Control Broadcast Station in each Operational Area for broadcast at the earliest opportunity.

Sec. 73.940 *Termination of Emergency Action Condition.* Upon receipt of an Emergency Action Condition Termination, all stations operating in the Emergency Broadcast System (EBS) will broadcast the following Termination Message twice:

This concludes operations under the Emergency Broadcast System. All broadcast stations may now resume normal broadcast operation.

Unlimited time stations operating in the Emergency Broadcast System (EBS) will transmit the Termination Message twice, and then resume normal operation. Daytime Only and Limited Time broadcast stations operating in the Emergency Broadcast System (EBS) shall also broadcast the Termination Message twice, then operate in accordance with their regular authorization.

Participation

Sec. 73.950 *Participation in the Emergency Broadcast System (EBS).* (a) Any licensee desiring to participate voluntarily in the Emergency Broadcast System (EBS) must prepare in narrative form an application directed to the establishment of eligibility based upon the criteria set forth in the Basic Emergency Broadcast System (EBS) Plan. The application should be mailed to the appropriate FCC Regional Liaison Officer for processing. The Federal Communications Commission may then issue a National Defense Emergency Authorization to the licensee authorizing participation in the Emergency Broadcast System (EBS) consistent with the provisions of the approved Detailed Regional and State Emergency Broadcast System (EBS) Operational Plans.

(b) Any station participating in the Emergency Broadcast System (EBS) may withdraw from participation by giving 30 days written notice and by submitting its National Defense Emergency Authorization to the Federal Communications Commission through the appropriate FCC Regional Liaison Officer for cancellation.

Tests

SEC. 73.961 *Tests of the Emergency Action Notification System.* Tests of the Emergency Action Notification System will be made at regular intervals with appropriate entries in the station operating log, as follows:

(a) Test transmissions using the First Method of the Emergency Action Notification System utilizing the facilities of the Associated Press (AP) and United Press International (UPI) Radio Wire Teletype Networks will be conducted twice each week. These tests will be conducted on Saturday at 9:30 a.m., EST, and on Sunday at 8:30 p.m., EST. The Blue Card, identified at First Method EAN Tests, which has been furnished to all standard, fm, and television broadcast stations, sets forth details of these test transmissions.

(b) Test transmissions using the Second Method of the Emergency Action Notification System via dedicated teletype network between the White House Communications Agency, specified control points of the nationwide commercial Radio and Television Broadcast Networks, the American Telephone and Telegraph Co. and other specified points will be conducted once each week at a selected time in accordance with the test procedures set forth in the Emergency Broadcast System (EBS) Standing Operating Procedures (EBS SOP–3). Testing of the internal alerting facilities of the nationwide commercial broadcast networks is not necessary since these facilities are utilized in day-to-day operations.

(c) Test transmissions of the Third Method of the Emergency Action Notification System will be conducted by standard, fm, and television broadcast stations once each week on a random basis between the hours of 8:30 a.m. and local sunset. Noncommercial educational fm broadcast stations with a transmitter output of 10 watts or less are not required to conduct these tests. The Blue Card, identified as Third Method EAN Tests, which has been furnished to all standard, fm, and television broadcast stations, sets forth details of these test transmissions.

SEC. 73.962 *Tests of Approved Interconnecting Systems and Facilities.* Tests of approved interconnecting systems and facilities voluntarily participating in the Emergency Broadcast System (EBS) will be conducted as set forth below. Appropriate entries shall be made made in the station operating log.

(a) National program distribution interconnecting systems and facilities (the total NIAC Order No. 1 program distribution facilities) will be tested on a scheduled basis. This test consists of a closed circuit transmission from 12:40 to 12:50 p.m., Washington, D.C., time on the first Wednesday of every odd-numbered month except when such a Wednesday is a national holiday, then the test is conducted on the following day. Due to varying program scheduling of the commercial Radio Broadcast Networks involved, the individual network facilities shall remain as separate entities for these tests. The audio networks associated with the video networks of ABC–TV, CBS–TV, or NBC–TV shall not be utilized nor are the Telephone Companies authorized to add any of the unaffiliated stations participating in the Emergency Broadcast System (EBS). The American Telephone and Telegraph Co. is authorized to interconnect the facilities of the Intermountain (IMN) Radio Network and the New York control office of the UPI Audio Network to any one of the nationwide commercial Radio Broadcast Networks for the duration of these closed circuit tests, then remove such interconnections.

(b) Closed circuit tests of technical program origination and distribution channels associated with NIAC Orders No. 2 through No. 63 will be conducted when considered desirable and when advance coordinated arrangements and voluntary agreement are accomplished among the White House Communications Agency, the nationwide commercial Radio Broadcast Networks and the American Telephone and Telegraph Co.

(c) Tests of regional program distribution interconnecting systems and facilities will be conducted periodically on a closed circuit basis as a coordinated Regional/State operation and as provided in approved Detailed Regional and State Emergency Broadcast System (EBS) Operation Plans.

(d) Tests of State program distribution interconnecting systems and facilities should be conducted on a day-to-day basis as periodic broadcast operations such as State Weather Networks, or State Association of Broadcasters Networks. Letters granting rebroadcast authority shall be exchanged between all participarting licensees in accordance with the provisions of section 325(a) of the Communications Act of 1934, as amended, and Part 73 of this chapter.

(e) Operational Area common program distribution interconnecting systems, facilities, and procedures shall be tested on a closed circuit basis to insure emergency readiness of such interconnecting facilities in accordance with approved Detailed State Emergency Broadcast System (EBS) Operational Plans.

Day-to-Day Emergency Operation

SEC. 73.971 *Day-to-day emergencies posing a threat to the safety of life and property; use of Attention Signal.* (a) The Emergency Action Notification Attention Signal may be transmitted for the following purposes by all standard, fm and television broadcast stations, at their discretion, in connection with day-to-day emergency situations posing a threat to the safety of life and property:

(1) Activation of State program distribution interconnecting systems and facilities for the origination of emergency cueing announcements and broadcasts by the management of the State Network Primary Control Station in accordance with previous arrangements and agreement of the State Industry Advisory Committee in day-to-day emergency situations in the public interest. These include both situations where the time element is short, and those which develop slowly. (For example: Tornado warnings or tornado sightings; toxic gases threatening a community; flash floods; widespread fires threatening populated areas; tidal waves; earthquakes; widespread commercial electric power failures; large scale industrial explosions and fires; tornado watches, hurricane watches, and hurricane warnings; civil disorders; heavy rains—developing dangerous flood conditions; icing conditions—developing dangerous road hazards; heavy snows—developing blizzard conditions; appeals for medical assistance and facilities; appeals for emergency food and housing; call-back of off-duty police personnel; call-back of off-duty fire personnel; call-back of off-duty military personnel.)

(2) Activation of Operational Area interconnecting systems and facilities for the origination of emergency cueing announcements and broadcasts by the management of the Primary Broadcast Stations for the Operational Area in accordance with previous arrangements and agreement of the Operational Area Industry Advisory Committee in day-to-day emergency situations in the public interest. (Examples set forth in subparagraph (1) of this paragraph.)

(b) Stations originating emergency communications under this section shall be deemed to have conferred rebroadcast authority, as required by section 325(a) of the Communications Act, on other participating stations. Neither the notice and certification of consent called for by Sections 73.121(b), 73.291(b), 73.591(b), and 73.655(b), nor prior Commission approval as otherwise required by Sections 73.121(d), 73.291(d), 73.591(c), and 73.655(c) in the case of aural-TV cross-service rebroadcasting, is necessary under these circumstances.

Network Connection

SEC. 73.981 *Participation by Telephone Companies.* (a) Telephone Companies which have facilities avalable in place may, without charge, connect an unaffiliated broadcast station to commercial networks operated by ABC, CBS, MBS, NBC, or IMN for the duration of an Emergency Action Condition: *Provided*, That:

(1) The station is authorized by the Federal Communications Commission to participate in the Emergency Broadcast System (EBS) under Sec. 73.950, and is required by an approved Detailed State Emergency Broadcast System (EBS) Operational Plan to carry Presidential or National Programing and News.

(2) The station has in service a local channel from the station studio or transmitter directly to the nearest telephone company Principal Central Office (toll test).

(b) During an Emergency Action Condition and for testing the arrangements for the origination of Presidential Messages and National Programing and News as provided for in NIAC Orders No. 1 through No. 63, telephone companies which have facilities in place may, without charge, connect an originating source associated with an appropriate NIAC Order Number from the nearest Telephone Company Exchange to a selected Toll Test Center, thence to the authorized commercial Radio and Television (aural) Broadcast Networks: *Provided:*

(1) That the originating source has in service a telephone company local channel from the originating point to the nearest Telephone Company Exchange.

(2) That a NIAC Order covering this service is requested by the White House Communications Agency in accordance with the provisions of the Basic Emergency Broadcast System (EBS) Plan.

(c) Upon issuance of the Emergency Action Condition Termination, or completion of tests as provided in paragraph (b) of this section, such telephone companies shall disconnect the unaffiliated broadcast stations and the authorized origination source and then restore the Broadcast Networks to their original configuration as individual entities.

(d) Closed circuit tests of technical program origination and distribution channels associated with NIAC Order No. 1 will be conducted as provided in Sec. 73.962(a). These tests are in conformance with the provisions of this section.

(e) Closed circuit tests of technical program origination and distribution channels associated with NIAC Orders No. 2 through No. 63 will be conducted when considered desirable and when advance coordinated arrangements and voluntary agreement is accomplished among the White House Communications Agency, the nationwide commercial Radio Broadcast Networks, and the AT&T. These tests are in conformance with the provisions of this section.

(f) Every such carrier rendering any such free service shall make and file, in duplicate, with the Federal Communications Commission, on or before the 31st day of July and on or before the 31st day of January in each year, reports covering the periods of 6 months ending on the 30th day of June and the 31st day of December, respectively, next prior to said dates. These reports shall show the call letters and locations of the broadcast stations to which free service was rendered pursuant to this rule and the charges in dollars which would have accrued to the carrier for such service rendered if charges therefor had been collected at the published tariff rates.

APPENDIX II

Extracts From Part 74 FCC Rules and Regulations

REMOTE PICKUP BROADCAST STATIONS

SEC. 74.435 *Power limitations.* Remote pickup broadcast stations will be licensed with a power output not in excess of that necessary to render satisfactory service. The license for these stations will specify the maximum authorized power. The operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. Engineering standards have not been established for these stations. The efficiency factor for the last radio stage of transmitters employed will be subject to individual determination but shall be in general agreement with values normally employed for similar equipment operated within the frequency range authorized.

SEC. 74.481 *Logs.* (a) The licensee of a remote pickup broadcast base or mobile station shall maintain an operating log to show when and for what purpose the station is operated. The following basic data shall be recorded.

(1) The date and time of operation.

(2) The purpose of the operation.

(3) The location of the transmitter, if a mobile or portable station.

(4) The station with which it communicates.

(5) Frequency check, if made.

(6) Entries required by Sec. 17.49 of this chapter concerning daily observations of tower lights and quarterly inspections of the condition of the tower lights and associated control equipment and an entry when towers are cleaned or repainted as required by Sec. 17.50 of this chapter.

(7) Any pertinent remarks concerning the transmissions or equipment deemed desirable or necessary by the operator.

(b) In cases where a series of intermittent transmissions relating coverage of a single event are made, an entry showing the time of the beginning of the series and time of the conclusion of the series will suffice. A notation such as "intermittent transmissions in connection with coverage of automobile accident at Main and Fern Streets" will explain the purpose of the operation and location of the transmitter. The station with which it communicates could be the base station (call sign) or the associated broadcast station (call sign). Intermittent but unrelated transmissions shall be logged separately. A single time entry may be made for short transmissions of less than one minute duration. The time of beginning and ending shall be logged for longer transmissions. In all cases, the purpose of the transmission shall be shown and the approximate location of the mobile unit. If the mobile unit is halted, the exact location should be known.

(c) In cases where a base station is used for dispatching mobile units, a running log may be kept at the base station, containing entries for both the base station and one or more mobile units. Each entry should be identified by the call sign of the station making the transmission. The operator in the mobile unit shall keep a record of all transmissions by the mobile unit which are not acknowledged by the base station so that these missed transmissions may be inserted at the appropriate place in the log kept at the base station.

(d) In cases where only mobile units are used, the logs shall be kept by the operator in the mobile unit. A rough log may be kept by the operator in the mobile unit and these notes entered in a permanent log at the end of the tour of duty.

(e) An entry shall be made of any frequency check made pursuant to the requirements of Sec. 74.462.

(f) If the station instrument of authorization requires painting and the lighting of the antenna structure, the log entries concerning lighting shall be made daily whether or not the transmitter is used.

(g) Station records shall be kept in such manner as to be available for inspection by a duly authorized representative of the Commission upon request. The records shall be retained for a period of 2 years.

AURAL BROADCAST STL AND INTERCITY RELAY STATIONS

SEC. 74.501 *Classes of stations.* (a) *Aural broadcast STL station.* A fixed station utilizing telephony for the transmission of aural program material between a studio and the transmitter of a broadcasting station other than an international broadcasting station, for simultaneous or delayed broadcast.

(b) *Aural broadcast intercity relay station.* A fixed station utilizing telephony for the transmission of aural program material between broadcasting stations other than international broadcasting stations, for simultaneous or delayed broadcast.

SEC. 74.536 *Directional antenna required.* Each aural broadcast STL and intercity relay station is required to employ a directional antenna. Considering one kilowatt of radiated power as a standard for comparative purposes, such antenna shall provide a free space field intensity at one mile of not less than 435 mv/m in the main lobe of radiation toward the receiver and not more than 20 percent of the maximum value in any azimuth 30 degrees or more off the line to the receiver. Where more than one antenna is authorized for use with a single station, the radiation pattern of each shall be in accordance with the foregoing requirement.

SEC. 74.561 *Frequency tolerance.* The licensee of each aural broadcast STL and intercity relay station shall maintain the operating frequency of the station within plus or minus 0.005 percent of the assigned frequency.

APPENDIX III

Extracts From Part 17 FCC Rules and Regulations

SPECIFICATIONS FOR OBSTRUCTION MARKING AND LIGHTING OF ANTENNA STRUCTURES

SEC. 17.21 *Painting and lighting, when required.* Antenna structures shall be painted and lighted when:

(a) They exceed 200 feet in height above the ground or they require special aeronautical study.

(b) The Commission may modify the above requirement for painting and/or lighting of antenna structures, when it is shown by the applicant that the absence of such marking would not impair the safety of air navigation, or that a lesser marking requirement would insure the safety thereof.

SEC. 17.23 *Specifications for the painting of antenna structures in accordance with Sec. 17.21.* Antenna structures shall be painted throughout their height with alternate bands of aviation surface orange and white, terminating with aviation surface orange bands at both top and bottom. The width of the bands shall be equal and approximately one-seventh the height of the structure, provided, however, that the bands shall not be more than 40 feet nor less than 1½ feet in width.

SEC. 17.25 *Specifications for the lighting of antenna structures over 150 feet up to and including 300 feet in height.* (a) Antenna structures over 150 feet, up to and including 200 feet in height above ground, which are required to be lighted as a result of notification to the FAA under Sec. 17.7 and antenna structures over 200 feet, up to and including 300 feet in height above ground, shall be lighted as follows:

(1) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500-, 620-, or 700-watt lamps (PS–40 Code Beacon type) both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any normal angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any normal angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute, with a period of darkness equal to approximately one-half of the luminous period.

(2) At the approximate midpoint of the overall height of the tower there shall be installed at least two 100-, 107-, or 116-watt lamps (#100 A21/TS, #107 A21/TS, or #116 A21/TS, respectively) enclosed in aviation red obstruction light globes. Each light shall be mounted so as to insure unobstructed visibility of at least one light at each level from aircraft at any normal angle of approach.

(3) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity

level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

SEC. 17.27 *Specifications for the lighting of antenna structures over 450 feet up to and including 600 feet in height.* (a) Antenna structures over 450 feet up to and including 600 feet in height above the ground shall be lighted as follows:

(a) There shall be installed at the top of the structure one 300 m/m electric code beacon equipped with two 500-, 620-, or 700-watt lamps (PS-40 Code Beacon type) both lamps to burn simultaneously, and equipped with aviation red color filters. Where a rod or other construction of not more than 20 feet in height and incapable of supporting this beacon is mounted on top of the structure and it is determined that this additional construction does not permit unobstructed visibility of the code beacon from aircraft at any normal angle of approach, there shall be installed two such beacons positioned so as to insure unobstructed visibility of at least one of the beacons from aircraft at any normal angle of approach. The beacons shall be equipped with a flashing mechanism producing not more than 40 flashes per minute nor less than 12 flashes per minute, with a period of darkness equal to approximately one-half of the luminous period.

(2) At approximately one-half of the overall height of the tower one similar flashing 300 m/m electric code beacon shall be installed in such position within the tower proper that the structural members will not impair the visibility of this beacon from aircraft at any normal angle of approach. In the event this beacon cannot be installed in a manner to insure unobstructed visibility of it from aircraft at any normal angle of approach, there shall be installed two such beacons at each level. Each beacon shall be mounted on the outside of diagonally opposite corners or opposite sides of the tower at the prescribed height.

(3) On levels at approximately three-fourths and one-fourth of the overall height of the tower, at least one 100-, 107-, or 116-watt lamp (#100 A21/TS, #107 A21/TS, or #116 A21/TS, respectively) enclosed in an aviation red obstruction light globe shall be installed on each outside corner of the tower at each level.

(4) All lights shall burn continuously or shall be controlled by a light sensitive device adjusted so that the lights will be turned on at a north sky light intensity level of about 35 foot candles and turned off at a north sky light intensity level of about 58 foot candles.

SEC. 17.47 *Inspection of tower lights and associated control equipment.* The licensee of any radio station which has an antenna structure requiring illumination pursuant to the provisions of section 303(q) of the Communications Act of 1934, as amended, as outlined elsewhere in this part:

(a) (1) Shall make an observation of the tower lights at least once each 24 hours either visually or by observing an automatic properly maintained indicator designed to register any failure of such lights, to insure that all such lights are functioning properly as required; or alternatively,

(2) Shall provide and properly maintain an automatic alarm system designed to detect any failure of such lights and to provide indication of such failure to the licensee.

(b) Shall inspect at intervals not to exceed 3 months all automatic or mechanical control devices, indicators, and alarm systems associated with the tower lighting to insure that such apparatus is functioning properly.

SEC. 17.48 *Notification of extinguishment or improper functioning of lights.* The licensee of any radio station which has an antenna structure requiring illumination pursuant to the provisions of section 303(q) of the Communications Act of 1934, as amended, as outlined elsewhere in this part:

(a) Shall report immediately by telephone or telegraph to the nearest Flight Service Station or office of the Federal Aviation Administration any observed or otherwise known extinguishment or improper functioning of a code or rotating beacon light or top light not corrected within 30 minutes. Further notification by telephone or telegraph shall be given immediately upon resumption of the required illumination.

(b) An extinguishment or improper functioning of a steady burning side or intermediate light or lights, shall be corrected as soon as possible, but notification to the FAA of such extinguishment or improper functioning is not required.

SEC. 17.49 *Recording of tower light inspections in the station record.* The licensee of any radio station which has an antenna structure requiring illumination shall make the following entries in the station record of the inspections required by Sec. 17.47:

(a) The time the tower lights are turned on and off each day if manually controlled.

(b) The time the daily check of proper operation of the tower lights was made, if automatic alarm system is not provided.

(c) In the event of any observed or otherwise known extinguishment or improper functioning of a tower light:

(1) Nature of such extinguishment or improper functioning.

(2) Date and time the extinguishment or improper functioning was observed, or otherwise noted.

(3) Date, time, and nature of the adjustments, repairs, or replacements made.

(4) Identification of Flight Service Station (Federal Aviation Administration) notified of the extinguishment of improper functioning of any code or rotating beacon light or top light not corrected within 30 minutes, and the date and time such notice was given.

(5) Date and time notice was given to the Flight Service Station (Federal Aviation Administration) that the required illumination was resumed.

(d) Upon completion of the periodic inspection required at least once each 3 months:

(1) The date of the inspection and the condition of all tower lights and associated tower lighting control devices, indicators and alarm systems.

(2) Any adjustments, replacements, or repairs made to insure compliance with the lighting requirements and the date such adjustments, replacements or repairs were made.

SEC. 17.50 *Cleaning and repainting.* All towers shall be cleaned or repainted as often as necessary to maintain good visibility.

SEC. 17.51 *Time when lights shall be exhibited.* All lighting shall be exhibited from sunset to sunrise unless otherwise specified.

SEC. 17.52 *Spare lamps.* A sufficient supply of spare lamps shall be maintained for immediate replacement purposes at all times.

SEC. 17.53 *Lighting equipment and paint.* The lighting equipment, color of filters, and shade of paint referred to in the specifications are further defined in the following government and/or Army-Navy Aeronautical Specifications, Bulletins, and Drawings: (Lamps are referred to by standard numbers). (*See chart on page 403.*)

SEC. 17.54 *Rated lamp voltage.* To provide satisfactory output by obstruction lights, the rated voltage of the lamp used should, in each case, correspond to or be within 3 percent higher than the average voltage across the lamp during the normal hours of operation.

SEC. 17.56 *Maintenance of lighting equipment.* Replacing or repairing of lights, automatic indicators or automatic alarm systems shall be accomplished as soon as practicable.

SEC. 17.57 *Report of radio transmitting antenna construction, alteration and/or removal.* Any permittee or licensee who, pursuant to any instrument of authorization from the Commission to erect or make changes affecting antenna height or location of an antenna tower for which obstruction marking is required, shall, prior to start of tower construction and upon completion of such construction or changes, fill out and file with the Director, U.S. Coast and Geodetic Survey, C & GS Form 844 (Report of Radio Transmitting Antenna Construction, Alteration and/or Removal) in order that antenna tower information may be provided promptly for use on aeronautical charts and related publications in the interest of safety of air navigation.

Outside white	Federal Specifications	TT-P-102[1]
Aviation surface orange	do	TT-P-59[1] (Color No. 12197 of Federal Standard 595).
Aviation surface orange, enamel	do	TT-E-489[1] (Color No. 12197 of Federal Standard 595).
Code beacon	FAA specifications	446 (Sec. II-d-Style 4).[3]
Obstruction light globe, prismatic	Army-Navy drawing	AN-L-10A[2] or FAA Specification L-810.[3]
Obstruction light globe, Fresnel	do	
Single multiple obstruction light fitting assembly	do	
Obstruction light fitting assembly	do	
100-watt lamp		#100 A21/TS.[4]
107-watt lamp		#107 A21TS (3000 hours).
116-watt lamp		#116 A21/TS (6000 hours).
500-watt lamp		#500 PS-40/0 (1000 hours).[4]
620-watt lamp		#620 PS-40 (3000 hours).
700-watt lamp		#700 PS-40/0 (6000 hours).

[1]Copies of this specification can be obtained from the Specification Activity, Room 1643, Federal Supply Service Center, eneral Services Administration, 7th and D Sts. SW., Washington, D.C. 20407 (Outside white, 5 cents; aviation surface orange: paint, 5 cents; enamel, 10 cents).

[2]Copies of Army-Navy specifications or drawings can be obtained by contacting the Commanding General, Air aterial Command, Wright-Patterson Field, Dayton, Ohio 45433, or the Naval Air Systems Command, Navy Department, Washington D.C. 20360. Information concerning Army-Navy specifications or drawings can also be obtained from the Federal Aviation Administration, Washington, D.C. 20553.

[3]Copies of this specification can be obtained from the Federal Aviation Administration, Washington, D.C. 20553.

[4]The 116-watt, 6000-hour lamp and the 700-watt, 6000-hour lamp may be used instead of the 100-watt and the 500-watt lamps whenever possible in view of the extended life, lower maintenance cost, and greater safety which they provide.

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FIRST-CLASS RADIOTELEPHONE LICENSE HANDBOOK

THIRD EDITION

by Edward M. Noll

According to the FCC Rules and Regulations, the operation and maintenance of all television, fm, and a-m broadcasting stations must be directly supervised by the holder of a first-class radiotelephone license.

Essentially this book comprises four parts. Theory is covered in the first part. Some of the subjects are: station frequency assignments; broadcast duties; microphones, recorders and tape players; studio and control room facilities; a-m and fm transmitters; stereo broadcasting; antennas and transmission lines, etc.

The second portion of the book is a series of questions and answers. These questions are designed to give you the necessary groundwork to pass the FCC test for a first-class license.

The third portion of the book has three simulated FCC examinations. They are presented in the multiple-choice form of the FCC tests. The answers are given at the end of each test.

Finally, the book has appendices which contain extracts from the FCC Rules and Regulations. These extracts contain valuable information that you can use as reference material.

First-Class Radiotelephone License Handbook will help you acquire your license, and it can also serve as an invaluable reference book after you have obtained your license.

ABOUT THE AUTHOR

In addition to being an accomplished author of technical books, lessons, articles, and instruction manuals, Ed Noll is also a consulting engineer and lecturer. His other SAMS books include: *Second-Class Radiotelephone License Handbook; Radar License Endorsement Handbook; Radio Operator's License Handbook* (Third-Class with Broadcast Endorsement); *Science Projects in Electricity; Science Projects in Electronics; FET Principles, Experiments, and Projects;* and *SWL Antenna Construction Projects.*

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