CHAPTER 5

RADAR

Radar (from the words radio detection and ranging) is one of the greatest scientific developments that emerged from World War II. It makes possible the detection and range determination of such objects as ships and airplanes over long distances. The range of radar is unaffected by darkness, but it often is affected by various weather conditions; for example, heavy fog or violent storms.

THEORY OF OPERATION

The basic principles of radar are similar to those of sound echoes or wave reflections. If a person shouts in the direction of a cliff or some other sound-reflecting surface, he hears his shout return from the direction of the cliff. Sound waves, generated by the shout, travel through the air until they strike the cliff. There they are reflected or bounced off, and some are returned to the originating spot. These reflected waves are the echo that the person hears.

Time elapses between the instant the sound originates and the time the echo is heard. Because sound waves travel through air at approximately 1100 feet per second, the distance of the reflecting surface from the shouter can be computed as (1100)t/2, where t/2 is one-half the elapsed time, corresponding to one-half the round trip distance out and back.

Most radar systems operate on a principle very much like that just described. The major difference is that radar utilizes radiofrequency electromagnetic waves, instead of sound waves, to detect the presence of reflecting surfaces.

At least three methods of radar detection are in use today. These are (1) the continuous-wave method, (2) the frequency-modulation method, and (3) the pulse-modulation method. This last method is the most common.

In the pulse-modulated method (fig. 5-1), the transmitter sends out short pulses of RF energy at regular intervals. Depending on the particular radar, the duration of the transmitter pulse ranges between 0.1 and 5.0 microseconds. Each transmitting period is followed by a receiving period of relatively much longer duration than the transmitting period. The transmit-receive cycle is repeated many times per second. This repetition rate depends on the design of the set.

RANGE DETERMINATION

The employment of radar to determine the range (distance) to a target is made possible by (1) our knowledge of the velocity of the transmitted radiofrequency energy in space, and (2) the measurement of the time required for the energy to reach a target and return.

Once radiated into space, radiofrequency energy travels at the speed of light. In terms of distance traveled per unit of time, it travels approximately 186,000 land miles per second, or 164,000 nautical miles per second. To make practical use of this velocity-distance relationship, it is necessary to consider distance in terms of yards, and time in terms of microseconds (μs). Computing mathematically, we find that RF energy travels 328 nautical yards in 1 microsecond. This means that approximately 6.18 microseconds are required for the energy to travel 1 nautical mile, or 2027 yards (6080 feet). For convenience, however, all Navy radar ranging (including equipment calibration) is based on a flat figure of 2000 yards (6000 feet) per nautical mile; and the 6.18 microseconds is rounded of to 6.1.

The action of range determination is explained with the aid of figure 5-2 and a target at a 20-mile range. Information obtained during the radar operation is presented visually on the face of a cathode-ray tube (scope). (See discussion of A-scope later in this chapter.) The tube face (screen) for certain types of

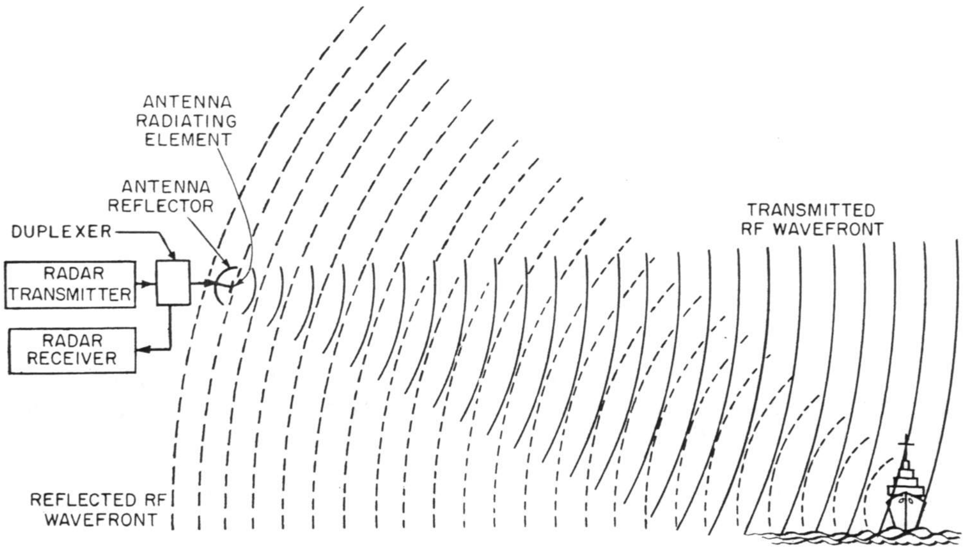

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Figure 5-1. —Pulse-modulated method.

indicators usually is covered with a translucent scale graduated from 0 to the maximum range (in yards or miles). In this instance the maximum range is 20 miles. A horizontal sweep voltage causes the cathode ray beam to trace across the screen beneath the scale. Scale readings indicate the actual target range.

We discuss the A-scope only because it is an easy method of explaining how distance is determined by radar. The A-scope has been replaced by the PPI (planned position indicator) in general-purpose radar sets. See discussion of PPI-scope later in this chapter.

In figure 5-2A, a radiofrequency pulse is transmitted and is just leaving the antenna. A small "pip" is produced at the zero-mile mark on the scope at the instant the radar energy is transmitted. The leading edge of this pulse serves as the reference from which target distance is measured.

In part B, 61 μ s later, the transmitted pulse has traveled 10 miles toward the target. The sweep trace, which is timed to show true range by indicating one-half the distance the RF pulse has traveled, is now at the 5-mile mark.

In view C of figure 5-2, 122 μs after the transmission interval, the RF energy has reached the target, 20 miles away; a relatively small RF reflection, or echo, has started back. The scope trace is now at the 10-mile mark.

In part D, 183 μ s after transmission, the echo has returned half the distance from the target, and the scope is now at the 15-mile mark.

Finally, at part E of the illustration, 244 μ s after transmission of the initial pulse, the echo has returned to the radar receiving antenna. This relatively small amount of RF energy is amplified and applied to the vertical deflection system of the scope, and an echo pip of smaller amplitude than the initial pip is displayed at the 20-mile mark.

If two or more targets are in the path of the transmitted pulse, each returns a portion of the transmitted energy in the form of echoes. The target at the greatest distance away (assuming all targets are similar in size and type of material) will return the weakest echo.

BEARING DETERMINATION

Bearing (also called azimuth) is the direction of an object from the observer, expressed in degrees clockwise through 360° around the horizon. True bearing is measured from true north; relative bearing is measured from the heading of the ship. In radar applications,

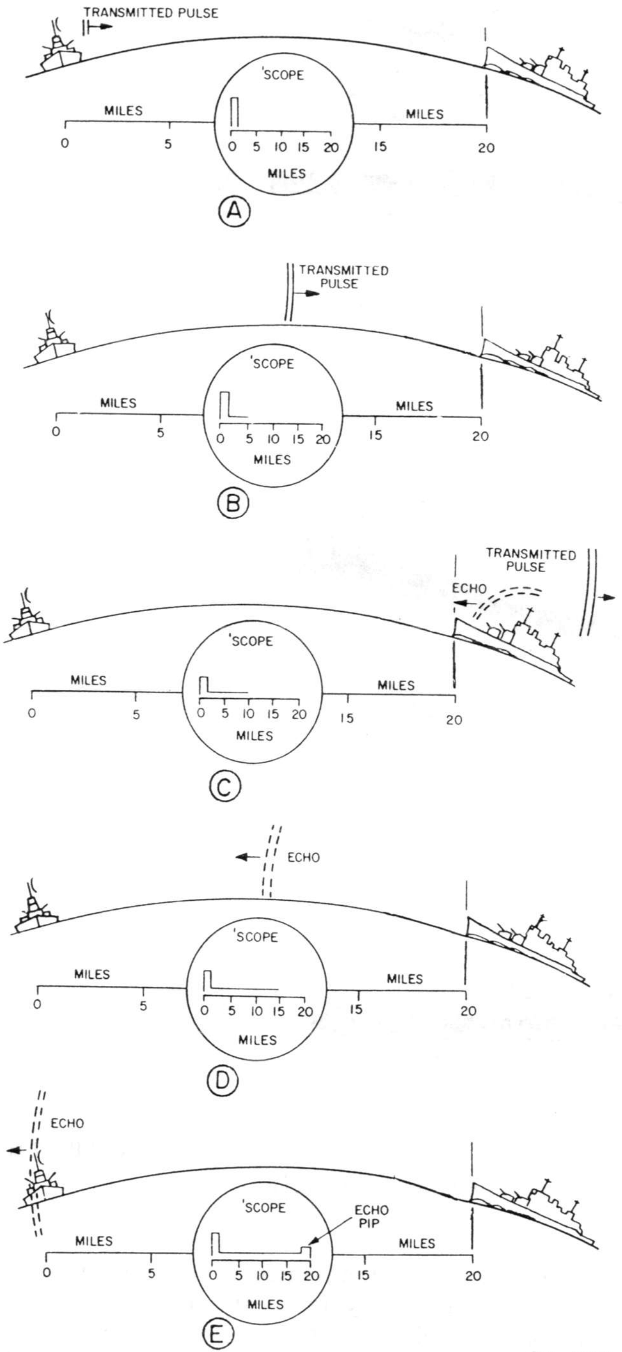

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Figure 5-2.—Radar range determination.

bearing (true or relative) of the target may be determined by concentrating the radiated energy in a narrow beam, and by knowing the beam direction when a target pip is picked up.

Radar antennas are designed to produce a single narrow beam of energy in one direction (fig. 5-3). The receiving pattern is the same as the transmitting pattern. The antenna and associated lobe of RF energy are either rotated in the horizontal plane through 360° or "rocked" back and forth so that they sweep over a given area. When a target is encountered (fig. 5-3A), a return signal is received. The antenna may then be positioned so that the received echo signal is maximum (fig. 5-3B). The maximum signal strength indicates that the axis of the lobe passes through the target. The radar set is equipped with bearing indicators so that target bearing can be measured either from true north or with respect to the heading of a ship (or aircraft) containing the radar set.

The bearing of a target can be determined in several ways. When the single-lobe method is used, the sensitivity of the system depends on the angular width of the lobe pattern. If the signal strength changes appreciably when the antenna is rotated through a small angle, the accuracy with which the on-target position can be selected is great.

When the antenna lobe is rotated from position A to position B (fig. 5-3), the increase in the signal strength received is small. Thus, the bearing of the target cannot be determined accurately. When a radar has a narrow lobe of concentrated energy (fig. 5-3C), the change in signal strength is greater as the antenna is rotated to the target and a more accurate determination of bearing is possible.

ALTITUDE DETERMINATION

The remaining dimension necessary to locate completely an object in space can be expressed either as an angle of elevation or as an altitude. If one is known, the other can be calculated from one of the basic trigonometric ratios. A method of determining the angle of elevation and the altitude is shown in figure 5-4. Slant range (fig. 5-4A) is obtained from the radarscope indication as the range to the target. The angle of elevation is the same as that of the radar antenna (fig. 5-4B). Altitude is equal to the slant range multiplied by the sine of the angle of elevation.

In radar equipment with antennas that can be elevated, altitude determination by slant range is computed automatically be electronic means.

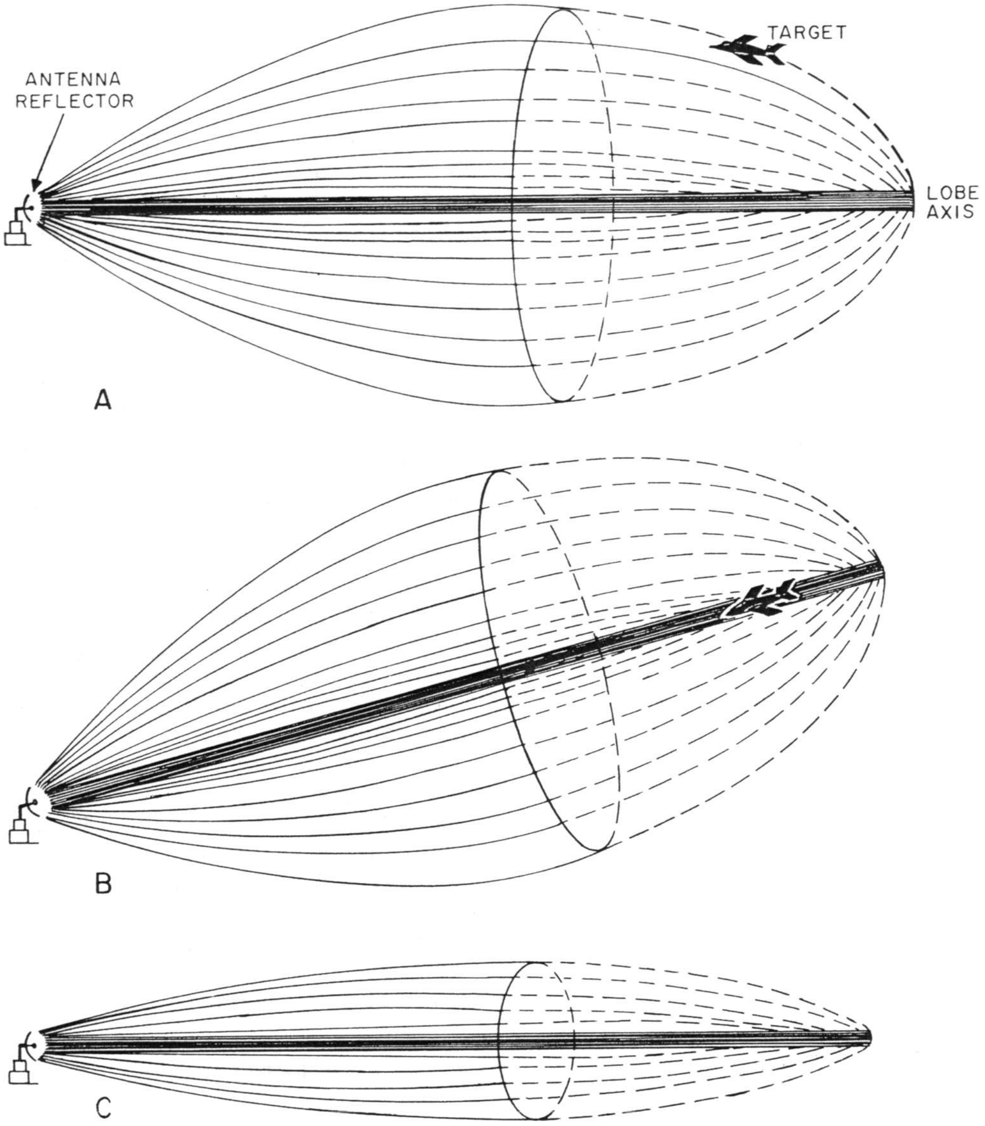

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Figure 5-3. —Radar determination of azimuth or bearing.

BASIC PULSED RADAR SYSTEM

A block diagram of the basic units of a pulse-modulated radar system is shown in figure 5-5. The modulator produces the timing pulses that trigger the transmitter and indicator. These timing pulses are converted by the transmitter into high-power pulses of RF energy at the assigned frequency. The use of one antenna for both transmitting and receiving is made possible by the duplexer. It directs the transmitter outgoing pulses to the antenna (away from the receiver) and the incoming echo pulses to the receiver (away from the transmitter). The antenna system radiates the RF energy as a directional beam, and receives the echo pulses only from the direction in which the antenna reflector is pointing. The receiver amplifies the received echo pulses reflected from the target, and applies them to the indicator. There they are displayed on a cathode-ray tube. Necessary

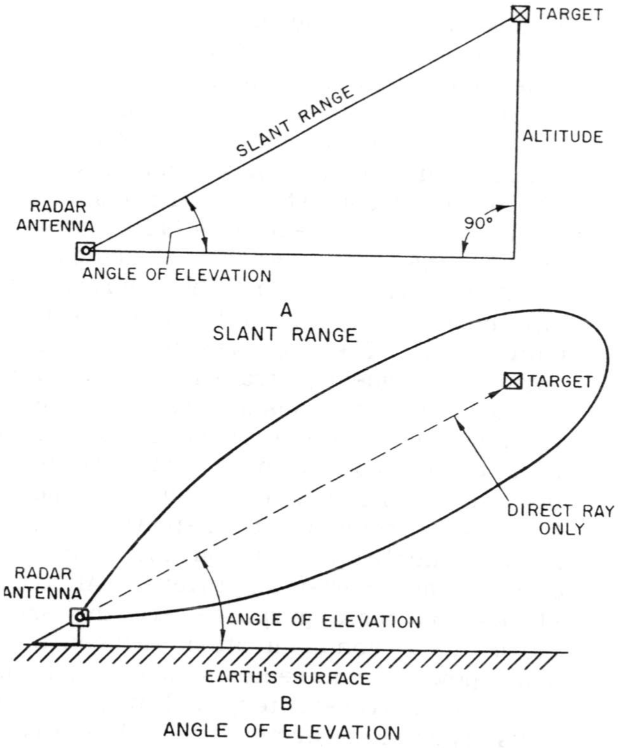

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Figure 5-4.—Radar determination of altitude.

power for the various radar functions is supplied by the power supply. A more detailed description of some of the individual blocks follows.

MODULATOR

The transmit-receive periods in a pulsed radar system are controlled by synchronizing signals generated in the modulator or synchronizer. Usually, the basic control device within the modulator is a very stable oscillator. The oscillator output is amplified, shaped as required, and fed as synchronizing pulses to the transmitting, receiving, and indicating sections.

The transmit period in a radar system is much shorter in duration than the receive period. Sufficient time must be allowed during the receive period (between transmissions) to ensure the return of echoes from the maximum desirable range of the system. Thus, the maximum range from which echoes can be received for a target of given size depends on the relationship of the time between transmission bursts (pulse repetition) and the RF power generated.

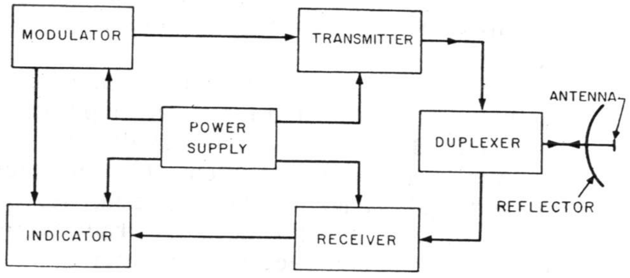

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Figure 5-5.—Block diagram of a pulse-modulated radar system.

The relationship between pulse repetition rate (PRR) and maximum range is explained with the aid of the following example. Assume that sufficient power is transmitted to produce useful echoes from a target of appreciable size. The pulse repetition period is the reciprocal of the pulse repetition rate. Thus, PRP=1/PRR. If the PRR is 250 pulses per second (PPS), the period is 1/250=.004 sec or 4000 μ s. Assuming further that the transmission period contained in this time period is of negligible duration, and by knowing that each mile traversed by the RF energy requires approximately 6.1 μ s to travel in each direction (or 12.2 μ s per mile), it is seen that the maximum range is 4000 μ s/12.2 μ s = 328 miles.

Although maximum range increases with a decrease in pulse repetition rate, it should be noted that the antenna system is rotated at a relatively rapid rate, and the beam of energy strikes a target for a relatively short time. During this time, a sufficient number of pulses must be transmitted and their echoes received to produce a visual indication of target presence. The most desirable pulse repetition rate, then, is a compromise between maximum range and indicator requirements.

The minimum range at which a target can be detected is governed largely by the width (duration) of the transmitted pulse. If a target is so close to the transmitter that the echo is returned before the transmitter is turned off, reception of the echo is masked by the transmitted pulse. Hence, for short ranges, the transmitted pulse must be of short duration to permit the detection of close-in targets.

The choice of pulse repetition rate, pulse width, frequency, and transmitter power output is decided by these five conditons: (1) the tactical use of the system, (2) accuracy required, (3) range to be covered, (4) overall physical size, and (5) the most practical method of generating and receiving the signal.

TRANSMITTER

An outgoing radiofrequency pulse of extremely short duration is generated by the transmitter each time a keying pulse is received from the modulator. The frequency of the RF pulse is high. The directivity of the radiated beam is greater at high frequencies. Moreover, the higher the frequency, the shorter the wavelength; hence, the smaller and lighter will be the antenna system components.

A special microwave oscillator tube, called a magnetron (fig. 5-6), frequently is used as the transmitting tube in radar systems. A pulse from the modulator, shaped and amplified to form a strong negative pulse, is applied to the magnetron cathode. The presence of this pulse causes the tube to oscillate for the duration of the pulse. The frequency of the magnetron oscillations may approximate several thousand megahertz. Usually the peak power output ranges between 100 and 1000 KW but, because the short duration of the pulse results in a much lower average power, the components are relatively small.

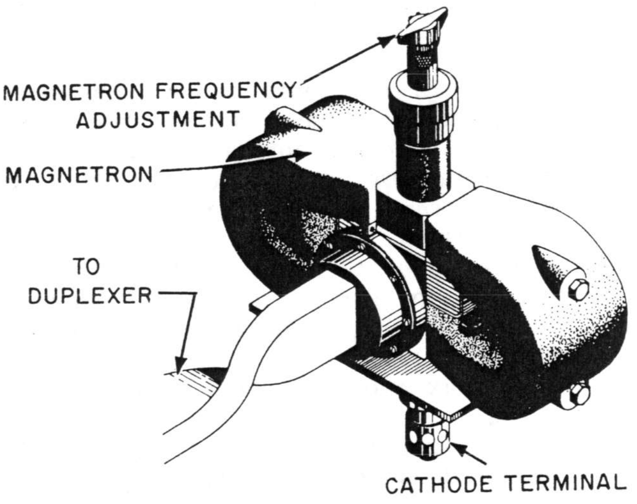

Figure 5-6.—Magnetron.

In a radar system using a magnetron (fig. 5-7), the magnetron output is fed to the radar antenna through a duplexer and a waveguide. The duplexer consists of antitransmit-receive (ATR) and transmit-receive (TR) switches that prevent the high-powered RF output of the transmitter from entering the receiver, but permit the returning signal to enter the receiver unimpeded. The duplexer and the waveguide physically connect the transmitter to the antenna.

Some radar transmitters are similar to radio (communication) transmitters. Figure 5-8 is a block diagram of a radar transmitter. Instead of the single magnetron, the radar transmitter consists of an electron tube oscillator, amplifiers, frequency multipliers, drivers, and power amplifiers. Although the stages and their purposes are the same as those in a communication transmitter, the peak power requirements are much higher in a radar transmitter, and it is necessary to use special power amplifier tubes. Klystrons and traveling wave tubes are examples of these tubes, but, because of their complexity, they are not treated in this text.

In the electron tube type of radar transmitter, frequency stability is ensured by using only the most stable type of oscillator-buffer arrangement, and by operating the oscillator at a submultiple of the transmitter output frequency. Frequency multipliers then are used to produce the desired output frequency. The driver stages increase the RF power. The modulator supplies keying pulses to the final power amplifier stages, thereby controlling the duration and repetition rate of the transmitted pulses. Finally, as in the magnetron type of transmitter, the duplexer and the waveguide provide the physical connection between the transmitter and the antenna. Monitoring circuits along the waveguide produce information necessary for tuning the transmitter and receiver, as well as for various tests.

RECEIVER

The receiver used in a particular radar system depends on the design of the transmitter. In the system with the magnetron, the receiver (fig. 5-9) does not have RF amplifiers

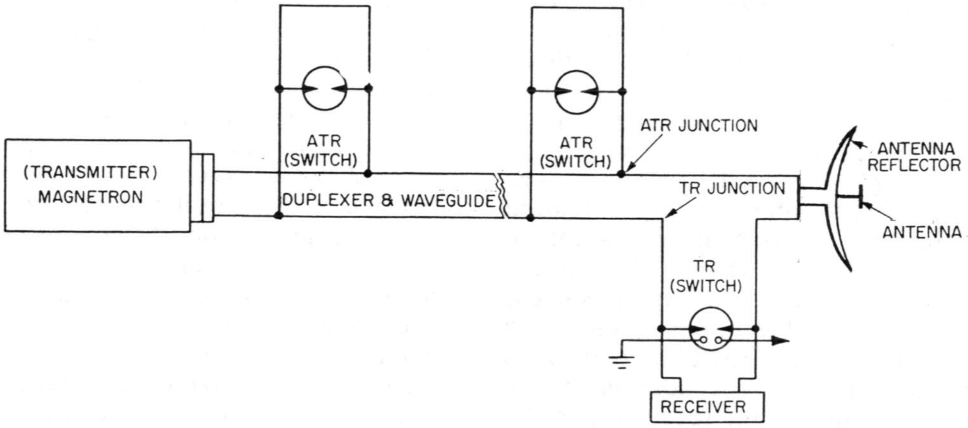

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Figure 5-7. —Transmitting section of pulsed radar system using a magnetron.

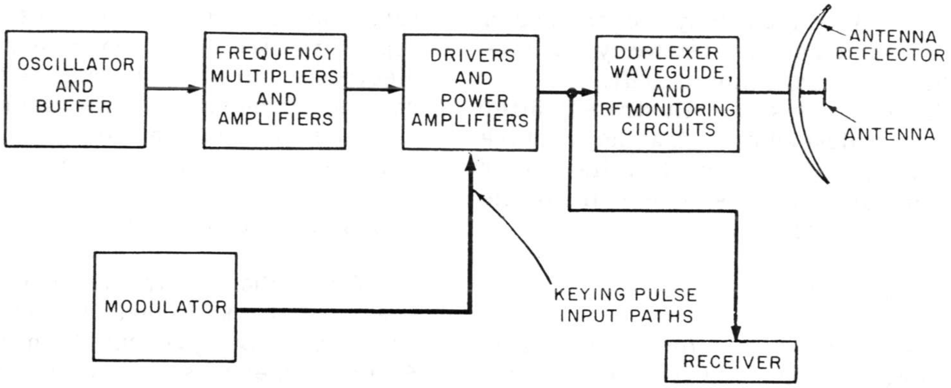

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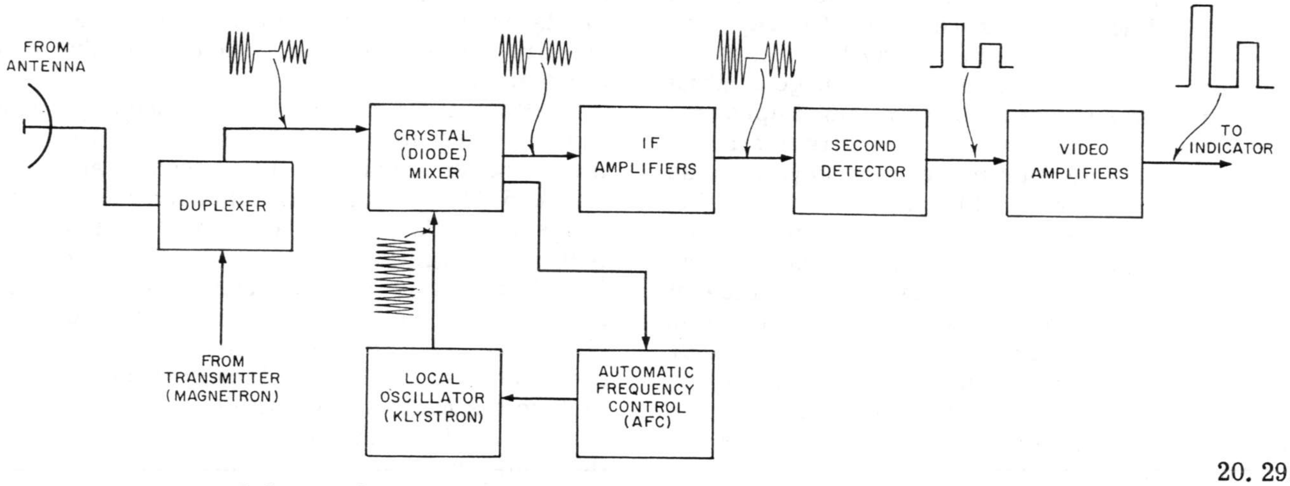
Figure 5-8. —Transmitting section of pulsed radar system using oscillator, multipliers, and amplifiers.



20. 293

Figure 5-9. —Radar receiver used in conjunction with a magnetron transmitter.

preceding the mixer stage. The incoming signal (echo) is fed, via the duplexer, directly from the antenna to the mixer. In the mixer, the incoming signal is mixed (heterodyned) with an unmodulated RF signal generated by the local oscillator. Heterodyning in the mixer produces the intermediate frequency, which, in turn, is fed through several IF stages before it is detected. The detector output (called "video") is amplified in several stages before being fed to the indicator where a visual indication of the received echo is produced.

Another output from the mixer goes to the automatic frequency control (AFC) circuit. This circuit produces a DC voltage proportional to the amount of error (if any) in the frequency of the IF signal. The error voltage is applied to the local oscillator in such a manner that it changes the oscillator frequency until the mixer output IF is on frequency. This action ensures a constant intermediate frequency, regardless of changes in the magnetron frequency or tendencies of the local oscillator to drift.

Some radar receivers (not illustrated) differ from the type just described in that they require the use of RF amplifiers ahead of the mixer stage. Essentially, these receivers are of the conventional superheterodyne type.

INDICATOR (REPEATER)

The purpose of the indicator is to present visually the information gathered by the radar set. In the early days of radar, the indicator was a part of the main radar console. With the increase in numbers and purposes of radar sets aboard ship, however, remote indicators (radar repeaters) became necessary.

A representative radar repeater is shown by block diagram in figure 5-10. The repeater consists of a scope (cathode-ray tube), a power supply, video amplifiers, a sweep generating section, a sweep positioning system, impedance matching circuits, and a range marker circuit.

When the modulator sends a keying pulse to the transmitter, it also sends a triggering pulse to the indicator. This trigger pulse, processed through the sweep generating section of the indicator, appears on the face of the scope coincidently with the transmission of the RF pulse from the antenna. In other words, the trigger pulse initiates the trace or sweep across the face of the scope, and the beginning of the trace indicates the time the radar signal is transmitted.

The target echo pulse (video) from the receiver is increased in amplitude by video amplifiers. It then is applied to the scope via impedance matching circuits. Depending on the type of presentation employed, the echo appears on the trace (or sweep) as a pip or a bright spot. As stated earlier, the time of appearance of the echo pulse is indicative of the target range.

Information from the ship's gyrocompass and the radar antenna assembly is applied to the indicator through a sweep positioning system. This system positions the sweep to a true bearing. At the same time the sweep positioning system synchronizes the rotation of the sweep with the rotation of the antenna. Without true bearing data from the gyro, the position of the sweep indicates a relative bearing.

Range markers can be displayed on the screen to aid the operator in estimating the range of a target. In addition, most radar repeaters are equipped with a mechanical or electronic cursor that facilitates the accurate reading of bearing. Some radar repeaters also are equipped with a range strobe or bug that permits accurate measurement of range.

Types of Presentations

While the radar beam is systematically scanning the surrounding area, the results of each scan are presented on various scopes. Several types of scope presentations (or scans) are used to display the target information. Only the basic types are discussed here, however. In each type, the screen of the cathode ray tube is illuminated by an electron beam (spot), which moves swiftly across the screen, leaving a line of light (called the sweep or trace) in its wake. The manner in which the sweep appears on the screen depends on the type of presentation.

A-SCOPE.—Earlier types of scope presentations were identified by a single letter of the alphabet, such as the A-scope shown in figure 5-11. The A-scope is used to determine range only. Its screen has a short persistence; that is, it glows for only a short time after the illuminating spot is removed. The echo is presented on the screen as a vertical displacement of the horizontal trace, and the point at which the displacement occurs indicates the range to the target.

At one time, the A-scope presentation was the major type of display. For accurate

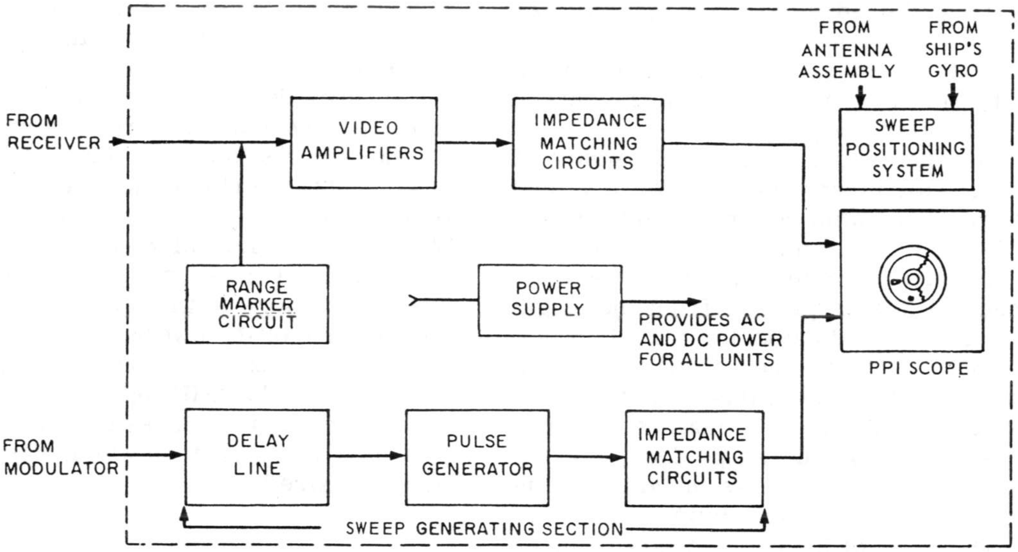


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Figure 5-10.—Radar indicator.

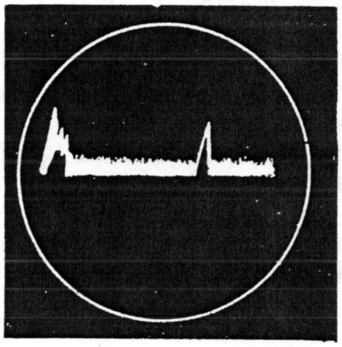

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Figure 5-11.—A-scope presentation.

measurements, however, the antenna had to be stopped and pointed directly at the target. This disadvantage was overcome by the development of the planned position indicator (PPI) type of display.

PPI SCOPE.—The PPI scope (fig. 5-12) presents both range and bearing information. Usually this scope is employed in a radar system whose antenna is uniformly rotated around the vertical axis. The trace on the scope rotates in synchronization with the antenna.

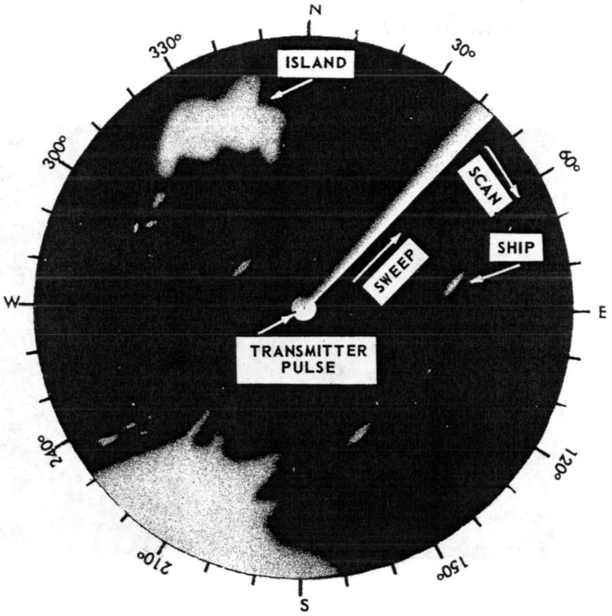

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Figure 5-12.—PPI presentation.

Large numbers of pulses are transmitted for each rotation of the antenna. As each pulse is transmitted, the scan spot starts at the center of the screen and moves toward the edge of the screen along a radial line. Upon reaching the edge, the spot quickly returns to the center and begins another trace with the next transmitted pulse. The return trace of the spot is eliminated from the screen by a process called blanking.

When an echo is received, the intensity of the scanning spot increases considerably, and a bright spot remains at that point on the screen. The position of the radial line on which the echo appears indicates the target bearing. The distance of the target pip from the origin of the radial line indicates the target range.

Unlike the A-scope, the PPI scope has long persistence. Because of this characteristic, it is possible to produce a map of the surrounding territory on the scope face, making the PPI presentation useful as an aid to navigation. The PPI scope presentations also provide the observer with instantaneous changes of target positions in all directions.

RHI SCOPE.—Some radars are equipped with special antennas that enable altitude information to be obtained. The range height indicator (RHI) scope is used to display altitude data. (See fig. 5-13.)

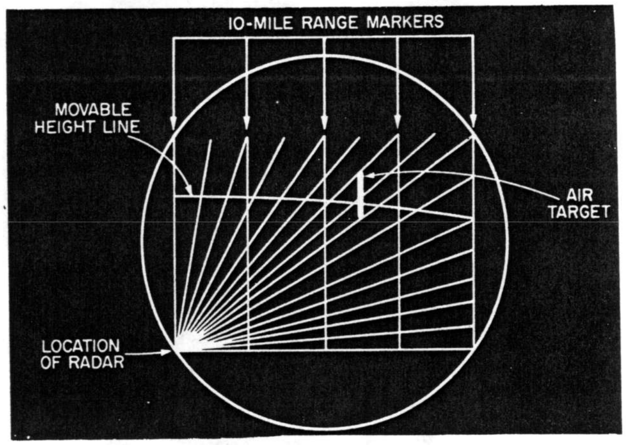

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Figure 5-13.—RHI presentation.

Except for the type of information displayed, the RHI is similar to the PPI. On both scopes, the sweep pivots from one point, and target echoes are shown in bright relief against the background. The sweep on the RHI screen, however, does not go through 360°. Instead, the sweep is synchronized with an antenna that scans vertically through a few degrees and returns to a preset elevation.

An altitude cursor appears across the face of the RHI scope. The cursor, curved to conform to the earth's surface, can be moved up or down. The vertical movement of the cursor is recorded by an associated set of counters. With the cursor aligned so that it bisects the target, altitude is read on these counters. The slant range to the target is indicated along the baseline of the sweep.

Because bearings cannot be read from an RHI scope, the RHI operator usually works in conjunction with the PPI operator who coaches him onto the target on which altitude information is desired.

ANTENNAS

Instead of emitting radio waves in all directions, the radar antenna must send them out in a concentrated beam. One method of obtaining this directional effect is to arrange two or more dipoles so that radiation from the dipoles adds in some directions and cancels in other directions. (Dipoles are conductors that are one-half wavelength long at the carrier frequency of the radar.) When a reflector (either metal or another set of dipoles) is placed behind the dipoles, radiation occurs in one direction, and the resulting lobes of transmitted energy are similar to those shown in figure 5-14.

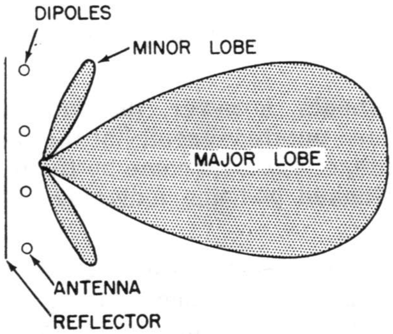

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Figure 5-14.—Directivity of radar beams.

Another method of obtaining directivity in the emitted radar beam is to situate the open, flanged end (feed horn) of the waveguide so that the RF energy is sprayed against the reflector. Then, the reflector is shaped so that the beam is concentrated as desired.

Many types of antennas are used with military radar systems, and they vary in appearance considerable. Although the radiating element actually is the antenna, the entire antenna array is implied when the term "antenna" is used in this text.

BEDSPRING ARRAY

The bedspring array (fig. 5-15), so called because of its resemblance to a bedspring, is used with air-search radars. It consists of a stacked dipole array with an untuned reflector. The more dipoles that are used or stacked in one dimension (horizontal, for example), the more narrow the beam of radiated energy becomes in that same plane. Consequently, the size of the antenna is not the same for all installations.

PARABOLOIDAL ANTENNA

The paraboloidal (or parabolic) antenna, (fig. 5-16), consists of a dipole or feed horn radiator and a parabolic or dish type reflector. This type of antenna produces a narrow beam, the degree of whose concentration is determined by the size and shape of the reflector.

Because the lobe produced by the parabolic antenna is narrow and sharp, its chief function is with fire control and special-purpose radars. It is not used with most shipboard air-search or surface-search radars, because the roll of the ship could cause the very narrow vertical beam to miss a target. It is currently being used, however, with height-finding radars which do have the pitch and roll stabilization systems.

BARREL STAVE ANTENNA

With a simple modification to the reflector, the parabolic antenna becomes the barrel stave antenna. (See fig. 5-17.) Essentially, the barrel stave reflector is a parabolic reflector with the top and bottom cut away, leaving only the center part of the reflecting surface.

The lobe produced by the barrel stave reflector still is narrow horizontally. But, because there is no surface to restrict its vertical height, the lobe becomes a high vertical beam suitable for surface-search. The height of the lobe is great enough to prevent the roll of the ship from causing a target to go undetected.

BILLBOARD ARRAY

A billboard or fixed array is one in which an antenna or antenna system is placed in front of a large plane-reflecting surface. Such an antenna is shown in figure 5-18. The reflecting surface may consist of rods (joined at the end), mesh, or a solid sheet of conducting material.

Because of their large size and weight, fixed array installations presently are limited to larger ships. The installation consists of four billboard antennas built into the superstructure so that each antenna covers a 90° sector around the ship. This type of installation ordinarily is used with air-search radars.

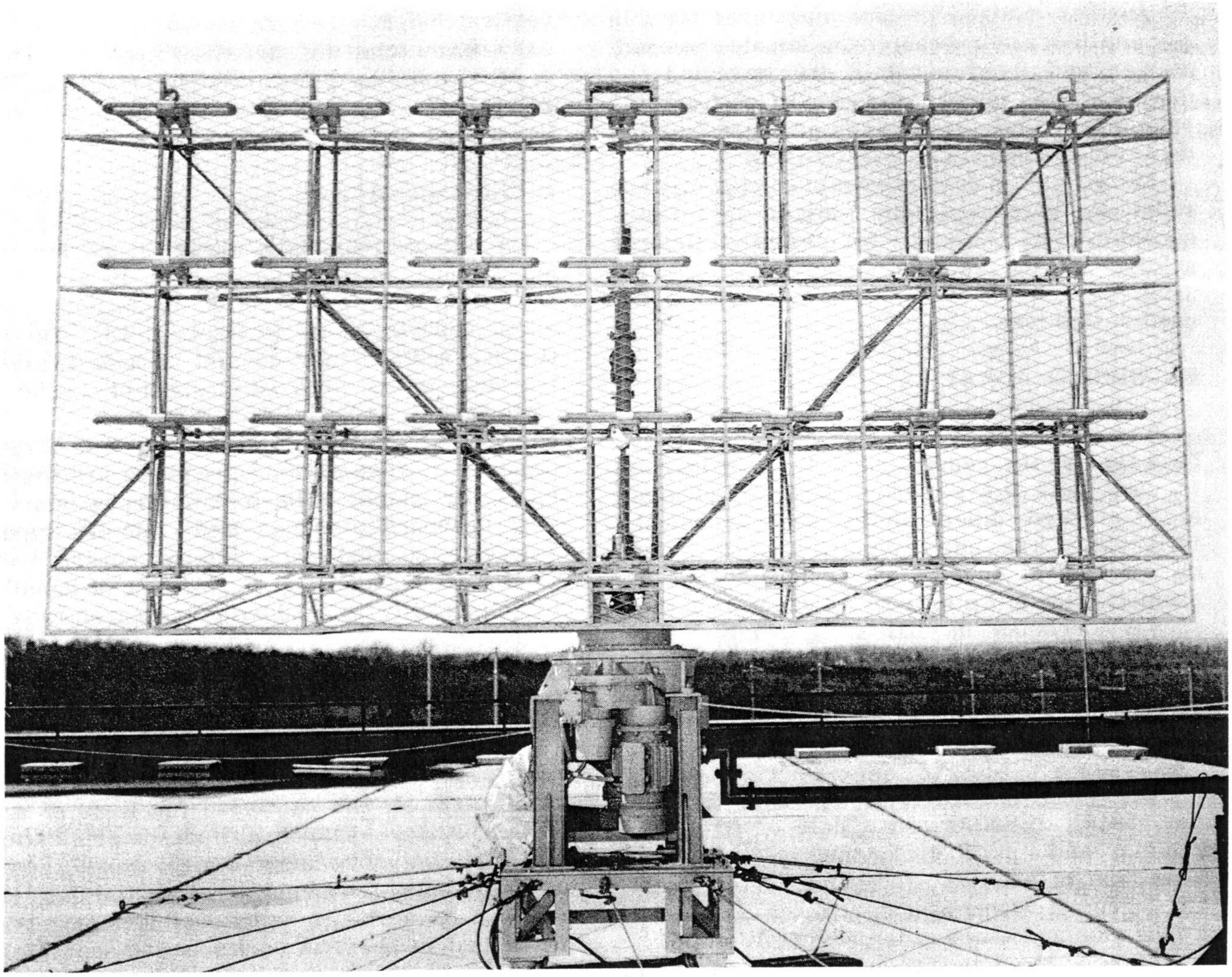
RADAR FUNCTIONS AND CHARACTERISTICS

No single radar set has yet been developed to perform all the combined functions of air-search, surface-search, altitude-determination, and fire control because of size, weight, power requirements, frequency band limitations, and so on. As a result, individual sets have been developed to perform each function separately.

Most of the radar sets that are designed for a specific purpose, such as surface-search, have certain system constants or general characteristics in common. The remainder of this chapter is devoted to a brief discussion of the functions and characteristics of various radar and radar ancillary systems.

SURFACE-SEARCH RADARS

The principal function of surface-search radars is the detection and determination of accurate range and bearing of surface targets and low-flying aircraft while maintaining 360° search for all surface targets within line of sight distance of the radar antenna. The system constants of this radar vary from those of the air-search radar. Because the maximum range requirement of a surface-search radar is limited mainly by the radar horizon, very high frequencies are used to



33.109

Figure 5-15.—Bedspring array.

give maximum reflection from such small target-reflecting areas as ship masthead structures and submarine periscopes. Narrow pulse widths permit short minimum ranges, a high degree of range resolution, and greater range accuracy. High pulse repetition rates are used for best illumination of targets. Medium peak powers can be used to detect small targets at line of sight distances. Wide vertical beam widths are used to compensate for pitch and roll of own ship and to detect low-flying aircraft. Narrow horizontal beam widths permit accurate bearing determination and good bearing resolution.

AIR-SEARCH RADARS

The chief function of an air-search radar is the detection and determination of ranges and bearings of aircraft targets at long ranges (greater than 50 miles), maintaining complete 360° search from the surface to high altitude. System constants must be selected with this function in mind. Low frequencies are chosen (P- or L-band) to permit long-range transmissions with minimum loss of signal. Wide pulse widths (2 to 4 microseconds) increase the transmitting power and are used to aid in detecting small targets at greater distances.

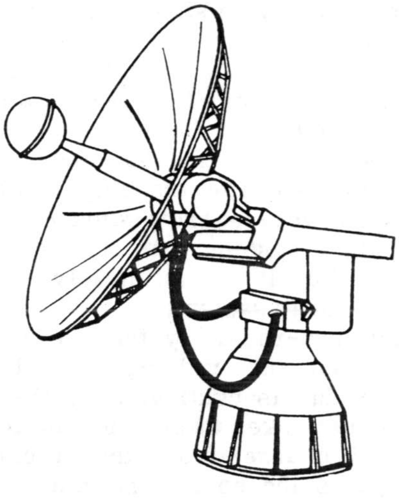


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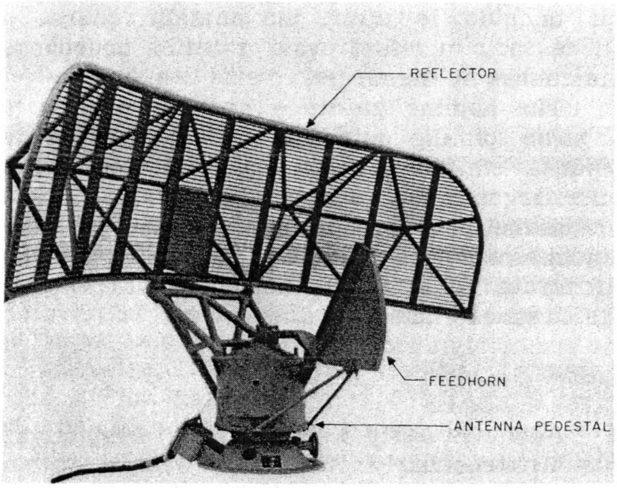
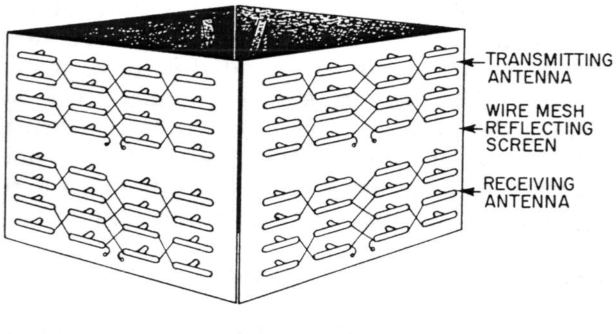
Figure 5-16.—Parabolic antenna.



32.186
Figure 5-17.—Barrel stave antenna.

Low pulse repetition rates are selected for greater maximum measurable range. High peak power permits detection of small targets at long ranges. Wide vertical beam width is used to ensure detection of targets from the surface to relatively high altitude and to compensate for the pitch and roll of the ship. Medium horizontal beam width gives fairly accurate bearing determination and bearing resolution while maintaining 360° search coverage.



120.29(120C)
Figure 5-18.—Billboard array.

ALTITUDE-DETERMINING RADARS

The function of the altitude-determining radar is to find the accurate range, bearing, and altitude of aircraft targets detected by air-search radar. Its antenna must be tilt-stabilized to provide a stable reference for altitude determination. High frequencies (S-band) are chosen as a compromise between the long-range capabilities of lower frequencies and the narrow beam-forming characteristics of higher frequencies. Narrow pulse widths (1 microsecond) are chosen to permit good range resolution. High pulse repetition rates (600 to 1000 PPS) permit detection of small aircraft targets at medium ranges (30 to 50 miles). High peak power permits the detection of small aircraft targets at medium ranges while using narrow pulse width. Narrow vertical and horizontal beam widths (1° to 3°) are selected to permit accurate bearing and position angle determination and good bearing and elevation resolution.

FIRE CONTROL RADARS

The principal function of fire control radars is the acquisition of targets originally detected and designated from search radars, and the determination of extremely accurate ranges, bearings, and position angles of targets. Antennas must be tilt-stabilized to compensate for pitch and roll of own ship. Very high frequencies are chosen (X-band and K-band) to permit the formation of narrow beam widths with comparatively small antenna arrays, detection of targets with small reflecting areas, and good definition of all targets. Pulse widths (0.1 to 3 microseconds) provide a high degree of range accuracy, short minimum range, and excellent range resolution. Repetition rates (1500 to 2000) afford maximum target detection while using narrow pulse widths. Because very long ranges are not required, low peak power permits the use of smaller components by keeping the average power low. Narrow vertical and horizontal beam widths (0.9° to 3°) provide accurate bearing and position angles and a high degree of bearing and elevation resolution.

MISSILE GUIDANCE RADARS

In general, missile guidance radars operate on the same principles as the air-search, altitude-determining, and fire control radars just described. The guidance systems for the missiles we are concerned with can be divided into four groups: (1) self-contained, (2) command, (3) beam-rider, and (4) homing.

In a self-contained (inertial) guidance system all the guidance and control equipment is inside the missile. The guidance system neither transmits nor receives signals during the missile's flight. This is a major advantage, since only limited countermeasures can be used against it. This means that the trajectory that the missile must follow to hit the target must be calculated and fed into the missile before it is launched. The heart of the inertial guidance system is an arrangement of accelerometers that detect motions along their sensitive axes. The inertial guidance system is used for long range surface-to-surface missiles, such as the Polaris.

A command guidance system is one in which directional commands are sent to the missile from some outside source. One radar aboard ship tracks the target, another radar tracks the missile, and a computer takes the two sets of tracking data and issues radar signals which guide the missile to the target. The equipment in the missile consists of a receiver and a control system. The shipboard equipment consists of two radars and a computer.

The beam-rider guidance method is very similar to the radar command guidance method. The principle difference is that the command system gives specific signals to "turn right, or turn left, etc.," while in the beam-rider system the shipboard control equipment transmits information only, not commands. The missile guidance equipment must interpret this information contained in the received radar beam and formulate its own correction signals. Therefore, we say the missile rides the beam to the target. The beam-rider system is highly effective for use with short-range and medium-range surface-to-air and air-to-air missiles.

Two types of beam-rider systems are possible. In the simplest type, a single radar director is used for both target tracking and missile guidance. In the other, one radar director is used for tracking, while another provides the very narrow guidance beam. The single-radar system has the advantage of simplicity, but it is not nearly as effective as the two-radar system.

In the two-radar system, a computer is used between the radars, and the missile guidance radar is controlled by the computer. The computer takes target information--speed, range, and course—from the tracking radar, and computes the course that must be followed by the missile. The output of the computer controls the direction of the guidance radar antenna, and points the guidance beam toward the point of target interception. Because the computer receives information constantly, it is able to alter the missile course as necessary to offset evasive action or changes in course by the target.

The homing guidance system controls the course of the missile by a device in the missile that reacts to radiation given off by the target, such as heat, light, radio, or radar radiation. The radiation may be generated by the target or reflected from the target when generated by some outside source. This system is commonly used.

AEW RADARS

Airborne early warning (AEW) systems are used extensively in the Navy. These systems are special shipboard and aircraft radar equipment that work together as a single unit.

The purpose of the AEW system is to extend the normal radar horizon by placing the radar set in an airplane, and relaying the radar information to the AEW ship for presentation on the ship's indicator. Thus, targets can be seen at considerable greater distances than is possible with standard shipboard radar sets. For example, a plane at a 1000-foot altitude will have a minimum radar detection range of 55 miles on a target 50 feet high. If the plane is relaying radar information to a mother ship 50 miles away, then the ship has an effective search range of 105 miles in the plane's direction. If a relay is directly over a mother ship at 5000 feet, the ship has an effective 360° search range of 100 miles.

DOPPLER EFFECT

The doppler effect is the change in the frequency resulting from motion between a source and a receiver. To illustrate this concept, consider two persons, source (S) and receiver (R) (fig. 5-19A), standing along a swift-flowing stream some distance apart. Source (S) is tossing fishing bobs into the water at a steady rate, say 10 BPM (bobs per minute). Receiver (R) has a stopwatch, and as the bobs begin to pass he takes a count for one minute, counting 10 bobs. In this illustration the time was one minute, distance remained constant between S and R and rate of frequency of the bobs was the same at S and at R. This would be known as zero-doppler.

Source (S) begins moving steadily away, tossing bobs into the stream at the same rate 10 BPM, figure 5-19B. Again receiver (R) counted bobs for one minute as they passed (say that he counted only 8 BPM). R observed that the bobs were spaced farther apart, therefore the frequency at R is less (lower). The time interval has stayed the same, but distance between bobs has increased; the rate of frequency has decreased, although the source frequency has remained constant. This would be known as down or low doppler.

Likewise, if S moves toward R tossing bobs at the same rate (fig. 5-19C), the bobs will be closer together and observer (receiver) R would see a higher frequency (say 12 BPM). Again the time interval is the same. Distance between bobs has decreased and frequency increased. This would be up or high doppler.

High doppler is explained again in figure 5-19D. If the receiver runs toward the source, who is stationary, he views the bobs more frequently and the effect is the same as in figure 5-19C.

Doppler effect may be observed in sound waves when listening to a phonograph turntable, if the turntable's speed is varied. At a higher RPM, the voice is at a higher pitch, and at a lower RPM the voice is at a lower pitch. Another common example of the doppler effect by sound waves is at a train crossing (fig. 5-20). You listen to the high-pitch whistling sound as the train approaches, and the low-pitch sound as the train passes and goes away. As the train approaches you, the relative motion will cause your ear to receive more cycles per second than when there is no relative motion, and as the train moves away your ear encounters fewer cycles per second. This is the doppler effect and is due to frequency change of the sound signal in relation to the observer.

The doppler effect is also noted in electromagnetic frequency waves, and extensive use is made of this phenomena in electronics.

CONTINUOUS WAVE RADAR

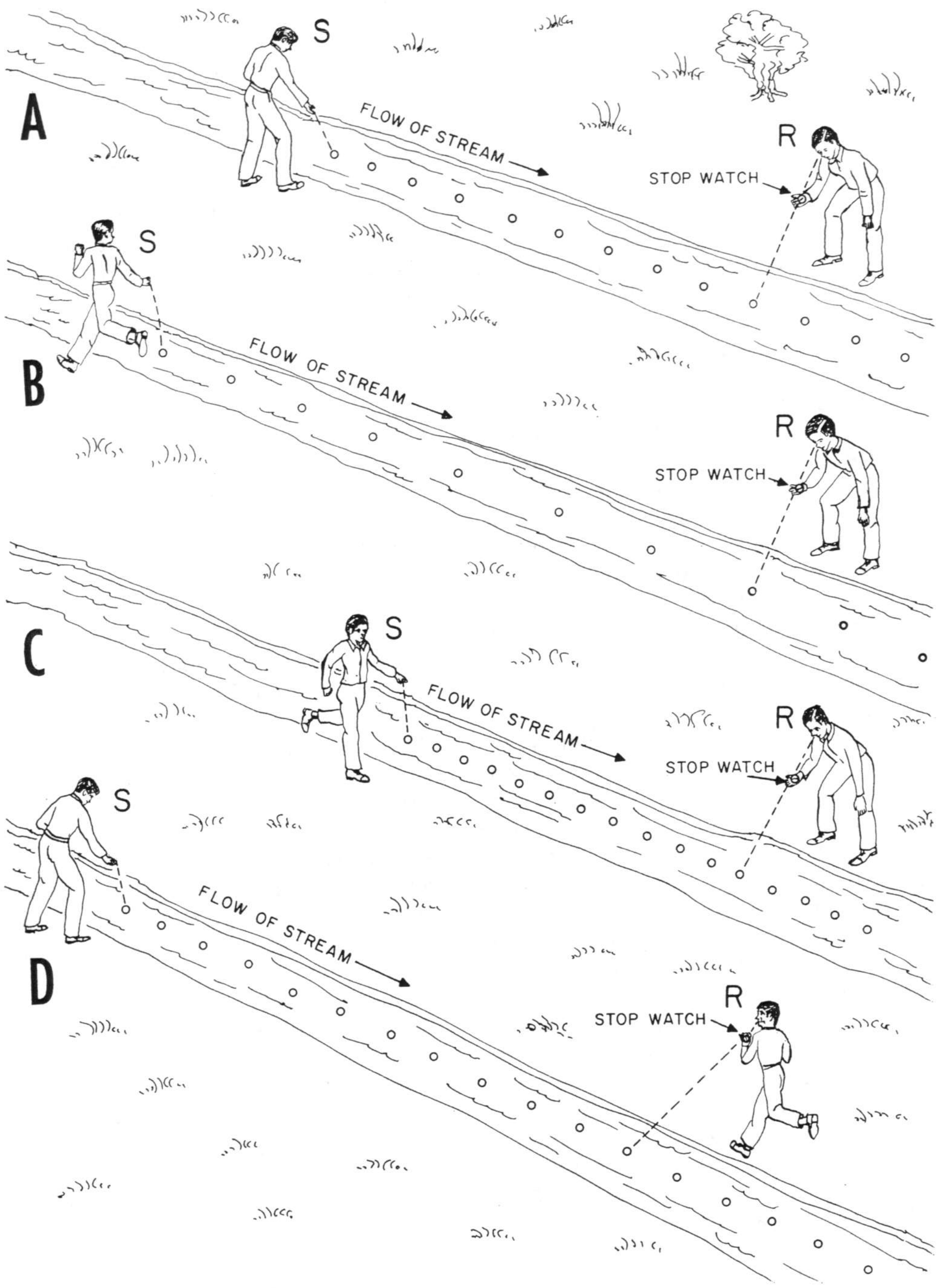
Continuous-wave radar is used as a speed measuring device. CW radar cannot measure distance because the wave is continuous and has no time reference as compared to pulse radar. CW radar (fig. 5-21) uses two separate antennas since the transmitter and receiver operate simultaneously.

The transmitter (fig. 5-21) has a modulator to shape the high power input of the RF oscillator. The RF oscillator sends two signals. One is a weak signal sent directly to the receiver mixer which can be compared to figure 5-19A having no-doppler and the other is a very strong signal radiated at the transmitter antenna which has a high-doppler as compared with figure 5-19D. The aircraft in this radar beam is shown reflecting some of the RF energy to the receiver antenna. The aircraft, in effect, becomes a second emitter of waves which gives the high-doppler effect as shown in figure 5-19C.

The heterodyne receiver compares the internally received frequency, which has no-doppler, with the transmitted frequency which has high-doppler, the difference being the frequency shift. The radar can only indicate the aircraft's presence and its relative speed. To determine direction of the aircraft, high- or low-doppler must be determined by the addition of a local oscillator.

The doppler frequency shift is then amplified, detected, and sent to the indicator system for interpretation. If the doppler frequency is in the audio range, a head set can be used to indicate the presence of a target.

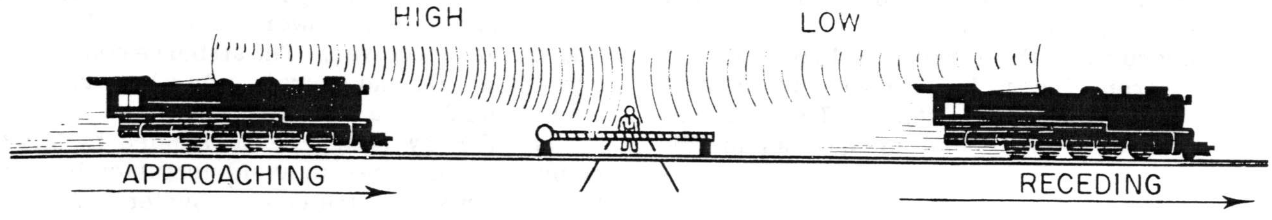
Continuous wave radar and pulse radar systems can be combined to measure a target's velocity toward or away from you and also measure the distance and transit time. This is known as pulse-doppler radar.



120.79

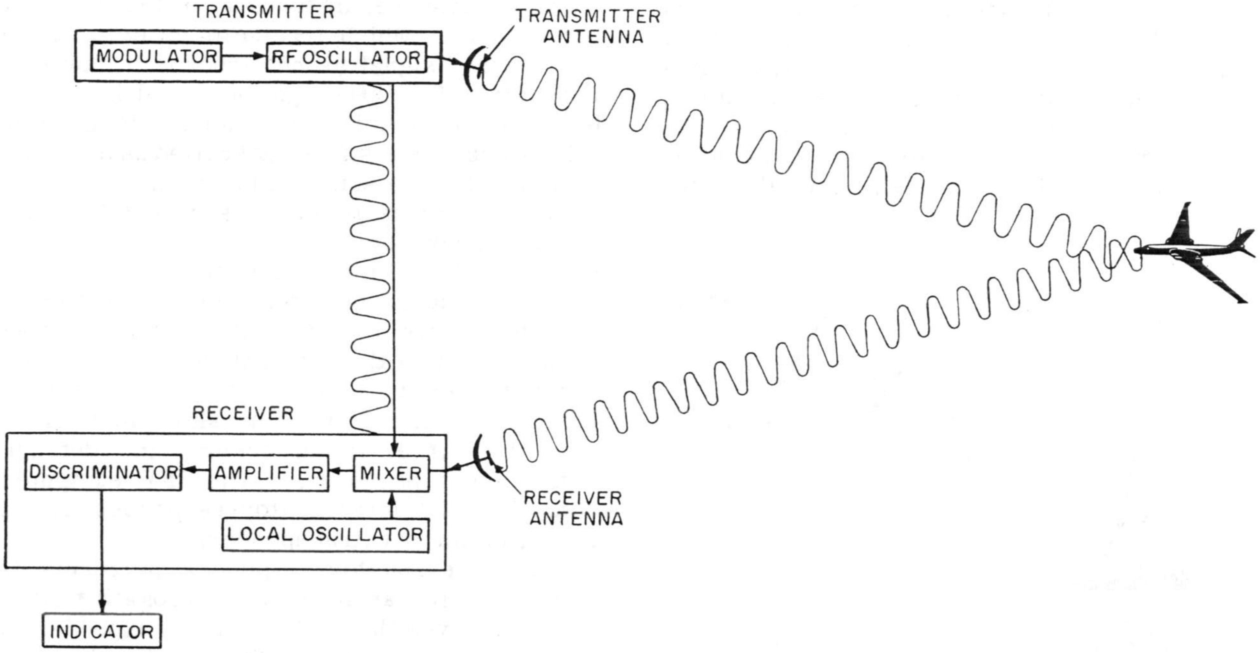
Figure 5-19.—Doppler principle.

Let's look at a pulse radar in its simplest form. The transmitter generates a very short pulse of high energy radiofrequency. As the transmitter pulse leaves the antenna, the radar's receiver becomes operative, allowing it to receive and amplify any RF energy reflected by a target. The time between the transmission of the RF energy and the echo return is measured electronically and displayed graphically by a CRT (cathode-ray tube).



71.37(120C)

Figure 5-20.—Principle of doppler sound waves.



55.58(120C)

Figure 5-21.—Principle of continuous wave doppler radar.

Thus the pulse radar can measure range accurately, and does not depend on target's movement for detection. Therefore it can detect both stationary and moving targets.

The CW echo is changed in frequency by a moving target. This change, as you remember, is called Doppler shift. The Doppler frequency is used for target detection, and to indicate the target's range rate. It is possible, by use of filter circuits, to reject all targets except those traveling at or near a selected velocity. Normally a CW radar will not detect stationary targets. If the CW radar radiates energy continuously, at a constant frequency, there is no reference by which we can measure range directly. Even with a form of carrier modulation its ranging is crude.

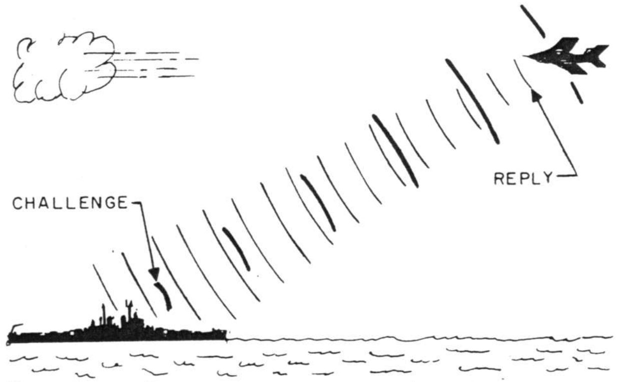
On the other hand, pulsed radar radiates energy at a selected time interval. This interval determines the usable range of the radar. Pulse radar, with its precise measurement of transit time, has a very accurate range measurement capability.

The pulse-Doppler radar combines the best features of CW and pulse radar. The pulse-Doppler method uses high frequency CW, in the form of short bursts, or pulses. The pulse repetition rate (PRR) is much higher than that of a conventional pulse radar, and the pulse length is longer.

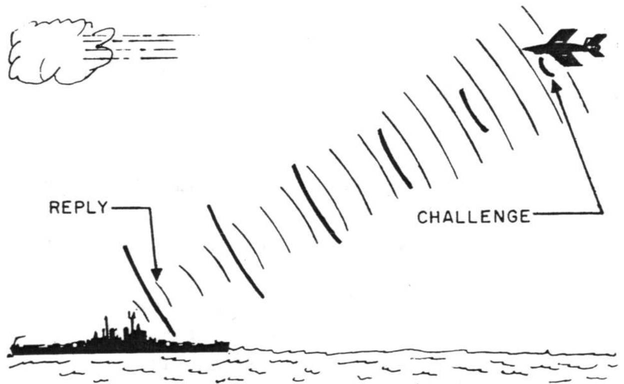
A measure of the target's velocity toward or away from the radar can be obtained by means of the Doppler shift. This can be accomplished in the same manner as in CW radar.

IFF SYSTEMS

Although technically not a radar equipment, an electronic system that is employed with radar permits a friendly craft to identify itself automatically before approaching near enough to threaten the security of other naval units. This system is called identification, friend or foe (IFF) (fig. 5-22). It consists of a pair of special transmitter-receiver units. One set is aboard the friendly ship; the other is aboard the friendly unit (ship or aircraft). Because space and weight aboard aircraft are limited, the airborne system is smaller, lighter, and requires less power than the shipboard transmitter-receiver. The airborne equipments are automatic, and operate only when triggered by a signal from a shipboard unit.



A. SHIP'S CHALLENGE, AIRCRAFT'S REPLY



B. AIRCRAFT'S CHALLENGE, SHIP'S REPLY

120.80

Figure 5-22.—IFF systems.

The IFF systems are designated by MARK numbers. In order to avoid confusion between IFF systems and fire control systems, the IFF mark number is a Roman numeral (Mk III), whereas the fire control number is an Arabic numeral (Mk 29).

The IFF system operates as follows: An air-search radar operator sees an unidentified target on his radarscope. He turns on the IFF transmitter-receiver, which transmits an interrogating or "asking" signal to the airborne transmitter-receiver. The interrogating signal is received by the airborne unit, which automatically transmits a characteristic signal called an identification signal. The shipboard system receives the signal, amplifies it, decodes it, and displays it on the radarscope or on a separate indicator scope. When the radar operator sees the identifying signal and identifies it as the proper one, he knows that the aircraft is friendly.

If the aircraft does not reply when interrogated, however, or if it sends the wrong identifying signal, then the ship must assume that the target is an enemy, and defensive action must be taken. The IFF equipments comprise the interrogator-responder and the identification set (transponder).

The interrogator-responder performs two functions. It transmits an interrogating signal, and it receives the reply. The transponder also performs two functions. Not only does it receive the interrogating signal, but it replies automatically to the interrogating signal by transmitting an identifying signal. The two types of interrogation are direct and indirect. Interrogation is direct when the interrogating signal that triggers the transponder is a pulse from the radar equipment. Interrogation is indirect when the interrogating signal is a pulse from a separate recognition set operating at a different frequency from that of the master radar.

Early IFF systems used direct interrogation. Direct interrogation proved unsatisfactory, however, because the transponder was required to respond to radars that differed widely in frequency. Later IFF systems, consequently, make use of indirect interrogation within a special frequency band reserved for IFF operation.