SECTION 11

DETECTOR (DEMODULATION CIRCUITS)

PART A. ELECTRON TUBE CIRCUITS

AM DETECTORS.

Detector circuits are used to remove the modulation (transmitted intelligence) from a received r-f signal and transfer it back into its original form, so that it may be used for listening, viewing, communication, or other purposes. The process of detection is also called **demodulation,** which should not be confused with the special methods used for reducing the percentage of modulation.

There are many methods of detection and many circuit variations. In this paragraph only amplitude-modulation detectors will be discussed. Other types of detectors are discussed later in this section. While the diode forms the basic detector, triodes (or other multielement electron tubes) can also be used to obtain additional amplification, or can be connected to operate as diodes. When triodes (or other types) are used, the detector circuits are divided into two general classes — grid detectors and plate detectors. Square-law-detectors, small-signal detectors, large-signal detectors, or power detectors may be either grid or plate types. When detection occurs in the grid circuit, it is called **grid detection;** when it occurs in the plate circuit, it is called ***plate detection.*** Grid detectors are usually small-signal detectors, and nearly always have a "square law" response, with the output varying as the square of the input voltage. This type of detection is characterized by extreme distortion (as high as 25 percent) at high percentages of modulation, in contrast to practically linear operation for diodes or plate detectors. Strictly speaking, from a technical standpoint every detector, whether considered linear or not, produces a certain amount of distortion; however, some circuits produce less than others.

Generally speaking, small-signal detectors are linear over a very small range of input voltages, and, as the input increases, so does the distortion. On the other hand, plate detectors are also linear when operating over small ranges at small amplitudes; but even though considered linear, the tube grid-plate transfer characteristic is never a perfectly straight line, so that for large-signal inputs some distortion is produced. Large-signal detectors are called power detectors. They are designed to handle large input signal swings with as little distortion as permissible, and to produce large output voltages capable of driving power amplifier tubes directly. The actual power involved is relatively small though being on the order of milliwatts; consequently, with the present day multipurpose tubes and techniques, the power detector is used mostly for special purpose applications. In fact, with the present day trend to superheterodyne receivers, which feed the large output of the i-f stages into the detector, most of the high-gain detector circuits are no longer used (or needed) and are supplanted by the simple diode detector. In the less complex types of receivers, however, the high-gain detectors are still favored.

The grid-leak type detectors depend on the flow of grid current for their operation, and are used where sensitivity is more important than lack of distortion. The grid-bias detector (also known as the **linear plate detector,** the **infinite-impedance detector,** etc) is used where a large output with low distortion is needed. The heterodyne detector is used for the reception of unmodulated (CW) signals and for single-sideband applications. The regenerative detector (which may be grid or plate) is used where high sensitivity provided by regenerative feedback is desired, usually in two or three-tube receivers. The super-regenerative detector, which utilizes maximum regenerative feedback without producing oscillations, is used where the lack of gain in the stages preceding the detector makes its use desirable. The autodyne detector is essentially a regenerative detector with sufficient feedback to produce oscillation so that it can be used for unmodulated CW reception, as well as AM reception. Each of these detectors will be more thoroughly discussed in the following paragraphs.

DIODE DETECTORS.

APPLICATION.

Diode detectors are used to remove the modulation from the received r-f carrier and convert it into the original intelligence transmitted. These types of detectors are usually used in superheterodyne receivers, or in receivers supplying a large input signal to the detector. They are also used in test equipment where linear detection is required (particularly in vacuum-tube voltmeter applications) and as field strength indicators for transmitters.

CHARACTERISTICS.

Operates linearly over a large range of input voltages.

Has a relatively constant input impedance which is independent of the input voltage.

Does not amplify the input signal.

Distortion produced for normal operation is on the order of 1 to 2 percent.

CIRCUIT ANALYSIS.

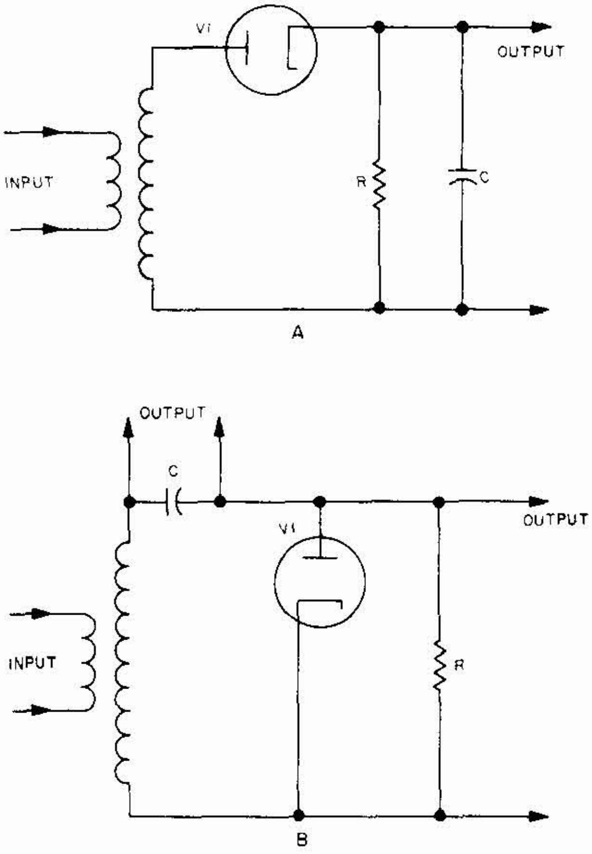
General. The ideal detector produces no distortion in the process of detection, and reproduces the modulation signal exactly as it was before modulation of the carrier. There are three forms of distortion possible in the detection process, namely, amplitude, frequency, and phase distortion. When extra frequencies are developed in the demodulation process that did not exist in the original modulation, the result is a form of amplitude distortion. When the detector is more responsive to some frequencies than to others, frequency distortion results. When the phase relationships between the modulation frequencies are changed, phase distortion is produced. The diode operation, while considered linear, is not perfectly so; that is, instead of a straight line relationship between the input and output, the tube transfer characteristic is curved, especially at the low end. Thus, for small signals (on the order of millivolts), a nonlinear or distorted output is obtained. Actually, for small signals the diode operates as a square-law detector; that is, the output varies as the square of the input voltage. Thus like the grid detector, which also operates on a curved transfer characteristic, the greater the percentage of modulation, the greater the distortion (a maximum of 25% distortion). To minimize this form of amplitude distortion, which is inherent in the diode construction and cannot be eliminated, the diode detector is usually operated with large input voltages. In other words, it is used only after numerous stages of r-f or i-f amplification, so that the signal to be demodulated is on the order of volts. It is evident that while a steady signal can be made to produce no distortion, a signal which varies in amplitude from zero to some maximum value will produce a slight amount of distortion while operating near its zero value, even with many stages of amplification. Hence the nominal rating of 1 to 2 percent distortion for diode detection. Finally, excessive capacitive reactance shunting the detector load will cause a dropping of output at the high audio frequencies (above 10 kc), producing a phase shift of the high frequencies as compared with the low and medium frequencies, and thereby causing distortion. Thus it is clear that, while the diode is considered the best of the large-signal detectors, it does produce some distortion.

Since the diode is a two-element electron tube, it operates essentially as a simple half-wave rectifier, similar to the power rectifier used to supply plate voltages, except that it operates at radio frequencies rather than at power-line frequencies. Like the power rectifier, the diode detector must also have a filter (rf) to minimize ripple voltage at the carrier frequency. Similarly, it produces a d-c output voltage, plus the audio-frequency modulation component. Since the detector supplies a voltage to the audio amplifier stages following it, full-wave rectifier circuits are occasionally used to supply greater output with less filtering. For most applications, however, the simple half-wave rectifier connection is used because it requires fewer components, is cheaper to produce, and has sufficient output for present-day audio stages.

Although the diode consumes little power in the detection process, it does place a load on the input stage; it is usually considered to act as if it were a resistor of half the load-resistance value, shunted across the input circuit. Normal efficiency ratings are better than 80 percent, with 90 percent being the rule rather than the exception. This is true because the loss in the diode is small, since the diode plate resistance is usually much less than the detector load resistance.

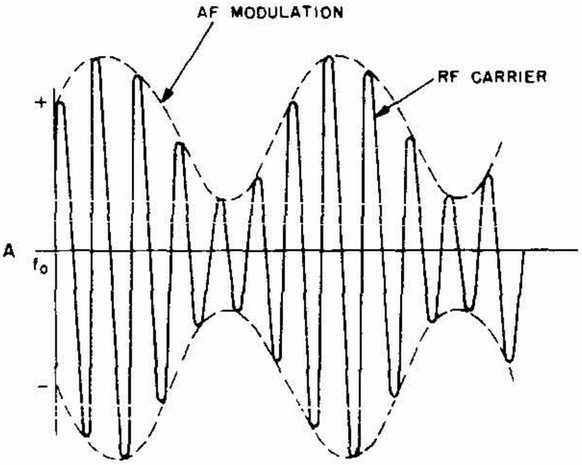
Circuit Operation. Two forms of the basic diode circuit are shown in the accompanying illustration, with circuit A being the most prevalent in use. Both diode circuits are identical in operation, but circuit B offers an alternative output connection (across capacitor C) if desired, and, since the capacitor is in series with the input and the diode, it prevents the low d-c resistance of the input transformer secondary from shunting the diode load at the signal frequency.

For simplicity, the illustration shows an untuned input transformer; actually, in most modern receivers, both the primary and secondary circuits are tuned. Where high-Q circuits with extreme selectivity are employed, some of the high-frequency sidebands are removed by the narrow pass band; as a result, there is a lack of high-frequency response in the detector output. This effect, however, is not inherent in the detector - it is due to poor design of the tuned circuits.

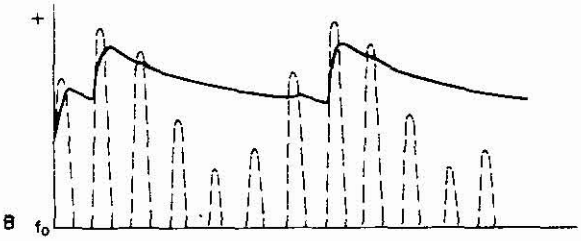


Basic Diode Detector Circuits

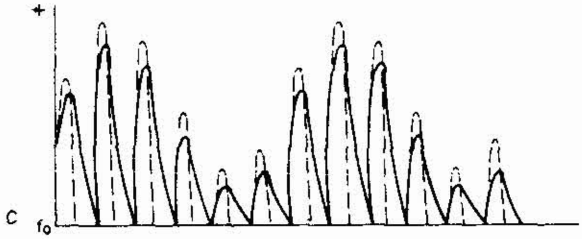
Basic operation consists of the charge and discharge of the R-C circuit, which uses the voltage developed across R to charge C to nearly the peak voltage of the input signal. When the plate is positive with respect to the cathode, the diode conducts and charges capacitor C. Since there is a small voltage drop in the diode between cathode and plate when conduction occurs, it is apparent that the maximum developed detector voltage can never be exactly equal to the peak applied voltage, but will depend upon the ratio of load resistor R to the resistance of the diode. Therefore, the detector efficiency can never reach 100 percent, though it does average around 90 percent. However, if C is too large, its low reactance in parallel with R will shunt the signal, and a lower output will result. Detector charge action and discharge action are shown in the accompanying figure for the tone-modulated input waveform of A; B, C, and D illustrate the charge and discharge of the capacitor. On each positive half-cycle of the radio-frequency signal, capacitor C charges to a maximum value as determined by the percentage of modulation. On each negative half-cycle,



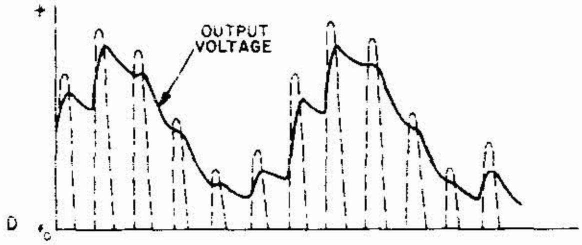
VOLTAGE INPUT WAVEFORM



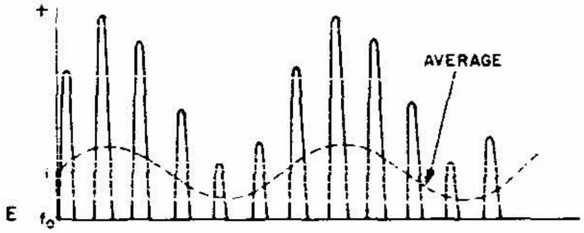
RC TIME TOO SLOW



RC TIME TOO FAST



PROPER TIME CONSTANT



RECTIFIED SIGNAL

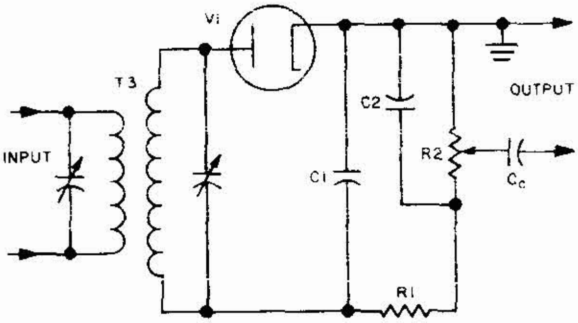
Detector Charge and Discharge Action

capacitor C discharges at a rate fixed by its circuit time constant. As shown in waveform B, the time constant is too slow, and C cannot discharge fast enough to follow the modulation on the negative swing before the next positive r-f half-cycle begins; consequently, the negative portion of the modulation signal is effectively chopped off, and a distorted output results. The time scale is exaggerated to convey the idea more clearly. In contrast to the time constant just considered, the time constant of example C is too fast, and the average output drops to a low value. Example D shows the effect of a proper time constant. It is evident from the examples that either too fast or too slow a discharge rate (time constant) will distort the received-signal waveform.

From part E of the figure, it is evident that the modulation consists of pulses at the carrier frequency and that the amplitude is proportional to the modulation percentage. Also, it can be seen that at zero modulation a carrier frequency voltage exists which is proportional to the carrier amplitude. Thus across load resistor R is developed a d-c voltage for automatic volume control use, which will be discussed more fully in a following paragraph. It can also be seen that a carrier-frequency ripple will exist; that is eliminated by use of a low-pass filter (in addition to the bypassing action of C, whose reactance is small at the carrier frequency).

From part E of the figure, it is also evident why the diode detector can be considered as a half-wave rectifier. For linear operation and assuming perfect rectification, the diode would conduct only on the positive excursions of the modulation signal, remaining inoperative on the negative signal excursions. In this case, the positive excursions are the signal above the f_o line, and the negative excursions are the signal below the line. Thus, only the positive portion of the modulation signal is rectified, and the output consists of pulses of current at the modulation frequency. These pulses of current are used to charge and discharge capacitor C and thereby produce the audio output voltage of part D, as explained previously.

A typical diode detector circuit with an r-f filter is illustrated in the following figure. The input transformer (T3) has both primary and secondary tuned for maximum selectivity.



Typical Diode Detector

The r-f filter consists of C1 and R1 acting as a low-pass filter arrangement assisted by C2. Capacitor C2 performs a dual function: in conjunction with R2 it can be considered to form a low-pass r-f filter, and it can also be considered as a straight bypass across load resistor R2. In either instance, however, it helps eliminate any r-f remaining in the i-f carrier, and also develops an audio output voltage in accordance with the average value of the diode load current passing through load resistor R2.

Design Considerations. When the plate of the diode is more positive than the cathode, current flows, producing a voltage drop across load resistor R2 which follows the modulation signal. Current flow on the positive signal swing is limited only at saturation, which normally does not occur even with very strong signals at 100 percent modulation. As the modulation signal swings in the negative direction, the current flow diminishes until the negative peak is reached, where it again reverses and increases (assuming a sine-wave signal). On strong signals with high percentages of modulation (over 75%), however, peak clipping may occur. The clipping effect is produced by the inability of the diode to conduct when the plate becomes negative with respect to the cathode. Even with the unmodulated carrier signal, noise effects produce conduction in the diode and provide a small residual average d-c voltage which makes the cathode positive with respect to the plate. Thus, on the negative peaks of the modulation signal, with large signal swings and percentages of modulation between 80 and 100 percent, the output voltage is driven to zero, the extreme portions of the negative peaks are clipped off, and the output voltage no longer follows the modulation signal. With improper design, this distortion can be as great as 10 to 12 percent; the practical diode detector, however, is not operated at levels which produce such excessive distortion, and a nominal value of 1 to 2 percent is maintained.

The diode detector is also subject to a reduction of output at the higher audio frequencies (above 10 kc) because of the capacitive shunting effect of C2 on load resistor R. Note also that when the reactance values of any of the detector bypass capacitors become low for the frequency of the modulation signal being detected, R1 and R2 are effectively connected in parallel, reducing the load resistance and output voltage. The same effect holds true for the resistance-coupled load of the amplifier stage following the detector. When the reactance of the coupling capacitor becomes a low-resistance path for the audio signal, then the grid input resistance of the audio stage is effectively in parallel with both R1 and R2, and the reduction in output voltage is particularly noticeable at high gain settings of the volume control. This a-c shunting of the diode load is taken into consideration in the design, so that normally no effect on operation is noticed unless parts values have changed.

FAILURE ANALYSIS.

No Output. A no-output condition is usually limited to an open or short-circuited component or a defective diode. With an open input transformer, stray capacitive coupling may feed enough signal through to produce an output. With an open diode load resistor or a short-circuited bypass capacitor, however, no output will be obtained. Usually, a resistance analysis will quickly locate the defective component.

Low Output. Lack of sufficient input signal will cause a low output, and could be due to poorly soldered (high-resistance) joints or to a defective input transformer. Low tube emission may also cause a weak output, although it usually shows up as a fading signal on a strong local station. An open load bypass capacitor will reduce the output, as only the average current flow through the load resistor will now produce an output. A lack of r-f or i-f amplification preceding the detector can also cause low output; therefore, it is necessary to isolate the detector by checking with a VTVM for adequate input and output. Since no amplification is produced in the diode detector, but the detection efficiency is high, an output indication lower than 10 percent of the input indication would be indicative of possible detector trouble.

Distorted Output. Since diode detection is linear, a distorted output signal usually indicates component changes. Amplitude distortion is a definite indication of nonlinearity in the detector, provided that the input signal to the detector is linear. Lack of high audio frequency response would be directly traceable to excessive selectivity, caused by regeneration in the preceding i-f stages or to excessive capacitive shunting of the detector, particularly in video applications. Distortion at high volume levels with a strong, heavily modulated local signal would indicate normal peak-clipping effects. Poorly soldered (high-resistance) joints can be suspected when component values and tube emission are normal. Fringe howl or a tendency toward oscillation would indicate a lack of r-f filtering. Because of the simplicity of the circuit, an oscilloscope waveform check should quickly locate the trouble.

DIODE DETECTOR WITH AVC.

APPLICATION.

The diode detector with AVC is universally used in broadcast, TV, communications receivers, and other high-gain superheterodyne circuits to provide automatic gain or volume control with detection, in a single tube or envelope.

CHARACTERISTICS.

Operates linearly over a large range of voltage.

Input impedance is relatively constant and independent of the input voltage.

Does not amplify the input signal.

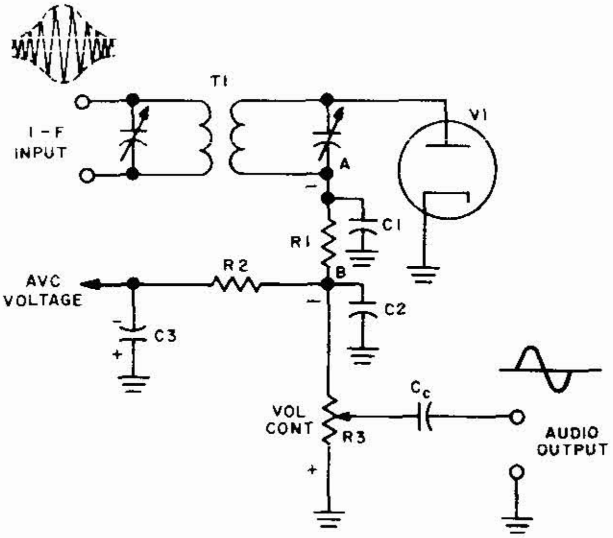
Maximum distortion is of the order of 1-to-2 percent.

AVC output voltage varies directly with the amplitude of the input carrier.

CIRCUIT ANALYSIS.

General. The diode detector with AVC is identical to the diode detector without AVC, except for the circuit arrangements provided for AVC take-off. Discussion of the operation of the detector in stripping-off the modulation from the carrier is covered completely in the discussion of the Diode Detector earlier in this section of the Handbook. The reader should refer to the previous discussion for proper background before proceding with this discussion.

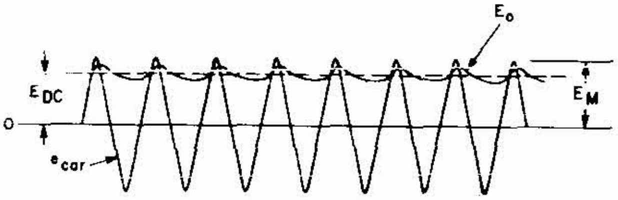
Circuit Operation. The schematic of a typical diode detector arranged for AVC take-off is shown in the accompanying illustration.



Diode Detector With AVC

The plate of V1 is connected to IF input transformer T1 and the cathode is grounded. Resistor R1 with capacitors C1 and C2 form low-pass RF filters, while C3 and R2 are audio and decoupling filters. The audio voltage is developed across volume control R3, and applied through coupling capacitor Cc to the following audio amplifier stages.

When unmodulated, the input consists of a single frequency. When modulated, the input consists of a basic carrier frequency plus an upper and lower sideband containing the modulation. Thus the diode detector output always contains a d-c component which is directly proportional to the carrier amplitude or strength. This is the voltage which is used for AVC. For large signal detection the diode detector is considered to be a simple half-wave rectifier, which conducts as long as V1 plate is positive with respect to the cathode. When V1 conducts, electron flow is from the grounded cathode to the plate, through the secondary coil of IF transformer T1, R1, and R3 to ground. Thus current flow through R1 produces a negative voltage at point A (which is not used), and the AVC voltage is developed across volume control R3 at point B. This negative voltage drop is applied through R2, back to the grids of the r-f and i-f stages. Because the feedback of the AVC bias is to the grids of the preceding stages it is clear that there must be no extraneous modulation or RF on this lead. Otherwise, both the audio and RF components could again be amplified and re-detected causing distortion and unwanted feedback. Therefore, R1 and C1 and C2 are connected as a conventional low-pass filter in series with the current flowing through R3. The output waveform at point A consists of the d-c and r-f component as shown in the accompanying waveform illustration for an unmodulated carrier for ease of discussion. The instantaneous r-f carrier component (e_{car}) is bypassed to ground partially by C1. During the positive portion of each carrier cycle C2 is charged through R1, and during the negative portion of the carrier signal the capacitor tends to discharge. The result is the heavy curve labelled E_o. The average value of pulsating voltage E_{DC} is the actual AVC voltage. Since these pulsations occur at radio frequency rates, the effective voltage variation between charge and discharge of the capacitor is so small as to be negligible. Recall from the above discussion that the modulation component of the signal is also present, However, when modulated signals are detected, these audio ripples are smoothed out by another low-pass filter consisting of R2 and C3. In this instance, the value of the filter time constant are such that output voltage E_o appears as a straight line (pure DC). The time constant of R2 and C3 is made sufficiently large so that it takes more than a single audio cycle to charge or discharge. Although this increase of time constant prevents an instantaneous change of AVC voltage for an instantaneous change in carrier level it is usually satisfactory for most types of fading encountered. Particularly, since decoupling RC networks similar to R2 and C3 are also inserted at each tube grid associated with the AVC and increase the effective values of R2 and C3. The fast time constant response necessary for single sideband or CW use is obtained by making the value of C3 much lower than is normally used in AM circuits. Since the grids of the controlled stages do not draw grid current, there is no flow of current through R2, other than that required to charge the other decoupling capacitors on the AVC line. Hence there is no large voltage drop, and the RC filter can be used without encountering any losses because of excessive current drain. The detected audio or a-c component appears across volume control R3 and is applied through coupling capacitor Cc to the audio amplifier stage.



Detector Voltage Relationships

FAILURE ANALYSIS.

No Output. Lack of an input signal due to failure of the *associated receiver circuits*, a detuned or defective IF transformer, T1, a defective diode, V1, or open or short circuited parts will cause a no-output condition. Measure the voltage to ground at points A and B with a high resistance voltmeter. A negative voltage at these points indicates normal functioning. Lack of voltage at these points indicates either lack of an input signal or a defective component. Use a VTVM or an oscilloscope to determine if an input is present. With an r-f signal on the primary, but not on the secondary, T1 is defective. If the secondary voltage is much lower than the primary the secondary tuning needs adjustment. When adjusting, if it still provides a low output and does not respond to the adjustment, T1 is defective and should be replaced with a good transformer. If either R1, R2, R3 are open, the series circuit will be interrupted and no AVC voltage will *appear at points* A or B. If R1 or R3 is shorted no AVC voltage will be developed, however, if R2 is shorted the circuit will still operate. With normal AVC voltage but no audio output, either volume control R3 is tuned down, R3 is defective, or coupling capacitor Cc may be open. A resistance check will determine if these parts are open or shorted. If C1 or C2 are shorted, no AVC voltage or detected output will be obtained. Use an ohmmeter to measure the resistance to ground, or an in-circuit capacitance checker C1 and C2. If the parts are satisfactory, diode V1 must be at fault; replace it with a known good tube. If previous operation indicated a general falling off in output, the diode could have been replaced immediately. The indiscriminate replacing of electron tubes at the first sign of trouble, without due cause, however, must be avoided.

Low Output. A weak input signal, or low emission in the detector diode are the prime cause of low output, as well as mistuning of T1. The effects of humidity can also cause circuit leakages which reduce the output. Although a slight change in parts values with age may cause a reduction of output, it most probably would go unnoticed, since turning up the volume slightly would restore the output to normal. If it becomes necessary to turn the volume control excessitively for a known signal, first check the preceding circuits to be certain that they are operating properly and are not at fault, before trouble-shooting the detector.

Distorted Output. If the values of C1 and C2 changed sufficiently to produce the wrong time constant, either too fast or too slow, distortion would occur. Likewise, if the emission of V1 is so low as not to supply the full peak current demand, *distortion caused by clipping will also occur.* Replace the diode with a known good tube and check the values of C1 and C2 with an in-circuit capacitance checker. A change in the values of R2 and C3 will change the attack time of the AVC loop but will not normally cause distortion. However, if C3 should short-circuit, the AVC voltage would be grounded out and the stages preceding the detector would operate at maximum sensitivity, and probably cause overloading with consequent distortion.

DIODE DETECTOR (WITH NOISE LIMITER).

APPLICATION.

The diode detector with noise limiter is usually used in radiotelephone reception to prevent noise pulses from interfering with, or garbling, voice transmissions.

CHARACTERISTICS.

Operates linearly over a large range of voltage.

Input impedance is relatively constant and independent *of the input voltage.*

Does not amplify the input signal.

Noise peaks are clipped without excessively increasing the distortion.

CIRCUIT ANALYSIS.

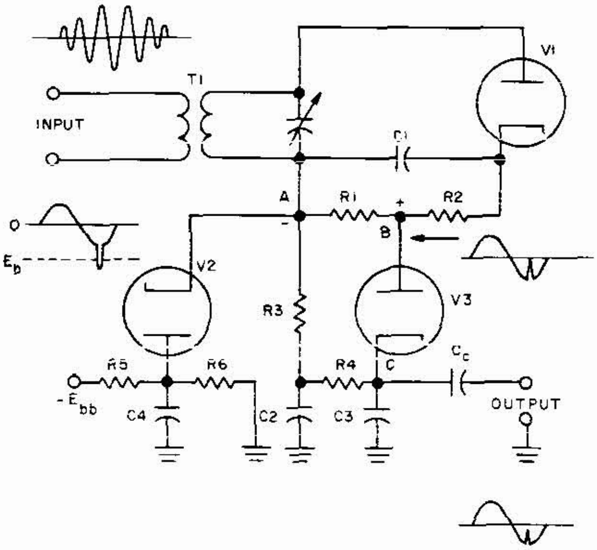
General. The diode detector with noise limiter is identical in operation with the Diode Detector described earlier in this section of the Handbook, except for the noise limiting circuitry. The reader should refer to the previous discussion for proper background before proceeding with this discussion.

Both shunt and series types of noise limiters are used. The series type continually conducts but stops conducting when a noise pulse arrives, and thus leaves a gap in the *signal in place of the noise pulse. The shunt type noise* limiter conducts only when the noise pulse exceeds a predetermined bias level, shorting the input to ground, and also leaves a void in the signal. Since these noise pulses and consequent signal holes are of short duration, the integrating effect of the ear on the sound minimizes this effect. In most practical noise limiters, the limiter becomes effective at around the 85 percent modulation level, so that subsequent peak flattening causes some distortion and a slight loss of audio volume. The voice, however, is understandable through heavy noise interference, which would otherwise completely mask or garble the intelligence being transmitted.

Circuit Operation. The schematic of a typical diode detector with noise limiters is shown in the accompanying *illustration.*

Diode V1 is the detector diode which rectifies the input signal from I-F transformer T1. Resistors R1 and R2 form a voltage divider load for diode detector V1, bypassed for RF by C1. The detector voltage appearing across R1 is applied to the anode of series noise limiter V3. Resistors R5 and R6 form a bias voltage divider from a separate negative supply to ground, to supply a fixed negative cutoff bias to the anode of shunt diode limiter V2. Resistor R6 is bypassed by capacitor C4 so that any instantaneous voltage change appearing at the anode of V2 is bypassed to ground. Resistors R3 and R4 together with capacitors C2 and C3 form a low-pass filter and load circuit for series diode V2. Capacitor Cc is the detector output coupling capacitor.

When an unmodulated input signal is applied to the *primary of IF transformer T1, the secondary voltage appears* across diode V1 and V1 conducts for the duration of each positive r-f pulse, causing a flow of current from the



Diode Detector With Noise Limiters

cathode to plate, through T1 secondary, R1, and R3, back to the cathode [illegible]. A negative [illegible] thus exists at point A which varies in amplitude directly with the r-f carrier amplitude. This is the AVC voltage mentioned in the previous discussion of simple detector (with AVC), in the section on the feedback. When the input signal is modulated, the negative voltage at point A also varies slowly at audio frequencies in accordance with the modulation. At point B the detected voltage is identical with that at point A except that it is smaller than at point A because of the drop across resistor R1. The RC low-pass filter combination of R3 and C2 charges capacitor C2 relatively slowly so that audio frequency signals are effectively shunted out. Low pass filter R4, C3 operates similarly except that the time constant is faster to ensure that no r-f component appears at point C to cause feedback. Thus both filters place the cathode of series diode [illegible] across R1 [illegible] bias on [illegible] point B). Thus diode V3 normally conducts, and the detected [illegible] point C, and is applied through coupling capacitor Cc as the audio output [illegible] a voltage divider [illegible] appears across R4 is comparatively small with the developed AVC voltage. When a negative noise burst appears at point B, the anode of series limiter V3 is instantly driven highly negative, while the [illegible] voltage changes very slowly because of the slow filter time constants provided by R3, C2 and R4, C3. Thus for most of the noise burst, conduction of diode V3 is stopped and no output appears (a hole occurs in the output). Thus the noise spike is chopped off the detector waveform, and because it occurs for such a short time, the instantaneous loss of signal goes unnoticed. When the noise burst occurs for a long period of time or is a repetitive occurrence, the loss of signal may be noticed. For random short noise pulses this type of limiter is fairly effective.

Note also that when the negative noise bursts occur, the negative voltage at point A is increased, and if it is fed back as an AVC voltage change the overall sensitivity of the receiver will simultaneously decrease, just when a strong signal is needed to overcome the adverse signal to noise ratio. Therefore, shunt limiting diode V2 is connected from point A to ground. Normally, the negative plate voltage, which appears on V2 from voltage divider R5 and R6 connected across the separate negative bias supply, holds V2 in a nonconducting condition. When a negative noise burst appears and is of sufficient amplitude to drive the cathode of V2 more negative than the fixed-biased anode, V2 conducts and the voltage at point A is temporarily shunted to ground via V2 and resistor R6. Capacitor C4 bypasses R6 and allows the instantaneous noise burst to be discharged to ground. Meanwhile, the relatively slowly moving d-c component produced by AVC action remains relatively unaffected. Consequently, the AVC voltage does not instantaneously increase (or decrease) and is effectively prevented from desensitizing the receiver during the noise burst. Thus conduction of diode V2 effectively removes the noise spike from the signal. Although the entire noise spike is not eliminated, the large peak amplitude above the fixed-bias level is removed so that the effect of the noise is considerably reduced by the shunt diode. In addition, the shunting effect of diode V2 on the detected audio temporarily reduces the signal supplied to the audio [illegible] via series diode V3, and produces a noise silencing effect. The use of both a shunt and series diode although not absolutely necessary provides better overall noise limiting performance.

FAILURE ANALYSIS.

No Output. Any open circuited or short circuited condition as well as defective diodes can result in a loss of output. Lack of negative voltage to ground at point A indicates a possible open primary or secondary of T1, diode V1, or that R1 or R3 are open, or C1 is shorted. Use an oscilloscope with an r-f probe to determine if an input exists on the primary of T1. A large signal on the primary but none at all or a very small one on the secondary indicates that T1 is defective. If an input appears at the diode, check the [illegible] with an ohmmeter, and check C1 for a short. If an output can be observed at point C with the oscilloscope, but not on the other side of Cc, check coupling capacitor Cc with an in-circuit capacitance checker. If these parts are satisfactory, diode V1 or V2 is at fault (an output at point C indicates that V3 is not at fault). [illegible] will not normally produce a no-output condition, but instead will produce a low output or ineffective noise elimination.

Low Output. A partial shunting of the detector output through diode V2 can occur if V2 is shorted, if the negative bias supply voltage fails, if R5 or R6 change in value, or if capacitors C2, C3, or C4 are either shorted or leaky. The capacitors may be checked for shorts with either an ohmmeter or an in-circuit capacitance checker, and the resistors can be checked with an ohmmeter. If diode V3 is defective, the output will probably be very low and distorted, depending upon the stray capacitance in the circuit.

Distorted Output. Since in normal operation the noise limiter effectively eliminates a noise signal, it is evident that the output waveform will always be different than the input waveform to a certain extent. Thus a slightly distorted output will practically always be obtained. The degree of the distortion depends upon the design of the circuit. Theoretically, the limiter should operate only on noise pulses which are larger in amplitude than the signal, however, most practical circuits start operating at about the 85 percent modulation level. Hence some peak clipping of the signal usually occurs and causes distortion on the modulation peaks. In normal operation, a slight amount of distortion will be noticed and the strength of the output signal will drop noticeably when the noise limiters are activated. Follow the signal through the circuit with an oscilloscope and notice where the distortion occurs. Further resistance checks of the associated parts with an ohmmeter will usually locate the defective part.

GRID-LEAK DETECTOR.

APPLICATION.

The grid-leak detector is used in simple two-or-three tube receivers, such as the regenerative type. Since this type of detector is particularly susceptible to overload and distortion at high levels of modulation, it is never used in modern high-gain superheterodyne receivers.

CHARACTERISTICS.

Is self-biased by a grid-leak.

Provides good sensitivity with increased signal gain.

Operates as a square-law detector for small signals and as a linear detector for large signals.

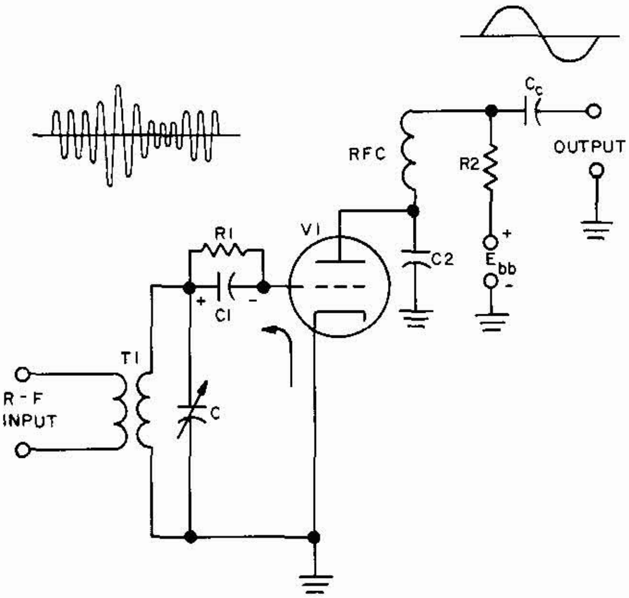
Is subject to overload and blocking effects on strong signals.

Although it produces a relatively larger output voltage than other comparable AM detectors, it is subject to more distortion.

CIRCUIT ANALYSIS.

General. The grid-leak detector, basically, uses a triode electron tube, and is considered to operate similarly to a diode detector with the added advantage of triode amplification. Although pentodes have been used to provide additional gain, the triode with a low plate voltage is usually preferred because of a reduction in tube noise and distortion. In operation, the grid and cathode of the triode operate similarly to the anode and cathode of the conventional diode detector (discussed previously in this section of the Handbook). The d-c bias produced by carrier rectification and the detected modulation appear across an RC network known as the grid-leak, and the modulation appears in amplified form in the plate of the triode. Since the detection occurs in the grid circuit it is known as grid detection. Because the developed grid bias is automatically controlled by the carrier amplitude, the grid-leak detector operates over a wide range of input voltage. On weak signals it operates near zero bias and uses the curved lower portion of the grid-current, grid-voltage characteristic to provide an output which varies as the square of the input signal, and is known as non-linear (square-law) operation. For large signals and large self-bias it operates over the linear portion of the characteristic curve. When overloaded by extremely strong signals, the bias reaches cutoff and conduction occurs for only part of the cycle, and the peaks are clipped, creating excessive distortion. The detailed operation of this detector under different conditions is discussed in the following paragraphs.

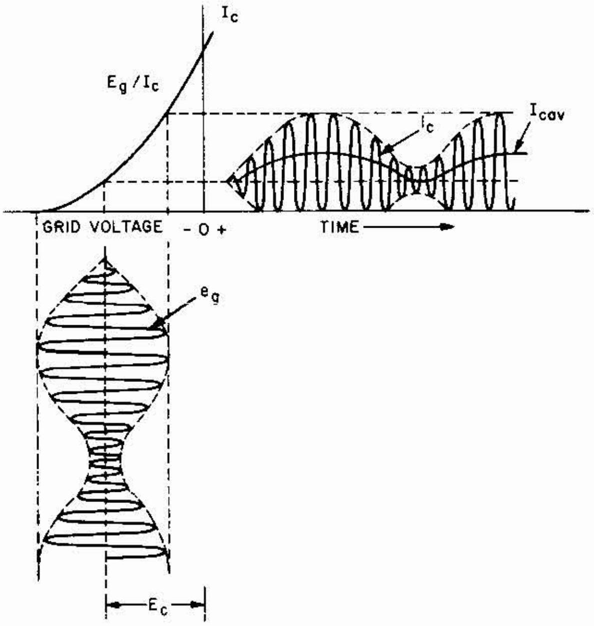
Circuit Operation. The schematic of a typical grid-leak detector is shown in the accompanying illustration.



Basic (Series) Grid-Leak Detector

The r-f input is applied through r-f transformer T1, and the grid-leak network consisting of R1 and C1 are connected in series with the grid of V1 and the output of T1 secondary, while the cathode is grounded. In the plate circuit, resistor R2 is the plate load, and is isolated from the plate r-f component by radio frequency choke RFC. The plate is also bypassed to ground by capacitor C2, which is small enough to act as a shunt for the r-f carrier voltage appearing in the plate circuit but not the modulation. Thus only the amplified modulation appears across load resistor R2 and is applied to the output through coupling and plate voltage blocking capacitor Cc.

In the absence of an input signal, V1 is contact-biased by grid-leak resistor R1, and operates near zero bias. In this condition, only a small potential is built up across R1 by grid current flow, biasing the grid slightly negative. Thus V1 is in a position to respond to both positive and negative signal variations for small signal detection. The accompanying waveform illustration demonstrates how the curvature of the grid current versus grid voltage characteristic of V1 distorts the basic signal and produces amplification with distortion.



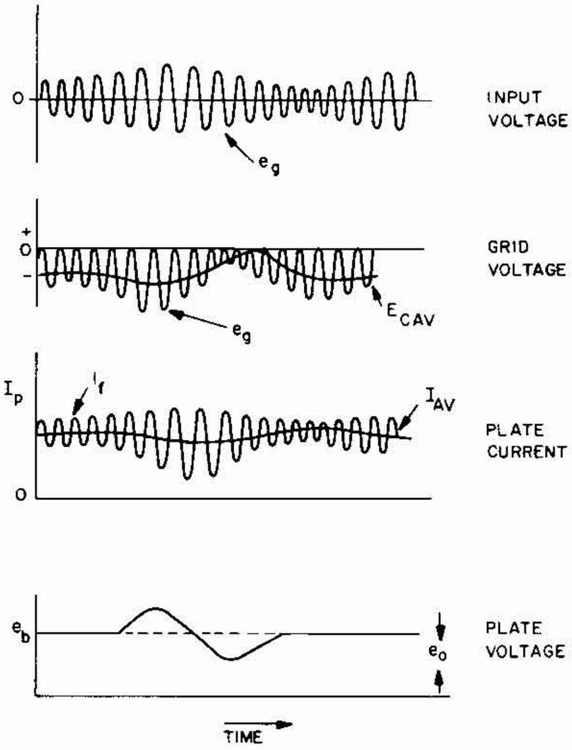
Small Signal Detection Characteristics

As shown in the illustration, when the input signal increases in amplitude grid current increases, flowing in the direction of the arrow on the schematic. Thus grid capacitor C1 is charged negatively during the positive grid swing. On the negative grid swing, grid current flow is reduced and the capacitor discharges slightly through the grid-to-cathode resistance which is lower than the high resistance grid-leak. Because of the curvature of the grid characteristic curve, the positive excursions are larger than the negative excursions. Therefore, a slowly increasing average grid current is developed as the signal modulation rises, and the average grid current falls when the signal modulation decreases, in synchronism with the modulation envelope. This develops a negative voltage across R1, which varies at the audio rate of the modulation around the negative bias level produced by the constant amplitude carrier pulses. Since the grid of V1 controls the operation and plate current of the triode, the change of grid voltage produced by the detected signal causes an identical but amplified plate current fluctuation. As this plate current varies in accordance with the modulation, a similar but amplified voltage is developed across plate load resistor R2. This is the audio output voltage which is coupled through Cc to the following audio amplifier stage. Because the r-f carrier voltage appears between the grid and the cathode of V1 it also appears in the plate circuit. Therefore, there is an r-f plate component of voltage which must be eliminated so that it can not cause spurious beats with the modulated signal, or unwanted oscillation by feedback within the tube. This is the function of RFC and C2. The r-f choke offers a high inductive impedance at the carrier frequency, while capacitor C2 offers a low impedance shunt path to ground. Hence, the r-f component is bypassed around the load resistor and power supply, and has no effect on circuit operation. Only the relatively slowly moving audio frequency current component flows through load resistor R2, to produce a corresponding audio frequency output voltage.

For large signals, the average carrier amplitude also rises, so that the grid is biased considerably negative, and only the positive excursions of r-f voltage on the input signal are effective in causing grid current flow. In this condition the detector operation is similar to a half-wave rectifier, and operates as a linear detector. The positive signal excursions produce a negative voltage across the grid leak by charging capacitor C1. During the negative signal excursions the charge on C1 keeps V1 inoperative so that the tube operates for a half cycle or less. Because maximum modulation peaks produce maximum negative grid voltage, the plate current of V1 is reduced during modulation. The reduction of plate current occurs at an audio rate and produces a corresponding audio output. As the current through detector output load resistor R2 reduces, the voltage across it and the output rises, as shown in the waveforms illustrated in the accompanying figure of large signal detection characteristics.

The linear grid detector is also known as a grid-leak **power** detector. In the small-signal or square-law grid-leak detector the output voltage although amplified is usually greatly distorted, therefore, large output voltages create greater overall distortion. In the power detector, the grid-leak values are reduced to prevent excessive distortion, and the input signal and the detector plate voltage are increased to provide a greater output. Thus the larger input signal produces operation over a larger output voltage swing, producing a greater output voltage with less overall distortion.

In operation, the major difference between the two types of detectors is obtained by making the large-signal, power-detector grid potential swing sufficiently negative that the flow of grid current is stopped for the major portion of the negative half cycle. During the positive half cycle

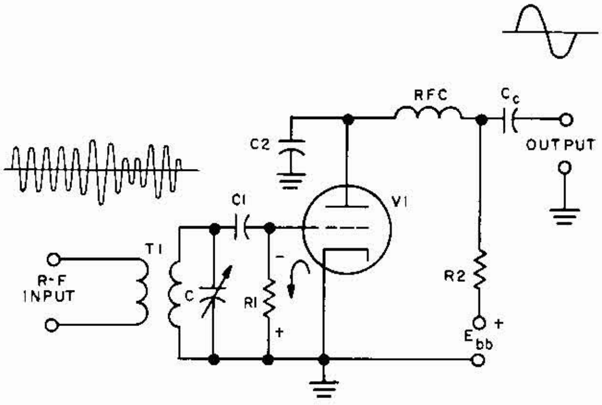


Large Signal Detection Characteristics

of carrier voltage, grid current flow charges the grid capacitor negatively. During the next negative half cycle, some of this accumulated charge leaks off through the grid-leak resistor (which is connected across C1), and is replenished during the next positive swing. Thus grid current can only flow for a small portion of the positive cycle. In the small-signal grid detector, however, grid current flows continuously, since the grid is never driven sufficiently negative to reduce grid current flow to zero. Under these conditions, the charge on the grid capacitor leaks off through the internal grid-to-cathode resistance, which is much lower than the high value of grid leak resistance used. In the large signal power detector the grid-to-cathode resistance is practically infinite during most of the cycle (because grid current is cut off). Operation of both detectors is essentially the same as shown in the waveform illustration for the small signal detector, except that the grid amplitude of the large signal detector is greater, and the grid current cut-off point corresponds to the value of bias developed by the carrier signal. Whereas in the small signal detector the grid bias is always less than grid-current cutoff.

As in all electron tube amplifiers, the plate-current, grid-voltage characteristic curve is linear up to the point where saturation begins. So that both the lower and upper regions of operation are curved. If the large signal power detector is driven sufficiently, the bend on the upper portion of the curve will also cause plate rectification to occur. Thus second and third harmonic distortion components will be produced and the overall detector distortion will increase. It is also necessary that the charge and discharge of the grid-leak follow the signal amplitude during large signal detection, otherwise, blocking and distortion will occur. With proper choice of grid-leak constants (which is inherent in good design) and an adequate plate voltage which does not exceed tube ratings, the distortion can be kept to low values almost equivalent to that of the diode detector. If the input signal is reduced to a very small value, the large signal power detector merely operates as a small-signal, square-law detector with a low output and the advantages of power detection are lost.

The schematic of a typical shunt grid-leak detector is shown in the accompanying illustration. Components are symbolized identical to, and operate exactly as explained for the series grid-leak detector discussed above. This circuit is generally used for the power type detector because slight advantages are claimed for avoiding blocking effects. The shunt grid resistor provides more loading on the tuned r-f input circuit, however, and produces a reduction in selectivity.



Shunt Grid-Leak Detector

FAILURE ANALYSIS.

No Output. An open or shorted grid or plate circuit, a defective tube, or an open coupling capacitor, Cc, can cause loss of output. Measure the plate supply and plate voltage with a high resistance voltmeter. Normal plate voltage indicates that load resistor R2 and the RFC are probably satisfactory and that C2 is not shorted. Apply a modulated signal from a signal generator to the input terminals of r-f transformer T1. Use a VTVM, electronic voltmeter or an oscilloscope (it must offer high impedance so as not to load or disturb the circuit operation) connected between grid and ground, to determine if the input signal produces a slight negative bias and if a signal is present. If no signal is present, T1 is defective. If the detected signal can be observed in the grid circuit but not in the plate circuit, V1 is defective. If the signal is present in both grid and plate circuits but no output exists, check coupling capacitor Cc for an open circuit. (Use an in-circuit capacitance checker).

Low Output. Low plate voltage, a defective tube or too weak an input will each cause a reduced output. The weak input signal may occur because r-f transformer T1 is not tuned to resonance. If T1 will not tune to resonance, either the signal frequency is out of range or T1 is defective. When in doubt, apply a modulated input from a local signal generator and note that the signal peaks in intensity as the resonance point of T1 is reached. If this occurs but the desired signal is still weak, additional r-f amplification or a better antenna are required. If the signal generator cannot produce a strong output, the detector is probably at fault. Check the plate voltage of V1; if the plate voltage is normal, either V1 is defective or output coupling capacitor Cc is leaky or partially open. If the plate voltage is not normal but is lower than usual, R2 may have changed value, the rfc may have developed a high resistance, or C2 may be leaky or shorted. Use an ohmmeter to check the resistance of R2 and the RFC, and check the resistance of C2 to ground. Replace any part which has a resistance higher or lower than that specified in the technical manual for the equipment. If the detector seems to be operable but the receiver output is low, it is possible that the audio stages following the detector are at fault, and not the detector circuits. To check the audio stages, use an audio signal generator and apply it to the output stage plate, then to the grid and note if the signal increases. Follow this procedure back to the detector to locate the defective audio stage.

Distorted Output. Excessive distortion can be produced by a change in the constants of the grid-leak network, by too high a plate voltage, or as a result of low emission from V1. If replacing the tube with a known good one does not eliminate the distortion, check the plate voltage with a high resistance voltmeter. If the plate voltage is normal, check the value of R1 and C1 with an ohmmeter and capacitance checker. If the grid-leak components are within tolerance value and distortion still occurs, it is possible that the input signal is too strong and overloading is causing the distortion. It is also possible that T1 is only tuned near resonance and the sidebands are being clipped. Tune T1 properly, and reduce the input signal, if possible.

PLATE DETECTOR.

APPLICATION.

The plate detector is used in small receivers as a power detector. It is usually used in tuned r-f receivers to supply a large audio output. While it can be used in the modern superheterodyne, it cannot be used to supply a simple AVC voltage. Thus, it is usually more economical and simpler to use a diode detector. The plate detector is, however, extensively used as the detector circuit in vacuum tube voltmeters and similar test equipment.

CHARACTERISTICS.

May use either self-or fixed-bias (self-bias is most prevalent).

Provides good sensitivity and increased signal gain.

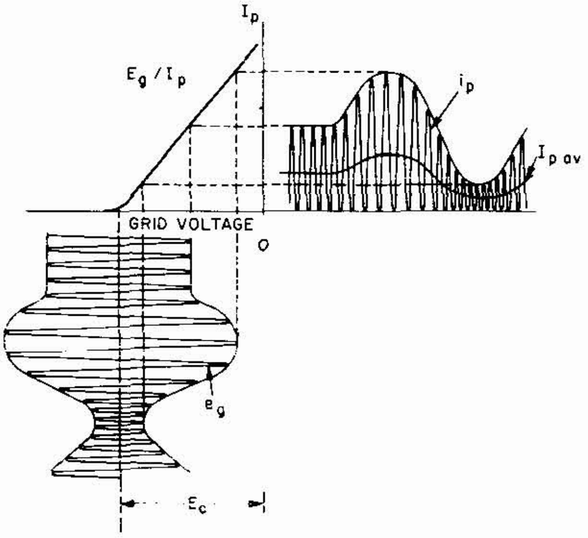
Operates as a linear detector for large signals.

Is normally operated with large input signals as a power detector.

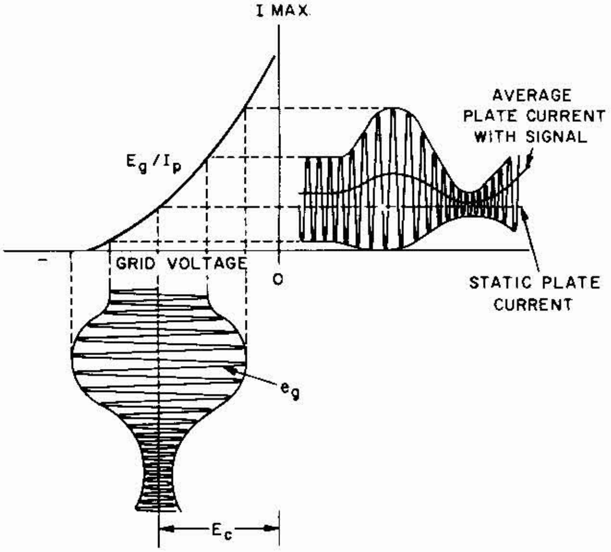
Distortion is considered to be slightly less than that of the grid-leak detector, and not better than the diode detector.

CIRCUIT ANALYSIS.

General. The plate detector usually operates class B, that is, it is biased to plate current cutoff, and for this condition it operates as a large signal linear detector. When used for small signals, or as the detector of a vacuum-tube voltmeter it operates on the lower curvature of a class A biased tube characteristic, and is a square law detector. In the plate detector there is no rectification of the signal in the grid circuit. The r-f input signal causes the a-c grid voltage to vary the tube plate current, producing both amplification and detection. Detection occurs in the linear plate detector because only one side of the signal (the positive portion) causes the tube to conduct, while the negative portion remains below cutoff and has no effect. Thus the plate output varies in accordance with the r-f envelope of the modulated carrier as shown in the accompanying waveform for linear detection. The square law detector operates over both the positive and negative variations of the input signal. Because of the curvature of the tube e_g/i_p characteristic for small input signals, an amplified but distorted plate output results. The large positive grid swing produces a greater plate current than the smaller negative swing. Thus the average output is greater during modulation than without modulation, as shown in the accompanying waveform illustration.



Linear Operation



Square Law Operation

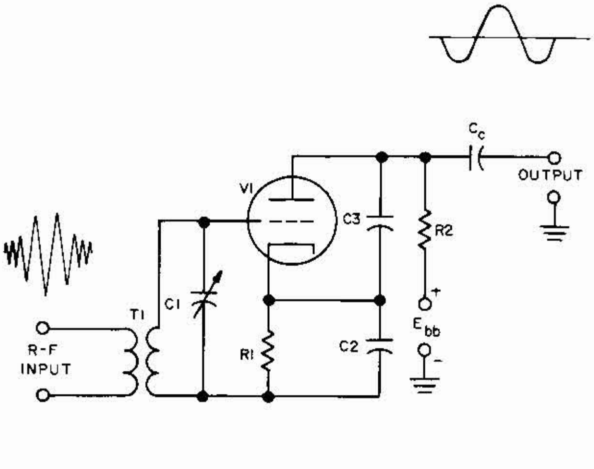
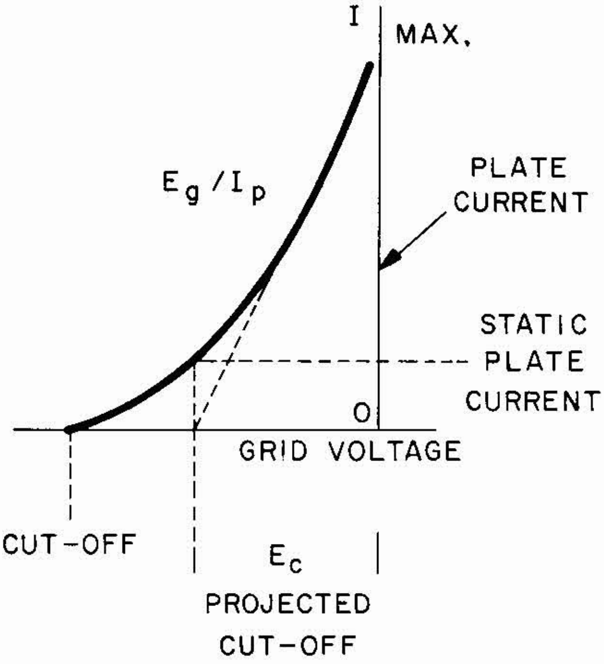


Plate Detector



Detector Operation Characteristic

Since the output varies as the square of the input signal, at 100 percent modulation the maximum distortion can be as high as 25 percent. Operating as a linear detector the distortion is considerably less, as long as the signal is strong enough to keep it from operating in the lower curved portion of the tube characteristic, and not so large as to include operation over the upper curved portion. However, since the e_g/i_p characteristic curve of a triode is never perfectly straight but has a slightly bowed appearance, there is greater basic distortion than in the half-wave diode detector.

Circuit Operation. The schematic of a typical plate detector is shown in the accompanying illustration.

Transformer T1 is the r-f input transformer, with the transformer secondary tuned by C1. Cathode bias is obtained from R1 and C2. The plate load R2, is bypassed for r-f by C3. The output is capacitively coupled through Cc.

With no signal applied, the average bias produced by cathode current flow through R1 holds the grid to plate current cut off. Although spoken of as cutoff bias, the tube is actually biased to projected cutoff, as shown in the accompanying illustration. (See section 2, paragraph 2.2.1 in this handbook for a detailed explanation of cathode bias.) Therefore, negative input signal excursions occur over the curved portion and produce some slight distortion. For full linear operation a separate and higher fixed bias is always applied and the complete negative excursion of the input signal is eliminated with a consequent reduction of overall distortion.

When an input signal is applied, the positive portion of the signal increases the grid voltage, and the plate current of V1 follows, likewise. Thus the plate waveform of V1 consists of pulses of current at the input frequency, whose peak values trace out a curve which varies exactly as the modulated r-f. Thus the audio frequency component of plate current develops a similar plate voltage output waveform across the plate load resistor R2 of opposite polarity or phase. Thus at the peak of current, the plate and output voltage is a minimum, while at the minimum value of plate current the output voltage is maximum. Capacitor C3 bypasses any r-f which might appear on the plate of V1 after rectification, to avoid feedback through the plate to grid capacity causing oscillation or unwanted beats. In some instances, C3 may be bypassed to ground instead of to the cathode, this is usually done in receivers operating at the higher radio frequencies.

Normally, no grid current is drawn and the plate detector offers an extremely high input impedance with practically no input loading. Since the input circuit is not loaded down, a slight improvement in selectivity is usually observed over that of the grid-leak detector. If, however, the input is large enough to draw grid current (signal exceeds the bias), additional plate distortion is obtained by curvature of the upper portion of the tube characteristic, and the lowered grid input impedance also reduces the selectivity, so that the overall performance is lower than for the grid-leak detector.

FAILURE ANALYSIS.

No Output. An open input or output circuit, or a defective tube, as well as lack of plate voltage, will cause a no-output condition. Check the plate supply and plate voltage with a high resistance voltmeter. No output with a normal supply voltage, but with no plate voltage indicates that plate load resistor R2 may be open, or that bypass capacitor C3 is shorted. Check the resistance of R2 with the plate voltage off, and check C3 with an in-circuit capacitance checker. If plate voltage is normal but no output is obtained, use an oscilloscope and r-f probe to observe that an input signal exists on the grid of V1. If it does and no output exists, either cathode resistor R1 is open or V1 is defective. Check the bias voltage across R1 with a voltmeter. Since bias bypass capacitor C2 may be shorted, it is usually simpler to measure the resistance of R1. If the resistance across R1 is zero, then C2 is shorted. If R1 is infinite it is open. Also, do not neglect the possibility of a shorted secondary winding or tuning capacitor C1.

Low Output. A low plate voltage, a defective tube, or a small input signal will produce a low output. Check the supply voltage with a voltmeter. If normal, check the plate voltage of V1; lower than normal voltage on the plate indicates that R2 has increased in value, or that an abnormal plate current exists. Check the voltage between cathode and ground, if it is normal or slightly low check R2 for the proper resistance value (with plate voltage off). If T1 is defective, or if C1 is not tuned to resonance a low output can also occur. If T1 primary is open, a weak output signal may still be obtained if there is sufficient capacitive coupling between primary and secondary, or to V1 grid. In this case, while C1 will tune through resonance there will not be the normal large build up of output signal as the resonant point is passed. If T1 is defective, a resistance analysis can be made with an ohmmeter to verify if the windings are open, but there is also the possibility of a short circuit or leakage across one of these windings. To determine if T1 is at fault, temporarily disconnect it from V1 grid and connect the input signal through an isolating capacitor direct to V1 grid. A large increase in signal indicates that T1 must be defective. The output of a modulated signal generator tuned to the input frequency can be used to supply an input directly to the grid of V1, if a known strong local signal is not available.* If the output signal obtained in this case still is weak, but increases considerably when the generator output is applied to the plate circuit, tube V1 is at fault. Where all signals fade in and out and the output is low, V1 is usually at fault because of low emission.

Distortion. Since there is normally some distortion from the linear detector, particularly on strong signals at high percentages of modulation, there may be some doubt as to whether or not the distortion is normal or excessive. When distortion is suspected, check the plate voltage and cathode bias with a voltmeter. Abnormal voltages indicate that the detector is probably at fault. If, however, it is found that tuning C1 eliminates the distortion, or that it only exists on extremely strong signals, the detector is most likely performing normally. When the distortion continuously occurs with either weak or strong signals the detector is definitely at fault. Note, however, that when strong fading exists it is possible that selective fading is phasing out some of the sideband frequencies and causing the distortion. Such distortion will not appear on signals having a steady amplitude.

INFINITE IMPEDANCE DETECTOR.

APPLICATION.

The infinite impedance detector is used in tuned radio frequency receivers where less distortion than that supplied by the conventional plate detector is required, and no gain through the detector stage can be tolerated. Its light loading effects improve sensitivity and selectivity.

CHARACTERISTICS.

Uses self-bias, but can be fixed-biased, if desired.

Provides good sensitivity, with reduced distortion.

Operates as a linear detector for large signals.

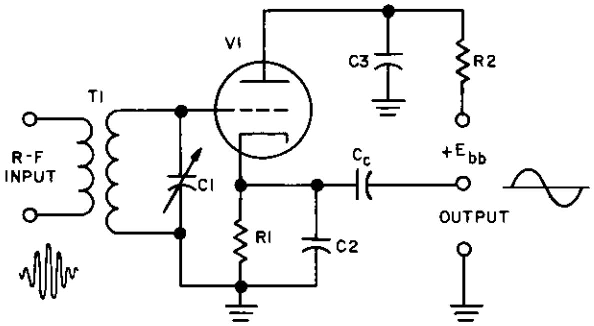
Is normally operated as a modified power detector. The cathode output connection prevents any large increase of gain.

Presents a very high or infinite impedance to the input signal.

CIRCUIT ANALYSIS.

General. The infinite impedance detector is also known in other texts as a **reflex** detector because of the large value of degenerative feedback provided in this arrangement. However, this nomenclature is misleading since it also applies to reflex circuits where both detection and amplification through positive feedback occur in the same stage, and these circuits are not infinite impedance detectors. The basic infinite impedance detector used a bypassed plate load to achieve more than unity gain. In effect, it combined the advantages of plate detection with the equivalent of diode detection which offered no load to the source. The circuit is always easily recognized because of the cathode output connection, large cathode resistance, and relatively small r-f bypass (about 250 picofarads), plus the fact that when the plate resistor is used the plate bypass is sufficiently large enough for both RF and audio bypassing (about 0.1 microfarad). Because of the infinite impedance offered this circuit does not load the input. Consequently, greater sensitivity and selectivity is obtained than with conventional plate detectors. On the other hand, it is not as sensitive as the grid-leak detector, but the output is practically distortionless and much lower than is normally obtained by either the plate or grid types of detectors previously discussed. If not better, it is at least as good as the conventional diode detector. The two major disadvantages which restrict its use, is that it cannot supply a simple source of AVC, and the negative feedback through cathode degeneration produces less than unity gain.

Circuit Operation. The schematic of a typical infinite impedance detector is shown in the accompanying illustration.



Infinite Impedance Detector

Transformer T1 is the r-f input transformer, and is tuned by C1 (in superheterodyne receivers T1 represents the i-f input transformer). Cathode bias is supplied by R1 which is only bypassed for RF by C2 so that it is degenerative at audio frequencies. The output is taken from across R1 through coupling capacitor C_c. Resistor R2 and capacitor C3 form a plate filter and voltage dropping network, which reduces the plate voltage and bypasses to ground any rf or audio currents in the plate circuit. In some circuits R2 is not used, while in other circuits both R2 and C3 are eliminated. In either event, there is no change in circuit operation.

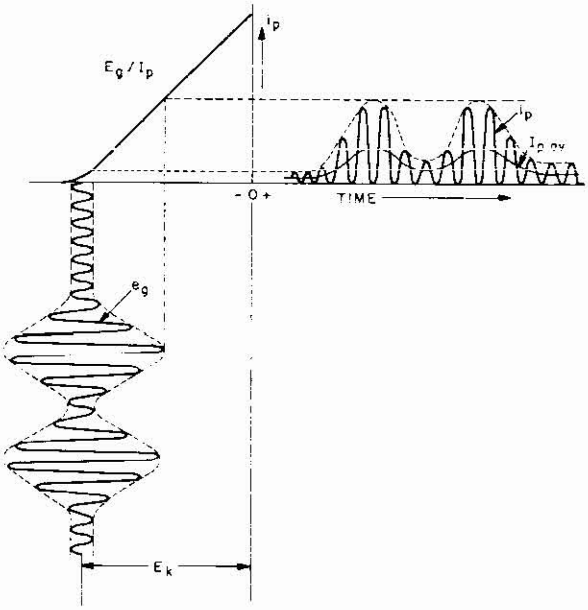
By using a large value of resistance for R1, the average plate current flow through this resistor develops a high bias. Thus, in the absence of an input signal only a small plate current flows because of the cathode bias is almost at plate current cutoff value. Since current flow through the tube is from cathode to plate, any increase in cathode current develops a positive voltage at the cathode with respect to ground and increases the instantaneous bias. However, R1 is bypassed by C2, which is chosen to offer a low impedance to ground for radio frequencies, but not for audio frequencies. Consequently, the r-f signal does not pass through the load (cathode resistor R1) but the audio frequency variations of the modulation on the detected signal do. Thus a degenerative voltage is developed on the cathode, which makes the output signal amplitude always less than the input signal which produces it. This is a form of negative feedback which places the output signal in series with the grid-cathode circuit. Since the output signal appears in opposite polarity to the input it helps cancel a portion of the input signal, elimiantes distortion, and improves linearity. (See Section 6 of this Handbook covering Feedback Amplifiers for a complete discussion of inverse or degenerative feedback.) Because of the degenerative feedback inherent in a cathode output connection, the output signal amplitude can never exceed the input signal, and the gain is always less than unity.

Another result of the feedback action is to prevent the flow of grid current. The increase of bias with increase of signal ensures that the input signal never exceeds the bias, hence grid current will never flow. Thus the infinite impedance detector always presents a very high (infinite) impedance between grid and cathode, and produces no load on the input circuit. Consequently, there is no shunt load across the secondary of T1 and C1, and the selectivity of the tuned input circuit depends only on the Q of the tank circuit. Thus better selectivity is obtained. When the input signal reduces in amplitude, the decreased grid voltage produces a reduction of plate and cathode current, accordingly. Since cathode resistor R1 is not bypassed for audio frequencies, the instantaneous audio current variations through R1 develop an output voltage which varies with a modulation envelope of the received signal. The process is practically identical to that of the diode detector discussed previously in this section of the Handbook, since only the positive portion of the input is effective as shown in the accompanying illustration, (the negative portion is biased off).

With a large input signal the circuit always operates over the straight (linear) portion of the plate current-grid voltage characteristic. Since plate load resistor R2 is bypassed by C3, any instantaneous r-f or audio current variations are bypassed to ground, and the plate voltage remains constant regardless of cathode current fluctuations.

FAILURE ANALYSIS.

No Output. An open or shorted input or output circuit, lack of plate voltage, or a defective tube can create a no-output condition. Check the supply voltage with a high resistance voltmeter to determine that the fault is not in the power supply, and then check the plate voltage. No plate voltage indicates possibility of R2 being open or C3 being shorted. Check R3 for proper resistance with an ohmmeter, and C3 for a low resistance to ground. Check the cathode bias voltage developed across R1. If no bias exists, either V1 is defective, R1 is open, or C2 is shorted. Check R1 and C2 with an ohmmeter. If normal



Detection Characteristics

plate and cathode voltages exist use a VTVM to check the grid input voltage. If no grid signal voltage is found, make certain that C1 is set to the proper frequency for the desired input signal, and if still no input exists, check T1 for continuity with an ohmmeter. If an input signal exists on the grid of V1, check coupling capacitor Cc to make certain it is not open (use an in-circuit capacitance checker).

Low Output. A weak input signal can cause a low output. A low emission tube usually causes erratic fading on all signals and a low output. Low plate voltage will also cause a reduced output. Check the plate and cathode bias voltages. If the plate voltage is low with a normal supply voltage, check R2 for an increased resistance value and C3 for a partially shorted or leaky condition. If the cathode bias is low, R1 may have changed value, C2 may be leaking and shunting R1 with a low value of resistance, or V1 plate current may be weak because of low emission. Check R1 with an ohmmeter and C2 for leakage. A weak input signal can also be caused by defective r-f transformer, T1, or by a defective or mistuned tank tuning capacitor, C1. If there is any change in signal as C1 is tuned, the tuning capacitor is probably satisfactory and the primary of T1 is probably open. Check T1 for continuity with an ohmmeter. If the transformer continuity is complete and weak signals still occur on a known local signal, there is still the remaining possibility that T1 is shorted.

Distortion. Since the infinite impedance detector is noted for its fidelity and lack of distortion, it is evident that noticeable distortion indicates improper performance. Check the bias with a voltmeter. Low bias will place the operating point on the bend of the E_g/I_p curve, and square law detection with its high distortion products will result instead of linear detection. Distortion accompanied with a low output can also be caused by a defective tube.

REGENERATIVE DETECTOR.

APPLICATION.

The regenerative detector is used in simple one or two tube receivers, particularly in the high frequency regions where normal r-f amplifiers do not provide much gain. It is mostly used for CW and voice reception.

CHARACTERISTICS.

Uses a grid-leak detector with regenerative feedback from plate to grid.

Has better sensitivity than any non-regenerative detector.

Has better selectivity than any nonregenerative detector.

Has poor fidelity with relatively high distortion for music and, therefore, is mostly used for voice and CW (code) reception.

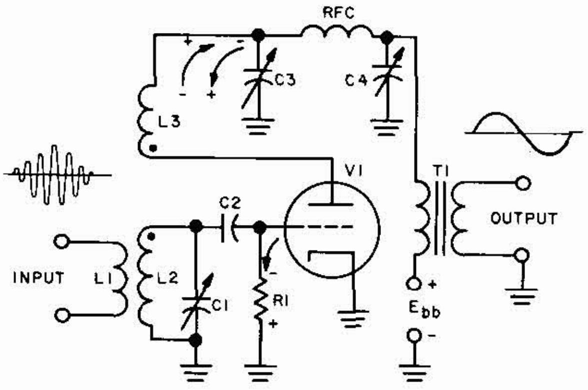
CIRCUIT ANALYSIS.

General. The regenerative detector utilizes the high sensitivity of a grid-leak detector, together with the increased amplification afforded by regenerative feedback to provide a unique detector with extreme sensitivity and high gain. Since grid-leak detection is used, the distortion level is high, and because regeneration increases the selectivity of the tuned input circuit, a narrow band-width is obtained. Thus, the high frequency components of a modulated signal are effectively eliminated by circuit selectivity of the order of 2-to-3 kc. Hence, this circuit is restricted in use mainly to communications applications involving only voice and code reception.

There are a number of circuit variations, most of which involve the method of controlling the regenerative feedback. Because feedback varies with the frequency range covered, fixed forms of feedback are suitable only over a very narrow range of operation. With smooth control of feedback, it is possible to increase the regeneration until the feedback reaches the critical point where any further regeneration will cause continuous oscillation of the circuit. Voice reception is amplified the greatest just below this point. For code reception, the amount of regeneration is increased until the circuit just oscillates, and the desired signal is tuned in by adjusting the tuning capacitor slightly off resonance until an audible note is produced. This type of reception is known as **autodyne** reception, which uses a single tube to perform detection and oscillation simultaneously, as contrasted with **heterodyne** reception, which uses a separate oscillator to produce a heterodyne signal.

Circuit Operation. The schematic of a typical regenerative detector is shown in the accompanying illustration.

The r-f input signal is applied to L1, the primary winding of the r-f input transformer, of which L2 is the secondary, tuned by capacitor C1. The feedback winding L3 is in



Regenerative Detector Circuit

ductively coupled to L2, and consists of a few turns wound in the same direction as those of the secondary coil and located at the ground end of the secondary coil (L3 is called the "tickler" coil). Variable capacitor C3 is connected in series between ground and tickler coil winding to control the amount of regenerative feedback. The radio frequency choke, RFC, and capacitor C4, form a low-pass filter which bypasses any r-f component in the plate circuit to ground. Capacitor C2 and resistor R1 form a conventional parallel grid-leak arrangement. The audio output is applied to the primary of transformer T1, used to provide a step-up in output voltage between primary and secondary. Although any other method of audio coupling may be used, the transformer is usually used because of the large output it produces in comparison with other types of coupling.

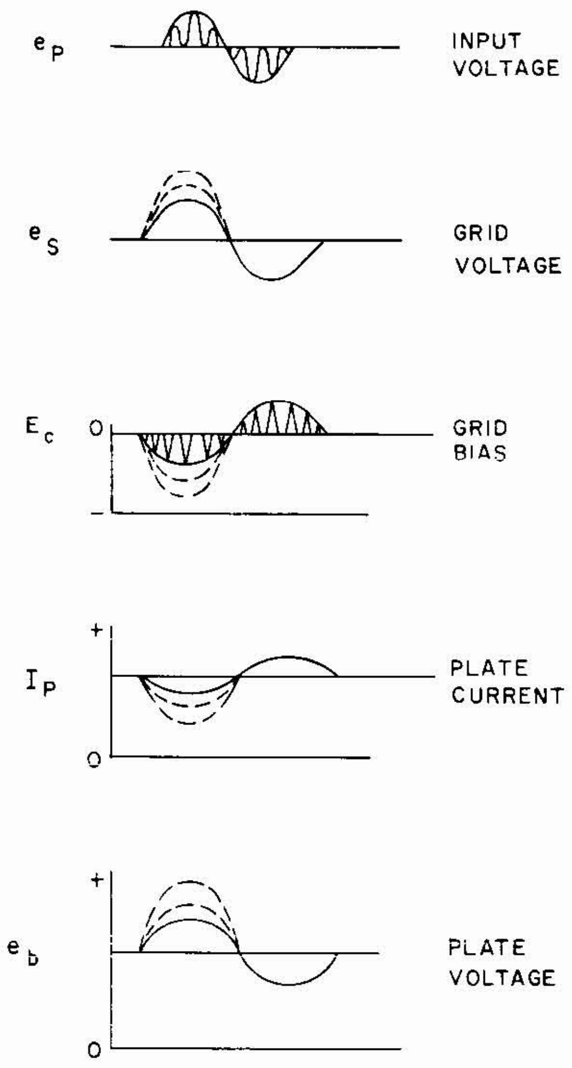
Initially, the circuit rests in its quiescent condition with no signal applied, and draws heavy plate current because only contact bias is supplied by R1 (see Section 2 paragraph 2.2 in this Handbook for a complete explanation of contact bias). We shall also assume that feedback capacitor C3 is set to the middle of its range and offers a low capacitive reactance to ground. Tickler coil L3 is fixed-coupled to L2, and wound so that both grid and plate ends of the winding are of additive polarity.

When an input signal is applied to L1 it is inductively coupled into the resonant tank consisting of L2 and C1. The low reactance of the grid-leak capacitor, in turn, allows the tank signal to appear at the grid of V1, across R1. On the positive half cycle grid current flow is increased, and capacitor C2 is charged negatively as shown by the polarities and current flow arrow on the schematic. Thus as the signal rises in a positive direction the negative grid bias on V1 increases. This negative grid bias increment decreases plate current flow because of control grid action within the tube. In the quiescent condition, plate current flows through the tickler coil winding in such a direction as to produce a polarity similar to that of L2 across L3. Thus the plate end of the tickler is negative when the grid is positive. Since, in the absence of an input signal there is a steady unchanging flow of plate current, the field built up around L3 remains steady and constant so that no feedback voltage is induced into L2. When the input signal is applied, however, the reduction of plate current with the increase of grid-leak bias produces a change in the lines of magnetic flux cutting the two coils, and a feedback voltage is induced in L2 by the current change in L3. The reduction of plate current causes the field around L3 to collapse and induce a voltage of opposite polarity to that normally produced in the increasing current direction. Hence a positive voltage is fed back to further activate the grid of V1. Since the input signal and the feedback voltage are of the same polarity they add, and produce a still greater negative grid bias. The increased bias, in turn, causes a further reduction of plate current, and a larger feedback voltage. This cycle of signal build-up by regenerative feedback continues until the input signal amplitude changes. As the amplitude changes, the feedback action follows. That is, as the signal increases the feedback increases, and as the signal decreases the feedback, likewise, decreases. With feedback, the combined signal value is always greater than without feedback. Thus, weak signals are greatly enhanced and the sensitivity of this type of detector is greater than for non-regenerative types.

On the negative half-cycle of input signal, the flow of grid current is reduced, and a small amount of the charge on capacitor C2 leaks off to ground through grid-leak R1. Therefore, the grid bias on V1 is reduced and an increased plate current flows. The increased current flow is in the direction of original (quiescent) current flow and produces a feedback voltage of negative polarity, which adds to the negative signal voltage on the grid. This regenerative build up in the opposite direction during the negative half-cycle of operation is limited to a value less than zero bias, since the tube is operating on the lower bend of the characteristic transfer curve. Hence the positive and negative swings developed across the primary of audio output transformer T1 are unequal and distortion is produced.

The accompanying waveform illustration shows the relationships between the grid and plate voltages and currents. The dotted lines in the waveforms indicate the build up of signal by regenerative action during the positive half-cycle. When the input voltage increases, the secondary voltages increases and is further enhanced by feedback, while the detected signal produces a grid bias which increases and is further enhanced by the feedback. The plate current, in turn, is progressively reduced, while the plate voltage increases. The changes of plate current occurring at audio frequencies in the primary of T1 induces a similar output voltage in the secondary.

When the capacitance of feedback capacitor C3 is increased, the reactance to ground is reduced and a greater r-f current flows through tickler coil L3, and produces a larger feedback voltage. As long as the feedback is kept below the point of oscillation, maximum amplification is obtained. Once the feedback becomes great enough to drive the grid to cut-off and beyond, the tube conducts only during the peak of the signal and for less than a half cycle



Grid and Plate Voltage Waveforms

(class C operation). During the cutoff period the tank circuit supplies the missing portion of the signal and continuous amplitude sine-wave oscillations occur.

Although the r-f component in the plate circuit is effectively bypassed to ground by regeneration capacitor C3, radio frequency choke RFC, is placed in series with the plate lead to offer a high r-f resistance (impedance) and prevent the possibility of r-f feedback through the load consisting of audio output transformer T1 and the power supply. To ensure that no RF remains to cause a fringe howl and deteriorate detector performance, capacitor C4 is also used to bypass the primary of T1. Thus, any remaining RF which might exist at the load end of the RFC is bypassed to ground by C4, so that only the slow current variations caused by modulation and occurring at audio frequencies appear in the transformer primary, and induce an output voltage in the secondary.

When voltage is fed back from the plate to the grid circuit, the result is to effectively reduce the losses in the grid circuit. Since the Q of an inductance is the ratio of the reactance to the resistance in the circuit. It is evident that when the r-f resistance in the circuit is decreased and the same reactance exists, a higher Q results. Thus, with a higher Q tank circuit resulting from feedback, a greater selectivity exists. This improved selectivity makes for sharper tuning, and will cut off the higher modulation frequencies in wide-band transmission such as is used for music at broadcast frequencies. At high frequencies, however, the side bands are a much smaller percentage of the signal so that not as much sideband clipping occurs and usable voice reception is possible without excessive distortion. Since code transmissions occupy a very narrow frequency spectrum of one thousand cycles or less the increased selectivity of the tuned circuit during feedback is not sufficient to affect code reception. One of the major disadvantages of this circuit for Military use is that, when oscillating it reradiates and produces a low powered CW output; which, besides interferring with nearby receivers tuned to the same frequency, offers a convenient means for the enemy to locate the source with direction finders. This radiation can be eliminated by use of an r-f stage between the detector and antenna, which acts as a buffer stage when properly neutralized.

FAILURE ANALYSIS.

No Output. Lack of an input signal, loss of plate voltage, an open or shorted input or output circuit, or a defective tube can result in a loss of output. First measure the supply voltage with a high resistance voltmeter to make certain that the supply or a blown supply fuse is not at fault. Then measure the plate voltage to ground. If the plate voltage is normal, plate circuit components C3, C4, RFC and the primary of T1 are not at fault. If removing and replacing the tube produces a click in the output device it indicates that the secondary of T1 is not open or shorted, and that the trouble is most probably located in the grid circuit. Turn regeneration control C3 past the point where oscillation usually begins and touch the grid of V1 with your finger. A click in the output indicates the circuit is oscillating and that the tube and feedback portion of the circuit are operating. If there still is no output, the input coil is probably open or shorted. Use an ohmmeter to check the input coil for continuity. If the coil is not open, the possibility of a grid to ground short or an open grid capacitor, C2, still exists. Therefore, it is usually easier to connect the antenna or the output of a signal generator direct to the grid of V1. If the input or tuning portion of the circuit is at fault and C2 is not open, a weak signal will usually be heard. Also rotate tuning capacitor C1, and listen for a noise indicating shorted tuning capacitor plates.

If no plate voltage is obtained, either T1 or the RFC is open, or capacitors C3 or C4 are shorted, or tube V1 is defective. An infinite resistance when measuring across T1, RFC, or L3, indicates an open circuit.

Low Output. Low plate voltage, a defective tube, or partially shorted or open parts can cause a reduced output. If the plate voltage is low, check T1 primary, the RFC, and coil L3 for high resistance soldered joints and partially open windings, as indicated by a high resistance reading on an ohmmeter. Also check C3 and C4 for leakage to ground with an in-circuit capacitance checker. If the plate voltage is normal but the output is low, check the secondary of T1 for continuity with an ohmmeter (if sufficient stray capacitance coupling between primary and secondary windings exists weak signals may be heard even though the secondary is open). Rotate tuning capacitor C1 to determine if it is tuning. If it tunes the signal, check input coil L1 for high resistance or an open, since a small, stray capacitive coupling from primary L1 to secondary L2 will produce an output signal even if L1 is open, especially at the higher radio frequencies. Where a stong local signal exists, touching the input winding (or V1 grid) with the finger will increase the signal if the antenna is defective or too small (this type of indicator may not be too effective below decks or in a well-shielded compartment).

Distorted Output. Since grid-leak detection is used there will normally be noticeable distortion, particularly on strong, heavily modulated signals. A continuous tone beat-note heard with the modulation indicates the detector is oscillating and that a readjustment of the regeneration control is necessary to prevent self-oscillation. A high-pitched audio squeal which occurs when the audio gain is increased is known as fringe howl, and occurs only if the RFC and capacitor C4 are not operating properly to bypass the excess r-f plate component to ground. This could occur if the RFC were shorted or C4 were open. First substitute a good RFC, then if the squeal persists shunt C4 with a capacitor of similar value. If V1 is low in emission, there will usually be distorted signals coupled with continuous fading and a weak output. Should the values of the grid-leak resistor or capacitor change noticeably, both blocking and excessive distortion may occur.

SUPER-REGENERATIVE DETECTOR.

APPLICATION.

The super-regenerative detector is used in cheap, one or two tube receivers for the VHF and UHF regions where RF amplification does not provide much gain, and good selectivity is not required. It is is particularly popular in portable-mobile transceivers and walkie-talkies, where small size and low power consumption is important.

CHARACTERISTICS.

May be separately quenched or self-quenched.

Uses a low quenching frequency to obtain high gain.

Selectivity is much less than for any other form of detector.

Has an inherent noise reducing and limiting action.

Responds almost equally as well to strong signals as to weak signals.

Provides high sensitivity and gain in a single tube.

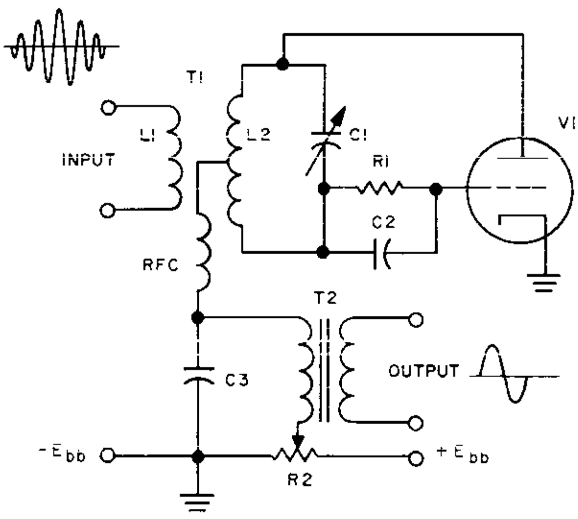
CIRCUIT ANALYSIS.

General. The super-regenerative detector uses a low frequency (from 15 kc to 100 kc) as a **quench** oscillator, generated either internally or separately, to control the regeneration applied to a grid-leak detector, and thus supply an extremely high gain from a single tube. The use of a quenching frequency effectively broadens the selectivity of the tuned input circuit to the point where it acts almost as if it were not tuned. Hence, a major disadvantage is that any strong signal within a few hundred kilocycles of the desired frequency will override it and blank out the desired signal. It also responds somewhat logarithmically to input signal strength so that an amplitude limiting and AVC action is obtained. Thus, extremely weak signals below the threshold level are not detected, and both weak and strong signals above the threshold appear at the output with nearly the same intensity. In addition, high amplitude noise interference, such as produced by spark ignition systems is minimized without the necessity of adding a limiter stage. Signals with low levels of modulation (less than 50 to 60 percent) produce only a weak or garbled output, whereas signals with high percentages of modulation produce a loud output, accompanied by high distortion. In most instances, the interruptions of the quenching oscillator produce an audio output in the form of a high-pitched hiss caused by noise, which appears between stations, and disappears as the signal is tuned in (on extremely weak signals the hiss will mask out the signal). Since the super-regenerator is oscillating, except during the quench period, it is usually necessary to use an r-f amplifier as a buffer to prevent reradiation and interference with other reception. This is also a major disadvantage when used in Military equipment, since interception by enemy direction finders is still possible even with an r-f stage if it is not perfectly neutralized.

Circuit Operation. The schematic of a typical super-regenerative detector is shown in the accompanying illustration.

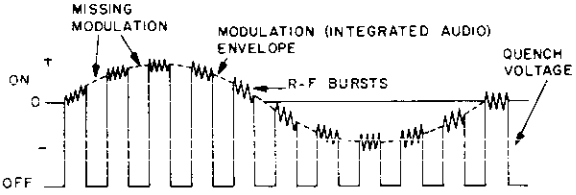
Transformer T1 is an r-f input transformer, with primary L1 (antenna winding) untuned, and secondary L2 tuned by C1. The tuned secondary tank is connected between the grid and plate of triode V1 as a conventional ultraudion oscillator. Grid-leak bias and low frequency quenching is provided by R1 and C2. The audio output is taken through r-f isolating choke RFC and applied to the primary of audio output transformer T2. The plate voltage is varied to control regeneration by potentiometer R2, and the primary of T2 is bypassed by C3 to prevent r-f feedback.

In the absence of an input signal, the grid-leak produces contact bias (see paragraph 2.2.2. in Section 2 of this Handbook for a detailed explanation of grid-leak bias action), and a steady plate current flows. When an unmodulated carrier signal is applied to the input, the grid is driven positive on the positive peaks, and grid current



Typical Self-Quenched Super-Regenerative Detector

flows from cathode to grid and back to ground via grid-leak R1, charging grid capacitor C2 negatively. This negative grid bias, in turn, causes a slight reduction in plate current, and a consequent rise in plate voltage. When the carrier is modulated by an audio signal, the grid bias varies at an audio rate in accordance with the modulation. When the grid bias increases, the plate current decreases. So far, this is conventional grid rectification and detection. In the regenerative detector this change of plate current induces a field around tank coil L2 which produces an in-phase voltage in the grid portion of the tank coil. Hence, as the plate current decreases a positive voltage is fed back to the grid, and causes still smaller plate current to flow. In the conventional regenerator, this feedback is limited to an amplitude which is just below the point where continuous oscillations are produced. Consequently, even though this type of regenerative feedback results in a gain, it is not as large a gain as could be obtained if the circuit were prevented from oscillating until a larger feedback amplitude was obtained. Such action is accomplished in the super-regenerator by developing a low frequency oscillation in the grid circuit known as the **quench** voltage. In the self-quenched circuit described above, the quench voltage is obtained by using a large grid-leak resistance and capacitance to provide a long time-constant. Because of the large time-constant very little voltage can leak off capacitor C2 during the negative portions of each r-f input cycle, so a cumulative build-up in negative bias voltage develops as the input signal is applied, until the bias is sufficiently large to drive the grid to plate current cut off and beyond. When C2 is charged to this cut-off voltage, grid and plate current flow ceases while capacitor C2 discharges through the long time-constant grid-leak. During this discharge period the detector circuit is inoperative.

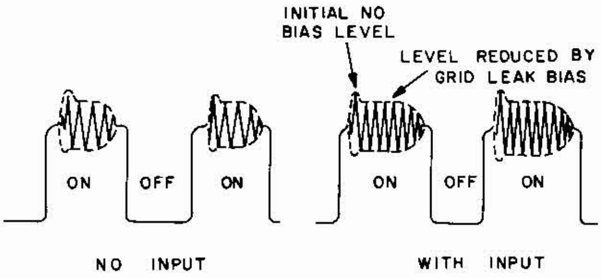


Output Waveforms

Thus, the action consists of an ON period followed by an OFF period. During the ON period the audio output is developed, while during the OFF period no output is developed, although this action results in a signal consisting of chopped up pieces of the original modulation, the modulation frequencies are very low in comparison to the operating frequencies (cycles compared with megacycles), so that only a small portion of the modulation is lost during any one OFF cycle, as shown in the exaggerated waveform in the accompanying illustration. It is evident that the overall waveform shape is retained, but a ripple component at the **quench** frequency is introduced. This ripple of quench voltage is filtered out by capacitor C3 which bypasses it to ground. Thus, only the audio frequencies pass through the primary of output transformer T2, and induce an output voltage in the secondary. Since the output waveform is chopped up and is not exactly the same as the input waveform, distortion is produced (this is in addition to any normal distortion caused by grid-leak detection). Thus, it is evident that the output of the super-regenerator must always contain more distortion than in the ordinary regenerative detector. However, this inherent distortion is somewhat nullified by the large gain possible through super-regeneration. The gain is of the order of one hundred times or more than that of the ordinary regenerative detector.

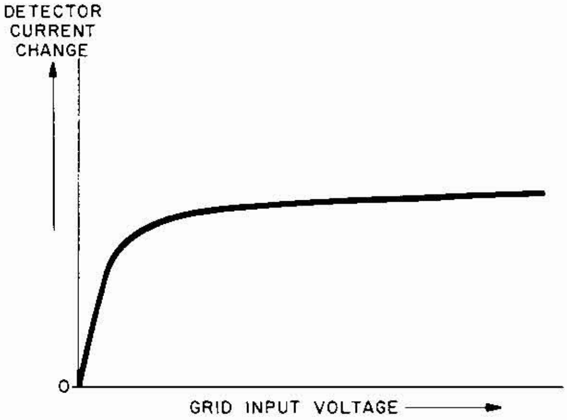
When a separate quench oscillator is used, it is connected in series with either the grid or plate circuit, and the grid-leak values are changed to provide additional gain, since the tube does not have to develop its own quench voltage. However, for the sake of economy and simplicity the single tube self-quenching circuit is usually used. Since the super-regenerator is unique in its action, operating at very high frequencies, at low frequencies and at audio frequencies practically simultaneously, it is necessary to examine the operating sequence more closely to completely understand operation. First consider the quench voltage, regardless of whether or not it is externally supplied, or is generated internally, it primarily serves to gate the grid circuit. During the positive half cycle it permits operation, and during the negative half cycle it reduces operation to almost zero. At the same time, this quench voltage control permits the circuit to oscillate at a very high frequency (the tuned tank frequency) during the conducting half cycles and prevents these oscillations during the non-conducting half cycle. In the self-quencher, the off period allows time for the grid-leak network to discharge, so that a train of r-f pulses may be generated during each on-period. Grid-leak bias is developed by rectifying the positive half cycles of this train of r-f pulses each time they cause a flow of grid current. Thus, the grid-capacitor is charged negatively at an r-f rate, and since the discharge time constant is longer than the charge time constant (the conduction of grid current presents a low resistance charge path), the charge cannot leak off the grid between r-f pulses and, therefore, builds up and eventually reaches cutoff bias. This cut-off bias point in the self-quencher determines the start of the off-period, and the tube is held inoperative during this period until grid capacitor C2 discharges through the large grid-leak resistance.

It is important to note that during the on-period r-f oscillations occur at the tank frequency, regardless of whether or not an input signal is applied. This action occurs because of the large feedback from plate to grid. Thus, in the absence of an input signal, the tank circuit is started oscillating by random current flow in the tube due to noise, which through feedback quickly builds up to a high amplitude and develops a d-c bias across the grid-leak. This grid bias, in turn, reduces the amplitude of the r-f oscillation slightly and maintains it at this value for the remainder of the on-period. When an input signal is applied, the amplitude of the r-f oscillation does not change, but instead, the oscillation starts sooner (it has the signal to help it), and the duration of oscillation for the on-period lasts for a slightly longer time than without an input signal, as shown in the accompanying illustration.



Typical Grid Waveforms

Since a negative grid bias is produced by the rectification of this r-f oscillation, the plate current is decreased slightly when a signal appears. Because the high-frequency oscillations exist even when no input signal is applied, the output response is limited to the average change of plate current which can occur from the start of the on-period to the beginning of quiescent oscillation. The result is that if the incoming signal is strong enough to mask out the hiss noise, there is little difference between weak and strong signals, since the detector output current varies logarithmically as shown in the accompanying graph. As a result, large amplitude noise variations caused by ignition interference, static, and similar impulse sources are also reduced in intensity. What would be a loud crash in the conventional detector appears as a rather small noise in the super-regenerator, and can be more easily tolerated without distraction from the desired signals. In a similar manner, small variations in amplitude caused by low percentages of modulation produce weak and unreadable signals, while the large variations in 100 percent modulated signals are sufficient to produce an appreciable output.



Detector Response Characteristics

The amount of feedback and plate voltage is controlled by potentiometer R2. For larger feedback and greater amplification the plate voltage is increased, while for less amplification and feedback it is reduced. For each setting of the control the r-f oscillations will reach a maximum value limited by the saturation voltage for this operating condition, and fixed by the developed grid-leak bias.

FAILURE ANALYSIS.

No Output. A defective tube, loss of plate voltage, or open or shorted input or output circuits will cause a loss of output. Use a high resistance voltmeter to measure the supply and plate voltages and eliminate the possibility of an inoperative power supply or blown fuse. Since the plate voltage will depend on the position of plate potentiometer R2, it is good practice to vary R2 over its range to determine whether or not an output can be obtained. If R2 is open at some point between the slider and ground, the plate voltage will be higher than normal, if open on the slider side there will be no voltage (provided T2 primary and the RFC and upper half of coil L2 have continuity). No voltage for any setting of R2 indicates that T2 primary, the RFC, or coil L2 is open. Check for continuity with an ohmmeter or measure voltage to ground. If there appears to be sufficient plate voltage present, check the values of the grid-leak resistor and capacitor using a voltohmmeter and an in-circuit capacitance checker. Check L2 for possibility of a defective tuning condenser C1 which will usually create a noise when rotated, if shorted. If still no output exists it is possible that T2 secondary is open or shorted. Place a pair of headphones across the primary winding or couple a speaker to the primary by a coupling capacitor. Any output indicates the secondary of T2 is at fault. Note also, that if C3 is shorted, plate voltage will appear about normal but no output will occur because of the shorted load winding. However, this condition usually is determined at the time that continuity checks are made of L2, T2, and R2. It is important to note that lack of an input signal will not result in a no-output condition, since the circuit will still operate, and produce a hiss.

Low Output. A low or reduced output can be caused by a weak input signal, a partially shorted input circuit, an improperly modulated signal, a defective tube, low plate voltage or a defective output transformer, T2. Signals below the threshold level for detection and those signals with low percentages of modulation (say 50% or less) will not be detected, this is normal operation. If, however, the signal is weak because of an open or a partially shorted input transformer, it can be found by checking the coils with an ohmmeter. Likewise, with a low plate voltage indicated on the voltmeter, both feedback and output will be low. If the trouble is not in the plate supply, most likely bypass capacitor C3 is at fault and leaky, check it with an in-circuit capacitance checker. Check the values of the grid-leak and grid capacitor, using an ohmmeter and capacitance checker. Continued low output indicates L1 is either open or partially shorted.

Distorted Output. The output will normally be somewhat distorted, particularly on voice peaks, however, the signal should be intelligible. If distortion is such that the voice is badly garbled, improper biasing is usually the cause. Check the grid-leak resistor with an ohmmeter and the grid capacitance with an in-circuit capacitance checker. To eliminate the following audio stages from suspicion, place a pair of headphones across the primary of T1. If the distortion disappears, the distortion is caused by the audio amplifier stages after the detector.

PRODUCT DETECTOR.

APPLICATION.

The product detector is universally used as a detector for heterodyning and demodulating single-sideband transmissions in modern communications type receivers.

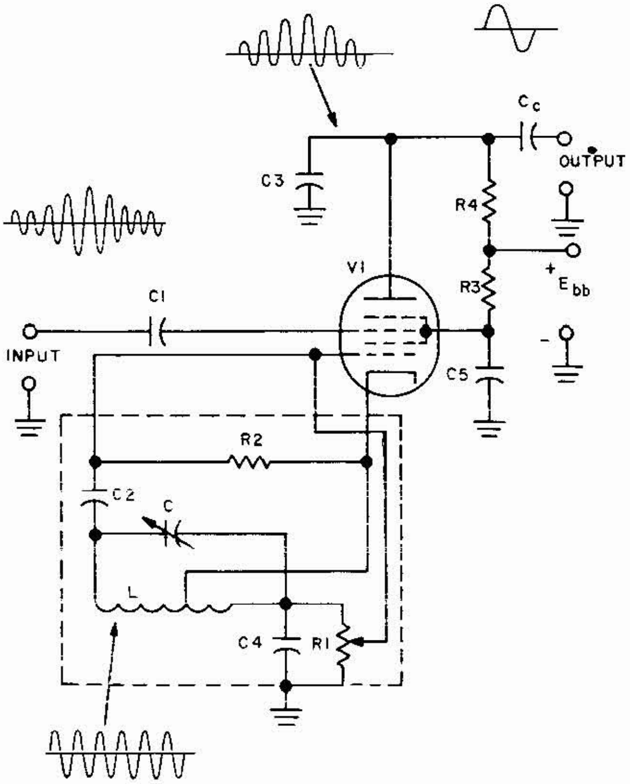
CHARACTERISTICS.

Is usually self-biased.
Operates as a combined heterodyne mixer and detector.
Has excellent selectivity.
Offers a slight improvement in gain.
Is more linear than the diode detector.

CIRCUIT ANALYSIS.

General. The product detector can be considered a form of heterodyne mixer with an audio output instead of the usual r-f output. The purpose of this detector is to mix locally generated low frequency carrier oscillations with the incoming r-f sideband signals to generate beat notes in the audio frequency range. For single-sideband the beat varies in both pitch and amplitude, producing the detected audio. The product detector may also be used for code reception using the beat frequency oscillator (BFO) to produce a single-tone audio beat. The use of mixing to develop the beat signal reduces the tendency to grid-block, when strong signals from a local oscillator are applied to the grid simultaneously with a weak input signal. Ordinary double-sideband AM signals can also be detected with the product detector, provided the BFO is tuned to zero-beat. When used with a strong BFO input and a weak signal input **exalted carrier** reception is simulated. With a strong (exalted) local carrier inserted, phase cancellation of the sideband frequencies during fading is minimized, as the local BFO substitutes for and fills in the carrier. Although during extreme fading this represents an improvement in ordinary AM reception it has the disadvantage that it is usually necessary to continually adjust the local BFO fine tuning control to keep the local oscillator at zero beat. Otherwise, the steady CW beat note produced by the two carriers (input signal and BFO) beating together garbles the signal.

Circuit Operation. While there are a number of product detector circuits, one of the most prevalent in use is the typical pentagrid converter illustrated in the accompanying schematic.



Pentagrid Product Detector

A single pentagrid tube is connected as a heterodyne converter, with the triode portion connected as a simple series-fed Hartley oscillator and operating as the beat frequency oscillator (BFO) to supply a carrier signal. The r-f input with its carrier missing is injected in mixer grid no. 2, which is shielded by the screen construction around it, and the audio output is taken from the plate of the pentode section. Tuned tank L and C is connected in a Hartley circuit with V1, and the lower end of the tank is bypassed to ground by C4, while C2 is the grid capacitor with R2 acting as a shunt grid-leak to supply the bias for the oscillator. The screen receives its supply voltage from dropping resistor R3 from the plate supply. Capacitor C5 bypasses the screen to ground and effectively connects it to the lower end of the tank thereby forming the triode oscillator portion of the circuit. The BFO signal is electron-coupled to the pentode section by electron flow from cathode to screen and plate. The input signal is capacitively coupled through C1 to the mixer grid, and R1 is the d-c return resistor supplying grid bias for the mixer grid. This resistor is made adjustable to set operation at the proper point for complete mixing and reduction of intermodulation distortion from input signals. The BFO signal is thus mixed with the r-f input signal and is heterodyned to produce audio beat signals, which vary in accordance with the modulation of the r-f input signal. Since the plate of V1 is bypassed to ground for rf by C3, only the audio frequency current variations appear in the plate circuit. These audio current variations develop an output voltage in passing through load resistor R4, and thus develop the audio output which is coupled through Cc to the following audio amplifier stage.

With no signal applied, V1 rests in its quiescent state with the triode section oscillating at the i-f (carrier) frequency, and with no input signal there is no output developed. Operation of the BFO is by feedback through tank coil L between the grid and screen (plate) to supply a continuous feedback from screen to grid and produce continuous oscillations at the frequency determined by the tuning of tank capacitor, C. Since C4 has a low r-f reactance to ground, and C5 which grounds the screen also has a low reactance to r-f, the screen is effectively connected to the lower end of the tank. During the oscillation period, grid-leak network C2 and R2 alternately charge and discharge. During the conduction period on positive half-cycles the grid capacitor is negatively charged, and develops a Class C bias on the grid of V1 through grid current flow from the cathode through R2 to ground. On the negative half of the oscillation, grid capacitor C2 discharges to ground through grid-leak R2, so that the bias is reduced to a value which will permit conduction on the next positive r-f excursion. Meanwhile r-f is supplied to the circuit by the tank during the non-conducting period thus producing continuous oscillation at the tank frequency. (See Chapter 7 in this Handbook for a complete discussion of Hartley oscillator operation.)

When an input signal is applied to the mixer grid of V1 through coupling capacitor C1 the input signal appears on the mixer grid. During the positive half-cycle of the input signal plate current flow is increased, and during the negative half-cycle it is decreased. As the electron flow from cathode to plate occurs, the electrons pass through the screen, and the BFO oscillations are heterodyned with the input signal to produce an audio beat note in the plate circuit. A portion of these electrons also flows through the mixer grid and return resistor R1 to provide bias for the mixer grid. Since the pentode section of V1 is connected as an amplifier, this bias fixes the operating point of the number 2 (mixer) grid at the position for maximum undistorted operation (usually in the Class A region). However, when undesired signals close to the tank frequency are strong, the strong signals tend to over-ride the weaker signal and cause response to both signals regardless of the tuning of tank capacitor C. Therefore, if R1 is adjusted to produce clear undistorted reception on the strongest signal, weak signals will not be pulled in frequency and the strong signal will not cause saturation and produce intermodulation distortion. The change in plate current caused by the input signal alternately increasing and decreasing plate current flow through load resistor R4 develops an output voltage across R4. Since C3 bypasses any r-f signal component and any BFO signal component to ground, only the audio beat note will be effective in producing output voltage across the load. Thus, the modulation amplitude variations of the r-f sideband signal, in effect, modulate the oscillating electron stream and produce the output. If the BFO stopped oscillating there would be no output, since there would be no beat note developed between the low frequency i-f signal and the high frequency r-f signal to produce audio variations in the electron stream between cathode and plate.

Although R1 is shown as variable in the schematic, some circuits use a fixed value of resistance which, together with screen resistor R3, is selected to provide optimum operation. In other circuit variations a separate BFO is employed and pentagrid tube V1 is connected as a simple mixer with both control grids biased to operate as amplifiers, so that only a simple mixing function is accomplished. The combined circuit discussed above represents a saving in tubes and economy of circuit components, hence its more prevalent use. Regardless of circuitry, the two signals are always heterodyned to produce a beat output which is in the audio range and thereby demodulates the sideband signal.

FAILURE ANALYSIS.

No Output. Loss of plate or screen voltage, lack of oscillation in the triode section of V1, an open or shorted input or output circuit, as well as a defective tube can produce a loss of output. Check the plate and screen voltages with a high resistance voltmeter, to make certain that a faulty supply or blown fuse is not at fault. If plate voltage is lacking, either R4 is open or C3 is shorted. Likewise, if no screen voltage is present, either R3 is open or C5 is shorted. Measure the resistors with an ohmmeter and check the resistance to ground across the capacitors, or use an in-circuit capacitance checker to check for shorts, leakage, and proper value. Determine if the BFO is oscillating, and if there is an input signal. Use on oscilloscope and an r-f probe connected between the no. 1 grid and ground to check that oscillation occurs. An alternative procedure is to use a high-resistance voltmeter, and place a 1-megohm resistor in series with the probe, and measure the voltage across grid-leak R2. If oscillating, usually a 10-volt or better indication is obtained and, in addition, when grid-leak is shorted with your fingers the oscillation will cease as indicated by a drop in voltage to about 1 volt or less. If oscillations do not occur check coil L for continuity, and tuning capacitor C for a short or leakage (use an in circuit capacitance checker). Check grid-leak R2 for proper resistance value and C2 for leakage and proper value. If still no oscillation, check C4 for an open circuit (if shorted it would still oscillate). With the BFO operating it is still possible that R1 is shorted and is bypassing the input to ground through C4, or for C1 or Cc to be open, check each capacitor with a capacity meter. Usually it is only when the BFO is not oscillating that a true no-output condition occurs, and the set sounds dead. If the BFO is working and only the input signal is missing, there will probably be some hum or occasional noise noticed, except of course if output coupling capacitor Cc is open.

Low Output. Low plate or screen voltage, a defective tube or a change in some parts values can produce a weak output. Measure the plate, screen, and supply voltages with a high resistance voltmeter. Low voltage indicates that C5 or C3 is leaky or that V1 is shorted and drawing larger than normal current. Check the capacitors with a capacity checker. With normal plate and screen voltages check the voltages on both grids with an oscilloscope and an r-f probe. On some detectors it is still possible to get a weak output even though the BFO is not operating. Also check the adjustment of R1 since the signal may be biased off too far and provide a weak output. Normally both the oscillator and incoming signal should be about the same level, but in no case should the BFO voltage be greater than the r-f sideband voltage. Check also the setting of the receiver RF GAIN control since it may be set too low.

Distorted Output. If the input signal is too strong, the detector can be overloaded and cause distortion, make certain the receiver R-F GAIN or AVC system is holding the input signal to the proper level. Also check the adjustment of R1, since if it is set up for weak signal reception the detector will overload and distort on strong signals. When it is adjusted so that the strongest signal is clear, the weaker signals will still be readable. It is also necessary that the receiver be tuned to the proper sideband in single-sideband reception otherwise, the modulation may be present but inverted and be garbled and unintelligible. In this case on a receiver equipped with upper and lower sideband switching, placing the switch to the opposite sideband position will eliminate the distortion. Since it is necessary to keep the inserted carrier within 10 to 12 cycles of the proper frequency, slight frequency instability in the receiver local oscillator may constantly keep the station frequency drifting. This will show up as distortion which disappears as the BFO tuning is slightly readjusted. In the last case the trouble exists in previous receiver stages, not the detector. It is, however, advisable to check the BFO for drift first using a stable primary standard, if available.

FM (OR PM) DETECTORS.

The process of detection (demodulation) removes the modulation (transmitted intelligence) from a received r-f signal and transforms it back to its original form so that it may be used for communications or other purposes. While the AM detectors explained previously in this section of the Handbook are used to demodulate an amplitude-modulated (AM) r-f signal, the FM detectors explained in the following paragraphs are used to demodulate a frequency-modulated (FM) r-f signal. Because of the similarity between a frequency-modulated (FM) signal and a phase-modulated (PM) signal, FM detectors may also be used (with minor circuit changes or adjustments) to demodulate a phase-modulated signal.

Although the circuits used in FM transmission and reception are more complex than those used in AM, FM has a number of advantages which far outweigh this disadvantage. An important advantage of FM over AM is the reduction of distortion due to natural and man-made noise. Most noise occurs in the form of amplitude variations in the r-f signal, and in AM, the intelligence is also carried by the amplitude variations. The AM receiver can not distinguish between the amplitude variations caused by the intelligence and those caused by noise, and consequently reproduces both the noise and the intelligence. In FM however, the intelligence is carried by frequency variations in the r-f signal and the FM receiver is designed so that it does not respond to amplitude variations. Consequently, the noise is not reproduced in the FM receiver output. Another important advantage of FM over AM is the possibility of wide-band transmission. Because of the higher carrier frequencies normally used in frequency modulation, it is possible to use a much wider band of modulating frequencies. This allows FM to be used for such applications as high fidelity transmission (such as in the FM broadcast band) and for multichannel communications (such as in commercial communications). Moreover, FM transmitters can also be designed to produce a narrow-band output signal (comparable to AM bandwidth) when it is desired to operate many FM transmitters within a small portion of the frequency spectrum.

The FM signal contains the transmitted intelligence in the form of instantaneous frequency variations to a constant amplitude r-f signal. Therefore, to demodulate the received FM signal without distortion, the FM detector must convert these frequency variations into voltage variations which are identical to the variations in the original modulating voltage. Any variations in the amplitude of the received FM signal are the result of unwanted noise or fading, and will result in distortion of the output signal if passed through the FM detector. Therefore, the FM detector must respond to input frequency variations, but not to input amplitude variations.

Three types of FM detectors are presently in common use: discriminators, ratio detectors, and gated-beam detectors. Discriminator circuits exhibit excellent response to frequency variations, but also respond to amplitude variations, and therefore, must be preceded by limiters to ensure that the discriminator input is of constant amplitude. Ratio and gated-beam detector circuits exhibit slightly poorer response to frequency variations than discriminator circuits, but when properly adjusted, do not respond to amplitude variations. Therefore, ratio or gated-beam detectors are used when economy and simplicity are desired, and some distortion can be tolerated. Discriminators are used when an extremely distortionless signal is desired, or precise control of frequency (AFC) is needed.

FOSTER-SEELEY DISCRIMINATOR.

APPLICATION.

The Foster-Seeley discriminator is used as the detector in high quality FM receivers to demodulate the received r-f signal, and in automatic frequency control (AFC) circuits to transform frequency changes into d-c control voltage changes.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a double-tuned transformer and two diodes.

Has very low inherent distortion.

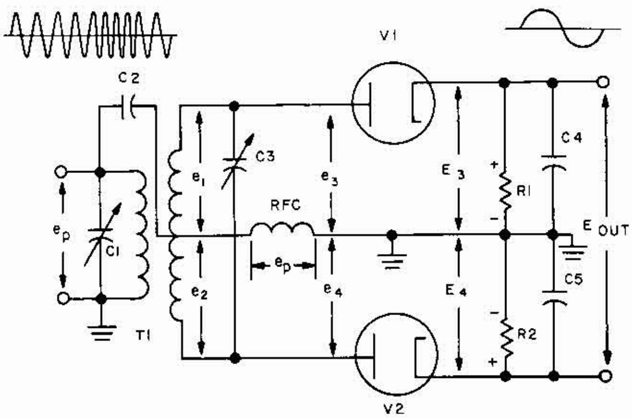
Must be preceded by a limiter since the output is affected by input amplitude variations.

CIRCUIT ANALYSIS.

General. The Foster-Seeley discriminator (also known as the phase-shift discriminator) uses a double-tuned transformer connected in such a way that the instantaneous frequency variations of the input FM signal are converted into instantaneous amplitude variations. The amplitude variations are then rectified and filtered in a manner similar to that employed in AM detectors to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output voltage is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, become more positive), and when the input frequency drops below the center frequency, the output voltage increases in the other direction (for example, becomes more negative). The specific polarity of output voltage obtained for an increase or a decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

The output of the Foster-Seeley discriminator is dependent not only on the input frequency but also, to a certain extent, on the input amplitude. Since variations in the amplitude of the FM signal are due to unwanted noise or fading, they must be prevented from reaching the discriminator. Therefore, the discriminator is normally preceded by a limiter stage. The limiter produces an output of constant amplitude regardless of variations in the input amplitude, and thus, effectively removes the noise from the received FM signal. (Refer to section 15 of this Handbook for a complete explanation of limiter circuits.)

Circuit Operation. The accompanying circuit schematic illustrates a typical Foster-Seeley discriminator.

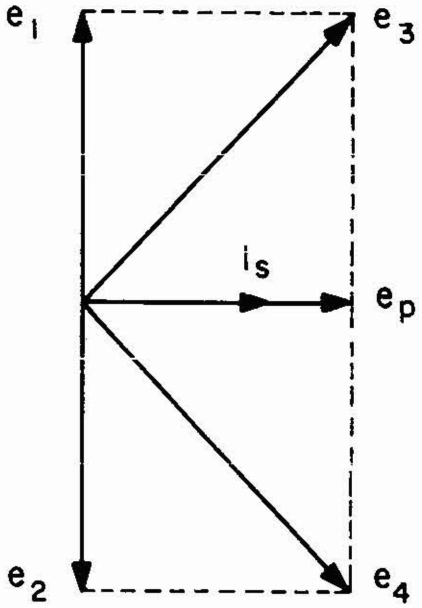


Foster-Seeley Discriminator

The input tank circuit, made up of capacitor C1 and the primary winding of transformer T1, is tuned to the center frequency (f_R) of the received r-f signal. Capacitor C3 and the secondary winding of transformer T1 also form a tank circuit tuned to the center frequency. Capacitor C2 couples the input signal to the center tap on the balanced secondary winding of transformer T1, which is returned to ground through radio-frequency choke RFC to form a dc return path for the diodes. Diodes V1 and V2 rectify the signal from the secondary tank circuit and develop opposing voltage drops across load resistors R1 and R2, respectively. Capacitors C4 and C5 are r-f filter capacitors which remove any remaining r-f signal from the output. The output is taken from across the series combination of the two load resistors (from the cathode of V1 to the cathode of V2).

The operation of the Foster-Seeley discriminator can be best explained with vector diagrams which show the various phase relationships between the voltages and currents in the circuit. The accompanying vector diagram illustrates the circuit phase relationships when the input frequency (f) is equal to the center frequency (f_R).

The input voltage applied to the primary tank circuit is shown as vector e_p on the diagram. Since coupling capacitor C2 has negligible reactance at the input frequency, and r-f choke RFC is effectively connected in parallel with the primary tank circuit, voltage e_p also appears across the choke. When voltage e_p is applied to the primary winding of transformer T1, a voltage is induced into the secondary winding which causes current to flow around the secondary tank circuit. When the input fre-

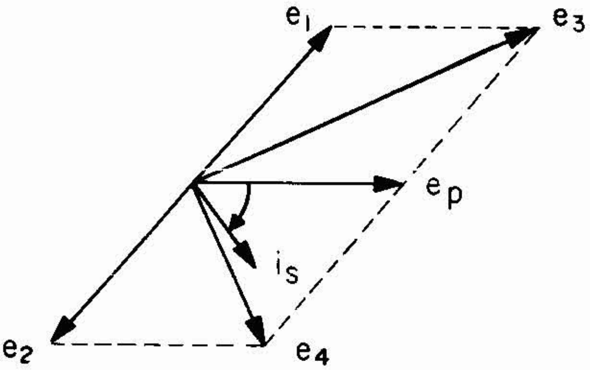


Vector Diagram at Resonance

quency is equal to the center frequency, the tank is at resonance and acts resistive. Therefore, tank current is is in phase with primary voltage e_p, as shown in the vector diagram. The current flowing in the tank causes voltage drops to be produced across each half of the balanced secondary winding of transformer T1, which are of equal magnitude and opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90° out of phase with the current through it. Because of the grounded center tap arrangement, the voltages to ground at each end of the secondary winding are 180° out of phase, and are shown as e_1 and e_2 on the vector diagram.

The voltage applied to the plate of V1 consists of the vector sum of voltages e_p and e_1, shown as e_3 on the diagram. Likewise, the voltage applied to the plate of V2 consists of the vector sum of voltages e_p and e_2, shown as e_4 on the diagram. Since at resonance there is no phase shift, voltages e_3 and e_4 are equal as shown by the same length vectors. Equal plate voltages on diodes V1 and V2 produce equal plate currents, and with identical load resistors produce equal and opposite voltages (E_3 and E_4) across R1 and R2, respectively. Thus capacitors C4 and C5 are charged to equal voltages, and, since these voltages are of opposite polarity, the output voltage at resonance is zero. Since the opposite ends of the secondary winding are out of phase, only one diode conducts at a time, and conduction occurs as a series of d-c pulses occuring at the center radio frequency. Although the output of the diode is a direct current it contains a ripple component at the center frequency. This r-f component is filtered out by capacitors C4 and C5 since they offer a low reactance path to ground (action is similar to a power supply filter capacitor except for the frequency).

When an input frequency higher than the center frequency is applied to the discriminator circuit a phase shift occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.

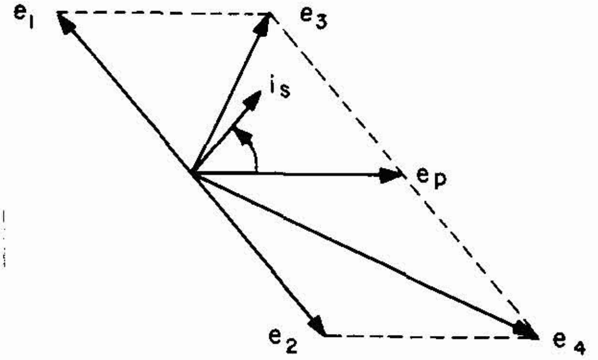


Vector Diagram For Higher Input Frequency

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance the tank is predominately inductive and acts like an inductor. Hence, secondary current is **lags** the primary tank voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them (i_s). Thus the change to a lagging secondary current rotates the vector in a clockwise direction. Referring to the vector diagram it is seen that e_1 is brought nearer in phase with e_p, while e_2 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_1 is larger than that of e_p and e_2. Therefore, above the center frequency, diode V1 conducts heavier than diode V2. Consequently, voltage E_3 developed across R1 is greater than E_4 developed across R2, and the voltage on capacitor C4 is likewise greater than on C5. The combined output voltage is therefore, a positive voltage.

When an input frequency lower than the center frequency is applied to the discriminator circuit a phase shift also occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.

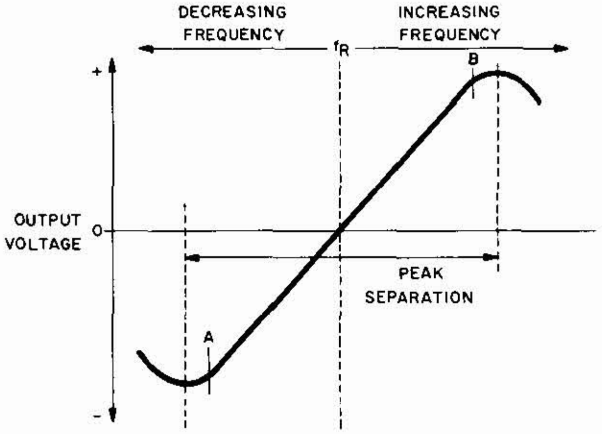
When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the coil decreases. Therefore, below resonance the tank is predominately capacitive and acts like a capacitor. Hence, secondary current is **leads** the primary tank voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counter-



Vector Diagram for Lower Input Frequency

clockwise direction. From the vector diagram it is seen that e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is larger than that of e_p and e_1. Therefore, below the center frequency, diode V2 conducts heavier than diode V1. Consequently, voltage drop E4 across R2 is greater than E3 across R1, and the voltage on capacitor C5 is, likewise, greater than on C4; thus the combined output voltage is a negative voltage.

When the input voltage is varied from a lower frequency through the resonance point of the discriminator and is then raised higher in frequency, the typical discriminator response curve shown in the accompanying illustration is obtained. The usable portion of the typical "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.



Discriminator Response Curve

When weak A-M signals which are too small in amplitude to reach the limiting level pass through the limiter stage, the amplitude variations cause primary voltage e_p to fluctuate with the modulation and induce a similar secondary voltage in T1. Since the diodes are connected as half-wave rectifiers, these small A-M signals are detected as in a diode and appear in the output. This unwanted AM interference is cancelled out in the ratio detector (to be discussed later in this section of the Handbook) and is the main disadvantage of the Foster-Seely circuit in comparison with other FM detectors.

FAILURE ANALYSIS.

No Output. A defect in the primary winding of transformer T1, in the RFC, or in capacitors C1, C2 or C3 may cause a no-output condition. Use an ohmmeter to check the primary winding of transformer T1 and the RFC for continuity; also check both for leakage or shorts to ground. If these checks fail to locate the trouble, use an in-circuit capacitance checker to check capacitors C1, C2 and C3. Note that the failure of either diode will cause distortion rather than a no-output condition; if both diodes fail, however, there will be no output.

Low or Distorted Output. A defect in nearly any component in the discriminator circuit may cause the output to be either low to distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to isolate the trouble. First, use the oscilloscope to observe the input to the discriminator to be certain that the preceding (limiter) stage is not at fault. If the input signal does not change in amplitude as the input frequency varies, the trouble is most likely in the discriminator circuit. To determine if the discriminator is at fault, ground the grid of the preceding limiter stage, connect the r-f sweep generator to the discriminator input, and connect the oscilloscope to the discriminator output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the circuit will cause either the entire curve, or a portion of it to be distorted or flattened.

If the entire response curve is distorted, the trouble may be caused by either improper alignment or by a defect in transformer T1. First check to be certain that both the primary and secondary tank circuits are properly tuned to the center frequency. If the discriminator is properly aligned, the trouble is most probably caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, capacitor C4, Resistor R1, or transformer T1. Use a capacitor checker to check capacitor C4 for value and leakage, and use an ohmmeter to check resistor R1 for a change of value. If these checks fail to locate the trouble, transformer T1 is probably defective.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode V2, capacitor C5, resistor R2, or transformer T1. Check capacitor C5 for value and leakage, and use an ohmmeter to check resistor R2 for a change of value. If these checks fail to locate the trouble, transformer T1 is probably defective.

TRAVIS DISCRIMINATOR.

APPLICATION.

The Travis discriminator is used as a detector in FM receivers and for automatic frequency control (AFC) circuits.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a triple-tuned transformer.

Has low inherent distortion.

Circuit is difficult to align.

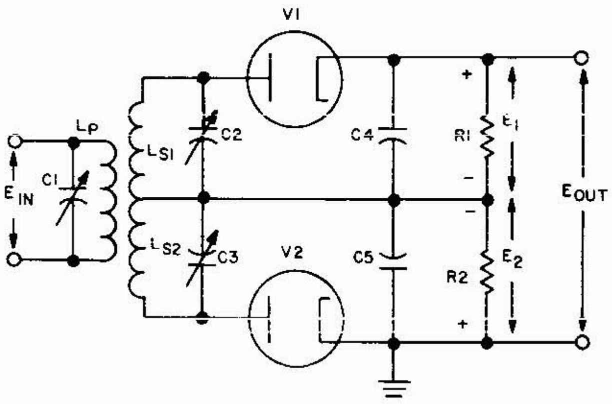
Must be preceded by a limiter since the output is ffected by input amplitude variations.

IRCUIT ANALYSIS.

General. The Travis discriminator uses two secondary tank circuits, with each tank turned so slightly different resonant frequencies to convert the FM input signal frequency variations into amplitude variations. The r-f amplitude variations are then rectified and filtered to produce a d-c output voltage which varies in accordance with the variations of the input frequency. When the input frequency is equal to the **center frequency** (unmodulated carrier frequency), the discriminator output voltage is zero. As the input frequency rises above the center frequency, the output voltage increases in one direction, for example, increases in the positive direction, and as the input frequency drops below the center frequency, the output voltage increases in the other direction (for example, increases in the negative direction). Thus, the instantaneous discriminator output voltage is dependent on the instantaneous input frequency deviation (shift) from the center frequency. The specific polarity of output voltage obtained for an increase or a decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

The Travis discriminator output is dependent not only on variations in the input frequency, but also to a certain extent, on variations in the input amplitude. Since variations in the amplitude of the FM signal are caused by unwanted noise or fading, they must be prevented from reaching the discriminator or the circuit will reproduce the unwanted noise as well as the desired intelligence. To prevent this, the discriminator is usually preceded by a limiter such as those explained in section 15 of this Handbook. The limiter produces an r-f output signal of constant amplitude regardless of input amplitude variations, and thus effectively eliminates any AM noise from the FM signal.

Circuit Operation. The accompanying schematic diagram illustrates a simple Travis discriminator.



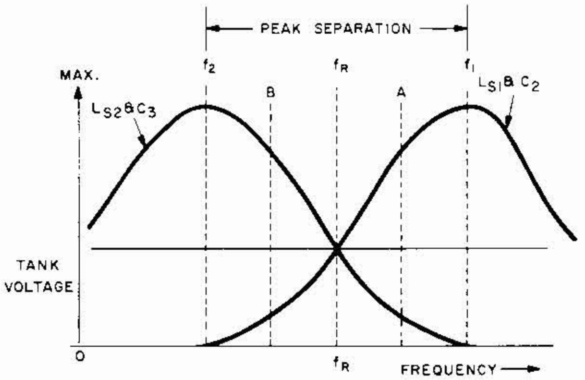
Travis Discriminator

Capacitor C1 and the primary winding (Lp) of transformer T1 form a resonant tank circuit which is tuned to the center frequency. The upper half of the secondary winding (Ls_1) of transformer T1 and capacitor C2 form a resonant tank circuit which is tuned above the center frequency by an amount slightly greater than the maximum input frequency deviation. The lower half of the secondary winding (Ls_2) of transformer T1 and capacitor C3 form a resonant tank circuit which is tuned below the center frequency by the same amount that the upper tank circuit is tuned above the center frequency. The r-f signals from the two tank circuits are rectified by diodes V1 and V2, and a d-c voltage is developed across load resistors R1 and R2. Capacitors C4 and C5 are filter capacitors which remove the r-f ripple component from the detected signals developed across resistors R1 and R2, and holds these voltages relatively constant. The total output voltage is taken across the **series** combination of resistors R1 and R2 (that is, from the cathode of diode V1 to ground).

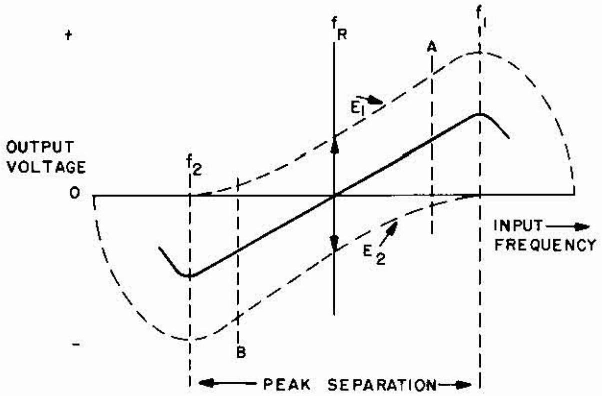
When an input signal with a frequency equal to the center frequency is applied to the primary tank circuit (LP and C1), a voltage is induced into the secondary winding of transformer T1 which develops r-f voltages of equal amplitudes in secondary tank circuits Ls_1 and C2, and Ls_2 and C3, as shown in the accompanying illustration of tank circuit response.

Since the two secondary tank circuits are tuned to resonant frequencies (f1 and f2) equidistant from the center frequency, both tank circuits are tuned off-resonance by equal amounts and equal r-f voltages are produced. On the positive half of the input cycle the anode of V1 is positive and current flows through resistor R1, developing a d-c output voltage with polarity as marked on the schematic. Simultaneously, the anode of diode V2 is also positive and the d-c output voltage produced across R2 by current flow is equal and opposite that of R1. Therefore, the total output voltage taken across the two resistors in series (from cathode of V1 to ground) is zero. This condition is shown at the center frequency (fr) on the accompanying discriminator response curve illustration.

Voltage E_1 is developed across load resistor R1 (with respect to ground), and voltage E_2 is developed across load resistor R2. As shown in the illustration, voltage E_1 is



Tank Circuit Response Curve



Discriminator Response Curve

equal in magnitude and opposite in polarity to voltage E1 at the center frequency. Thus, at the center frequency, the output voltage (E_{out}) is zero.

When an input frequency higher than the center frequency is applied to the primary tank circuit of the discriminator, a voltage is induced into the secondary winding of transformer T1 which is nearer to the resonant frequency of the upper tank, and therefore, a larger voltage is applied to V1 anode. Consequently, V1 conducts heavier and the larger current flow through R1 produces a larger d-c output voltage, E1, charging C4 to a higher value. In a similar manner, the voltage developed across the lower tank circuit as shown by response curve B is further away from the lower-tank resonant frequency and the positive anode voltage on V2 is lower than that of V1. Hence, the small current flow through resistor R2 develops a smaller output voltage, E2, and C5 is charged to a lower value. The net output voltage, E_{out}, across the two resistors is positive when the input frequency is higher than the center frequency, since E1 is always positive and greater than E2. When a still higher frequency is applied the primary tank, the same action occurs except that E1 becomes much larger and E2 becomes much smaller. Likewise, when the input frequency is lower and nearer the lower tank frequency the opposite condition prevails. That is E1 becomes smaller, while E2 becomes larger. Consequently, the net output voltage, E_{out}, across the two resistors is negative when the input frequency is lower than the center frequency, since E2 is always negative and larger than E1.

Thus, the output voltage of the Travis discriminator varies in magnitude and polarity as the input frequency varies above and below the center frequency. As mentioned previously, the discriminator output is dependent not only on the input frequency, but also to a certain extent on the input amplitude. If the input signal amplitude drops below the limiting level of the preceding limiter stage, the signal and any variations in the signal amplitude will appear at the discriminator. Since the discriminator diodes are essentially half-wave rectifiers, they will detect the amplitude variations in much the same manner as an AM detector, producing noise in the discriminator output. Thus, for proper operation, the input signal to the limiter must always remain above the limiting level of the stage. Another disadvantage of the Travis discriminator is that it is difficult to align because each of the three tank circuits must be tuned to a slightly different resonant frequency. Because it is sensitive to amplitude variations, and because it is difficult to align, the Travis discriminator is not often used in modern FM circuits.

FAILURE ANALYSIS.

No Output. Loss of input signal, the failure of capacitor C1, transformer T1, or both diodes can cause a no-output condition. (Note that if only one diode fails, the output will be distorted rather than completely absent.) If the diodes are not at fault, either transformer T1 is defective or capacitor C1 is shorted.

Low or Distorted Output. The failure of nearly any component in the Travis discriminator may cause the output to be low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to locate the specific portion of the circuit that is faulty. First, use the oscilloscope to observe the input to the discriminator to be certain that the trouble is not due to distorted input signal. If the correct discriminator input signal is present, ground the grid of the limiter stage preceding the discriminator, connect the r-f sweep generator to the discriminator input, and connect the oscilloscope to the discriminator output. With the sweep generator adjusted to produce an output signal which varies above and below the center frequency, a characteristic "S" shaped discriminator response curve will be obtained if the circuit is operating properly and aligned correctly. Defects in the circuit or alignment, however, will cause a portion of the response curve to be distorted.

If only the upper (positive) portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, resistor R1, capacitors C2 or C4, transformer

T1 or misalignment of tank C_2, L_{S_1}. Check resistor R1 for proper value with an ohmmeter, and check capacitor C4 for proper value, leakage, or a short with an in-circuit capacitance tester. If these checks fail to locate the defective component, the transformer assembly (consisting of T1 and C1, C2, and C3) is either misaligned or defective. Check the alignment.

When only the lower (negative) portion of the response curve is distorted, it may be caused by a defect in diode V2, resistor R2, capacitors C3 or C5, transformer T1, or misalignment of tank C3, L_{S_2}. Check resistor R2 for proper value with an ohmmeter, and check capacitor C5 for proper value, leakage, or a short, with an in-circuit capacitance tester. If these checks fail to locate the defective component, the transformer assembly (T1, C1, C2, and C3) is either misaligned or defective. Check the alignment.

Distortion or flattening of the entire response curve is usually caused by improper alignment of the discriminator, although it may also be caused by low diode emission.

RATIO DETECTOR.

APPLICATION.

The ratio detector is used in FM receivers to demodulate the received r-f signal, and in automatic volume control (AVC) circuits to transform frequency changes into d-c control voltage changes.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs a double tuned transformer and two diodes.

Has very low inherent distortion.

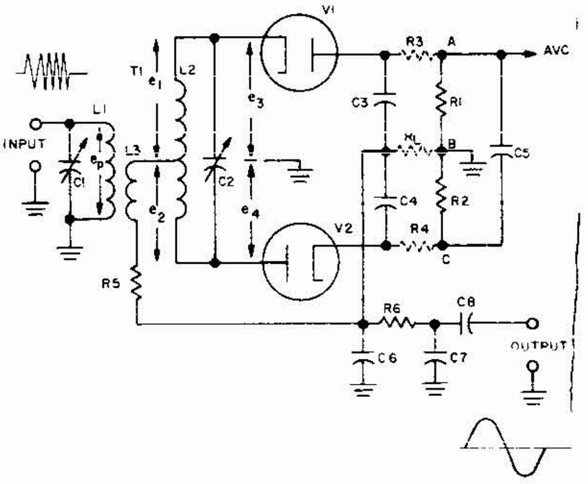
Output not affected by input amplitude variations.

CIRCUIT ANALYSIS.

General. The ratio detector uses a double tuned transformer, connected so that the instantaneous frequency variations of the FM input signal are converted into instantaneous amplitude variations. These amplitude variations are rectified to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, becomes more positive).

When the input frequency drops below the center frequency, the output voltage increases in the other direction (for example becomes more negative). The specific polarity of the output voltages obtained for an increase or decrease in input frequency is determined by the design of the circuit and may vary in different circuits.

Circuit Operation. The accompanying schematic diagram illustrates a typical ratio detector.

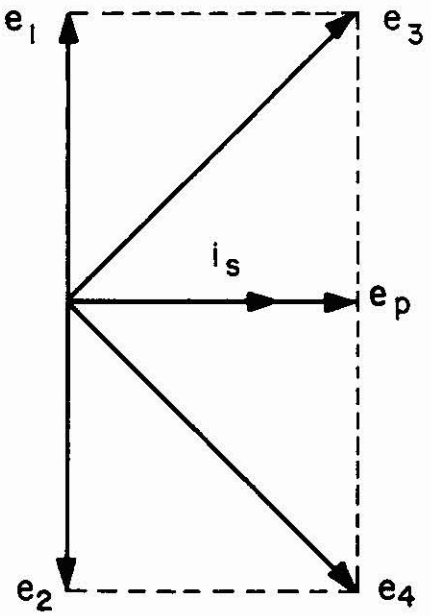


Ratio Detector

The input tank circuit, made up of capacitor C1 and the primary winding of transformer T1, is tuned to the center frequency (fr) of the received r-f signal. Capacitor C2 and secondary winding L2 of transformer T1 form a tank circuit also tuned to the center frequency. Tertiary winding L3 provides additional inductive coupling which reduces the loading effect of the secondary circuit of the detector on the primary circuit of the detector. Diodes V1 and V2 rectify the signal from the secondary tank circuit. Capacitor C5, in conjunction with resistors R1 and R2, determines the operating level of the detector, while capacitors C3 and C4 determine the amplitude and polarity of the output. Capacitors C6 and C7, together with R6, form a filtering network at the output. Resistor R5 modifies the peak diode currents. Resistors R3 and R4 (shown in dotted lines on the schematic) were used in the original design of the circuit to compensate for the changing reactance of the diodes for different amplitude input signals. In practical circuits, however, they are combined with R1 and R2, and achieve the same result. The output of the detector is taken from the common connection between C3 and C4 to the common connection between R1 and R2 which is also ground. Resistor RL represents the load.

Operation can be best explained with vector diagrams which show the various phase relationships between the voltages and currents in the circuits. The following vector diagram (1) illustrates the circuit phase relationships when the input frequency (f) is equal to the center frequency (fr).

The input voltage applied to the primary tank circuit is shown as vector e_p on the diagram. Since L3 is effectively connected in parallel with the primary tank circuit, voltage e_p appears across it. When voltage e_p is applied to the primary winding of transformer T1, a voltage is induced in the secondary winding which causes current to

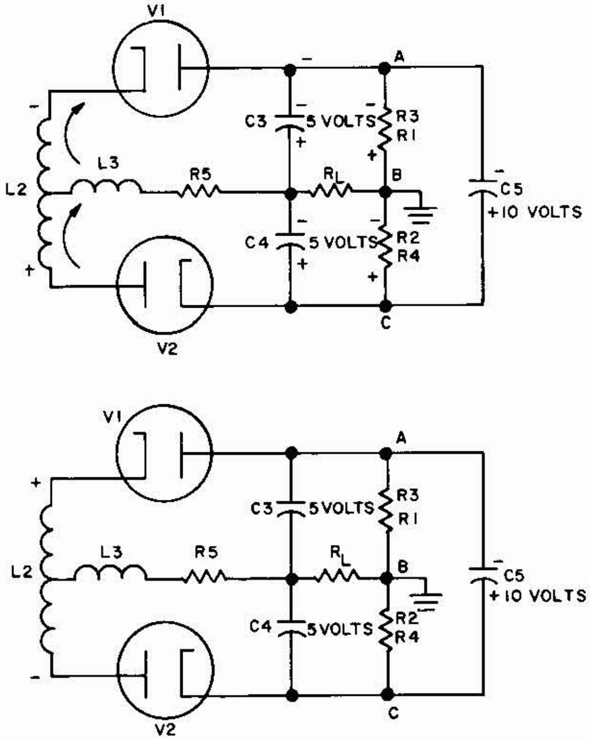


Vector Diagram at Resonance

flow around the secondary tank circuit. When the input frequency is at the center frequency, the tank is at resonance and acts resistive. Therefore, tank current is is in phase with the primary voltage e_p, as shown in the vector diagram. The current flowing in the tank causes voltage drops to be produced across each half of the balanced secondary winding of transformer T1, which are of equal magnitude and opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90° out of phase with the current through it. Because of the center tap arrangement, the voltages to ground at each end of the secondary are 180° out of phase, and are shown as e_1 and e_2 on the vector diagram.

The voltage applied to the cathode of V1 consists of the vector sum of voltages e_p and e_1 shown as e_3 on the diagram. Likewise, the voltage applied to plate of V2 consists of the vector sum of voltages e_p and e_2, shown as e_4 on the diagram. Since at resonance there is no phase shift, voltages e_3 and e_4 are equal as shown by the same length vectors.

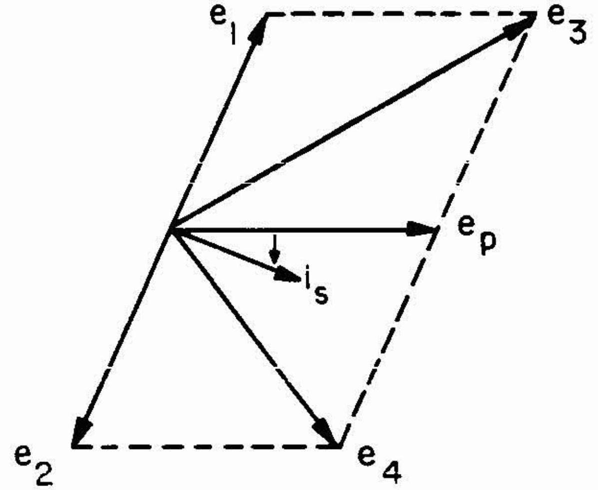
Consider now the manner in which the tubes operate with the discriminator voltages discussed above. When a positive input signal is applied to L1, a voltage of opposite polarity is induced into secondary L2. As shown in the accompanying simplified schematic, the cathode of V1 is negative with respect to its plate, while the plate of V2 is positive with respect to its cathode. Since both voltages are of equal magnitude at resonance, both tubes conduct equally. Hence, current flow through V1 is in one direction, while current flow through V2 is in the opposite direction. This direction of current flow causes a negative polarity at point A and a positive polarity at point B, and through R_L applies a positive charge to C3. In a similar manner current flow through V2 produces a negative polarity at point B and a positive polarity at C. Hence, capacitor C4 is charged negatively. Since the polarities are additive, capacitor C5 across the output charges to the series value of twice this voltage. In the example shown it is assumed that equal but opposite voltages of 5 volts exist across C3 and C4. Therefore, the total charge across C5 is 10 volts. Since the voltages across C3 and C4 are equal in amplitude and of opposite polarity the output across load R_L is the algebraic sum or zero.



Current Flow and Polarities at Resonance

When the input signal reverses polarity, the secondary voltage across L2 also reverses polarity. The cathode of V1 is now positive with respect to its plate, and the plate of V2 is negative with respect to its cathode. Under these conditions neither tube conducts, and there is no output. Meanwhile, C5 retains most of its charge because of the large time constant supplied by R1 and R2, and discharges very slightly.

When an input frequency higher than the center frequency is applied to the detector circuit, a phase shift occurs and the current and voltage phase relationships change as shown in the accompanying vector diagram.

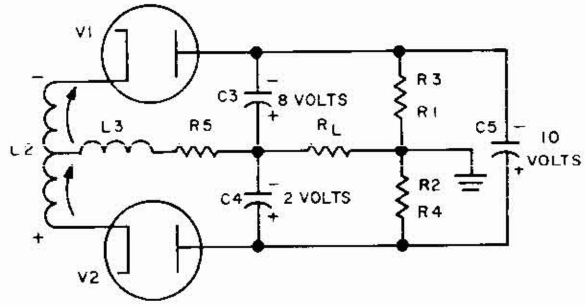


Vector Diagram for Higher Input Frequency

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance, the tank is predominately inductive and acts like an inductor. Hence the secondary current is **lags** the primary voltage e_p. Although secondary voltage e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them (i_s). Thus the change to a lagging secondary current rotates the vector in a clockwise direction. Referring to the vector diagram it can be seen that e_1 is brought nearer in phase with e_p, while e_2 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_1 is larger than that of e_p and e_2. Therefore, above the center frequency, e_3, which is applied to the cathode of V1 becomes greater than e_4, the voltage applied to the plate of V2.

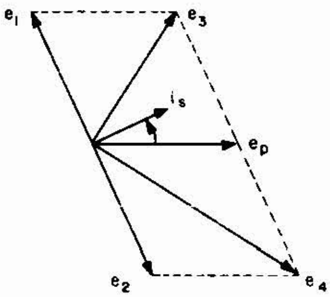
Let us now examine the manner in which the tubes operate with the discriminator voltages developed above resonance as discussed above. When a positive input signal is applied to L1, the same polarity as in the previous example discussed above exists, namely, V1 cathode is negative and V2 plate is positive and both tubes conduct. However, e_3 is now greater than e_4. Therefore, diode V1 conducts more than diode V2, and C3 charges to a higher voltage than at resonance, as shown in the accompanying simplified illustration.

Thus we assume in the figure an 8 volt charge on C3 and only a two volt charge on C4. Since C3 is positive with respect to C4, the output is a 6 volt positive signal. Meanwhile, capacitor C5 still remains charged to the sum of these voltages, or 10 volts, as originally stated. When the input signal reverses polarity, the polarity of the secondary also reverses, biasing both diodes in the opposite direction and preventing conduction. During the nonconducting period, C5 discharges very little because of its long time constant.



Current Flow and Polarities Above Resonance

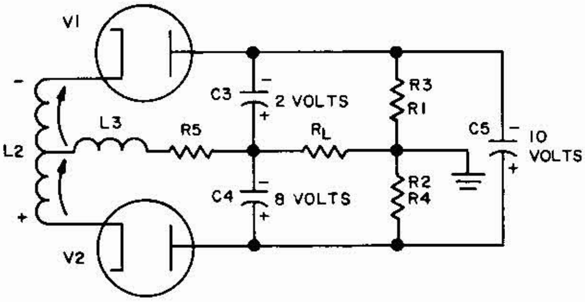
When an input frequency lower than the center frequency is applied to the detector circuit, a phase shift also occurs, and the current and voltage phase relationships change as shown in the accompanying vector diagram.



Vector Diagram for Lower Input Frequency

When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the coil decreases. Therefore, below resonance, the tank is predominately capacitive and acts like a capacitor. Hence, secondary current is **leads** the primary voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counterclockwise direction. From the vector diagram it can be seen that e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is larger than that of e_p and e_1. Therefore, below center frequency, e_4, which is applied to the plate of V2, becomes greater than e_3, the voltage applied to V1.

The following simplified schematic shows the polarities and voltages developed for the lower than resonance condition. Once again V1 and V2 are conducting, but this time V2 is conducting more than V1, and hence, capacitor C4 is charged to the larger voltage 8 volts while C3 is only charged to 2 volts. The output voltage across the load in this case is a negative 6 volts because C4 is negatively charged with respect to C3. Again the charge across capacitor C5 consists of the sum of the voltages across C3 and C4, or 10 volts as originally developed.



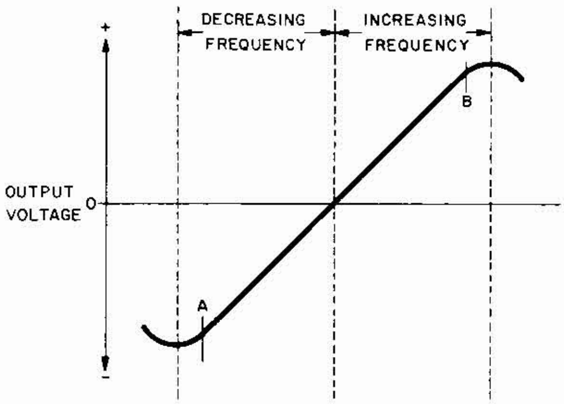
Current Flow and Polarities Below Resonance

When the input signal reverses its polarity, the signal across the secondary also reverses its polarity. The cathode of V1 is now positive with respect to its plate, and the plate of V2 is negative with respect to its cathode. Under these conditions, neither tube conducts, but the time constant of C3 and C4 maintains the current through the load in a negative direction until the next cycle of input.

When the input signal is varied from a lower than center frequency, through center frequency, and is raised to a frequency higher than the center frequency, the typical "S" shaped discriminator response curve shown in the accompanying illustration is obtained. The usable portion of the typical "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.

The output of the ratio detector adjusts itself automatically to the average r-f amplitude of the input signal. Through the action of resistors R1 and R2, together with capacitor C5, audio output variations which would occur due to r-f amplitude variations in the input (such as noise) are eliminated. As previously mentioned, C5 charges to the sum of e_3 and e_4. The average sum of e_3 and e_4 depends upon the average r-f amplitude of e_p. Any amplitude variations at the input of the detector tends to change the voltages across R1 and R2, but because of the long time constant of C5, across the resistors, these voltages are held constant. Before the capacitor can charge or discharge to the higher or lower amplitude variation the impulse disappears, and the difference in charge on C5 is so slight that it is not discernable in the output. Because the voltage across C5 remains relatively stable and changes only with the amplitude of the center frequency, and since it is negative with respect to ground it is usually used for automatic volume control (AVC) applications.

Capacitors C6 and C7 together with resistor R6 form a low pass filter which attenuates the high audio frequencies and passes the lower frequencies. This is known as a de-emphasis network, which compensates for the pre-emphasis with which the high frequencies are transmitted and returns the audio frequency balance to normal. When pre-emphasis is not employed these parts are not needed.



Ratio Detector Response Curve

FAILURE ANALYSIS.

No Output. A defective discriminator transformer, T1, shorted tuning capacitor C1 or C2, an open output resistor R6, an open coupling capacitor C8, or shorted filter capacitors (C6 or C7) will produce a no output condition. Check the continuity of the windings of T1 with an ohmmeter. Check capacitors C1, C2, C6 and C7 for shorts, and capacitor C8 for an open with an ohmmeter, and measure the resistance of R6. If above checks fail to restore the output, check all capacitors with an in-circuit capacitor checker. Note that one defective diode will produce a partial loss of output, and that both diodes must fail to cause a complete loss of output.

Low or Distorted Output. A defect in nearly any component in the detector circuit may cause the output to be either low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to isolate the trouble. Ground the grid of the last I-F tube, connect the r-f sweep generator to the detector input, and connect the oscilloscope to the detector output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the circuit will cause either the entire curve, or a portion of it to be distorted or flattened.

If the entire response curve is distorted, the trouble may be caused by either improper alignment or by a defect in the transformer T1. First check to be certain that both primary and secondary tank circuits are properly tuned to the center frequency. If the detector is properly aligned, check capacitors C1 and C2 with an in-circuit capacitor checker. Check R1 and R2 with an ohmmeter for their proper values, and capacitor C5 for value and leakage with an in-circuit capacitor checker. If the trouble is still not located, the trouble is most likely caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode V1, capacitor C3, or transformer T1. If the diode V1 checks good, use an in-circuit capacitor checker to check C3 for value and leakage. If these checks fail to locate the trouble, transformer T1 is probably defective.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode V2, capacitor C4, or transformer T1. Use an in-circuit capacitor checker to check C4 for value and leakage. If these checks fail to locate the trouble, transformer T1 is probably defective.

GATED-BEAM DETECTOR.

APPLICATION.

The gated-beam detector is used in FM receivers to demodulate the received r-f signal.

CHARACTERISTICS.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

Employs three tuned tank circuits and a special beam-power tube.

Has low inherent distortion.

Output is independent of input amplitude variations.

Provides both limiting and discriminator action in a single tube.

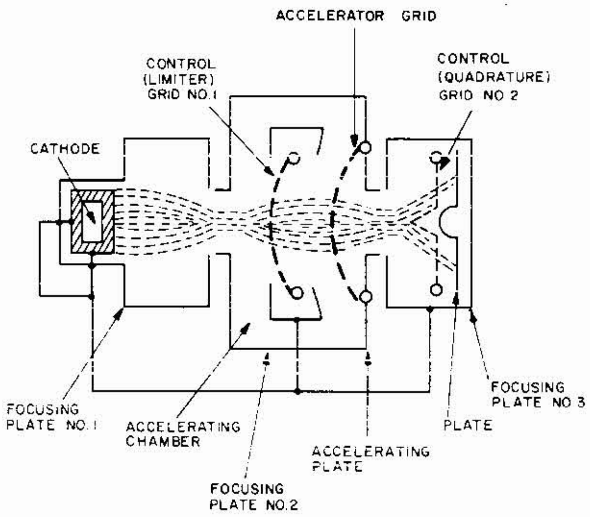
CIRCUIT ANALYSIS.

General. The gated-beam detector uses a gated-beam tube to limit, detect, and amplify the received f-m r-f signal. The output is a d-c voltage which varies in amplitude and polarity as the input varies in frequency. This output voltage is zero when the input frequency is equal to the center frequency (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in a positive direction, and when the input frequency drops below the center frequency, the output increases in a negative direction.

Circuit Operation. Before attempting to explain the circuit operation of the gated beam detector, a brief review of the tube used in the circuit is essential. The accompanying illustration shows a cross-sectional diagram of a typical gated-beam tube.

There are two major differences between the gated-beam tube and an ordinary pentode. First, the flow of electrons from the cathode to the plate is maintained in a concentrated beam formed by the elements of the tube, and secondly, cathode current flows at all times, even during the period of time during which no plate current flows.

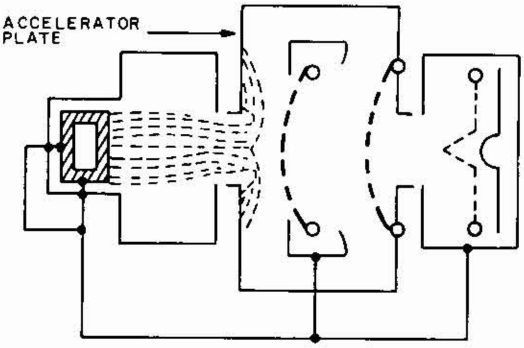
The shield around the cathode, known as focusing plate No. 1, is internally connected to the cathode, and as the electrons leave the cathode they pass through a narrow opening in the shield, which is at cathode potential and repels electrons. Thus a narrow stream of electrons is formed.



Gated-Beam Tube Cross-Section

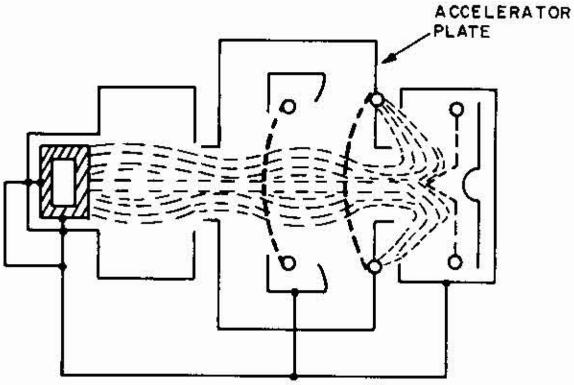
As the electron stream enters the accelerating chamber, which is at a high positive potential, it tends to spread, due to the attraction of the positive field. Ordinarily, the stream would continue to spread, but as it approaches the No. 1 control grid, it is prevented from spreading further by the repelling action of a second focusing plate, also connected to the cathode. Once the electrons pass through the first control grid, they are attracted towards the accelerator grid, which is at the same potential as the accelerator plate, and again the electron stream tends to spread. However, before the spreading becomes excessive, the stream enters the field of focusing plate No. 3 which is also at cathode potential, and further spreading is checked. The focusing plate is provided with a narrow opening, which concentrates the beam into a narrow stream again as it passes through this orifice. The electron stream then passes through a second control grid (referred to as the quadrature grid) and is attracted to the potential positive plate.

If a signal is applied to the first control grid, and it is sufficiently negative to prevent the electron stream from passing through it, the electrons approaching this grid rapidly build up a dense space charge in front of the grid. Because electrons repel each other, the accumulated space charge aids the control grid in quickly cutting off plate current flow, and accounts for the sharp cut-off tube characteristic. (This control grid is also referred to as the limiter grid for this reason.) The electrons cannot return to the cathode because of the narrow opening in the focusing plate, and they are attracted to the wall of the accelerator chamber instead, thus maintaining cathode current flow, as illustrated below.



First Control (Limiter) Grid at Cut-off

In a similar manner, when a signal of sufficient strength and of proper polarity to repel the electron stream is applied to the quadrature grid (No. 2 control grid), with the limiter grid above cut-off, plate current will not flow. Cathode current flow continues, however, because the electron stream is attracted to the accelerator wall instead, as illustrated below.

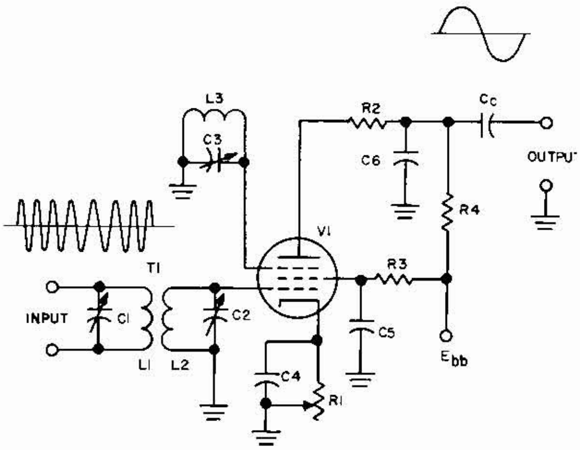


Second Control (Quadrature) Grid at Cut—off

To summarize tube operation, both the limiter grid and the quadrature grid must be sufficiently positive at the same time to permit passage of the electron stream to the plate.

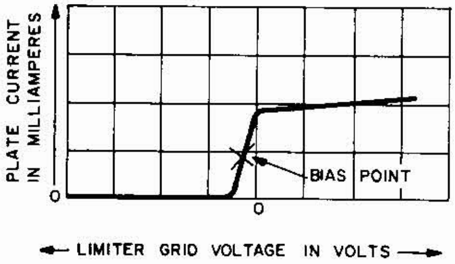
The accompanying circuit schematic illustrates the gated beam tube connected as a typical gated-beam detector.

The input tank circuit, consisting of L1, the primary of i-f transformer T1, and capacitor C1, is tuned to the center frequency of the incoming f-m signal. L2, the secondary of the transformer T1, and capacitor C2, also comprise another tank circuit, which is also tuned to the center frequency. The first grid of the tube and the cathode, perform the function of a limiter stage, with resistor R1 and capacitor C4 in the cathode circuit to provide a method of adjusting the limiter bias. The accelerator grid is connected to voltage-dropping resistor R3 which establishes the proper voltage on the accelerator grid, and C5 bypasses it to ground. Capacitor C3, together with L3, form another tank circuit also tuned to the center frequency, and is connected to the second control grid. Resistor R2, (usually of a small value) is placed in the plate lead to increase output linearity. Resistor R4 is the plate load, and together with capacitor C6 forms an integrating network which produces the sine-wave output. The output is taken from across C6, and applied to the audio stages through coupling capacitor Cc.



Typical Gated-Beam Detector

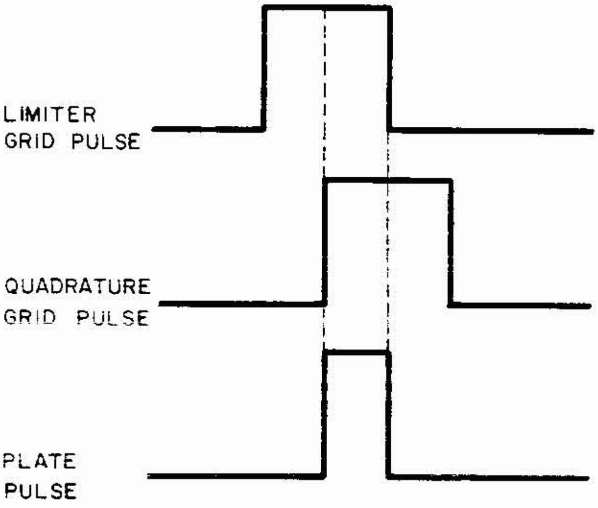
The limiting capabilities of the gated beam detector are much better than that of a conventional pentode, because of the sharp control characteristic, as shown in the graph below.



Limiter Grid Tube Control Curve

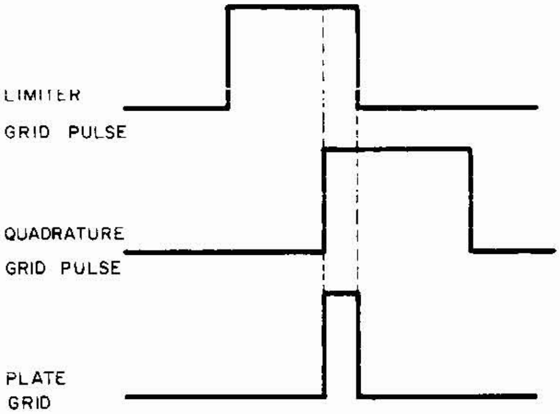
Cathode resistor R1 is adjusted to bias the limiter at the center of the steepest part of the control-characteristic curve. With no signal applied to the limiter grid, the tube conducts. When the electron stream arrives at the quadrature grid, some electrons are absorbed by this grid, and the resulting current flow charges C3 of the quadrature tank circuit. When C3 is charged sufficiently negative, the grid current stops and this negative charge momentarily maintains the quadrature grid at cut-off. Tank inductor L3, however, tries to keep the current moving in the same direction, but when its field collapses it causes a reverse flow of current which discharges C3. When C3 discharges sufficiently, the grid again becomes positive and begins drawing grid current, and the cycle repeats. Since the tank is tuned to the center frequency of the received signal, it oscillates at the tuned frequency. The voltage across C3 lags the current which produces it, and the result is a series of pulses appearing on the quadrature grid at the center frequency, but lagging the limiter grid voltage by 90 degrees. Because the quadrature grid has the same control characteristics as the limiter grid, these pulses place the tube alternately at cut-off and at saturation on alternate half cycles of oscillation.

When a signal appears on the limiter grid at the center frequency and increases slightly in a positive direction, the tube is effectively driven into saturation. That is, as the electron stream passes through the limiter and accelerator grids, and arrives at the quadrature grid, the quadrature grid is out-of-phase and is at cut-off, and the electron stream is attracted to the accelerator wall. However, some 90 degrees later, the quadrature grid shifts in a positive direction because of the favorable oscillation of the quadrature tank, and this time the electron stream is permitted to pass through the quadrature grid to the plate. Before the quadrature grid phase changes, the signal applied to the limiter grid drives the tube quickly into cut-off, and plate current again ceases. The resulting signal appearing on the plate, therefore, is a square shaped pulse, which starts with the delayed opening of the quadrature grid, and ends with the closing of the limiter grid, as illustrated below.



Relationship of Pulses at Center Frequency

If the signal on the limiter grid shifts to a frequency higher than the center frequency, the pulse appears on the limiter grid at an earlier time than at the center frequency, and therefore, also arrives at the quadrature grid at an earlier time. Since the pulses on the quadrature grid are still occurring at the center frequency (because of tank circuit oscillation), and the limiter pulse arrives earlier, the resulting pulse relationships are as shown in the second waveform illustration.



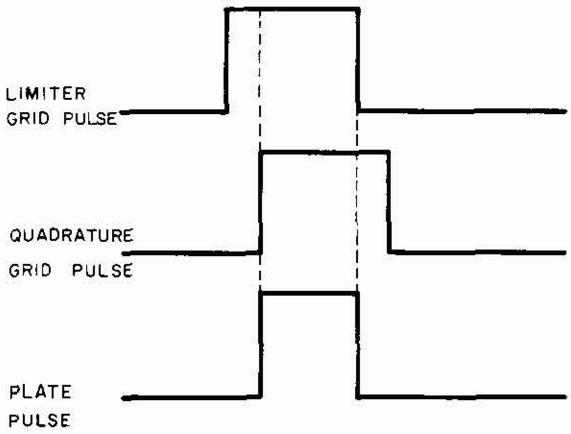
Relationship of Pulses above Center Frequency

Since plate current starts with the delayed opening of of the quadrature grid, and ends with the closing of the limiter grid, the plate pulse is now narrower than it was at the center frequency.

Conversely, if the signal on the limiter grid shifts to a frequency below the center frequency, the pulse arrives on the limiter grid at a later time, and thus arrives at the quadrature grid at a later time. It is therefore nearer in phase with the pulses on the quadrature grid, since these quadrature pulses are still occurring at the center frequency, and the resulting pulse relationships are as shown in the third waveform illustration.

Under the three circumstances discussed above, the peak amplitude of the plate current remains the same (it is effectively at saturation and limited), while the variations in the frequency of the input pulses are represented at the plate only by the length of time for which plate current flows. A higher input frequency produces a shorter duration of plate current, and a lower input frequency produces a longer duration of plate current.

These plate pulses, however, are occurring at an r-f rate, and therefore will not be reproduced by the following audio stages. However, since the width of the plate pulses constantly vary in accordance with the f-m modulation, the plate pulses also vary at an audio rate. Therefore, the average plate current varies at audio frequencies, and a useable audio output is obtained by an integrating network consisting of C6 and R4. Since the charge on C6



Relationship of Pulses below Center Frequency

varies at the same rate as the average plate current, taking the output from capacitor C6, provides an audio output, and at the same time, it changes the squared pulse into a useable sine-wave to minimize distortion.

The advantage of the Gated Beam Detector lies in its extreme simplicity. It employs only one tube, yet provides a very effective limiter with a linear detector. It requires relatively few components, and is very easily adjusted. Operation, however, is limited to the frequencies below 30 Mc. Since at the higher frequencies, the shunting effect of the interelectrode capacitance between the limiter and quadrature grids is sufficient to produce an out-of-phase voltage across the quadrature grid, which subtracts from the quadrature voltage and reduces the output. This effect is minimized in some circuits by the addition of a screen grid, to the tube or by careful shielding, but neither method completely eliminates the out-of-phase effect, and for this reason, the gated-beam circuit is usually used only in low frequency applications.

FAILURE ANALYSIS.

No Output. A defect in nearly any component in the circuit could cause a no-output condition to exist. Check the plate supply voltage at the tube socket, if plate voltage is not present, check resistors R2 and R4 and capacitor C6. If plate and grid voltages are normal, the tube is probably defective.

Check for a signal on the limiter grid with an oscilloscope. If no signal is present, check for a signal on the primary of the transformer. If still no signal appears, the trouble is somewhere in the preceding stages, and the detector is probably not faulty. If there is a signal on the primary of the transformer, check the tuning capacitors with an in-circuit capacitor checker. If they are found to be good, the trouble is probably a defective transformer. Check cathode resistor R1 for proper value and adjustment, and capacitor C4 also, using an in-circuit capacitor checker. With the oscilloscope, check for a signal on the quadrature grid. If a signal is present, make sure it is at the center frequency. If no signal is present, check C3 with an in-circuit capacitor checker, and L3 with an ohmmeter. Check R3 for proper value, and C5 for a short to ground.

Low or Distorted Output. It is unlikely that a low output condition will exist, but if it does, R2, R4, or C6 is most likely at fault. Check R2 and R4 for proper value, and C6 with an in-circuit capacitor checker.

If the output is distorted, make the checks just mentioned above for a low output condition, and if the distortion still occurs, make certain that the three tanks are aligned properly, and contain no defective components. Also check R1 for proper value and adjustment, using a voltohmmeter and also check capacitor C4 with an in-circuit capacitor checker.

VIDEO DETECTORS

A video detector is very similar to the standard AM detector, with the exception of the requirement for handling a broader range of frequencies. Since it is located between the IF and the video amplifier stages, it must be able to handle the same wide range of frequencies as the IF and video amplifier stages without distortion. The IF frequencies used in radar applications vary from about 30 Hz to 8 MHz, and in television, from about 20 MHz to 4.5 Hz. This requirement necessitates the use of high-frequency compensating circuits in the detector output, which consist of both series and shunt peaking circuits. (See paragraph 2.5.2 in section 2 of this Handbook for an explanation of RL peaking circuits). Another precaution, though less critical, is the selection of a diode with a low plate to cathode capacitance. Operation of the video detector is the same as that of a typical AM diode detector, except for the frequency response changes caused by use of the compensating circuits.

BASIC VIDEO DETECTOR

APPLICATION.

The video detector is used to change the received amplitude modulated video signal into a d-c voltage.

CHARACTERISTICS.

Employs a basic AM diode detector.

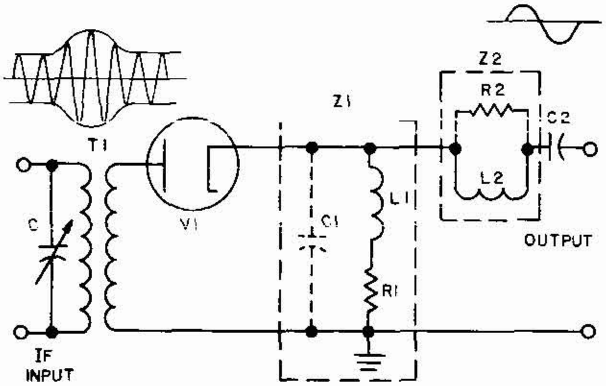
Has a wider bandwidth than the conventional AM detector.

Employs compensating networks for frequency compensation and to improve linearity.

CIRCUIT ANALYSIS.

General. The operation of the basic video detector is identical to the operation of the AM diode detector previously discussed in this section of the Handbook. The only difference lies in the addition of compensating circuits for the added frequency response requirements. Discussion of the operation of the detector in stripping off the modulation from the carrier is covered completely in the previous discussion of the diode detector. The reader should refer to the discussion of the Diode Detector in this section of the Handbook for proper background before proceeding with the discussion of the video detector.

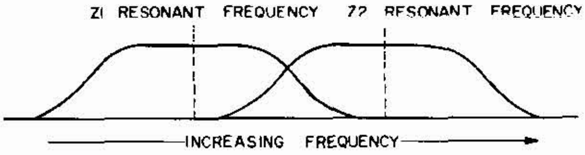
Circuit Operation. The schematic diagram of a typical video detector employing series and shunt peaking is shown in the accompanying illustration.



Basic Video Detector

The anode of diode V1 is connected to the untuned secondary of IF transformer, T1, with the primary tuned by capacitor C. Inductance L1, in series with resistor R1, together with capacitor C1, forms a shunt peaking circuit, referred to as impedance network Z1. Inductance L2, together with R2, forms a series peaking circuit, referred to as impedance network Z2. Capacitor C2 is the output coupling capacitor. Resistor R1 broadens the bandwidth of Z1, and R2 broadens the bandwidth of Z2.

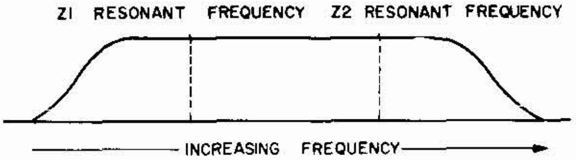
Peaking circuits Z1 and Z2 are utilized to improve the output linearity, and provide a wide band-pass characteristic. The circuit operates in the following manner. A frequency increase causes the capacitive reactance of the stray capacitance to decrease, and since this stray capacitance (represented by C1) shunts the output, the output voltage tends to decrease at high video frequencies. Z1 is a parallel-tuned circuit resonated to the high frequency at which the output first tends to decrease, by the stray and distributed wiring and circuit capacitance represented by C1. Since the impedance of the parallel tuned (shunt peaked) circuit is maximum at resonance, the output remains linear beyond the high frequency drop-off point (without compensation). The bandwidth of this tuned (shunt peaked) circuit is widened because the Q of the circuit is decreased by the presence of series resistor R1. As the output frequency is increased still further, it passes beyond the resonant peak of Z1, and as the impedance of Z1 now decreases, the output again tends to decrease. Z2, however, forms another broadly-tuned circuit, and is series-resonated at a point above the resonant frequency of Z1. These circuits are so tuned that some overlap of the tuned circuit response curves occurs, as shown in the following illustration.



Combined Response Curve of Z1 and Z2

Since the impedance of a series tuned circuit is minimum at resonance, and because Z2 is in series with the load, the output once again is extended. Actually L2 is series peaked using the stray capacitance to ground, and is also broadened by shunt resistor R2.

The resultant overall response curve for the video detector is as shown below.



Overall Response Curve for Video Detector

FAILURE ANALYSIS.

No Output. A defect in transformer T1, a defective tube, or an open C2 will cause a no-output condition. Check the continuity of the windings of T1 with an ohmmeter. Check C2 for an open with an ohmmeter. If a no-output condition still exists, check the value of the capacitor with an in-circuit capacitor checker.

Low or Distorted Output. A defective diode is about the only component in the circuit that would cause a low output condition to exist. While a low output is also possible because the values of L1 or L2 may change and change the response curve, this possibility is rather remote. Do not neglect the possibility of either R1 or R2 changing value sufficiently to affect the response.

If the output is distorted only at the lower frequencies, the defect is probably in one of the components of Z1. Check the value of L1. Check L1 for continuity and R1 for proper value with an ohmmeter.

If the output is distorted only at the higher frequencies, series peaking circuit Z2 is probably defective. Check C2 with an in-circuit capacitor checker. Check L2 for continuity and R2 for proper value.

PART B. SEMICONDUCTOR CIRCUITS

AM DETECTORS.

Detector circuits are used to remove the modulation from the received modulated r-f signal and transfer it back to its original form, so that it may be used for listening, viewing, communication, or other purposes. There are many forms of detector circuits and many variations of these circuits. The circuits used in the semiconductor field are similar to those used in the electron-tube field. The diode AM detector is a particularly good example of this parallelism, since the semiconductor diode merely replaces the diode tube. Only AM detectors will be discussed in the following paragraphs; other types of detectors will be discussed later.

The semiconductor diode evolved from the original "**crystal detector**" of the early radio era, which was basically a point-contact galena diode. Today's grown PN (or NP) junction diode is more stable and physically more rugged than the early galena detector. It is usually designed to handle fairly high voltage and current, since it acts as a large-signal detector after a number of r-f or i-f amplifiers. Because of its small size, good power-handling capabilities, lack of power consumption, and small cost, the design trend is to replace the electron tube diode with the semiconductor diode.

Generally speaking, the semiconductor diode detector for AM is used in one of two types of circuits: the **voltage-output** circuit and the **current-output** circuit. (In other texts these circuits may be called "series diode detector and shunt diode detector".) Although semiconductors operate basically by virtue of a changing **current**, when current is passed through a resistor a **voltage drop** is produced across the resistor. Therefore both types of circuits are applicable to either tubes or semiconductors, and the functioning is similar regardless of whether tubes or semiconductors are used. The voltage output circuit is usually preferred for electron-tube applications.

Because of the lack of gain in the diode detector, transistors are also used for detection. The transistor detector provides amplification of the detected signal. With the proper circuit connections and bias it can be made the semiconductor equivalent of the grid, plate, or infinite-impedance electron-tube detector. By suitable arrangement of biasing potentials and proper selection of the transistor, either square-law or linear detection can be achieved.

While the semiconductor diode detector is used universally in electron-tube equipment, the transistor triode detector is generally used only in all-transistor equipments. When used, the transistor detector is limited to the common-base and common-emitter configurations because of the less-than-unity gain provided by the common-collector circuit.

VOLTAGE OUTPUT DIODE DETECTOR.

APPLICATION.

The semiconductor diode detector with a voltage output is usually used as the second detector in superheterodyne receivers, or as a linear detector where large input signals are supplied. It is also used in test equipment where linear response is desired, as in VTVM's and field strength indicators.

CHARACTERISTICS.

Operates linearly over a large range of voltage.

Does not amplify the input signal.

Has an average efficiency of approximately 90 percent.

Normal large-signal distortion is on the order of 1 to 2 percent.

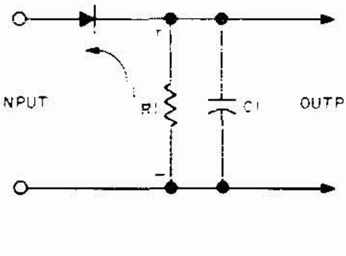
Is not restricted to any particular frequency range, but is operable on the entire electronic spectrum.

CIRCUIT ANALYSIS.

General. Since the electron tube diode detector is practically identical with the voltage-output semiconductor diode, read the discussion on Diode Detectors in Part A of this section, before continuing; refer also to the discussion on Junction Diode Theory, in paragraph 3.2.1 of Section 3, for a review of the basic operation of the diode. It should now be evident that the principal difference between a tube diode and a semiconductor diode is the reverse-leakage current of the semiconductor, plus a difference in current and voltage ratings. As far as the diode detector is concerned, the reverse-leakage current is usually negligible. Although it does produce a slightly increased loading effect on the input circuit, this increased loading is of interest only when the diode is operated as a small-signal detector. In this instance operation is not linear, but observes a square-law response (output varies as the square of the input voltage). It is this weak-signal square-law response which creates the inherent distortion in the diode detector. As normally operated, the diode voltage-output detector is employed after a number of stages of amplification. Thus, the input signal to the detector is relatively large in amplitude, the response is relatively linear, and the basic fidelity of the diode detector is achieved.

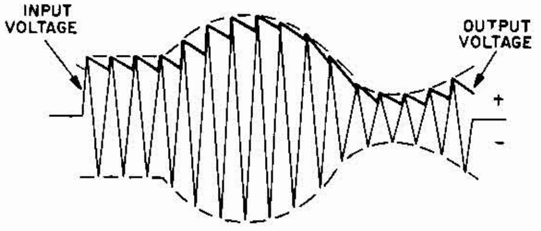
Circuit Operation. A simplified schematic of the voltage-output diode detector is shown in the accompanying figure.

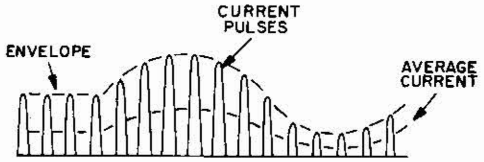
From this figure it can be seen that diode CR is in series with the input voltage; it acts as a simple rectifier, with R1 as the load and C1 as the filter. The diode conducts only during the positive half-cycle of the input signal. During the negative half-cycle it remains inoperative, since it is then reverse-biased. When the diode conducts, current flows through R1 and produces a voltage drop across



Voltage-Output Diode Detector

the resistor. The voltage developed across R1 is equal to the peak value minus the drop across the diode (which is very small and much less than in an electron tube diode). Since capacitor C1 is connected in parallel with R1 it charges to the same voltage. Since the diode response is considered linear, the larger the input voltage the greater the current through R1 and the larger the charge on C1. As the positive half-cycle ceases, the diode ceases conducting and capacitor C1 discharges through R1 for the duration of the negative half-cycle. The capacitor discharge is controlled by the time constant of R1 and C1, and is not quite completed before the positive half-cycle again begins. The diode again conducts, and capacitor C1 is again charged for the duration of the positive half-cycle. Since these alternations are at radio-frequency rates and the RC time constant is on the order of seconds, the voltage to which C1 is charged never has time enough to reach the full peak value of the input voltage, and the voltage to which C1 is discharged never has time enough to reach zero value. The voltage is, however, proportional to the envelope of the modulation, rising as the input signal amplitude increases, and falling as the input signal amplitude decreases, as shown in the following illustration. Thus, the voltage across C1 is a nearly linear replica of the original modulation.





DETECTOR WAVEFORMS

When the time constant of R1 and C1 is too short (cacapacitor, resistor, or both are too small), the capacitor voltage cannot follow the envelope (it reaches full charge before the signal reaches its peak), part of the signal is lost, and the detected modulation is distorted. When the time constant is too long, the capacitor tends to smooth out variations in the modulation (it cannot respond to very fast voltage variations—only slow variations), and distortion occurs. With the proper time constant, the capacitor is never fully charged or fully discharged, but rather follows the peak excursions of the envelope in accordance with the audio modulation.

FAILURE ANALYSIS.

No Output. A no-output condition can occur from failure of the diode to conduct, from an open or shorted load resistor, or from a defective capacitor. A resistance and continuity check will determine whether the resistor is satisfactory, whether the diode front-to-back resistance is normal, and whether the capacitor is short-circuited. With the resistor and diode checked out, it is a simple matter to connect a capacitor in parallel with the suspected capacitor to determine whether it is open (an output will appear if the capacitor is open). If an oscilloscope is available, it may be used to observe the waveform across the load resistor.

Low Output. Low output can occur from a change in the time constant of the circuit, or from a lack of sufficient input to the detector to produce the desired output amplitude. Poorly soldered connections, a leaky capacitor, or a defective diode can cause this condition. Under normal operation, the amplitude of the signal across the detector should be from 80 to 90 percent of the input amplitude. Less than this value indicates lack of efficiency due to increased resistance in the diode or leakage in the capacitor.

Distorted Output. This can result from a change in capacitor value. Either too large or too small a capacitor will cause distortion. A change in a resistor or capacitor value, producing too short or too long a time constant, will also cause distortion. The parts should be within 10 to 15 percent of their rated values. If the values are normal, the trouble must be in the diode. A high-resistance condition caused by a poorly soldered joint is always a possibility.

CURRENT OUTPUT, DIODE DETECTOR.

APPLICATION.

The current output diode detector is used to detect the audio modulation in semiconductor receivers, where the voltage output is small and does not vary sufficiently to produce full output from the audio amplifier stages.

CHARACTERISTICS.

Is usually self-biased.

Linear current swings produce linear output voltage swings.

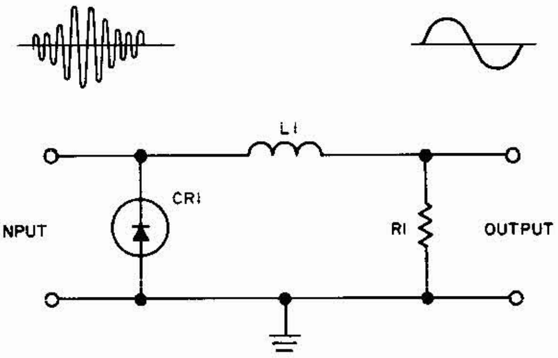
Impedance at the output is low, and usually direct coupling is employed.

Is inherently a small signal detector.

CIRCUIT ANALYSIS.

General. The current form of diode detector operates similarly to the voltage form of diode detector. Except that the output variations are in the form of current pulses rather than voltage pulses. However, by passing this current through a shunt resistor, a voltage output is developed across the resistor. The voltage output is, however, much reduced so that a current amplifier is required to build up the signal to a respectable output level. Thus, while the voltage detector will supply an output which can drive the following audio stage, the current detector usually utilizes direct coupling and an additional transistor stage to control another transistor stage in the output. Because of the direct coupling, response is somewhat better. On the other hand, the higher frequency signals are slightly attenuated by the coil reactance of the series inductor, which operates similar to the power supply low pass filter. This has the effect of eliminating any high frequency ripple and distortion in the output, so that practically the response is identical to the voltage diode but of lesser magnitude. Actually the current detector operates as a square law detector and is usually used in circuits other than the superheterodyne (which uses the voltage form of detector). Therefore, the shunt diode (current) detector is used mainly in regenerative receivers of the pocket variety and is usually combined with reflex audio circuits to provide a loud but distorted output.

Circuit Operation. The circuit of a typical current diode detector is shown in the accompanying illustration.



Current Diode (Shunt) Detector

As shown, the diode is connected in shunt with the input circuit, and L1 is connected in series, with load resistor R1 also connected in shunt to ground. The LR combination of L1 and R1 have a combined time constant which is satisfactory for detection.

When the input signal is applied across CR1 the output is shunted to ground for the negative half cycle of the r-f input signal because CR1 conducts and no output occurs. During the positive half-cycle the signal is applied to L1 and current flows through R1 to ground and produces an output current which follows the r-f envelope. This action occurs because of the integrating effect of the LR circuit. During the current flow through L1 and R1 to ground a field is built up around L1 which tends to keep current flowing in the same direction when conduction ceases, and during the time that the detector diode is shunting the signal to ground, the field discharges through R1. Thus an integratin action occurs similar to that which would be produced if R1 were shunted by a capacitor, and the output current follows the peak waveform closely. Because of the reactance offered to high frequencies by L1, there is always a loss of voltage which makes the output smaller than the applied signal. Since a conducting path to ground is offered on the positive half-cycle of input signal, the rectification efficiency is lower than for a series connected diode (voltage detector) hence this circuit is not often used. In addition the low shunting effect during conduction and the low overall impedance to ground during the nonconducting period provide a heavy load on the source, and creates distortion when sufficient driving power is not available. Thus, the shunt detector is usually less preferred than the higher impedance, voltage-output form.

FAILURE ANALYSIS.

No Output. If the diode is shorted, or if either L1 or R1 are open there will be no output. Because of the few components involved a resistance check with an ohmmeter will usually locate the defective part.

Low Output. A defective diode CR1, high resistance soldered joints, or large changes in L1 or R1 can reduce the output. Check the values of L1 and R1 with an ohmmeter.

Distorted Output. If the output is continuously distorted, check the diode. If the distortion still persists, use an oscilloscope to observe the input and output signals, since the distortion is probably located in an earlier r-f stage or a later audio stage.

COMMON-EMITTER DETECTOR.

APPLICATION.

The common-emitter transistor detector is usually used in semiconductor superheterodyne receivers to supply a detected and amplified output.

CHARACTERISTICS.

Uses self-bias.

Offers a high input impedance.

Is equivalent to the diode detector in quality, with more gain available.

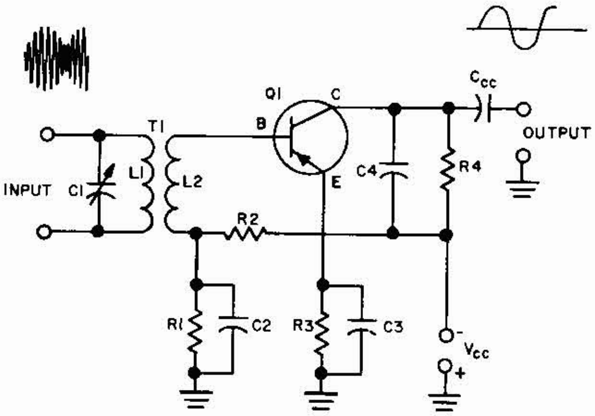
May be operated as either a small-signal, or a large-signal detector, depending upon bias voltage.

CIRCUIT ANALYSIS.

General. This detector is equivalent to the grid detector used in electron tubes. The base-emitter junction acts as a diode rectifier for large-signal linear detection when biased sufficiently, or as a square-law, small-signal detector when operating with low bias. When used in a receiver with only a few transistors it operates as a small signal detector, when used in superheterodynes it is used as a large signal detector. The operation is similar to that of the electron tube counterparts (grid and plate detectors) described earlier in Part A of this section.

Diode detection occurs in the base-emitter junction and amplification occurs using the emitter-collector junction. The combination can be considered the same as that of a diode and a transistor used separately.

Circuit Operation. The schematic of a typical transistor common-emitter detector is shown in the accompanying illustration.



Common-Emitter Detector

Tuned input transformer, T1, has a primary and secondary winding. The primary winding, L1 is tuned by capacitor C1 to the operating frequency (in superheterodyne receivers it is tuned to the IF), while secondary L2 remains untuned and inductively coupled. Resistors R1 and R2 are fixed-bias voltage dividers connected from the supply to the base and ground. Resistor R1 is bypassed by C2 for radio frequency and this RC combination also acts as the load resistor and bypass capacitor as used in a diode detector. The audio is detected in the base-emitter circuit and is applied as a d-c bias varying at audio frequencies to control collector current. The output is developed across collector load resistor R4, which is bypassed for r-f but not for audio frequencies. The emitter is connected to ground through a conventional swamping resistance (R3) for temperature stabilization, and is bypassed by C3 for both RF and audio.

In the absence of an input signal, transistor Q1 rests in a Class A-biased condition, drawing a moderate but steady collector current, and no output is obtained. When an input signal appears on the base of Q1 it is rectified by the base-emitter junction (operating as a diode) and appears as a d-c bias voltage with a varying audio frequency component across R1. This a-f component is developed across R1 as in the conventional diode detector previously discussed earlier in this section. Variations in base current flow caused by the input signal develop a voltage across R1 which follows the modulation envelope of the signal, any degenerative bias which tends to develop across emitter resistor R3 is eliminated by bypass capacitor C3. The output is developed by collector current flow from the supply through R4 which varies under control of the bias voltage across R1. Any radio frequency ripple in the output is bypassed across the collector load resistor by capacitor C4. The audio frequency variations, however, are not bypassed, and as the base is forward-biased by the negative half-cycle of input, it increases collector current flow, and a positive output voltage is developed across load R4. Likewise, when the base current is made to decrease on positive portion of the input signal (which reverse-biases the junction) collector current flow is reduced, and the collector output voltage rises towards the supply (becomes more negative). Thus since the output rises and falls in accordance with the modulation envelope, an amplified output of similar waveform is obtained and passed through coupling capacitor Ccc to drive the base of the following audio stage.

When a small fixed-bias is applied Q1, operation is on the lower (curved) portion of the base-emitter transfer curve and square law detection is obtained, with an increase of distortion. When biased higher (on the straight portion of the curve) the transistor operates as a linear diode detector with the additional amplification supplied by the collector circuit. The type of operation is determined during design by selecting the proper values of R1 and R2 to provide the desired bias for square law detection, and by choosing the proper value of emitter resistor R3 and bypass capacitor C3 for linear detection. The output in both instances is equivalent to that from a separate diode, amplified by a separate transistor operating at the same bias voltages. Usually when operating as a high-level (large signal) detector it is capable of driving an audio output stage directly. In this respect, it is the transistor equivalent of the electron tube power-detector.

FAILURE ANALYSIS.

No Output. Loss of an input signal, lack of bias, a defective transistor, loss of supply voltage, an open load resistor, or an open output capacitor can produce a no-output condition. Check the bias, supply, and collector voltages with a high resistance ohmmeter. If normal base bias is obtained, L2 and bias divider R1, and R2 are satisfactory, and C2 is not shorted. Likewise, with normal collector voltage R4 is okay and C4 is not shorted. An emitter voltage slightly larger than the bias applied and still no signal indicates that R3 and C3 are operating satisfactorily and that either L1 is open or C1 is shorted. Check the input circuit for continuity and shorts with an ohmmeter. The possibility exists that coupling capacitor Ccc may be open. In this instance, use of an oscilloscope would immediately show an output on the transistor side of Ccc, but nothing on the output side. When an oscilloscope is available, follow the signal through the circuit and note where it disappears or changes in shape or amplitude to locate the trouble.

Low Output. Improper bias, low collector voltage, or a defective transistor are the most likely causes of low output. Check for proper bias and collector voltage, and also check the supply to be certain that a blown fuse or the supply itself is not the cause. With normal voltages, the transistor must be defective.

Distortion. Normally the output is distorted to a certain extent, however, the modulation should be intelligible. When it is so distorted that it is garbled, check the output circuit to make certain the trouble is not in the following audio stage. When the distortion appears in the output stage but not in the detector, the trouble is in the output stage. Improper bias is usually the foremost cause of excessive distortion, and should be checked first with a voltmeter. If the bias voltages are normal, use an oscilloscope and follow the signal through the circuit until the pattern changes and shows the part at fault. It is important to remember to use an r-f probe when checking with the oscilloscope, since distortion in the r-f portion of the circuit will not show unless it is first detected by an r-f probe.

COMMON-BASE DETECTOR.

APPLICATION.

The common-base detector is usually used in small portable semiconductor receivers to provide detection with some amplification, and where extreme fidelity is not required.

CHARACTERISTICS.

Employs grid-leak bias.

Is equivalent in output to a diode and a separate amplifier stage.

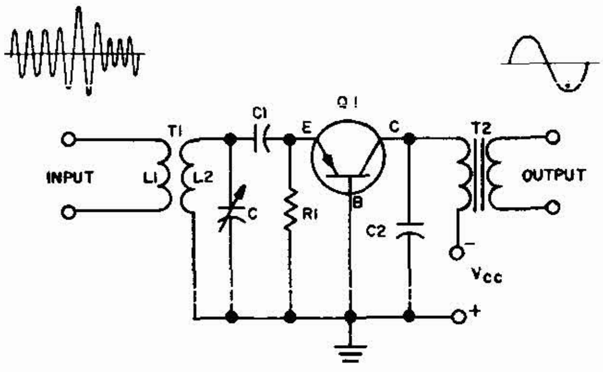
Produces more distortion than the common-emitter detector, or a diode detector.

Operates as a small signal detector which can easily be overloaded.

CIRCUIT ANALYSIS.

General. The common-base detector is the transistor equivalent of the electron tube grid-leak detector. Detection occurs in the base-emitter junction and amplification occurs through use of the collector junction. The output is the equivalent of a diode detector followed by a stage of audio amplification, but with more inherent distortion. Where less distortion and better quality are required a separate diode and transistor audio stage are used.

Circuit Operation. The schematic of a typical common-base detector is shown in the accompanying illustration.



Common-Base Detector

Transformer T1 is an r-f transformer when used in simple two or three stage receivers, or an i-f transformer when used in superheterodynes. It is tuned to either the i-f frequency or the operating frequency, as applicable. In the drawing T1 is single tuned in the secondary, but may also be tuned in the primary. Resistor R1 and capacitor C1 form a grid-leak bias network which sets the operating point of the emitter junction. The audio output is taken from the collector circuit through audio output transformer T2, however, RC coupling may be used to help improve fidelity if a smaller output is satisfactory. The primary of T2 forms the detector output load and is bypassed for r-f ripple by capacitor C2.

The input signal is applied to either the tuned or untuned primary and inductively coupled to the L2 secondary. When tuning capacitor C is tuned to the proper frequency, the input signal is coupled through C1 to the emitter. In the absence of a signal, contact bias exists as determined by resistor R1. The small flow of reverse current develops small bias voltage across R1 which is near zero and only the small normal reverse current flows. When the positive portion of the input signal occurs, current flows through the emitter-base junction driving the emitter positive (forward bias) and capacitor C1 is charged negatively, establishing the operating point. On the negative excursion of the input signal capacitor C1 is discharged through R1 creating a negative, reverse-bias which reduces conduction in the emitter junction. The bias developed follows the wave envelope of the modulated signal and produces a d-c emitter bias which varies at audio frequencies. Variation of the emitter bias causes the collector current to flow in accordance with the audio frequency variations of the modulation, and the output voltage is developed by collector current flow through the primary of audio transformer T2. Capacitor C2 effectively acts as a low pass filter, and filters out any r-f or i-f component (ripple) existing in the collector circuit. Thus only the audio variations induce a voltage in the primary of T2, and the field around the secondary of T2 varies in accordance with collector current changes, inducing an output voltage in the secondary. Strong signals may develop too much bias on the emitter, cut off collector current flow, and cause blocking. Since the bias ordinarily is small, the transistor operates on the lower portion of the emitter-base transfer characteristic curve and is a square law detector. Thus, at 100% modulation, distortion up to a maximum of 25 percent can exist. Such high values of distortion render this type of detector unsuitable for music or high fidelity broadcast use, except in cheap receivers in which the distortion can be tolerated for the sake of simplicity, economy, and portability.

FAILURE ANALYSIS.

General. When making voltage checks use a vacuum-tube voltmeter to avoid the low values of shunting resistance employed on the low voltage ranges of conventional volt-ohmmeters. Be careful, also, to observe proper polarity when checking for continuity with the ohmmeter, since a forward bias through any of the transistor junctions will cause a false low-resistance reading.

No Output. Lack of collector voltage, an open input or output circuit caused by a defective transformer (T1 or T2), or a defective transistor can cause a no-output condition. Measure the collector voltage with a VTVM. Normal collector voltage on Q1 indicates that T2 and the output circuit are satisfactory. If no collector voltage exists, either T2 is open or C2 is shorted. Use a volt-ohmmeter and a capacitance checker to check these two parts. When collector voltage exists but there is no output, check T1 primary and secondary for continuity with an ohmmeter and tuning capacitor C for a short circuit. There is also the possibility of C1 being open. Use an ohmmeter and capacitance checker to check continuity and the capacitor for proper value. If T1 is satisfactory the transistor must be at fault.

Low Output. Lack of collector voltage or an open output circuit, as well as a defective transistor can cause a reduced output. Measure the collector voltage, if it is normal, either output transformer T2 is open or shorted, or Q1 is defective. Check the transformer for continuity or short circuit with an ohmmeter, and check C2 with a capacitance checker.

Distorted Output. The output will normally be distorted, but should be intelligible. If the distortion is so bad that the modulation is garbled, check the input and output waveform with an oscilloscope. If the waveform is undistorted in the base circuit but appears distorted in the collector circuit, check the values of C1 and R1. Since these parts set the bias point, a change in the value of either one can cause clipping or peak distortion effects. If these parts values are proper and within the tolerance indicated in the instruction book on the equipment, the transistor is most likely at fault.

FM DETECTORS.

The f-m detectors discussed in the following paragraphs are used to demodulate a frequency modulated r-f signal. Because of the similarity between a frequency modulated (FM) signal and a phase modulated (PM) signal f-m detectors may also be used with minor changes to demodulate a phase-modulated signal. While the circuits used in FM transmission and reception are more complex than those used for AM, FM provides more advantages which outweigh the additional complex circuitry. One of the most important advantages is in noise reduction of both man-made and natural static. Since most of these noise variations occur as amplitude variations, and the FM receiver is designed so that it does not respond to amplitude variations, noise is automatically eliminated in FM reception.

Semiconductor FM detectors can be divided into roughly three groups of circuits, namely, discriminators, ratio detectors, or slope detectors. These detectors are very similar in circuitry to that of their electron tube counterparts in that crystal diodes are merely substituted for the vacuum-tube diodes. Although these diodes do not have the practically infinite back resistance of the electron tube, otherwise, their performance is similar. And, they do have the advantage of not requiring filament power. For precise frequency response or frequency control, discriminator circuits are usually employed. Whereas, the reduced response of the ratio detector is reserved for receivers where economy and simplicity are desired. Each of these circuits is discussed in detail in the following paragraphs.

FOSTER-SEELEY DISCRIMINATOR.

APPLICATION.

The Foster-Seeley discriminator is used in semiconductor communications receivers and particularly where automatic frequency control or high fidelity is required.

CHARACTERISTICS.

Must be preceded by limiter stages to eliminate any AM response.

Uses a double-tuned transformer.

Uses two separate diodes.

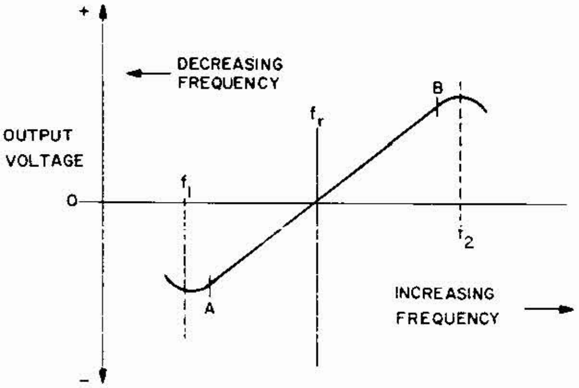
Has low inherent distortion.

Converts instantaneous frequency variations into instantaneous d-c voltage variations.

CIRCUIT ANALYSIS.

The Foster-Seeley discriminator (also known as the phase-shift discriminator) uses a double-tuned r-f transformer to convert the instantaneous frequency variations of the received f-m signal into instantaneous amplitude variations. The amplitude variations are then rectified and filtered to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output voltage is zero when the input frequency is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency the output increases in one direction (for example, becomes more positive), and when the input frequency drops below the center frequency, the output increases in the other direction (for example, becomes more negative).

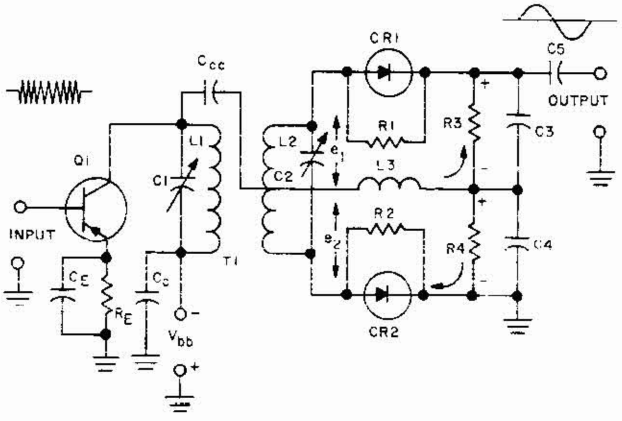
Since the output of the Foster-Seeley discriminator is dependent not only on the input frequency, but also to a certain extent upon the input amplitude, it is necessary to use one or two limiter stages before detection. When properly limited, and the input frequency is varied from a lower frequency through the resonance point of the discriminator, and is then raised higher in frequency, the typical discriminator response curve shown in the accompanying illustration is obtained.



Discriminator Response Curve

The usable portion of the typical "S" shaped response curve is from point A to point B in the illustration. Between these points, the curve is linear and the instantaneous output voltage is directly proportional to the instantaneous frequency deviation.

Circuit Operation. The accompanying circuit schematic illustrates a typical Foster-Seeley semiconductor discriminator.



Foster-Seeley Discriminator Circuit (including limiter stage)

The collector portion of the preceding i-f (limiter) amplifier Q1 is shown on the schematic with conventional emitter resistor R_E and bypass capacitor C_E. The collector circuit tank consisting of C1 and L1 is the primary tank of i-f input transformer T1, while L2 and C2 form the secondary tank circuit; both tanks are tuned to the center frequency. Choke L3 forms the d-c return for diode rectifiers CR1 and CR2. While CR1 and CR2 are shown bypassed by equalizing resistors R1 and R2, they are not always used (they are usually used when the diode back resistances are different). Resistors R3 and R4 are the load resistors bypassed by C3 and C4, respectively, for r-f, capacitor C5 is the output coupling capacitor.

The center tap on coil L2 is capacitively coupled through coupling capacitor C_{cc} to the primary. And the full voltage exists across choke L3. At resonance (the center frequency) equal voltages e_1 and e_2 are produced across both halves of L2, thus equal voltages are applied to the anodes of CR1 and CR2. Assuming these voltages are positive, conduction occurs and current flow through diode load resistors R3 and R4 produce equal and opposing voltages across filter capacitors C3 and C4. Since the output is taken from C5 to ground, the equal and oppositely polarized signals cancel and produce no output at the center frequency. However, as the frequency is raised above the center frequency, the phase relationships in the halves of the tank circuit cause a voltage change so that e_1 becomes larger than e_2. Since it is larger than the voltage across R4, the voltage of R3 predominates, creating a positive output voltage.

Conversely, when the input signal frequency drops below the center frequency and is lower, voltage e_2 is larger than e_1 and the voltage across R4 predominates, creating a negative output. As long as the input frequency variations remain within the limits of peak separation marked A and B on the discriminator curve, a linear frequency versus amplitude relationship is maintained. That is the higher the frequency the larger the positive output voltage becomes, and the lower the frequency the larger the negative output becomes. (If desired, the discriminator transformer can be wound and connected to produce opposite polarities from that described above.) In any event, the output voltage is always developed across both R3 and R4, and it is always the algebraic sum of these. Capacitors C3 and C4 are used to store the instantaneous voltages and develop an average output which varies at audio frequencies. This output, in turn, is coupled to the audio amplifying stages by coupling capacitor C5 (any coupling method may be used). Thus, while the input consists of a constantly varying f-m signal of steady amplitude, the output is an audio frequency which varies linearly both in frequency and amplitude in accordance with the frequency swing of the input signal.

FAILURE ANALYSIS.

No Output. A defect in the primary or secondary windings of T1, in the RFC, or in tank tuning capacitors C1, C2, or C3, as well as defective diodes can cause a no-outpu condition. It is also possible for coupling capacitors C_{cc} or C5 to be open, or for bypass capacitors C_E, as well as

C3 or C4 to be shorted and bypass the signal to ground. Use an ohmmeter to check the primary and secondary of T1 and the RFC for continuity, and for shorts to ground. If these checks fail to locate the trouble, use an in-circuit capacitance checker to measure the values of C1, Cc, Ccc, C3, and C4. Note also, that both diodes must fail to cause no-output, since if only one fails there still will be an output. When possible, use an oscilloscope to observe the waveform at the input and follow the signal through the circuit noting where the signal disappears to locate the source of the trouble.

Low or Distorted Output. A defect in nearly any component in the discriminator circuit may cause the output to be low or distorted. Use an R-F Sweep Generator and an oscilloscope to isolate the trouble. Connect the sweep generator to the input and check the output with the scope on Q1 and at the anode of diode CR1 or CR2. Lack of signal at Q1 indicates defective transistor or part in the transistor stage of Q1. A signal on Q1 but not at the diode anodes indicates Ccc is either open or shorted to ground. If the input signal does not change in amplitude as the input frequency varies, the trouble is most likely in the discriminator circuit. To determine if the discriminator is at fault, ground the base of limiter stage Q1 and connect the r-f sweep input to the discriminator input, with the oscilloscope connected to the discriminator output. Adjust the sweep generator to produce an output which varies both below and above the discriminator center frequency and observe if the pattern on the oscilloscope is that of the typical "S" curve shown in the first illustration of this discussion. Defects in the circuit will cause either the entire curve or a portion of it to be distorted, or flattened.

If the entire response curve is distorted the trouble may be caused by either improper alignment or by a defect in transformer T1. First check to be certain that both the primary and secondary tank circuits are tuned to the proper center frequency. If the discriminator is aligned properly, the trouble is most likely in the transformer.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR1, capacitor C3, resistor R3 or transformer T1. Use an in-circuit capacitance checker to check capacitor C3 for value and leakage, and use an ohmmeter to check resistor R3 for a change of value.

Conversely, if only the bottom portion of the discriminator response curve is distorted, the trouble may be caused by diode CR2, capacitor C4, resistor R4, or transformer T1. If the trouble persists use an in-circuit capacitance checker to check C4 for value and leakage, and use an ohmmeter to check resistor R4 for a change of value. If these checks fail to restore the output to normal, transformer T1 is most likely defective.

RATIO DETECTOR.

APPLICATION.

The semiconductor ratio detector is used in semiconductor type FM receivers to demodulate the received r-f, f-m signal, and in afc control circuits to transform frequency changes into d-c control voltages.

CHARACTERISTICS.

Employs a double tuned transformer and two solid state diodes.

Converts instantaneous frequency variations of the f-m signal into instantaneous d-c voltages.

Distortion is inherently low.

Output is not affected by input amplitude variations when preceded by a limiter stage.

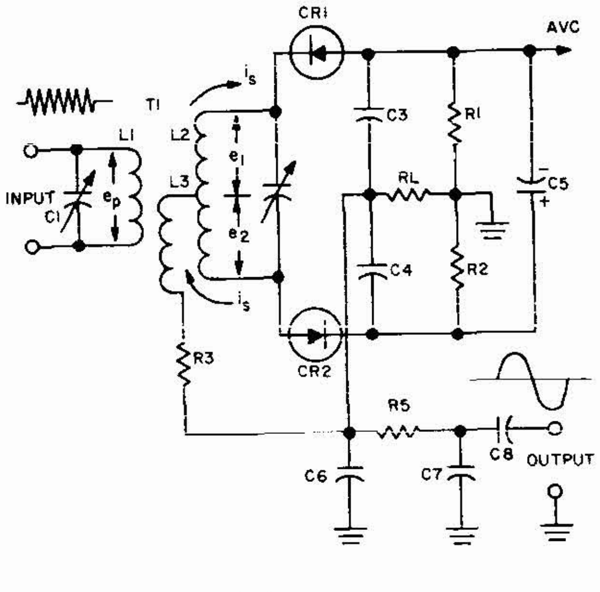
CIRCUIT ANALYSIS.

General. The semiconductor ratio detector, like the electron tube ratio detector previously discussed in Part A of this Handbook, uses a double tuned transformer (discriminator) connected so that the instantaneous frequency variations of the FM input signal are converted into instantaneous amplitude variations. These amplitude variations are rectified by the diodes to provide a d-c output voltage which varies in amplitude and polarity as the input signal varies in frequency. The output is zero when the input is equal to the **center frequency** (unmodulated carrier frequency). When the input frequency rises above the center frequency, the output voltage increases in one direction (for example, becomes more negative). The specific polarity of the output voltages obtained for an increase or decrease in input frequency is determined by the design of the circuits and may vary from circuit to circuit.

Circuit Operation. The accompanying schematic diagram illustrates a typical semiconductor ratio detector.

The input tank circuit comprised of C1 and primary winding L1 of T1 is tuned to the center frequency of the received f-m signal. Secondary winding L2 and capacitor C2 also form a tank circuit tuned to the center frequency. Tertiary winding L3 provides additional inductive coupling which reduces the loading effect of the secondary on the primary circuit of the detector. Solid state diodes CR1 and CR2 rectify the signal from the secondary tank. Capacitor C5, in conjunction with resistors R1 and R2 determines the operating level of the detector, while capacitors C3 and C4 determine the amplitude and polarity of the output. Resistor R3 modifies the peak diode current and furnishes a d-c return path to ground. The output of the detector is taken from the common connection between C3 and C4 to ground, which is also the common connection of R1 and R2. Resistor RL is the load resistor. A low-pass filter is formed by R5 together with C6 and C7 to provide high frequency deemphasis. Capacitor C8 is the output coupling capacitor.

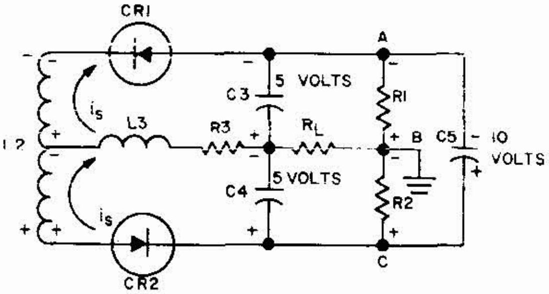
When input voltage e_p is applied to the primary, it also appears across L3 since it is effectively connected in



Ratio Detector

parallel with the primary tank circuit by inductive coupling. When voltage e_p is applied to the primary winding of transformer T1, a voltage is also induced in the secondary winding and causes current to flow around the secondary tank circuit. When the input frequency is at the center frequency, the tank is at resonance, is resistive, and acts like a resistor. Therefore, tank current is in phase with primary voltage e_p. The current flowing in the tank circuit causes equal voltage drops to be produced across each half of the balanced secondary winding of T1, which are of equal magnitude and of opposite polarity with respect to the center tap of the winding. Since the winding is predominately inductive, the voltage drop across it is 90 degrees out of phase with the current through it. At the same time, because of the center tap arrangement, the voltages to ground at each end of the secondary are 180 degrees out of phase and are shown as e_1 and e_2 on the schematic.

The voltage applied to the cathode of CR1 consists of the vector sum of e_1 and e_p. Likewise, the voltage applied to the anode of CR2 consists of the vector sum of voltages e_2 and e_p. Since at resonance there is no phase shift, both voltages are equal. Consider now the manner in which the diodes operate with the discriminator voltage discussed above. When a positive input signal is applied to L1, a voltage of opposite polarity is induced into secondary L2. As shown in the accompanying simplified schematic, the cathode of CR1 is negative with respect to its anode and is forward biased, while the anode of CR2 is positive with respect to its cathode and is likewise, forward biased. Since both voltages are of equal magnitude at resonance, both diodes conduct equally. Hence current flow through CR1 is in one direction, while the current flow through CR2 is in the opposite direction. This direction of current flow causes a negative polarity at point A and a positive polarity at point B. Through RL a positive charge is applied to C3. In a similar manner current flow through CR2 produces a negative polarity at point B and a positive polarity at C. Hence capacitor C4 is charged negatively. Since the polarities are additive, capacitor C5 across the output charges to the series value of twice this voltage.



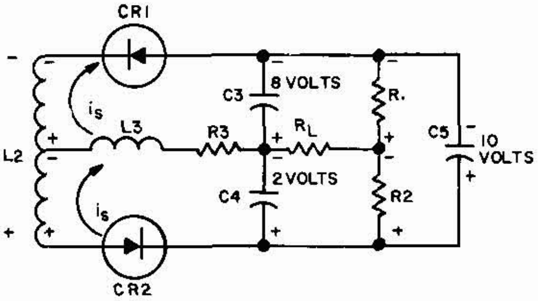
Simplified Schematic

In the example shown, it is assumed that equal but opposite voltages of 5 volts exist across C3 and C4. Therefore, the total charge across C5 is 10 volts. Since the voltage across C3 and C4 are equal in amplitude (5 volts) and of opposite polarity, the output across load resistor RL is the algebraic sum or zero.

When the input signal reverses polarity, the secondary voltage across L2 also reverses polarity. The cathode of CR1 is now positive with respect to its anode, and the anode of CR2 is negative with respect to its cathode. Under these reverse-bias conditions neither diode conducts, and there is also no output. Meanwhile C5 retains most of its charge because of the long time constant offered by R1 and R2 and discharges very slightly.

When a tuned circuit operates at a higher frequency than resonance, the inductive reactance of the coil increases, while the capacitive reactance of the tuning capacitor decreases. Therefore, above resonance the tank is predominately inductive and acts like an inductor. Hence the secondary current (i_s) **lags** the primary voltage e_p. Therefore, when an input frequency higher than the center frequency is applied to the detector circuit, a phase shift occurs. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase, they are also 90 degrees out of phase with the current (i_s) which produces them. Thus the change to a lagging secondary current rotates the vector in a clockwise direction and e_1 is brought nearer in phase with primary voltage e_p, while e_2 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_1 is now larger than that of e_p and e_2. Therefore, above the center frequency the voltage applied to the cathode of CR1 becomes greater than the voltage applied to the anode of CR2.

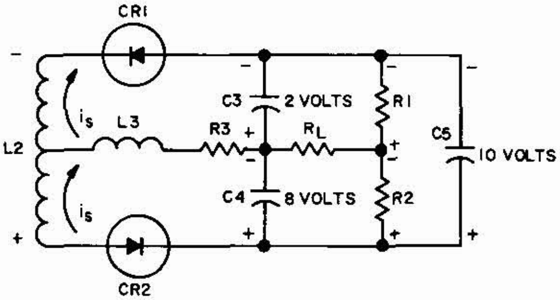
Consider now the manner in which the diodes operate with the discriminator voltages developed above resonance, as discussed above. When a positive input is applied to L1 the same polarity as in the previous example discussed above exists, namely CR1 cathode is negative and CR2 anode is positive, and both diodes conduct. However, e_1 is now greater than e_2. Therefore, diode CR1 conducts more than diode CR2, and C3 charges to a higher voltage than at resonance, as shown in the accompanying simplified illustration.



Current Flow and Polarities Above Resonance

Thus, we assume in the figure an 8-volt charge on C3 and only a 2-volt charge on C4. Since C3 is positive with respect to C4, the output is a 6-volt positive signal. Meanwhile, capacitor C5 still remains charged to the sum of these voltages or 10-volts, as originally stated. When the input signal reverses polarity, the polarity of the secondary also reverses, biasing both diodes in the opposite direction, and preventing conduction. During the non-conducting period, C5 discharges very little because of the long time constant.

When a tuned circuit operates at a lower frequency than resonance, the capacitive reactance of the tuning capacitor increases, while the inductive reactance of the tank coil decreases. Therefore, below resonance, the tank is predominately capacitive and acts like a capacitor. When an input frequency lower than the center frequency is applied to the detector circuit, a phase shift also occurs and secondary current is **leads** the primary voltage e_p. Although secondary voltages e_1 and e_2 are still 180 degrees out of phase they are also 90 degrees out of phase with the current which produces them. Thus the change to a leading secondary current rotates the vector in a counterclockwise direction, and e_2 is now brought nearer in phase with e_p, while e_1 is shifted further out of phase with e_p. Thus the vector sum of e_p and e_2 is now larger than that of e_p and e_1. Therefore, below the center frequency the voltage applied to the anode of CR2 becomes greater than the voltage applied to the cathode of CR1 as shown in the accompanying simplified schematic.



Current Flow and Polarities Below Resonance

Once again CR1 and CR2 are conducting, but this time CR2 is conducting more than CR1, hence, capacitor C4 is charged to the larger voltage of 8-volts, while C3 is only charged to 2-volts. The output voltage across the load in this case is a negative 6-volts because C4 is charged negatively with respect to C3. Again the charge across capacitor C5 consists of the sum of the voltages across C3 and C4, or 10-volts as originally developed.

When the input signal reverses its polarity, the signal across the secondary also reverses its polarity. The cathode of CR1 is now positive with respect to its anode and the anode of CR2 is negative with respect to its cathode. Under these conditions, neither diode conducts, but the time constant of C5 together with R1 and R2 maintains the current through the load in a negative direction until the next cycle of input, and C5 discharges but slightly.

The output of the ratio detector adjusts itself automatically to the average amplitude of the input signal. Through the action of resistors R1 and R2 together with capacitor C5, audio output variations which would occur due to r-f amplitude variations in the input (such as noise) are eliminated. Since C5 charges to the sum of the voltages developed across R1 and R2, any amplitude variations at the input of the detector tends to change the voltages across R1 and R2, but because of the long time constant of C5 across these resistors, these voltages are held to a minimum. Before C5 can charge or discharge to the higher or lower amplitude variation the impulse disappears, and the difference in charge across C5 is so slight that it is not discernible in the output. Because the voltage across C5 remains relatively stable and changes only with the amplitude of the center frequency, and since it is negative with respect to ground, it is usually used for automatic volume control (AVC) applications.

Capacitors C6 and C7 together with resistor R5 form a low pass filter which attenuates the high audio frequencies and passes the lower frequencies. This is known as a de-emphasis network, which compensates for the pre-emphasis with which the high frequencies are transmitted, and returns the audio frequency balance to normal. When *pre-emphasis is not employed these parts are not needed.*

FAILURE ANALYSIS.

No Output. A defective discriminator transformer, T1, shorted tuning capacitor C1 or C2, an open output resistor R5, an open coupling capacitor C8, or shorted filter capacitors (C6 or C7) will produce a no-output condition. Check the continuity of the windings of T1 with an ohmmeter. Check capacitors C1, C2, C6 and C7 for shorts and capacitor C8 for an open with an ohmmeter, and measure the resistance of R5. If any of these checks fail to restore the output check all capacitors for value with an in-circuit capacitance checker. Note that while one defec*tive diode will produce a partial loss of output, both diodes* must fail to cause a complete loss of output.

Low or Distorted Output. A defect in nearly any component of the detector will cause the output to be either low or distorted. Therefore, it is good practice to use an r-f sweep generator and an oscilloscope to locate the trouble. Ground the grid of the last I-F stage and connect the r-f sweep generator to the detector input, and connect the oscilloscope to the detector output. With the sweep generator set to produce an output which varies above and below the center frequency, the pattern observed on the oscilloscope should be similar to the discriminator response curve illustrated previously. Defects in the response curve *will cause either the entire curve or a portion of it* to be distorted or flattened.

If the entire curve is distorted, the trouble may be caused by improper alignment or by a defect in transformer T1. First check to be certain that both primary and secondary circuits are tuned properly to the center frequency. If the detector is properly aligned, check capacitors C1 and C2 with an in-circuit capacitance checker. Check R1 and R2 for their proper value with an ohmmeter, and capacitor C5 for value and leakage with an in-circuit capacitance checker. If the trouble is still not located, it is most likely caused by a defect in transformer T1.

If only the upper portion of the response curve is distorted, the trouble may be caused by a defect in diode CR1, capacitor C3, or transformer T1.

Conversely, if only the lower portion of the response curve is distorted, the trouble may be caused by a defect in diode CR2, capacitor C4, or transformer T1.

VIDEO DETECTORS.

The semiconductor video detector is very similar to the vacuum tube video detector. Generally speaking, the video detector must handle a larger range of frequencies than the standard detector. Thus we usually find either shunt or series peaking, or both systems, used to compensate for loss of the higher frequencies. Actually, whether or not there is excessive loss of high frequencies is sometimes doubtful. For example, using the standard diode detector provides a broad response and it is the relative amount of loss of output voltage in response to frequency that is important. Thus in the case where the high frequency output tapers off gradually it is questionable if peaking is necessary. On the other hand, where the cutoff is rather sharp, then boosting circuits are in order.

The simplest circuit, of course is that of the diode video detector, however, this provides little or no gain since inherently the diode has no amplification. On the other hand by using a transistor type of detector, the emitter-base junction can provide the detection while amplification is obtained from the collector-base junction. Thus, in one stage both detection and amplification are obtained and fewer driver circuits are needed to boost the output amplitude sufficient to drive an indicator.

If the diode is used it is necessary to keep the input impedance level on the high side to maintain the rectification efficiency of the diode at a high level. On the other hand, a transistor can serve efficiently as a video detector into a relatively low value of impedance. The high base impedance provides the necessary high impedance input, while the output at medium or moderately low impedance matches the following video amplifier stage. Hence the general trend is to use triode video detectors, rather than diodes followed by extra stages of video amplification which do require adequate equalizing and peaking.

BASIC VIDEO DETECTOR.

APPLICATION.

The basic video detector is used in semiconductor receivers of the superheterodyne type to provide a high gain video output.

CHARACTERISTICS.

Uses either fixed or self-bias.

Is equivalent of a diode and one stage of transistor amplification.

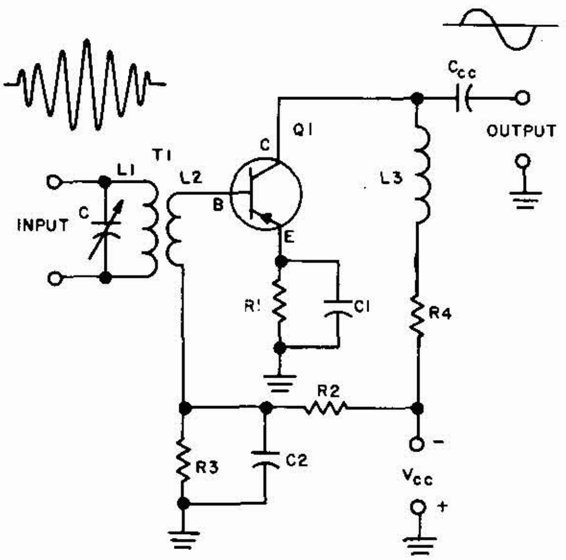
Uses video peaking circuits to provide good high frequency responses.

CIRCUIT ANALYSIS.

General. The operation of the basic video detector is *identical to the operation of the AM diode detector previous*ly discussed in Part A of this Handbook. The only difference lies in the use of the base-emitter junction of the transistor as a diode in place of a separate diode. Compensating circuits are added in the collector circuit to ensure better high frequency response. The reader should refer to the discussion of the Diode Detector, in Part A of this section of the Handbook, for proper background before proceding with the discussion of the semiconductor basic video detector.

Circuit Operation. The schematic of a typical transistor video detector using shunt peaking is shown in the accompanying illustration.

The base of transistor Q1 is connected to the untuned secondary of i-f transformer T1, with the primary tuned by capacitor C. Resistors R2 and R3 from a base bias voltage divider from the negative supply to ground, with the voltage drop across R3 supplying the base bias to Q1 through the



Basic Video Detector

secondary winding L2 of T1. R3 is bypassed by C2 to prevent a degenerative voltage from being developed across R3 with the instantaneous bias swings, thus allowing voltage divider R2 and R3 to provide a steady forward bias to the base of Q1. Resistor R1 is a conventional emitter swamping resistor used to stablize the transistor against thermal changes and, likewise, is bypassed by C1 to prevent degeneration in the emitter circuit and negative feedback effects. Inductor L3 is a shunt peaking inductance with R4 supplying resistance to widen the response. L3 also acts as the detector output load resistor across which the output voltage is developed and applied through coupling capacitor Ccc to the following stage, or direct to the CRT if sufficient drive exists.

When an input signal is applied to T1, the i-f frequency is selected by tuned circuit L1 and C, and this i-f together with any modulation component is inductively coupled through secondary L2 which is left untuned for a broad response, and the signal is applied to the base of Q1. The emitter-base junction of Q1 acts as a rectifier and instantaneously changes the bias in accordance with the low frequency variations of the modulation envelope. Any remaining i-f is bypassed through capacitors C1 and C2 to ground and has no effect on circuit operation. As the audio envelope of the received signal changes the bias on Q1, the collector current is varied likewise, and the collector current fluctuates in accordance with the modulation. The audio frequency variations are bypassed across emitter resistor R1 by capacitor C1 so that only the long time temperature variations can produce a voltage change across R1. However, the flow of collector current through L3 and R4 produces a change of collector voltage on the collector side of the choke. A positive modulation swing causes a decrease of forward conduction and raises the instantaneous collector voltage. Likewise, a negative audio excursion causes an increased forward bias and conduction, and the collector voltage of Q1 reduces. Since only a small change in base current causes a large change in collector current, amplification of the detected signal is obtained in the collector circuit of Q1 and appears as a larger output voltage across L3 and R4. By resonating L3 with the stray capacitance in the circuit, the normal drop off in amplitude at higher frequencies is compensated for and the high frequency range is extended. Resistor R4 keeps L3 loaded down so that the overall frequency response of the detector is broadened. As the output voltage is developed across L3 it also is applied through Ccc to the output. Where the output voltage is sufficient the CRT may be driven directly. Where the voltage is not sufficient, an additional voltage amplification driving amplifier stage is added to increase the overall drive, as required.

FAILURE ANALYSIS.

No Output. An open input transformer, an open base circuit, emitter circuit, or collector circuit, as well as a defective transistor or open coupling capacitor can cause a no-output condition. Check the collector, base, and emitter bias with a high resistance voltmeter. Voltage at the collector indicates that L3 and R4 are not open, while emitter voltage indicates that R1 is not open or shorted. Likewise, base bias indicates that voltage divider R2 and R3 is operating, and that secondary L2 of T1 has continuity. With these voltages obtained and no output, either winding L1 of T1 is open or shorted, or Ccc is open. Check C and Ccc with an in-circuit capacitance checker, and also check the continuity of T1 primary L1 with an ohmmeter. If base bias is zero R3 is shorted, also check C2 for capacity with an in-circuit capcaitance checker. If the emitter voltage is also zero R1 is shorted by C1, however, the transistor will still function and produce an output which will vary with temperature. If there is no collector voltage, check the supply voltage to make certain it is not at fault, check the value of R4 with an ohmmeter and check L3 for continuity.

Low Output. High base bias, low collector voltage, or a defective transistor can cause a no-output condition. If bias voltage divider resistor R3 changes to a higher value of resistance, or if R2 becomes lower in value, the net effect is to make the total base bias higher, check these resistors with an ohmmeter. If R4 becomes higher in resistance, the collector voltage will also drop and reduce the output. Check R4 with an ohmmeter. If a high bias is measured across emitter resistor R1, capacitor C1 is open, check C1 for value with an in-circuit capacitance checker. Do not neglect the possibility that the input tank controlled by capacitor C may be detuned from the desired i-f input frequency. If not shorted, tuning C will peak the response. If the response does not peak as C is tuned around the input frequency, check capacitor C for a short or open on a capacitance meter.