CHAPTER 9

ELECTRONIC NAVIGATIONAL AIDS

Basically, electronic navigation is a form of piloting. Piloting is that branch of navigation in which a ship's position is obtained by referring to visible objects on the earth whose locations are known. This reference usually consists of bearing and distance of a single object, cross bearings on two or more objects, or two bearings on the same objects with an interval between them.

Position in electronic navigation is determined in practically the same way that it is in piloting. There is one important difference, however. The objects by which the ship's position is determined need not be visible from the ship. Instead, their bearings (and in most instances their ranges) are obtained by electronic means—usually radio.

The advantages of piloting by radio are obvious. A ship's position may be fixed electronically in fog or thick weather that otherwise would make it impossible to obtain visual bearings. Moreover, it may be determined from stations located far beyond the range of even clear-weather visibility.

This chapter will deal with electronic navigation by Loran, Shoran, Omega, SINS, Satellite, and Tacan.

LORAN NAVIGATION SYSTEM

The long-range navigation (loran) system provides a means of obtaining accurate navigational fixes from pulsed radio signals radiated by shore-based transmitters. Depending on the mode of loran operation and the time of day or night, fixes are possible at distances up to 3000 nautical miles from the transmitting stations.

The loran system comprises two subsystems, or modes of operation, called loran A and loran C. Because loran A is the basic mode of operation, it is used as the vehicle for explaining the loran principle of operation. Loran C is a refinement of loran A, differing from the basic mode mainly in operating frequency and coding of signals employed. It has a much greater distance range than loran-A.

LORAN PRINCIPLE

The principle of loran is illustrated in figure 9-1. If part A, stations A and B are pulsed simultaneously, the two pulses arrive at any point on the center line at the same time. This is evident from the geometry of the figure; and an observer, with the proper receiving equipment, could tell if he was on this line.

Suppose, however, that an observer is located closer to station A than to station B. Then the pulse from station A will arrive at his location before the pulse from station B. Assume that the time difference is 800 μs, as shown in part B. There are many points at which the receiving equipment will indicate a time difference of 800μs; these points lie on a hyperbola. Connecting the points where the time difference is the same, forms a line of constant time difference, or hyperbolic line of position. This line (solid curved line) forms the LEFT BRANCH of the hyperbola. It is concave toward station A.

If the observer knows that he is closer to station A than station B and that the time difference is 800 μs, he still does not know his exact position on the hyperbolic line of position.

Assume now that the observer is nearer station B than station A and that the time difference between the arrival of the two pulses is 800 μs. The line of constant time difference is then the right-hand branch of the hyperbola, and appears as the dotted curve in figure 9-1B.

(Stations A and B are the foci of the hyperbola.) If the pulses from the transmitters are identical, the observer has no way of telling

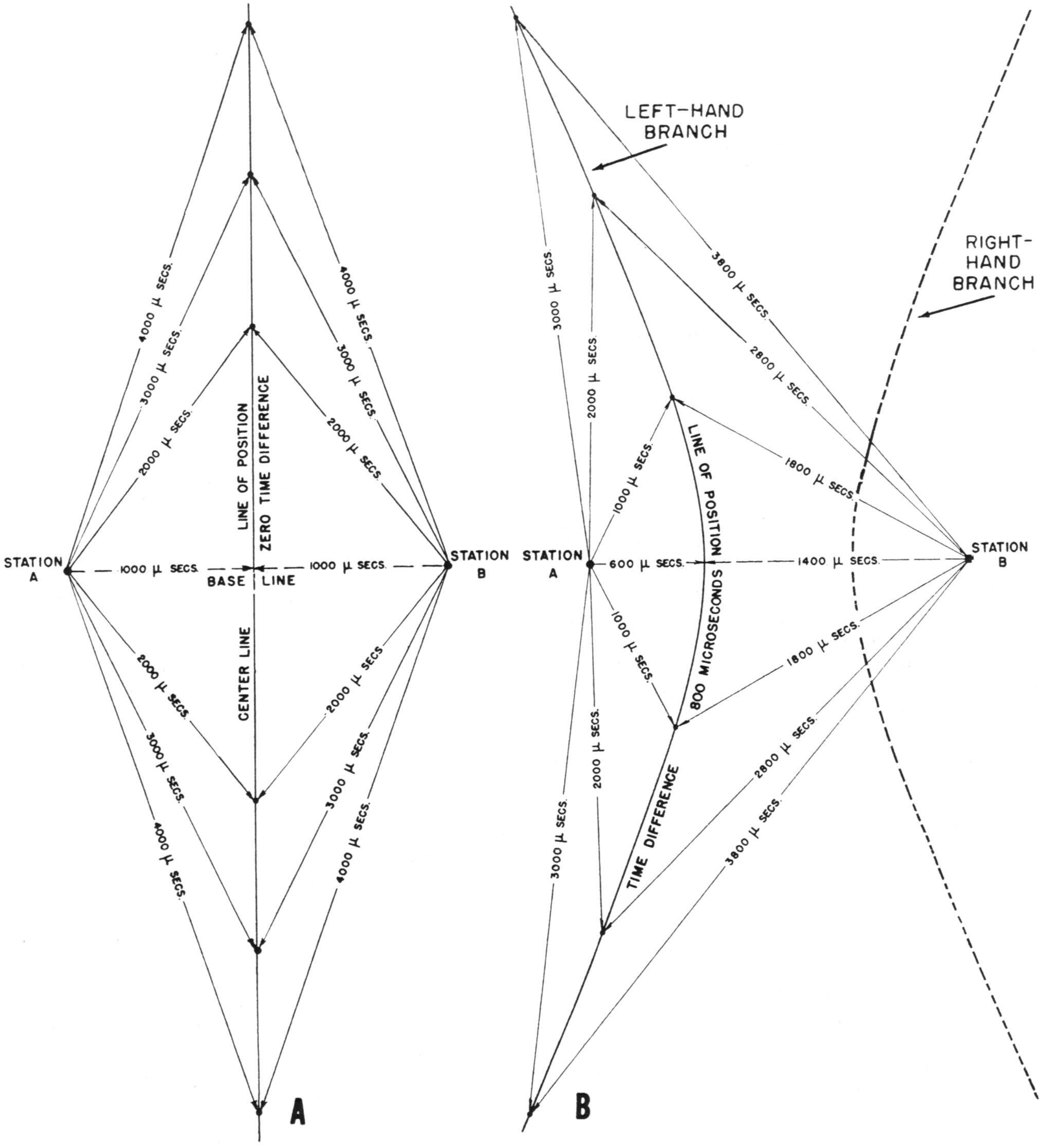

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Figure 9-1.—Principle of loran simplified.

which pulse arrives first. He then cannot determine on which branch of the hyperbola he is located. This difficulty is overcome, and at the same time the measurement made by the observer is simplified, by delaying the pulsing of one of the transmitters by an amount that is more than one-half the pulse-recurrence interval from the other station. For example, the interval between a pulse from A and the next pulse from B is always made greater than the interval between the B pulse and the next A pulse. Thus, the navigator can tell that the pulse followed by the longer interval is always from station A.

From the foregoing explanation it follows that many lines of position may be obtained. By selecting several time differences for a given pair of stations, the result is a family of hyperbolas like those shown in figure 9-2A. In this figure the pulses from both transmitters are identical and no time delay is introduced as indicated by zero on the center line.

In actual practice, one station of a loran pair (fig. 9-2B) is designated the master station. It establishes the Pulse Repetition Rate (PRR). The second, or slave station, receives the pulses of the master station and transmits its own pulses delayed in time but in synchronism with the master pulses. The time delay between the transmission of a pulse from the master station and the arrival of this pulse at the slave station depends chiefly upon the DISTANCE between the stations. This delay is caused by transit time.

After the pulse arrives at the slave station, there is a time delay of one-half the pulse-repetition period. This delay is necessary because of the two-trace method of

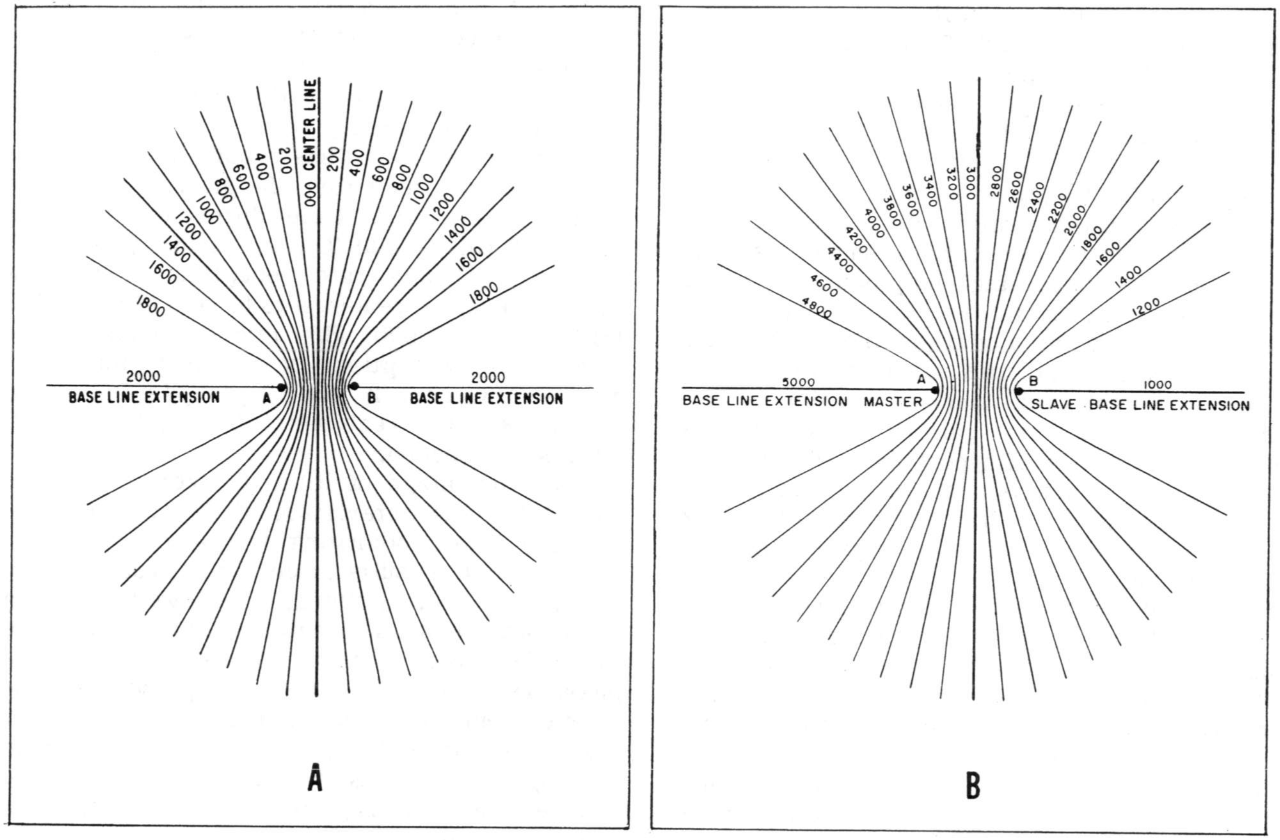

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Figure 9-2.—Loran lines of position.

cathode-ray-tube presentation at the loran indicator.

In addition to these two delays, another delay, called the CODING DELAY, is added. The sum of the three delays is called the ABSOLUTE DELAY. The absolute delay is the time between the transmission of a pulse from the master station and the transmission of a pulse from the slave station. The absolute delay in figure 9-2B, is 3000 μs, as indicated on the center line.

The PRR is different for different pairs of stations to enable the operator to identify the pair to which the receiver is tuned. There are four loran channels, numbered 1 through 4, corresponding to carrier frequencies of 1950, 1850, 1900, and 1750 kHz, respectively. The BASIC PRR is either 25 Hz (the LOW, or L, rate) or 33-1/3 Hz (the HIGH, or H, rate). A third basic recurrence rate of 20 Hz (the SPECIAL, or S, rate) is not in operational use, but is provided in new equipment to allow for expansion of the loran system.

The basic pulse recurrence rates are subdivided into SPECIFIC PRR. The specific low PRR is from 0 through 7, corresponding to 25 through 25-7/16 pulses per second in steps of 1/16 of a pulse per second. The specific high PRR is from 0 through 7, corresponding to 33-1/3 through 34-1/9 pulses per second in steps of 1/9 of a pulse per second.

To establish his position, the loran operator must have the proper loran charts, as well as the proper receiving equipment. A loran fix is the point of intersection of two lines of position. Two pairs of transmitting stations, or one master and two slave stations, are needed to establish the lines of position necessary for the fix. One pair of stations act as foci for one family of hyperbolas. The second pair of stations act as foci for another family of hyperbolas. As has been stated, a fix is the intersection of two hyperbolas, one from each family.

Figure 9-3 illustrates how a fix is obtained by using only one master and two slave stations. This is accomplished by causing the master station to transmit two distinct sets of pulses. The double-pulsed master station transmits one set of pulses at the PRR of the pulse transmitted by the first slave station and the other set of pulses at the PRR of the pulses from the second slave station.

Lines of position are identified by a letter and several numbers. The letter represents the basic PRR-Low (L), high (H), or special (S). The first number represents the channel (1 through 4), or carrier frequency; the second number denotes the specific PRR; and the last number is the time difference in microseconds. For example, 2L 6-2500 indicates channel 2, which is 1850 kHz; a low basic PRR of 25 Hz; a specific PRR of 6, corresponding to 25-6/16 Hz; and a time difference of 2500 μs.

For loran C operation, a master and two slave signals are transmitted on a carrier frequency of 100 kHz. These signals are multiple-group transmissions, identified as master or slave signals by the number of pulses transmitted in each group. The master group transmission is comprised of nine phase-coded pulses. The pulses are separated from one another by either 1000 or 500 μs, except that the ninth pulse is separated from the eighth by approximately 600 μs. The slave group transmission is comprised of eight pulses, each separated from the others by either 1000 or 500 μs to conform to the master station transmission. Phase coding is a method of changing the radiofrequency of each pulse relative to the frequency of the carrier. The phase is varied within each group of pulses in accordance with a prescribed program.

Loran C operation has capabilities for single or double rate reception. Single rate reception provides maximum time difference readings of 30,000 (H), 40,000 (L), and 50,000 (S) microseconds. Double rate reception extends the time difference readings to 60,000 (SH), 80,000 (SL), and 100,000 (SS) microseconds. For single rate reception, basic repetition rates are 16 2/3, 12 1/2, and 10 groups per second; for double rate reception, 33 1/3, 25, and 20 groups per second.

The advantage of loran C over loran A is due to the characteristics of the transmission and the lower operating frequency. Greater power output results from using group pulsing instead of single pulsing. The lower operating frequency permits greater distances with the available power output. Measurement of the phase relationship between the pulses and the carrier contributes to accurate fixes at greater distances. In addition, a fix may be made in one operation without changing the selected channel, the basic repetition rate, or the specific repetition rate.

The instrument used for measuring the small periods of time that elapse between the

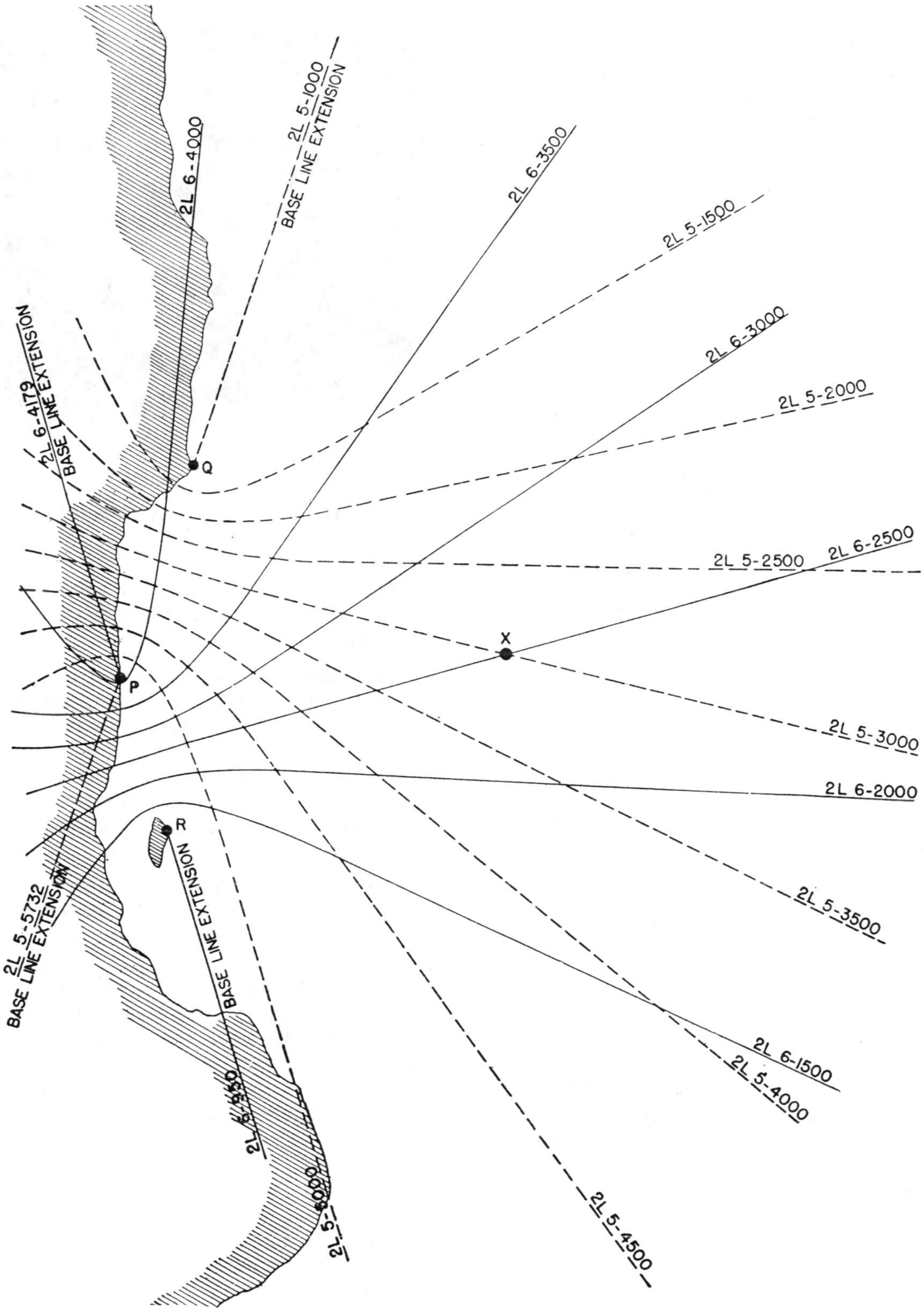

Figure 9-3.—Obtaining a fix with one master and two slave stations.

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arrival of signals from the loran transmitting stations is a combination radio receiver and video indicator. The receiver accepts the RF pulses, converts them to video pulses, and sends the video pulses to the indicator for display on the face of a small cathode-ray tube.

The master and slave pulses appear on two horizontal traces, as in figure 9-4. With the two signals aligned properly, the time difference between their reception is read from timing markers displayed on the scope or from revolution type counters on the front panel of the receiving set. Because the measuring process is quite lengthy and varies from equipment to equipment, it is not discussed in detail in this text.

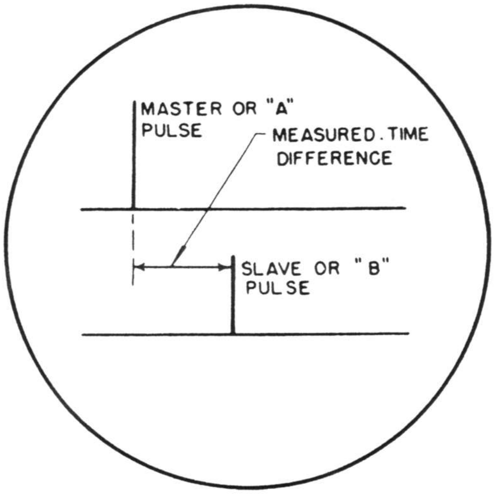

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Figure 9-4.—Traces on a loran indicator.

LORAN EQUIPMENTS

A loran set aboard ship is a receiving set or indicator that displays the pulses from loran transmitting stations ashore. Earlier models have a separate receiver and indicator while later models have a receiver set with a built-in indicator.

Loran Receiving Set Model DAS-4

Perhaps the oldest loran receiving set still installed aboard ships in the active fleet is the model DAS-4 (fig. 9-5).

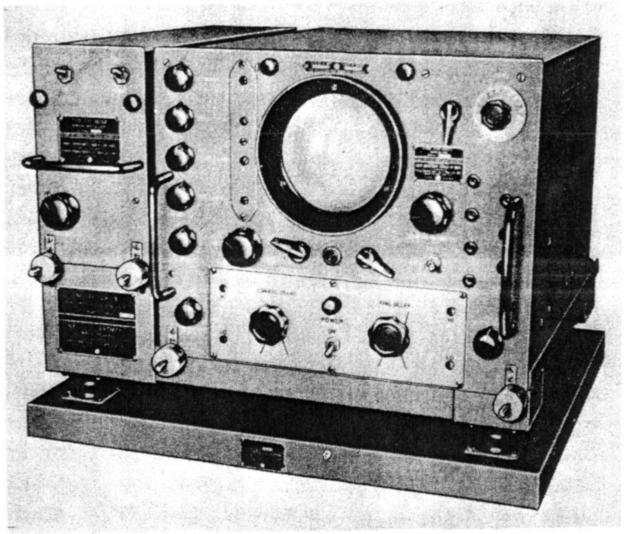

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Figure 9-5.—Loran A Receiver DAS-4.

This set, consisting of a receiver unit and an indicator unit, is capable of receiving loran A signals only.

The receiver (left-hand unit in the illustration) is a conventional superheterodyne receiver that covers the frequency range 1700 to 2000 kHz. It has no variable tuning. Instead, it is preset to four different frequencies, corresponding to the four loran A channels. Channels are selected by means of a switch located on the front panel of the receiver.

The indicator unit contains the circuitry necessary for measuring the difference in time of arrival of the pulses from a pair of loran transmitting stations. By manipulating the front panel controls (in the manner prescribed in the operating instructions accompanying the equipment), the received pulses and the timing markers are seen on the face of the scope. Interpretation of the timing markers results in a time difference measurement that is correct to 1 μs.

Loran Receiving Set AN/SPN-7( )

The AN/SPN-7( ), (fig. 9-6) is another loran A receiving set. Like the DAS-4, the receiver portion of this set is a crystal-controlled superheterodyne receiver that is preset to the four loran A frequencies. The indicator

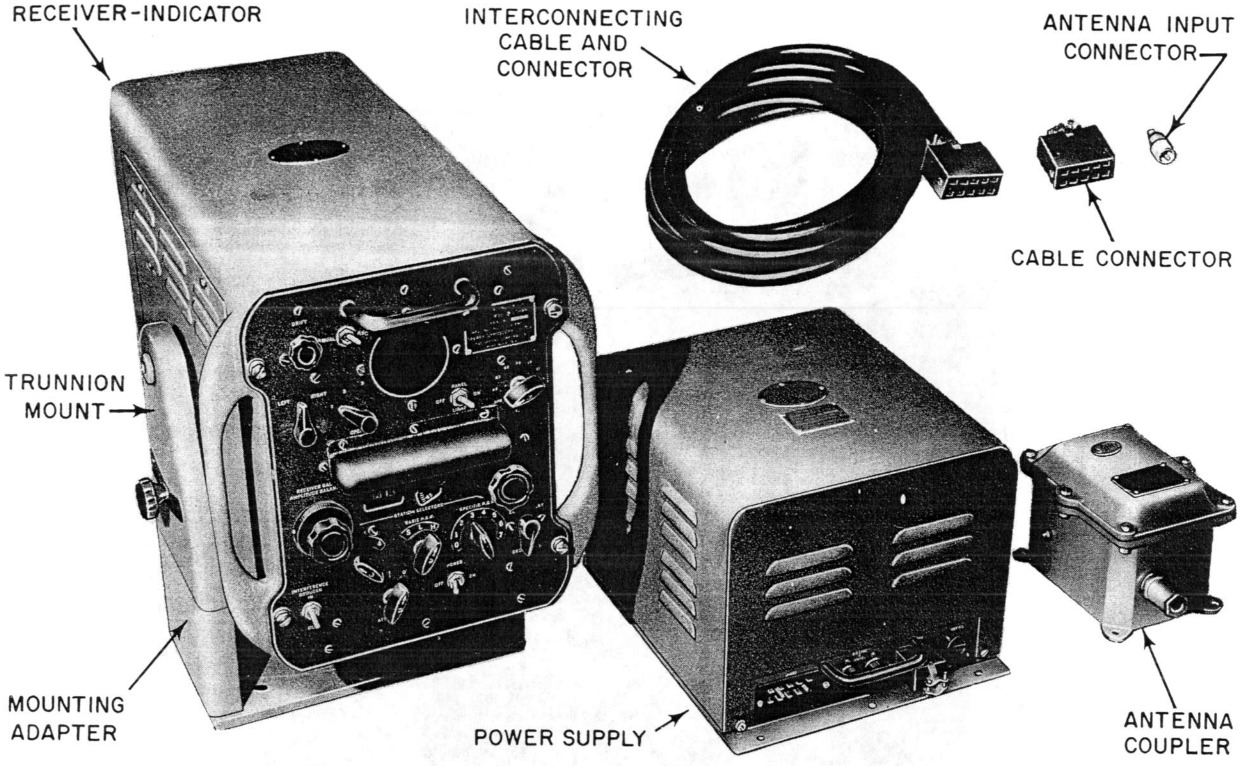

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Figure 9-6.—Loran A Receiver AN/SPN-7( ).

portion is an accurate timing device that measures the time difference in arrival of the signals from the loran transmitters.

The receiver-indicator accepts the loran signals from the transmitting stations and presents the two signals on the scope. When the two signals are matched properly, the time difference in their arrival is indicated directly on a revolution type counter and a dial. Thus, time measurements are simplified, and inaccuracies that could result from misinterpretation of timing markers are eliminated.

Loran Receiving Sets AN/UPN-12( ) and AN/UPN-15( )

Originally designed for loran A operation only, the AN/UPN-12( ) receiving set was modified to accommodate both loran A and loran C signals. Modification is accomplished by adding a small receiver-control unit and associated components to the existing AN/UPN-12( ) set. When so modified, the nomenclature of the receiving set is changed from AN/UPN-12( ) to AN/UPN-15( ). The AN/UPN-15( ) is shown in figure 9-7.

When functioning as a loran C receiver-indicator, the set utilizes the signals received by the receiver-control unit mounted atop the main chassis. This unit contains a 100 kHz radio receiver of the tuned radiofrequency type. The controls that affect its operation as a loran C receiver are on the front panel of the unit.

With the equipment set for loran A operation, the 100 kHz receiver is isolated from the set and the four-channel superheterodyne receiver in the main chassis is used to receive the loran signals.

The indicator unit of the set displays either loran A or loran C signals. When the received pulses are aligned as prescribed for the particular mode of operation, time difference readings

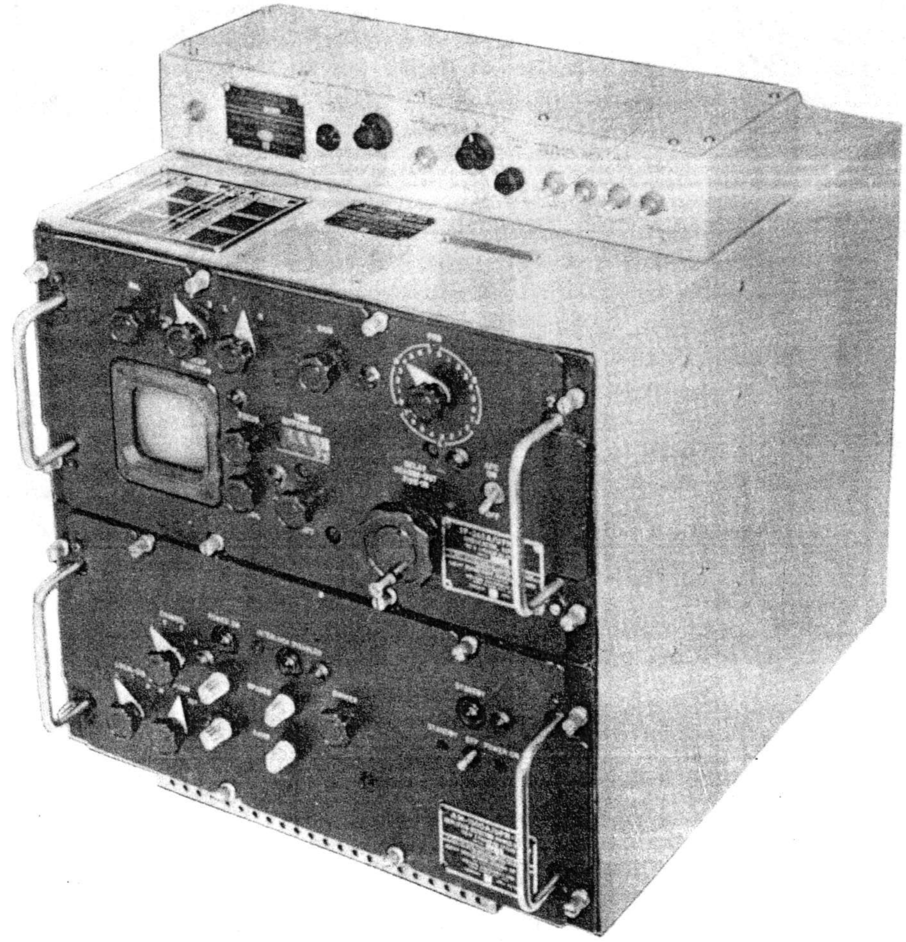

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Figure 9-7.—Loran C Receiver AN/UPN-15( ).

are taken from a counter. By taking a second reading from a different set of loran stations and referring to loran charts and tables the geographic position of the ship is determined.

Loran Receiving Sets AN/SPN-31,-32,-38

Loran receivers of this series operate in the Loran C mode. We will discuss the AN/SPN-38 (fig. 9-8) as a representative type of the series. The receiver displays precise long range navigation time-difference measurements or Loran signals automatically and continuously to 0.05μs accuracy.

The system provides visual and electrical outputs which can be used to operate computer and recorder navigational equipments. A three-inch rectangular display indicator is located in the upper right-hand corner of the receiver. Loran video and RF signals are displayed in both slow and fast CRT sweeps. The CRT also serves as a testing oscilloscope for diagnostic mantenance of the receiver. A signal produces simulated output signals for periodic

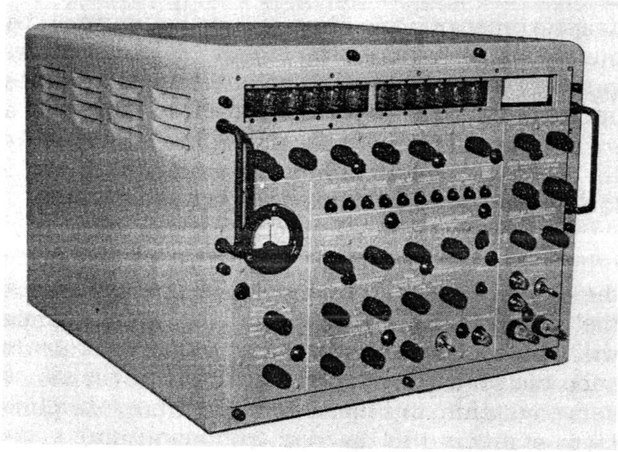

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Figure 9-8.—Loran C Receiver AN/SPN-38.

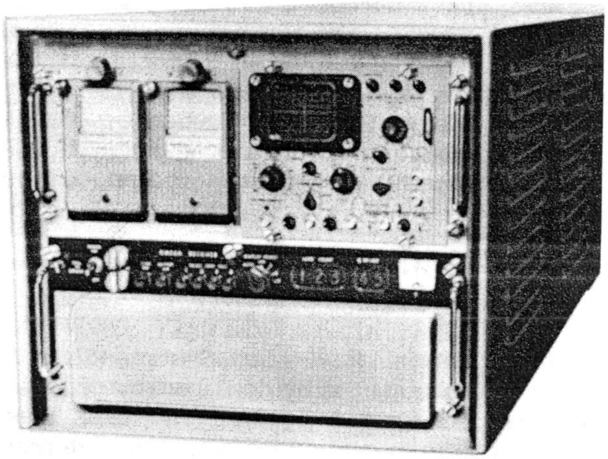

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Figure 9-9.—Omega Receiver AN/SRN-12.

performance checks and serves as test equipment for the receiver.

The AN/SPN-38 automatically searches out loran signals, locks on, and synchronizes with the ground wave. The two time difference measurements between each slave signal and master signal are read out on nixie tube displays from digital logic circuits.

OMEGA NAVIGATION SYSTEM

The Omega System is an outgrowth of the loran A and loran C systems. The system, presently being installed, will provide eight position-fixing transmitting stations located around the earth to accommodate land vehicles, aircraft, ships and submarines (at moderate antenna depths). The system has been made possible by recently uncovered facts concerning the propagation of very low-frequency radio signals over substantial distances.

The Omega Navigation Receiver AN/SRN-12 (fig. 9-9) is a single frequency, phase-locked superheterodyne receiver with a whip antenna and coupler for the reception of Omega navigational signals. The receiver operates in the VLF (10 to 14 kHz) range to provide a position readout in hyperbolic coordinates.

The fundamental measurement performed by the receiver is the relative phase comparisons (phase angles) of the VLF signals. The navigator can determine the line of position generated by any convenient pair of stations and then cross it with one or more lines derived from another pair or pairs of stations. He may make readings on four or five lines of position, but usually will choose the two pairs that jointly give the greatest precision at his particular location. After the selection of the two pairs (a minimum of 3 transmitters) the operation of the receiver is automatic in the tracking of these signals, until the operator modifies his choice of pairs, or until he arrives at his destination. The indication of position lines is continuous and may be recorded for the convenience of the navigator.

SHORAN

Shoran (short range navigation) was developed during World War II to permit bombing through undercast. It provided such great accuracy that it has since been further developed for surveying. It usually operates at frequencies between 230-310 MHz. Thus, it is limited to line-of-sight ranges. Shoran permits accuracies up to about 50 feet for a fix.

The basic principle of Shoran is as follows. Signals from one's own ship or aircraft automatically trigger two fixed beacon transmitters located ashore at some known distance apart. The signals emitted by these transmitters are received and displayed on an indicator scope aboard. The two distances in the form of pips on the scope are continually available permitting rapid determination of position. When measuring and plotting these two ranges on a chart, the point of intersection is the fix. Charts that show a number of concentric circles centered upon each beacon permits approximate positions to be plotted by inspection.

Shoran using a medium frequency of 1900 kHz was developed for use aboard ship to cover distances of several hundred miles from shore.

SHIPS INERTIAL NAVIGATION SYSTEM

Ships Inertial Navigation System (SINS) is a method of navigation by dead reckoning, which measures speed and heading and uses these measurements to compute position change from an initial position fix. This method is in contrast to the loran and omega system methods which fixed the ship's position by measuring position relative to some known object.

The basic components of an inertial navigation system (fig. 9-10) are the accelerometers, gyroscopes, servosystems, and computers (not shown). An accelerometer is a device which measures changes in speed or direction. Its output is usually in the form of a voltage proportional to the acceleration to which it is subjected. A set of two accelerometers are mounted on a gyro-stabilized platform in order to keep them in a horizontal position despite changes in the ship's movements. The accelerometers are attached to the platform by means of an equatorial mount (gimbal) whose vertical axis is aligned parallel to the earth's polar axis. This permits the N-S accelerometer to be aligned along a longitude meridian, while the E-W accelerometer is aligned along a latitude meridian.

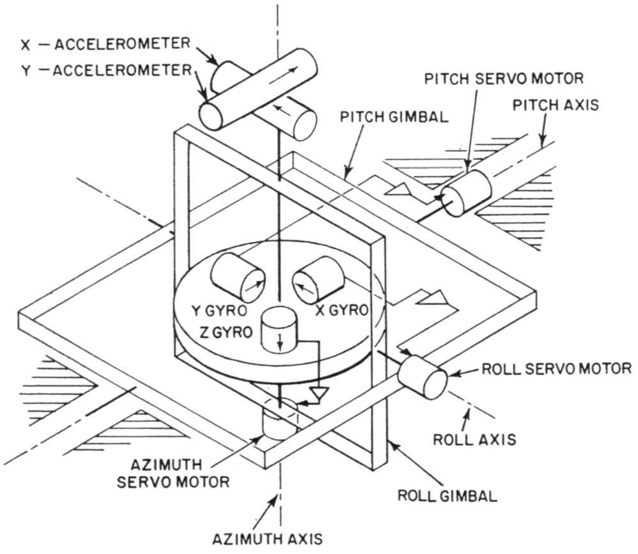

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Figure 9-10.—Stable platform with inertial components.

A three-gyro-stabilized platform is maintained in the horizontal position regardless of the pitch, roll, and yaw of the ship. When the ship's heading changes, the gyro signals will cause servosystem motors to operate to keep the platform stabilized. High-performance servosystems are needed to maintain the platform stabilized to the required accuracy.

The self-contain navigation system continuously computes latitude and longitude by accurately sensing the accelerations of the vehicle with respect to the earth's surface. A computer capable of converting distance traveled into corresponding changes in latitude and longitude is needed.

The system is expensive and its accuracy will decrease with time. A good coverage of the inertial system is found in ET 3&2, NavPers 10195.

SATELLITE NAVIGATION SYSTEM

Satellite Navigation was thought feasible after observation of Russia's first artificial earth satellite, Sputnik I. Scientists listened to the beep generated by Sputnik as it passed by and noted the Doppler-like shift in the received radio frequency signals. Doppler effect is an apparent change in a received frequency because of relative motion between the transmitter and receiver. If the distance between the transmitter and receiver is decreasing, the received frequency is higher than that which is actually transmitted; if the distance is increasing, the received frequency is lower than that transmitted. It was later demonstrated that accurate measurement of this doppler shift pattern would permit the determination of a satellite orbit. From this successfully proved technique it was further reasoned that, working from a known satellite orbit, a listener could determine his position on the surface of the earth from an observed doppler pattern. From this point followed the first successful satellite launch in April 1960, and the U.S. Navy Navigation Satellite System became an all-weather, highly accurate, fully operational navigation aid, that enables navigators to obtain accurate navigation fixes from the data collected during a single pass of an orbiting satellite.

NAVIGATION SYSTEM DESCRIPTION

The Navy navigation system (fig. 9-11), is a worldwide, all-weather system of high accuracy which enables navigators to obtain fixes approximately every two hours, day and night. It consists of four earth-orbiting satellites, four tracking stations, two injection stations, the U. S. Naval Observatory, a computing center, and shipboard navigational equipment.

Satellites

Four satellites (only two shown in fig. 9-12) are placed 45 latitudinal degrees apart in separate circular polar orbits longitudinally around the earth, at known altitudes. (The altitude of the satellites is between 500 and 700 nautical miles.) The earth rotates inside these satellite orbits. Each time the satellite makes a pass over the earth (about every 108 minutes) its orbital position seems to have moved farther westward. This is due to the rotation of the earth. Externally, the satellite is octagonal in shape (fig. 9-13). It has four solar cell vanes which are shaped like a windmill and used to generate DC electrical power. The satellite's directional antennas point earthward at all times since they have been stabilized in the earth's gravitational field.

Internally, the satellite is made up of a number of all-transistorized systems. These include

1. A command receiver and identification code facility for ground station communications.
2. A telemetering system for transmitting measured results to receiver sets located on the earth.
3. A digital memory system for storing two types of information:

    a. The fixed parameters for all data it transmits that doesn't change, such as the synchronization and identification signals, and the fixed parameters transmitted from ground station to the satellite every twelve to sixteen hours giving information describing all four of the satellite's nominal orbits.

    b. The variable parameters transmitted from the satellite to the earth receivers every two minutes giving information describing the fine structure in the satellite's nominal orbits, thereby keeping its time and location up-dated.

4. Two harmonically related transmitters (one for a standby unit) for sending out two different phase-modulated radiofrequency carrier waves.
5. Dual frequency systems, one at 400 MHz and the other at 150 MHz, used to minimize the effects of ionospheric refraction.
6. An ultrastable transformer oscillator for making accurate doppler-shift measurements. (The transformer oscillator is an arrangement of transformers and switching transistors.)
7. A digital clock for transmitting precise time information.
8. Battery power supplies for receiving, storing, and releasing electrical energy for operating the electrical powered equipment.

Tracking Stations

Four tracking stations, spaced to monitor the four polar circling navigational satellites, are located one in each of the States of Hawaii, California, Minnesota, and Maine. The purpose is to determine accurately the present and future orbits of each satellite. These stations having radio receiving and data processing equipment, will digitize and send the orbital and time information via control center to the computing center.

Naval Observatory

The Naval Observatory controls satellite transmission of the two-minute interval time period to an accuracy of one-millisecond of the even integer of universal time (UT-2). It accomplishes this by receiving the digital memory signals from the satellite during each pass and comparing them to the observatory's data processing equipment. The time and orbital information is sent to the control center.

Control Center

All satellite data is routed through the control center which acts as a switching central

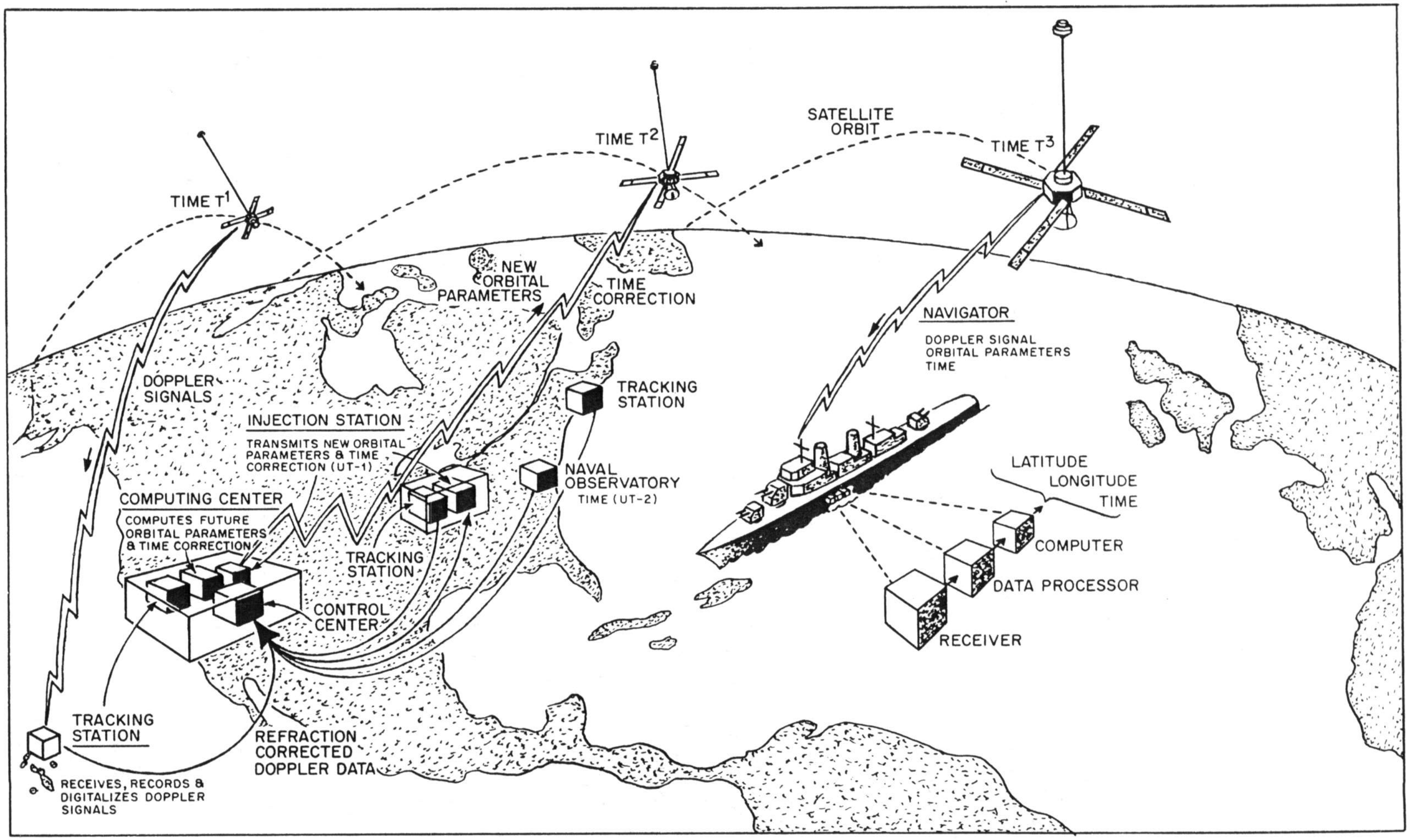

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Figure 9-11. —Navy navigation satellite system.

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Figure 9-12.—Four polar orbits with 45° nodes.

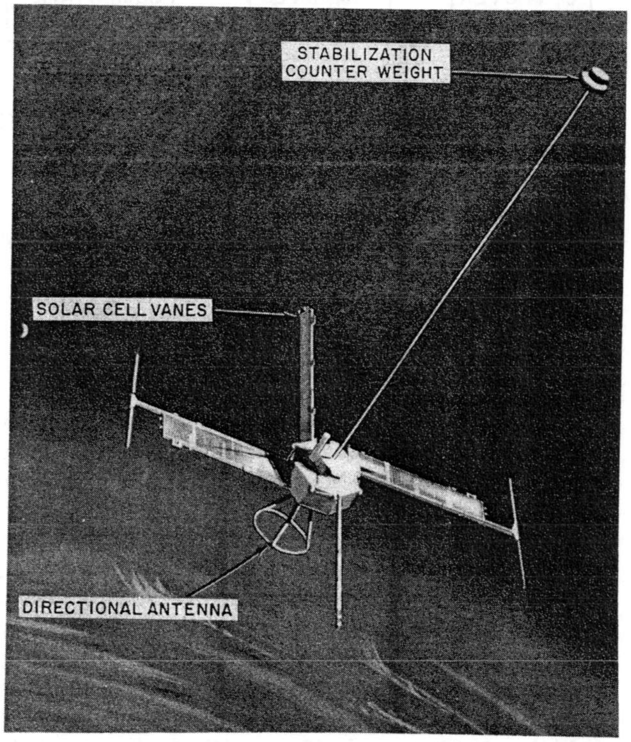

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Figure 9-13.—Navigation satellite.

for monitoring data to and from the Central Computer Center.

Central Computing Center

The Central Computing Center continuously accepts data inputs on the satellites from the four Tracking Stations and the Naval Observatory. Periodically, to obtain fixed orbital parameters for a satellite, the Central Computing Center computes an orbit for each satellite that best fits the doppler curves obtained from all Tracking Stations. Then using the computed orbital shape, the central computing center extrapolates the position of the satellite at each even two minutes in universal time for the next 12 to 16 hours, subsequent to data injection. These data together with data on the nominal shape of the orbits of the other three satellites, commands and time correction data for the satellite and antenna-pointing orders for the Injection Station antennas are supplied to the Injection Stations via the Control Center.

Injection Stations

The Injection Stations, after receiving and verifying the incoming message from the Central Computing Center, store the message until it is needed for transmission to the satellite. As soon as the receiving equipment at the Injection Station receives and locks on the satellite's signals, the Injection Station reads the injection data and commands from storage and transmits them to the satellite. Transmission to the satellite is on a frequency different from those frequencies used by the satellite, and the bit rate is much higher; therefore, injection is completed in a matter of seconds. Once data injection is complete, the satellite continues to transmit at the normal two-minute intervals.

Shipboard Navigation System

The final link in the satellite navigation system is the shipboard navigation system and the one you, as a naval officer, will be most concerned with.

The satellite is continuously transmitting messages. These phase-modulated data on two different radio frequency carrier waves are at two-minute intervals and start precisely on the even minute mark. This permits the navigator to check on any error in the ship's chronometer.

The satellite is continually up-dating itself giving its orbital latitude and longitude coordinates and signaling this information earthward.

The area in the sky where accurate satellite readings can be taken is between 10° and 70° above the horizon (fig. 9-14). The reception pattern is like a large donut in the sky with the hole overhead. When a satellite is passing overhead it has very little doppler frequency shift since the satellite and ship are closely paralleling each other. Since the navigation principle is based on measuring the doppler shift, any area above the 70° mark is avoided.

A minimum of 6 full minutes, or 3 complete simultaneous satellite messages (at 2-minute intervals) is required to calculate a navigation fix. Additional periods of received satellite transmissions will increase the accuracy of these computations. A satellite pass may last for as long as 16 minutes (eight 2-minute periods). Passes suitable for use in obtaining a navigational fix will generally occur at least every two hours since four earth-circling satellites are in orbit for this purpose.

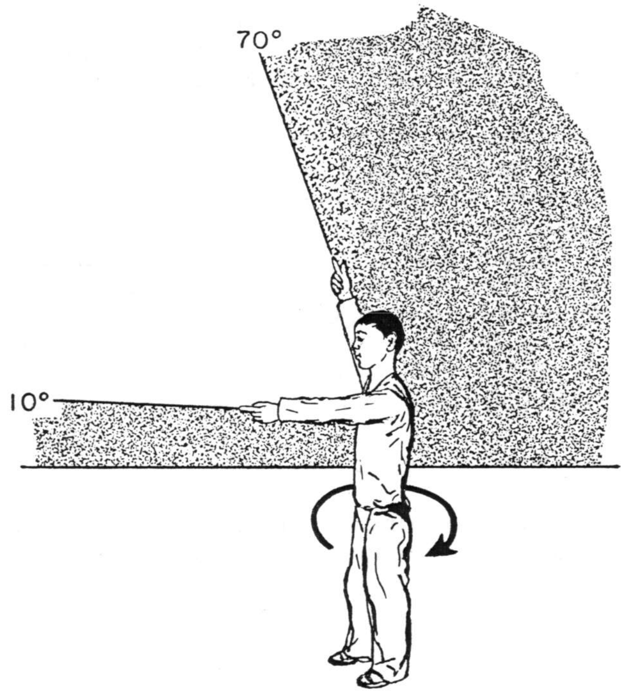

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Figure 9-14.—Determining satellites accurate calculation areas.

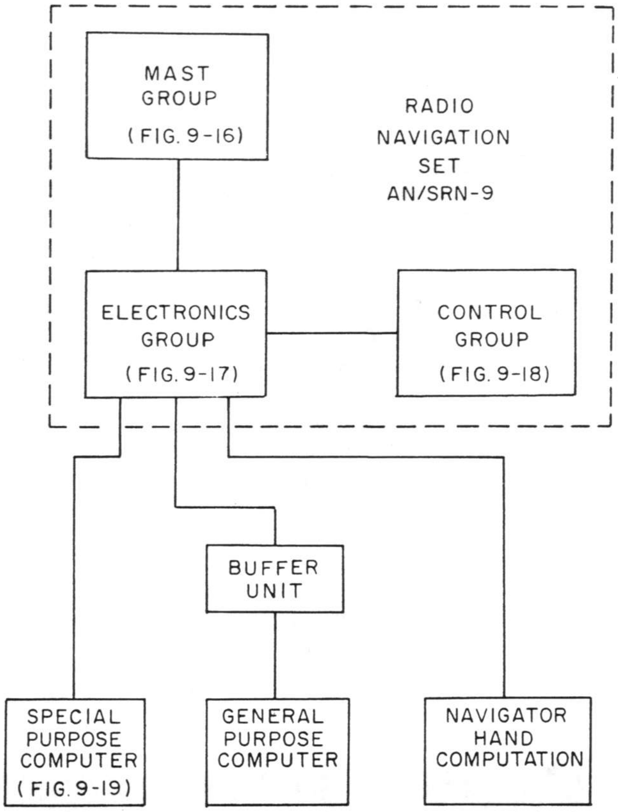

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Figure 9-15.—Shipboard navigation system, block diagram.

RADIO NAVIGATION SET AN/SRN-9

Radio Navigation Set AN/SRN-9 (fig. 9-15), represented in the dotted lines in the block diagram, consists of a mast group, electronics group, and a control group. The radio navigation set reduces the satellite data to a form which is suitable for navigational computations.

The output of the AN/SRN-9 is sent to the computing system. There are three methods of computation: the Special Purpose Computer CP-827 (XN-1), the general purpose computer (which requires a buffer unit) or by navigator hand computation.

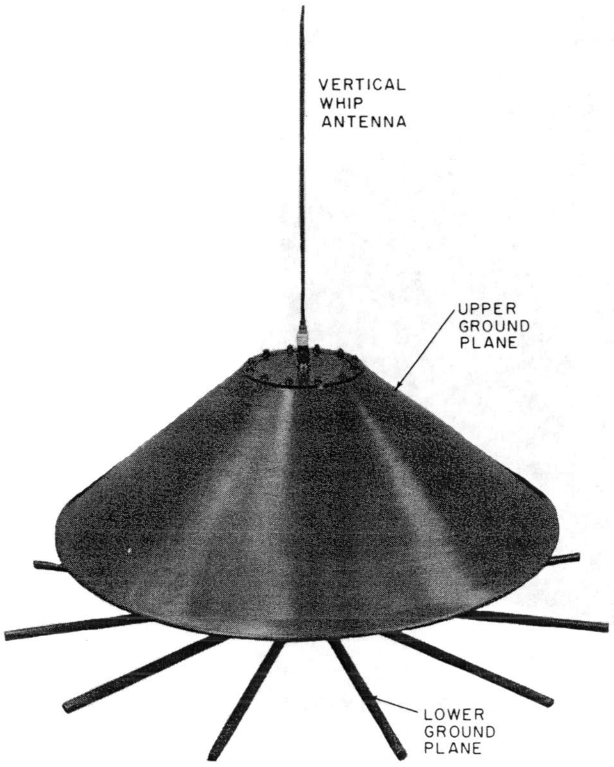

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Figure 9-16.—The mast group.

Mast Group

The mast group (fig. 9-16) receives, separates, and amplifies the two modulated incoming carriers from the satellite. The dual-frequency vertical whip antenna receives both the 400 MHz and 150 MHz satellite signals. A housing assembly inside the mast group, containing all the electronic circuits, will separate the signals and amplify each separately. The upper ground plane lowers the angle of radiation to establish a good antenna pattern. The lower ground plane has 12 radial rods at the base to isolate the mast group from any of the ship's hull effects and thus preserves the antenna pattern.

Electronic Group

The electronics group (fig. 9-17) consists of a receiver unit, data processor unit, and a power supply unit. This group receives, prepares, and records doppler data, satellite data, timing information, and refraction correction data for suitable navigation computations by the computer.

THE RECEIVER UNIT.—The Receiver Unit is the phase-modulation decoder for the coded binary signal received from the satellite. The oscillator in this receiver must be very stable. In case of temporary power failure, the oscillator requires a warmup period of 10 hours for each hour the power is off up to a maximum total of 72 hours. This amount of time is required for the frequency to stabilize sufficiently for high-accuracy navigation. Readings can be made immediately after power is restored, but accuracy will be decreased. It is recommended that the standby battery be kept in good condition to assure continuous power to the oscillator unit in event the ship looses its power supply. The battery connector (not shown in fig. 9-17) is located on the side of the electronic group.

THE DATA PROCESSOR UNIT.—The Data Processor Unit is located in the top drawer of the electronics group (fig. 9-17). It combines and processes the timing signals, satellite orbit parameters, and the doppler counts. This output information goes to the computer and the control group for printout.

THE POWER SUPPLY.—The Power Supply requirements for the radio navigation set is 115 ±10 VAC, 60 ±6 Hz with a maximum of 220 watts.

Control Group

The control group (fig. 9-18) performs the switching functions and is manually operated by the navigator. In the TRACK position of the main control switch, the control group automatically searches for, locks on, and tracks the satellite. The entire navigation fix is printed out, monitored, and controlled from the control group. The digital printer prints out the coordinate position of the ship.

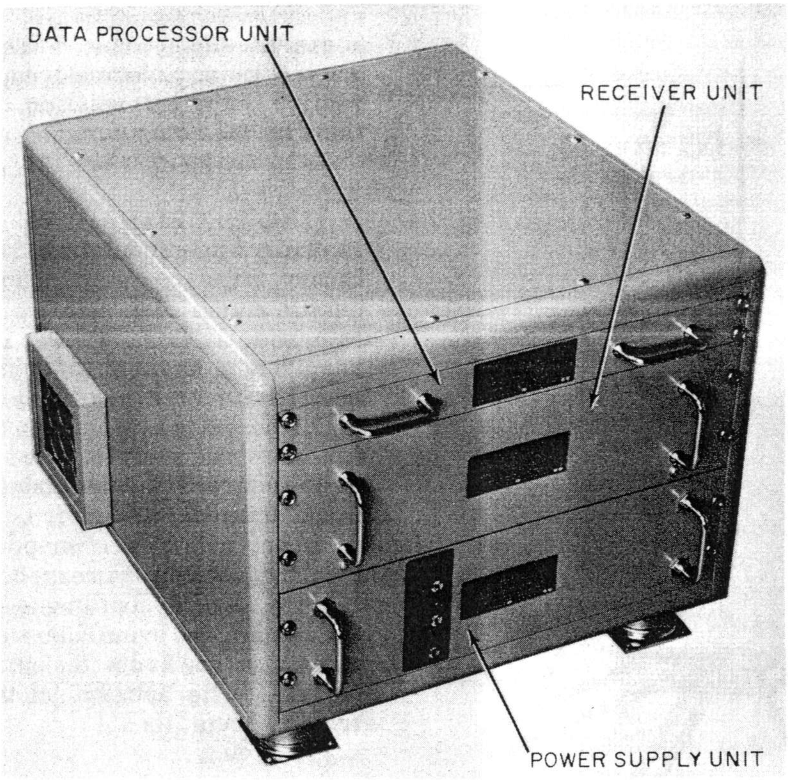


Figure 9-17.—Electronics group. 162.66

Computer

The computer uses the satellite's position data and the ship's position data to compute a fix in longitude, latitude, and coincident time. We have discussed the satellite data supplied by Radio Navigation Set AN/SRN-9. The navigator will calculate and enter into the computer the ship's heading and speed, water (currents) direction and speed, estimated ship's position, antenna height, and the time-of-day accurate to within ±15 minutes. These entries are made at the end of the satellite pass. Information is always rejected if the time is less than a 2-minute period or is otherwise invalid.

THE SPECIAL PURPOSE COMPUTER.—The Special Purpose Computer CP-827/SRN-9 (fig. 9-19) monitors all operations of the Navy's satellite navigation program. The two top drawers hold the electronic logic card circuits. The middle drawer also has the controls and indicators. The bottom drawer contains the 115 ±10 VAC 60 Hz single-phase power supply and the tape reader. The front panel of the Test Device (fig. 9-20), is equipped with neon indicators to give a visual display of the contents of all the registers and the sequence events as they occur in the computer.

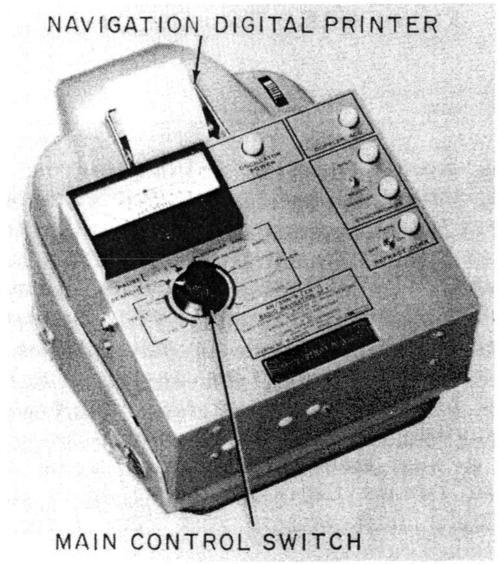


Figure 9-18.—Control group. 162.73

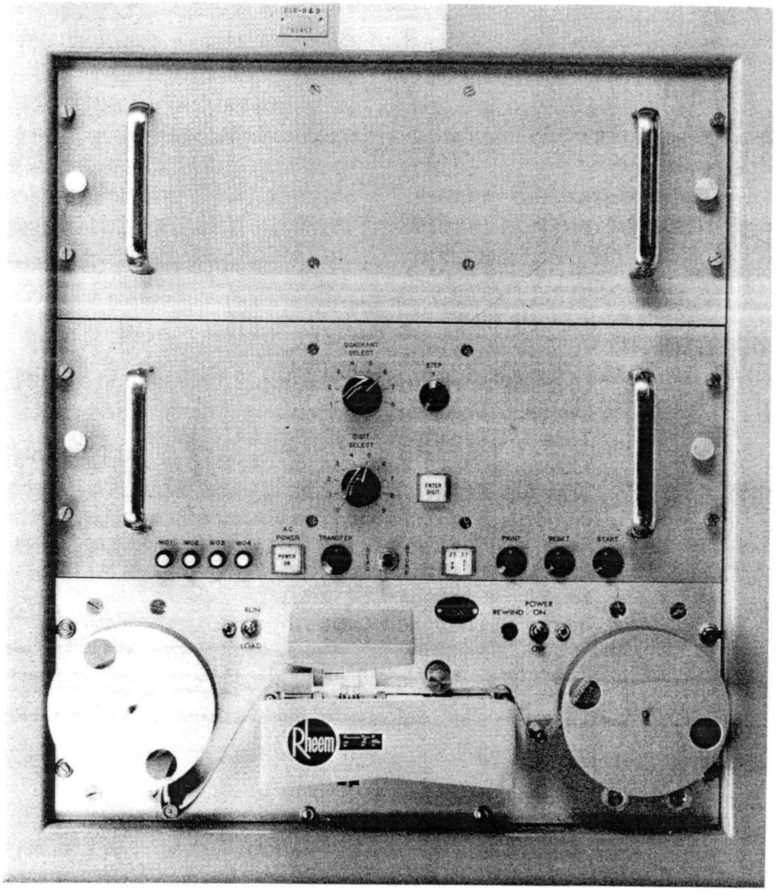
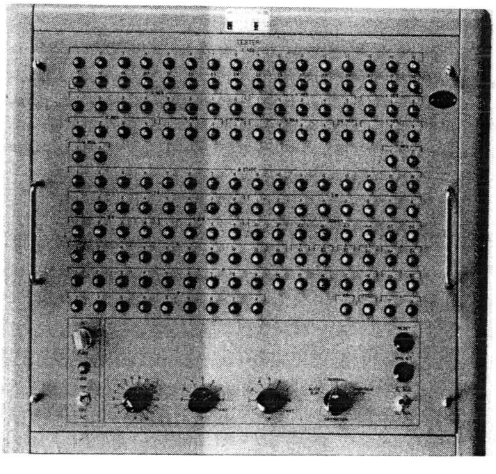


Figure 9-19.—Digital Computer CP-827/SRN-9. 162.74

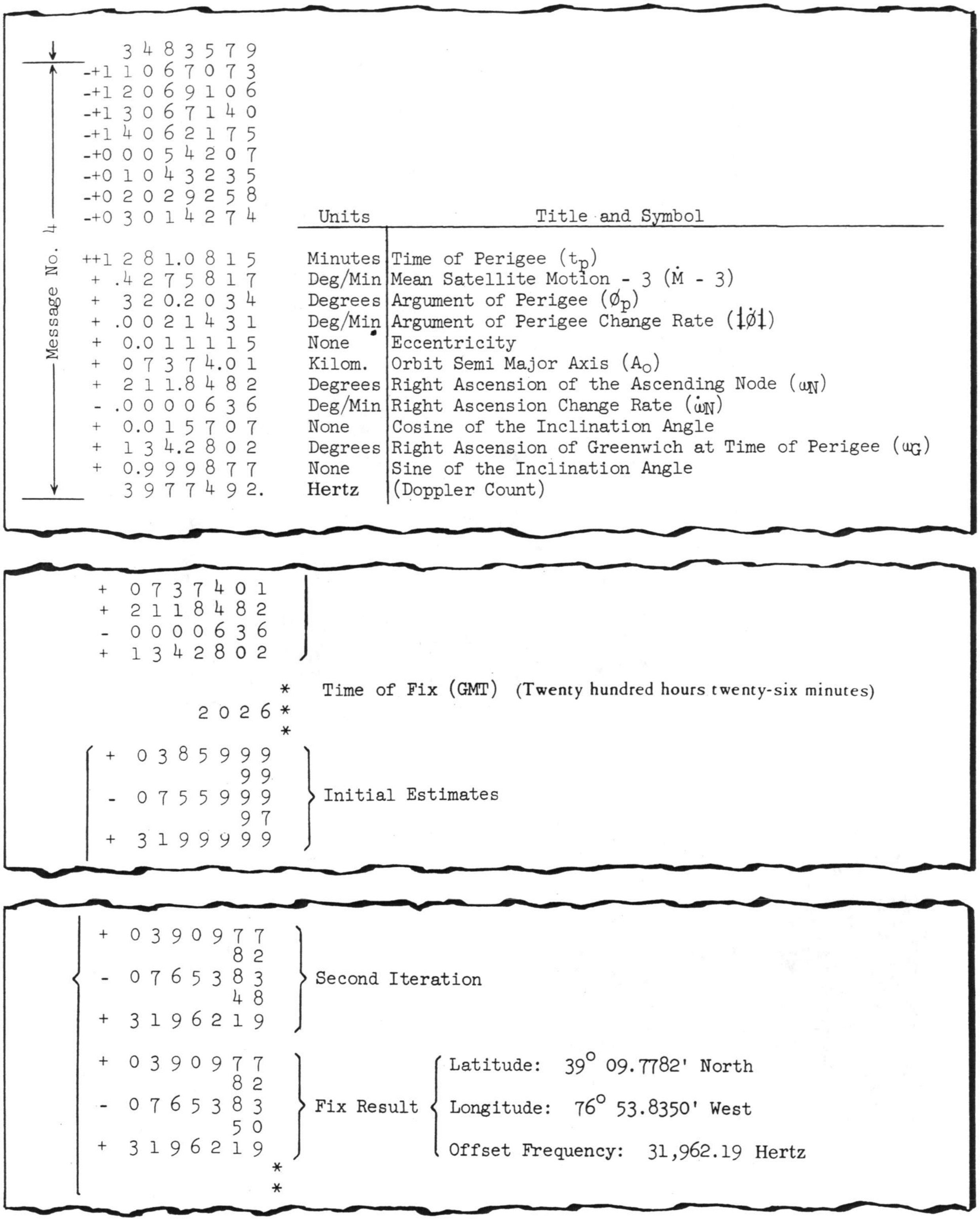


162.80
Figure 9-20.—Test Device CP-827/SRN-9.

The computer readout is located in the electronics control group (fig. 9-18). A partial sampling of the output printed data is shown in figure 9-21. Some of the information that has been extracted is the doppler count, time of fix, latitude and longitude, and the offset frequency.

THE GENERAL PURPOSE COMPUTER.—The General Purpose Computer may be used, but a buffer unit is necessary to process and convert information into the appropriate computer format. The availability and time sharing of a general purpose computer makes this a less desirable choice since it may be required for tactical data processing systems, etc.

HAND COMPUTATION.—Hand Computation using the printed data available from the control group printer of the AN/SRN-9 may be made to obtain a position fix. The complexity of such calculations, however, leads to hours of computation time and an almost certain probability of human error.



Message No. 4

	Units	Title and Symbol
3 4 8 3 5 7 9		
-+1 1 0 6 7 0 7 3		
-+1 2 0 6 9 1 0 6		
-+1 3 0 6 7 1 4 0		
-+1 4 0 6 2 1 7 5		
-+0 0 0 5 4 2 0 7		
-+0 1 0 4 3 2 3 5		
-+0 2 0 2 9 2 5 8		
-+0 3 0 1 4 2 7 4		
++1 2 8 1.0 8 1 5	Minutes	Time of Perigee (t_p)
+ .4 2 7 5 8 1 7	Deg/Min	Mean Satellite Motion - 3 ($\dot{M}$ - 3)
+ 3 2 0.2 0 3 4	Degrees	Argument of Perigee (ϕ_p)
+ .0 0 2 1 4 3 1	Deg/Min	Argument of Perigee Change Rate ($\lvert\dot{\phi}\rvert$)
+ 0.0 1 1 1 1 5	None	Eccentricity
+ 0 7 3 7 4.0 1	Kilom.	Orbit Semi Major Axis (A_o)
+ 2 1 1.8 4 8 2	Degrees	Right Ascension of the Ascending Node (ω_N)
- .0 0 0 0 6 3 6	Deg/Min	Right Ascension Change Rate ($\dot{\omega}_N$)
+ 0.0 1 5 7 0 7	None	Cosine of the Inclination Angle
+ 1 3 4.2 8 0 2	Degrees	Right Ascension of Greenwich at Time of Perigee (ω_G)
+ 0.9 9 9 8 7 7	None	Sine of the Inclination Angle
3 9 7 7 4 9 2.	Hertz	(Doppler Count)

```
+  0 7 3 7 4 0 1
+  2 1 1 8 4 8 2
-  0 0 0 0 6 3 6
+  1 3 4 2 8 0 2

                *   Time of Fix (GMT) (Twenty hundred hours twenty-six minutes)
         2 0 2 6 *
                *

+  0 3 8 5 9 9 9
             9 9
-  0 7 5 5 9 9 9    Initial Estimates
             9 7
+  3 1 9 9 9 9 9
```

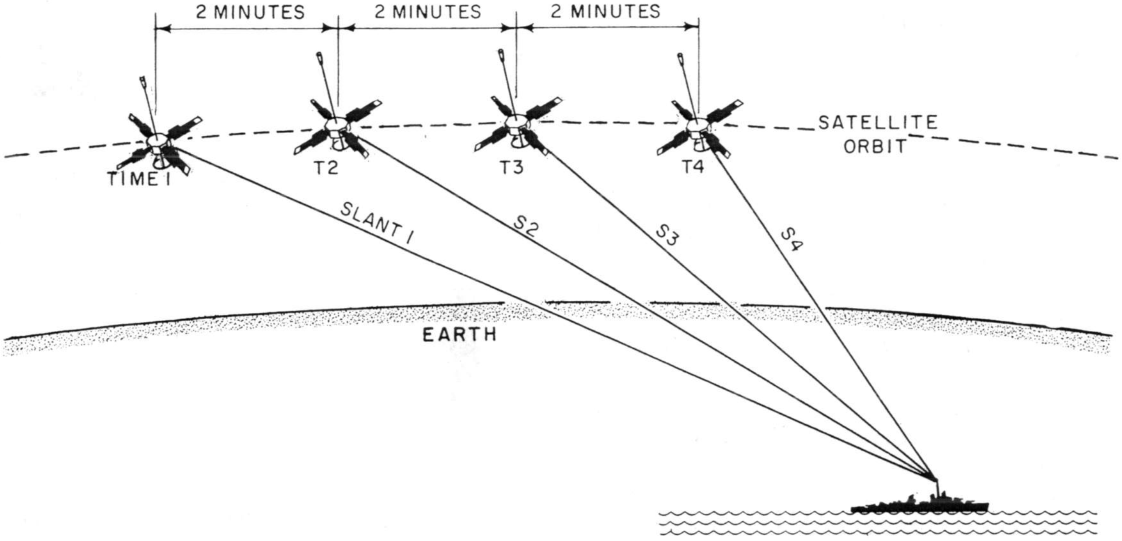
```
+  0 3 9 0 9 7 7
             8 2
-  0 7 6 5 3 8 3    Second Iteration
             4 8
+  3 1 9 6 2 1 9

+  0 3 9 0 9 7 7                  Latitude:  39° 09.7782' North
             8 2
-  0 7 6 5 3 8 3    Fix Result    Longitude:  76° 53.8350' West
             5 0
+  3 1 9 6 2 1 9                  Offset Frequency:  31,962.19 Hertz
                *
                *
```

120.97

Figure 9-21.—Printer readout navigation information.

INTEGRATED DOPPLER NAVIGATION

The navigational fix computed by Radio Navigation Set AN/SRN-9 is based on the shift in frequency (doppler frequency shift) that occurs whenever the relative distance between a transmitter and a receiver is changing. Such changes occur whenever a transmitting satellite passes within radio range of a receiver on earth and is due to the motion of the satellite in its orbit, the motion of the navigator on the surface of the earth, and the rotation of the earth about its axis. (You may choose to review the doppler effect in chapter five.)

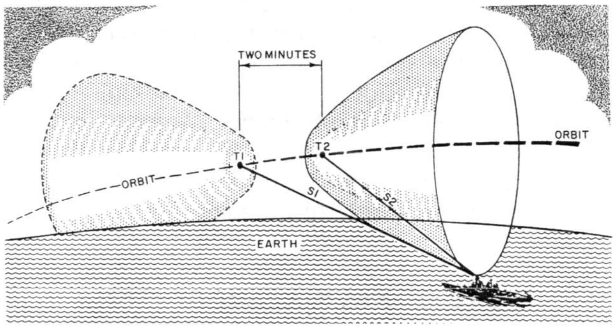


120.98

Figure 9-22.—Integrated doppler measurement.

As previously stated, the satellite message describes the orbital position of the satellite every two minutes on the even minute. To obtain a navigational fix, it is necessary only to determine the ship's location relative to the known satellite positions. The Radio Navigation Set AN/SRN-9 utilizes a so-called integrated doppler measurement for this purpose. Figure 9-22 illustrates four positions of the satellite in its orbit for arbitrary times shown as T1 through T4. The slant range from ship to satellite is given by S1 through S4. It is evident that the number of wavelengths of the transmitted signal en route at time T1 along S1 is greater than at time T2 along S2, which is the reason for the doppler frequency shift. As the satellite approaches, additional cycles must be received to account for a reduction in the number of wavelengths along the propagation path. Every positive doppler cycle received means the satellite has moved one wavelength closer. This is a very precise measurement because at 400 MHz a wavelength is only 3/4 meter long.

The principle of satellite navigation involves establishing a fix at the intersection of two or more hyperbolas of revolution. A hyperbola of revolution in satellite navigation (fig. 9-23)



120.99

Figure 9-23.—Principle of satellite navigation, hyperbola of revolution.

is a three-dimension geometric figure as compared to the two-dimension figure used in loran navigation (fig. 9-1B). Using the known positions of the satellite at T1 and T2 as foci and rotating a hyperbola (on the axes which will align with the satellite's orbit) establishes a hyperbola of revolution.

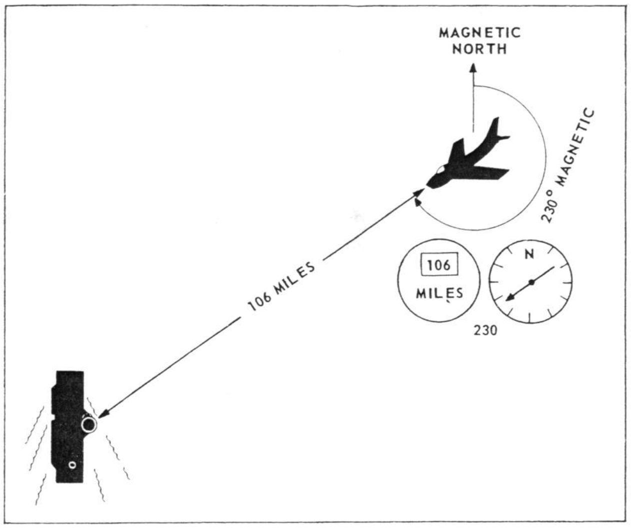
The hyperbola of revolution is electronically established when satellite positions at T1 and T2 are known and the integrated doppler measurement (being the count of the number of doppler cycles received between T1 and T2) has determined the direct measure of the total change in slant range during the two-minute time interval. The receiver must be on some surface defined by this measured slant range DIFFERENCE between these two points. The ship will be located, therefore, somewhere along the curve defined by the intersection of this hyperboloid and the earth's surface. This does not establish the location of the earth's surface nor does it tell upon which of the two branches of the hyperboloid the ship will lie. It does, however, establish electronically the shape of the hyperbola of revolution used.

The next doppler count (between T2 and T3) will define a second curve, and the intersection of these curves (not illustrated) gives the navigational fix.

In actual practice, two factors complicate this simple explanation. First, the doppler signal which is counted consists of the doppler frequency plus a fixed, but not very accurately known, bias frequency which is the inherent variations of frequency differences between the transmitter oscillator in the satellite and the receiver oscillator aboard ship. Therefore, a third doppler count is required in order to solve for the three variables—latitude, longitude, and bias frequency. This means that integral doppler counts for at least three two-minute intervals must be used (and preferably more than three) in order to determine the three unknowns. The second complication is the motion of the ship during the satellite pass. To account for this, the best estimate of a ship's motion must be entered into the navigational computation along with the doppler counts and the satellite message.

TACAN NAVIGATION SYSTEM

Tactical air navigation (tacan), is an electronic polar coordinate system that enables an aircraft pilot to read—instantaneously and continuously—the distance and bearing of a radio beacon transmitter installed on a ship or at a ground station. In aircraft equipped with tacan receiving equipment, an azimuth indicator shows the position of the transmitting sources in degrees of magnetic bearing from the aircraft. Also, the distance in nautical miles to the same reference point is registered as a numerical indication, similar to that of an automobile odometer. (Fig. 9-24) In the illustration, the aircraft is 106 miles from the carrier, and the ship is on a magnetic bearing of approximately 230° from the aircraft.



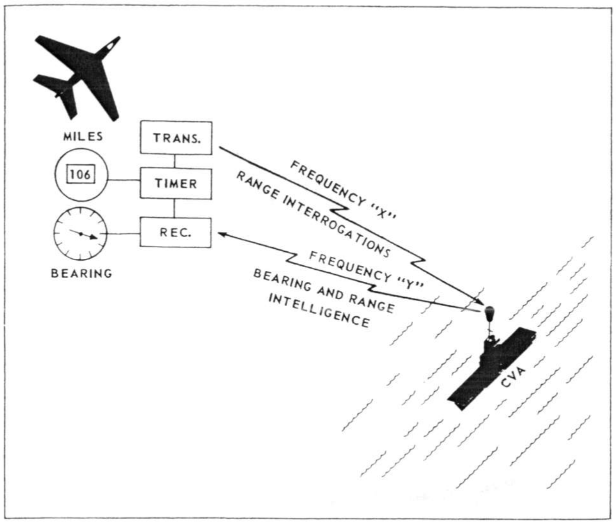
32.73

Figure 9-24.—Tacan polar coordinate presentation data.

To provide for a large number of transmitting stations, the system operates on 126 selectable channels. No two stations within interference distance of each other are assigned the same channel. The pilot can switch channels to select any tacan transmitter within range.

To aid the pilot in identifying a particular transmitter, the transmitter automatically transmits a three-letter tone signal in international Morse code every 37.5 seconds. The aircraft receiver converts the signal to an audible tone that is heard in the pilot's headset.

Two radio frequencies are employed, as indicated in figure 9-25. One frequency (Y)



70.16
Figure 9-25.—Dual-frequency transmission.

is used for transmissions to the aircraft; another frequency (X) is used for transmissions from the aircraft. The surface-to-air frequency carries bearing and range intelligence as well as station identification information. The transmission from the aircraft-to-surface unit is required to trigger the distance-measuring system.

When the pilot closes the proper switch on his set control, his receiver-transmitter radiates a series of range interrogation pulses (frequency X).

The interrogation pulses are detected by any ship or station operating on the same channel. The pulses cause the transmitter to radiate a response, which is a series of pulses on frequency Y.

When the reply signal is received in the aircraft, it is fed to range circuits that determine the time that elapsed during the round trip of the two signals. Other circuits convert the time difference to equivalent dial indication in miles. Bearing information is radiated continuously on frequency Y.

The shipboard end of the system is the AN/SRN-6( ) (discussed in the next topic) or its older counterpart, the AN/URN-3( ). The airborne installation is a combination transmitter-receiver-indicator, such as the AN/ARN-21( ).

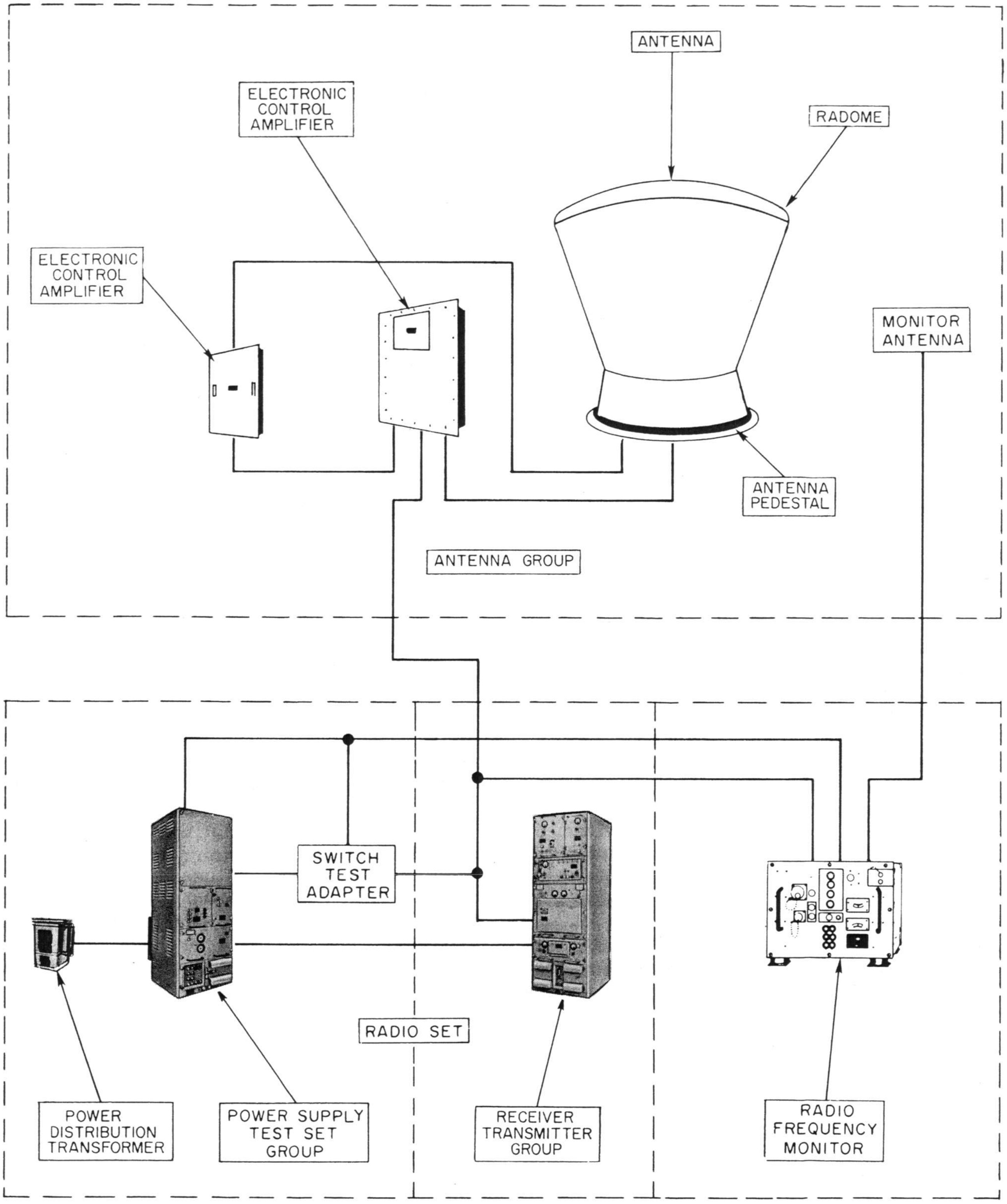
TACAN RADIO SET AN/SRN-6( )

Radio set AN/SRN-6( ) is replacing the AN/URN-3 as tacan radio sets on board ship. The AN/SRN-6( ) system (fig. 9-26) comprises three major groups: receiver-transmitter, antenna, and power supply assembly.

As many as 100 aircraft may simultaneously obtain navigational information in conjunction with a single installation of the AN/SRN-6( ). The set is capable of receiving on any one of 126 frequencies (channels) in the range of 1025 to 1150 MHz. Transmission of information also takes place on 126 channel frequencies in the ranges of 962 to 1024 MHz and 1151 to 1213 MHz.

Two types of antennas are available for use. Each antenna operates on 63 channels, corresponding to low band frequencies and high-band frequencies, respectively. Low-band installations transmit at frequencies between 962 and 1024 MHz inclusive, and receive at frequencies between 1025 and 1087 MHz. High-band installations transmit in the range of 1151 to 1213 MHz, and receive in the range of 1088 to 1150 MHz.

Two frequencies are used in each channel: one for receiving, and one for transmitting. The frequency used for receiving in low-band installations is 63 MHz above the frequency used for transmitting in the same channel.



32. 72

Figure 9-26. —Radio Beacon AN/SRN-6 major components.