CHAPTER 7

RADAR THEORY AND EQUIPMENT

Radar is an acronym for Radio Detection and Ranging. Shipboard radar systems are used primarily for early detection of surface or air objects for the purpose of obtaining data such as range, bearing, altitude and speed of targets. They are also used for general surveillance, navigation purposes, and for controlling own aircraft and small boats.

The principle upon which radar operates is very similar to the principle of sound wave reflection. If a person shouts in the direction of a cliff, or some other sound reflecting surface, an echo will be heard. The sound waves, generated by the shout, travel through the air until they strike the cliff. There, they are reflected and returned to the originating source as an echo. The strength, or loudness, of the echo is mainly dependent upon the strength of the shout, the distance of the reflecting surface, the ability of the surface to reflect sound waves, and the hearing acuity of the listener.

Because sound waves travel through the air at 1100 feet per second, there is a time lapse between the instant the sound wave leaves and the instant the sound wave is heard. Therefore, the farther the distance from the cliff, the longer the time before the echo is heard. For example, if the shout were made 2200 feet from the cliff, the echo would be heard four seconds later, two seconds for the sound to travel to the cliff and two seconds to return.

Radar utilizes radio frequency (rf) electromagnetic waves to take advantage of this principle by radiating a high powered rf beam from a directional antenna. A signal echo is returned from objects in the path of the beam and detected by a sensitive receiver. The echoes are then presented visually on an indicator. The radar system gives an indication of target distance (range) by measuring the time between the transmission of energy and the return echo; and an indication of target direction by the bearing of the directional antenna.

DETERMINING TARGET POSITION

The visual data required to determine and track target position is supplied by an indicator, which is a specially designed cathode-ray tube installed in a unit known as a plan position indicator (ppi). Bearing, range, and in the case of aircraft, altitude, are necessary to determine target movement. No single indicator, however, furnishes all three bits of information. In general, two scopes must be used—one for bearing and range, and one for range and altitude.

BEARING

The antennas of most radars are designed so that they radiate energy in one lobe that can be moved only by moving the antenna itself. The general shape of such a lobe is shown in figure 7-1. As can be seen in the illustration, the shape of the lobe is such that the echo signal strength varies more rapidly with a change of bearing on the sides of the lobe than near the axis. Therefore, the echo signal varies in amplitude as the antenna rotates. At antenna position A, the echo is relatively small, but at position B, where the lobe axis is aimed directly at the target, the echo strength is maximum. Thus, the bearing of the target can be obtained by training the antenna to the position at which echo size is greatest. In actual practice, however, the antenna is seldom manipulated in this manner. To do so might inform an enemy unit that it has

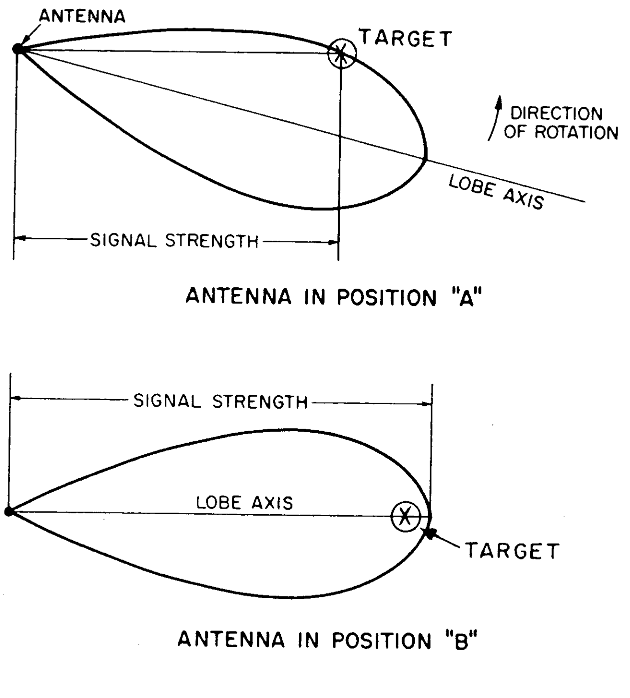

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Figure 7-1.—Determination of bearing.

been detected. Such practice also denies remote indicators full use of the radar.

RANGE

When a radar pulse strikes a reflecting object, no loss of time occurs. Reflection of the pulse off the object takes essentially zero time. The distance to an object, therefore, can be accurately determined by measuring the elapsed time from transmission of a pulse to the return of an echo at a receiver.

The propagation velocity of rf energy is considered to be the speed of light, which is 328 yards per microsecond (μsec). Fire control radars, which require greater precision, are calibrated in yards and thousands of yards. Search radars, however, are usually calibrated in hundreds of yards and miles, which provides sufficient accuracy for their function. For radars, then, it takes 6.1 μsec for an rf pulse to travel 1 mile (2000 yds), or 12.2 μsec per radar mile (round trip distance or 4000 yds). The so-called 2000 yard mile closely approximates the 2027 yard nautical mile but obviously is not identical to it.

Assume that a pulse of 1 μsec duration is transmitted toward a ship 20 miles away. In part 1 of figure 7-2a, the pulse is just leaving the antenna. In part 2, 61 μsec later, the pulse has traveled 10 miles toward the target. The scope is

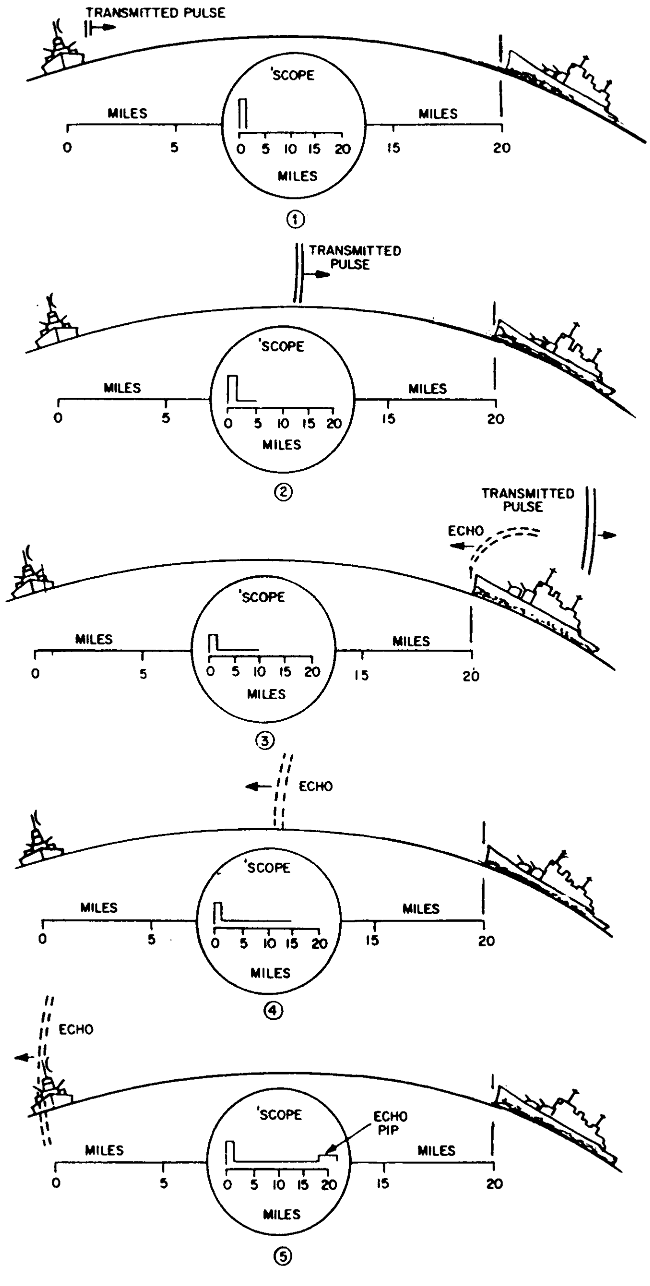

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Figure 7-2a.—Determination of range.

marked off in miles, and at this point the horizontal trace on the scope has reached only the five-mile mark, or half the distance actually traveled by the pulse. In part 3, the pulse has reached the target 20 miles away, and the echo has started back. The transmitted pulse is continuing beyond the target; 122 μsec have elapsed, and the scope reads 10 miles. In part 4, 183 μsec after start of the initial pulse, the echo has returned half the distance from the target. In view 5, the echo has returned to the receiver, and a blip is displayed on the scope at the 20-mile mark. Actual distance traveled by the pulse is 40 miles, and total elapsed time is 244 μsec. Figure 7-2b ppi shows the way a ppi scope would present the object.

ALTITUDE

Height finding radars use a very narrow vertical beam, which is scanned in elevation either mechanically or electronically to pinpoint targets. The electronic means, shown in figure 7-3, illustrates a frequency scanning pattern along the vertical plane. Lines originating at the antenna depict the number of beam positions required to ensure complete coverage. Each beam position, which corresponds to a slightly different radiated frequency, is set at a specific angle or step in relation to the base of the antenna. When the antenna base is stable, the initial radiated frequency sets up the top beam. A slight change in frequency activates the second beam, and the process continues until the entire plane is covered. When the antenna base is unstable, error signals are introduced by components of the system. A change then results in the transmitted frequency. This change compensates for ship's pitch and roll and ensures that the vertical plane is searched completely.

Special indicators are used with height-finding radar to facilitate determination of altitude by measuring position angle. Radar range to an aircraft is called slant range (figure 7-4). When both the position angle and slant range are known, the altitude of the plane can be found by solving the triangle. The solution may be by calculation, by reference to a graph, or by a computer built into the radar.

When solving by calculation, altitude equals the slant range multiplied by the sine of the elevation angle where slant range is the measured range to the target and elevation angle is that of the radiated beam.

Altitude found in this way is not the true height of the airplane above the earth because the calculation is based on the assumption that

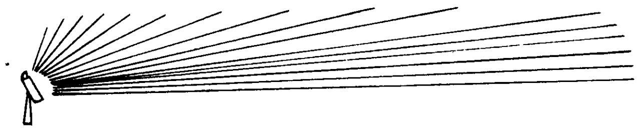

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Figure 7-3.—Frequency scanning.

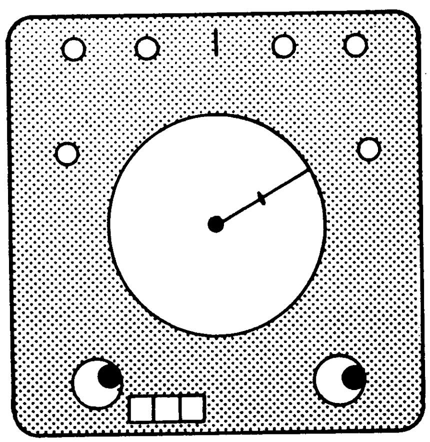

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Figure 7-2b.—Range shown on ppi scope on 40 mile scale.

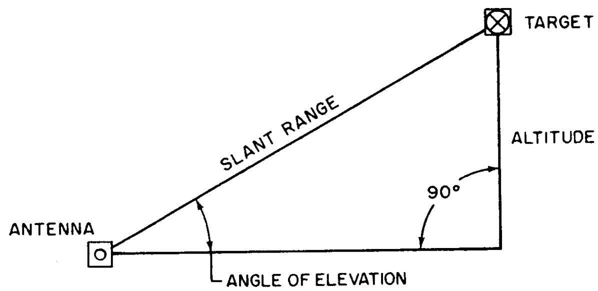

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Figure 7-4.—Determination of altitude.

the earth is flat. However, most altitude determination radars have a circuit that adds a figure corresponding to the error due to the curvature of the earth at the range of computation.

Fade Charts

When height-finding radar is not installed, fade charts can be used to estimate aircraft altitude. This technique uses a combination of air search radar fade zones and reception zones. When the antenna is elevated so that none of the radiated energy strikes the surface of the water, the pattern of radiation in a vertical plane will be a smooth lobe. If some of the radiated energy strikes the sea, however, the radiation pattern is modified considerably. This modification results from interference between the energy that is radiated directly toward the target and energy that reaches the target after reflection from the water. The effect of this interference is to break up the single lobe into a number of smaller lobes separated by areas called nulls, in which echoes cannot be obtained because of low field strength.

Positions of lobes and nulls in an antenna pattern remain the same as long as antenna height and radar frequency are unchanged; thus, a given radar installation will have an unchanging radiation pattern. This makes it possible to plot the positions of lobes and nulls on a chart which may be used as an aid in determining altitude of aircraft targets. To use such a chart, called a fade chart, a radar operator must notice the ranges at which a plane disappears in null areas. By applying these ranges to the chart, an estimate of altitude can be made. Because positions of nulls depend only on the geometry of the situation, a fade chart can be calculated mathematically. In fact, a circular calculating device has been developed which eliminates the need for plotting the chart.

For more dependable results, however, data should be determined experimentally by having an aircraft fly at several constant altitudes, recording both observed signal strengths and ranges.

RADAR DETECTING METHODS

Up to this point only one method of transmission has been used to show how a target is detected and tracked, the pulse-modulation method. Although this is the most common method, two other methods are sometimes used in special application radars. These are the continuous wave method, and the frequency modulation method.

Continuous Wave

The continuous wave (cw) method of detecting a target makes use of the doppler effect. The frequency of a radar echo is changed when the target is moving toward or away from the radar transmitter. This change in frequency is the doppler effect. It is similar to the effect at audible frequencies when the sound from the whistle of an approaching train appears (to the ear) to increase in pitch. The opposite effect (a decrease in pitch) occurs when the train is moving away from the listener. The radar application of this effect permits a measurement of the difference in frequency between the transmitted and reflected energy and thus a determination of both the presence and speed of the moving target. This method works well with fast-moving targets, but not well with those that are slow or stationary.

Frequency Modulation

In the frequency modulation (fm) method, the transmitted frequency is varied continuously over a specified band of frequencies. At any given instant, the frequency of energy radiated by the transmitting antenna differs from the frequency reflected from the target. This frequency difference can be used as a measure of range. Moving targets, however, produce a frequency shift in the returned signal because of doppler effect. This variation affects the accuracy of range measurement. This method works better, therefore, with stationary or slow-moving targets than with fast-moving objects.

Pulse Modulation

Radars employing pulse modulation transmit energy in short pulses that vary in duration from less than 1 to 200 microseconds, depending upon the type of radar. Echoes (energy reflected from a target) are amplified and applied to an indicator that measures the time interval between transmission of the pulse and reception of the echo. Half the time interval then becomes a measure of the distance to the target. In military applications, the pulse modulation method is used most prevalently; therefore, it will be the only method discussed in detail in this text.

BASIC RADAR SYSTEM

Although modern radar systems are quite complicated, their operation can be understood by learning the functions of the basic block diagram of a pulsed radar system (shown in figure 7-5).

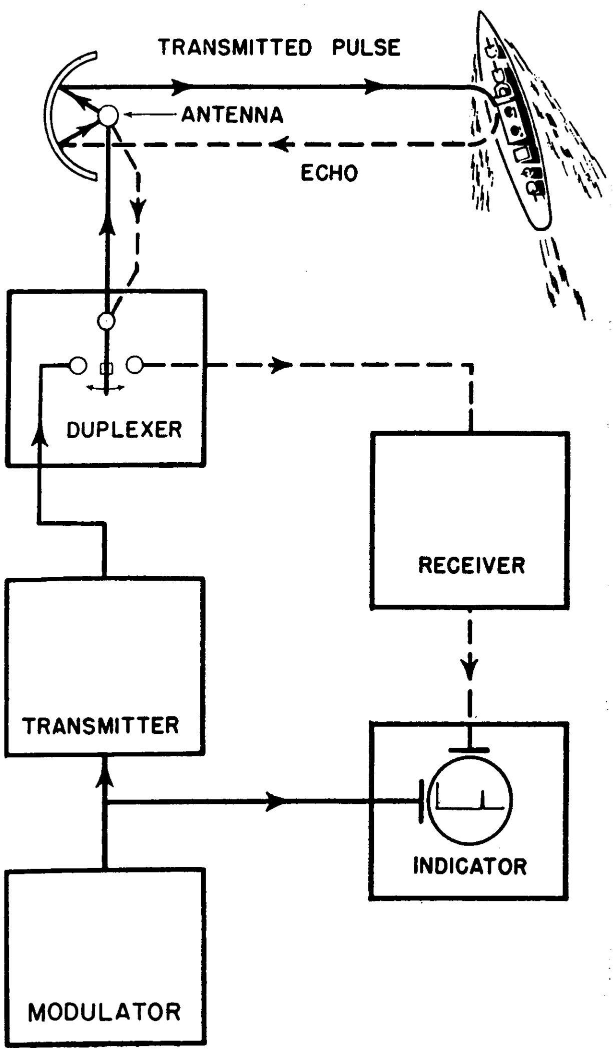

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Figure 7-5.—Block diagram of a fundamental radar system.

The heart of the radar system is the modulator. It generates all the necessary timing pulses (triggers) for use in the radar and associated systems. Its function is to ensure that all subsystems making up the radar system operate in a definite time relationship with each other; and that the intervals between pulses, as well as the pulses themselves, are of the proper length. Some of the more common pulses furnished by the modulator include transmitter trigger, receiver gate, indicator trigger, associated Identification Friend or Foe (IFF) System trigger, and Electronic Warfare (EW) blanking trigger. The rate at which the transmitter is triggered is called the pulse repetition rate (prr) or pulse repetition frequency (prf).

The transmitter supplies rf energy, often at extremely high power, for short intervals of time. A pulse transformer in the transmitter increases the voltage of the pulse received from the modulator, sends it to a magnetron oscillator, and acts as an impedance matching device. The magnetron oscillates at the designed transmission frequency of the radar for the duration of the pulse, and transmits its energy to the antenna assembly by way of a transmission line and a duplexer.

In some radar sets, especially air-search and height-finding, the magnetron is replaced by an output power tube usually referred to as a power amplifier (pa).

The duplexer permits the use of a common transmission line and a single antenna for transmitting and receiving. The duplexer consists of two electronic switches, the transmit-receive (tr) and the antitransmit-receive (atr). The tr switch functions to block the path to the receiver each time the transmitter is fired, thus preventing damage to the receiver by the high powered transmitted pulse. The atr switch functions to direct the received signal to the receiver while blocking the same signal from the transmitter, thereby preventing unwanted dissipation of the signal in the magnetron during the receive interval. Thus, the duplexer not only provides coupling to the antenna system, but also prevents damage to the receiver system, and loss of the return echo in the transmitter.

The functions of the radar antenna system are to take the rf energy pulse from the transmitter, radiate it in a directional electromagnetic beam, pick up the returning electromagnetic echo, and pass it on to the receiver as an rf pulse with a minimum of loss.

The receiver converts the weak rf echo to a discernible video signal. Modern radar receivers are of the superheterodyne type. They are highly sensitive and accept rf echo signals in the order of one microvolt. They amplify the received rf signal (echo) to a useful video signal.

The radar indicator converts the video output of the receiver to a visual display of range and bearing (or in the case of height finding indicators, range and height). To accomplish this display of data, a radar indicator must contain three basic components, a cathode-ray tube (crt) of the proper persistency, a sweep circuit and a gate circuit.

The sweep circuit is triggered by the modulator to produce proper displacement of the target image from the point of measurement (origin) of the display. This displacement is maintained proportional to the target range by the time relationship of the sweep signal to that of the transmitted pulse. The gating pulse blanks the scanning spot during its return to the point of origin (center of display on ppi presentation).

FACTORS AFFECTING RADAR PERFORMANCE

A few internal characteristics of radar equipment that affect range performance are: peak power transmitted, pulse width, pulse repetition rate, transmission line efficiency, height of the antenna, and receiver sensitivity. Among the external factors are: skill of the operator; size, composition, angle, and altitude of the target; weather conditions, and possibly ECM activity.

Maximum Range

In general, the maximum range that can be measured on an indicator is limited by the pulse repetition rate (prr). This is because with each transmitted pulse the indicator is reset to zero range. Therefore, if the time between transmitted pulses is shorter than the time it takes the transmitted pulse to reach the target and return, the indicator will have been reset and started as a new sweep; thus indicating a false range upon reception of the echo. For example, the interval between pulses is 610 μsec with a repetition rate of 1640 pulses per second. Within this time the radar pulse can go out and back a distance equal to 610 μsec $\times$ 164 yards per μsec, or 100,000 yards, which becomes the scope's sweep limit. Echoes from targets beyond this distance appear at a false range. Whether an echo is a true target or false target can be determined simply by changing the prr.

The pulse width (pw) also affects the maximum detection range. The wider the pulse, the greater the average power out, resulting in a greater detection range of small targets. Air search radars usually have a much greater pw than surface search radars.

The more sensitive the receiver, the less powerful the echo required to produce a visible blip on the indicator. As the receiver sensitivity is increased, the range at which a particular target can be detected is increased.

In general, the larger a target, the greater the range at which it can be detected. Land, particularly high, steep cliffs, can be detected at a much greater range than any other type of target, except, perhaps, high-altitude aircraft. Similarly, a group of aircraft can be detected at a greater range than a single aircraft because of the large reflecting area. Targets at high altitudes can be detected at a longer range than those at low altitudes simply because it is possible for the radar pulse to reach them.

Another factor affecting the maximum range is antenna height. The distance in nautical miles to the radar horizon (disregarding propagation phenomena) is approximately $1.25\sqrt{h}$, where the antenna height (h) is in feet. When determining the detection range of a target, the formula becomes $1.25\sqrt{h_1} + 1.25\sqrt{h_2}$, where h_1 is the height of the transmitting antenna and h_2 is the height of the target.

The antenna beam width also affects the maximum detection range. A more concentrated beam has a greater range capability since it provides higher energy density per unit area.

Still another factor that limits the maximum detection range is the antenna rotation rate. The slower an antenna rotates, the greater the detection range of the radar. When the antenna is rotated at 10 revolutions per minute (rpm), the beam of energy strikes each target for one-half the time it would if the rotation were five rpm. The number of strikes per antenna revolution is called "hits per scan." During this time, a sufficient number of pulses must be transmitted in order to return an echo that is strong enough to be detected. Long-range search radars normally have a slower antenna rotation rate than radars designed for short range coverage.

Minimum Range

The closest range at which radar can detect a target is controlled primarily by the length of the transmitted pulse. Some of the energy of the transmitted pulse leaks directly into the receiver. This results in overloading the receiver and causes it to be essentially blocked. At the end of the transmitted pulse, the receiver begins to recover, but recovery is not instantaneous. As long as the receiver is blocked, a saturation signal appears on the indicator, during which time no echo pulses can be seen. Modern radar receivers have recovery times measured in hundredths of a microsecond, and targets that are at a range just slightly greater than half the transmitted pulse width will be displayed. Theoretical minimum range is pw × 164 yards, and it varies from actual minimum range only by duplexer recovery time.

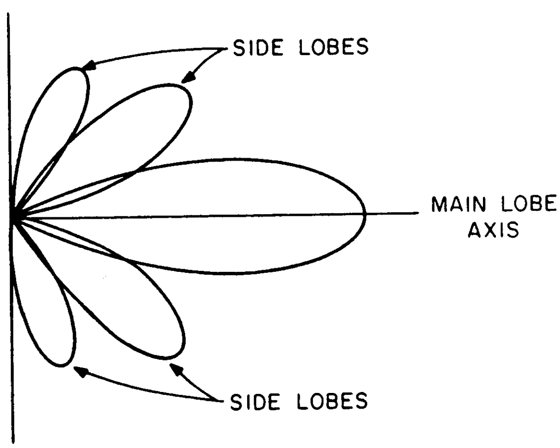

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Figure 7-6.—Side lobes.

When the high-powered radar is operated within a few miles of land, targets cannot be tracked into a short range because side lobe (figure 7-6) echoes clutter the first mile or two of the scope irrespective of the direction to which the antenna is trained. Because targets within the area covered by sea return (false return of signals from the nearby sea) usually produce very strong echoes, however, the receiver gain may be reduced considerably so that the echoes will stand out from the sea return. Sensitivity-time control (stc) is a modification of the receiver by which receiver gain is reduced for the first few thousand yards of each sweep and then restored to normal for the remainder of the sweep. The reduced gain at short range provided in this modification is of value in lessening sea return and in preventing side lobe echoes from obscuring the start of the trace.

The minimum range to which high-flying airplanes can be tracked depends on vertical coverage of the radar antenna. In most search radars, little energy is radiated directly overhead or at large elevation angles. Minimum range of a radar depends principally, therefore, on the duration of the transmitted pulse and the duplexer recovery time.

Range Resolution

Individual ships in a group do not show up separately on a scope unless there is considerable distance between ships. The characteristic of a radar that gives separate indications of individual targets is called resolution. Range resolution is the ability of a radar to resolve between two targets on the same bearing, but at slightly different ranges.

The principal factors that affect range resolution are width of the transmitted pulse, amount of receiver gain, and the range scale in use on the indicator. A high degree of range resolution requires a short pulse, lower receiver gain, and a short range scale.

When two targets are on the same bearing, the minimum distance they must be separated to show as two echoes is slightly greater than one-half the pulse length. This requirement is illustrated in figure 7-7.

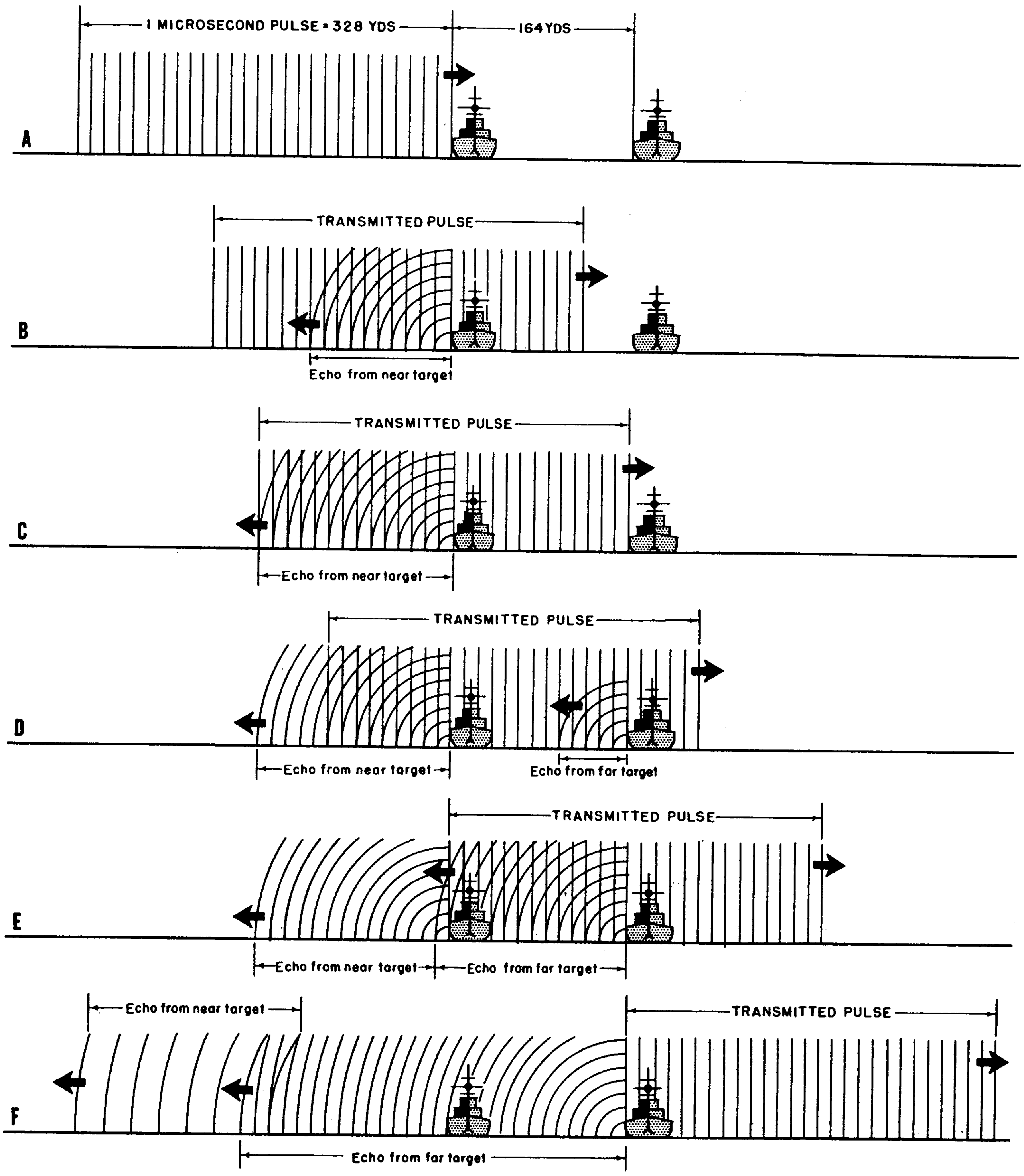

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Figure 7-7.—Minimum target separation required for range resolution.

In part A of the illustration, the transmitted pulse is just striking the near target. In B, energy is reflected from the near target, while the front of the transmitted pulse continues toward the far target. At C, the transmitted pulse is striking the far target and, simultaneously, the reflected energy from the near target has traveled 164 yards back toward the radar; hence, the reflection process at the near target is half completed. In D, the echoes are traveling back toward the radar from both targets. In view E, the leading edge of the echo from the far target has returned as far as the near target so that it coincides with the trailing edge of the first echo. In F, an echo of twice the normal width returns to the radar. When the echoes reach the antenna, energy is delivered to the set during a period of 2 μsec (microseconds) rather than 1 μsec, so that a single wide blip shows on the indicator.

Although pulse width is the primary factor in determining range resolution, the amount of receiver gain used also affects the resolution. Echoes from two targets that are close together may merge into a single indication when the gain setting is high, but they may separate into individual blips when the gain is reduced.

A third important factor in determining the range resolution of the radar set is the range scale used. On a long-range scale, a separation of a few hundred yards will not be apparent. In fact, two adjacent blips will seem to blend into one. If these same echoes can be displayed on a short-range scale, or on an off-centered ppi, a small separation will be visible.

Ideally, the electron beam in a crt should be focused to a pinpoint of light (actually, the beam cannot be focused to such a small spot). Additionally, the spot's edges (and, consequently, those of echoes) are hazy in some types of tubes; thus, the range separation required for resolution is increased. Using a larger crt does not improve the presentation to any great degree because the spot size increases in proportion to tube size.

TYPES OF RADAR SETS

Due to different design parameters, no single radar set has been produced that can perform all of the many radar functions required by combatant ships. As a result, the modern warship has several radar sets, each performing a specific function. A shipboard radar installation may include a surface search radar, an air search radar, a height finding radar, and various fire control radars.

Surface Search Radar

The primary functions of a surface search radar are the detection and determination of accurate ranges and bearings of surface targets and low-flying aircraft, while maintaining a 360° search for all targets within line-of-sight distance from the radar antenna.

Since the maximum range requirement of a surface search radar is primarily limited by the radar horizon, higher frequencies are employed to permit maximum reflection from small target-reflecting areas such as ship mast-head structures and submarine periscopes. Narrow pulse widths are used to permit a high degree of range resolution at short ranges, and to achieve greater range accuracy. High pulse repetition rates are used to permit maximum definition of targets. Medium peak powers can be used to permit detection of small targets at line-of-sight distances. Wide vertical beam widths permit compensation for pitch and roll of ownship and detection of low flying aircraft. Narrow horizontal beam widths permit accurate bearing determination and good bearing resolution. For example, a common shipboard surface search radar has the following design specifications: Transmitter frequency 5450-5825 MHz; pulse width .25 or 1.3 μsec; pulse repetition rate between 625 and 650 pulses per second; peak power between 190 and 285 kW; vertical beam width between 12 and 16 degrees; and horizontal beam width 1.5 degrees.

The following are some applications of surface-search radars:

- Indicate the presence of surface craft and facilitate determination of their course and speed

- Coach fire control radar onto a surface target

Provide security against attack at night, during conditions of poor visibility, or from behind a smokescreen

Aid in scouting

Obtain ranges and bearings on prominent landmarks and buoys as an aid to piloting, especially at night and in conditions of poor visibility

Facilitate station keeping

Detect low-flying aircraft

Detect certain weather phenomena

Detect submarine periscopes

Control small craft during boat or amphibious operations

Air Search Radar

The primary function of an air search radar is the detection and determination of ranges and bearings of aircraft targets over relatively large areas while maintaining a complete 360° surveillance from the surface to high altitudes. Relatively low radar frequencies are chosen to permit long-range transmissions with minimum attenuation. Wide pulse widths and high peak power are used to aid in detecting small targets at great distances. Low pulse repetition rates are selected to permit greater maximum measurable range. A wide vertical beam width is used to ensure detection of targets from the surface to relatively high altitudes, and to compensate for pitch and roll of the ship. Medium horizontal beam width is employed to permit fairly accurate bearing resolution while maintaining 360° search coverage. The output characteristics of specific air search radars are classified; therefore, they will not be mentioned in this manual.

Some applications of air-search radars include the following:

1. Warn of approaching aircraft and missiles before they can be sighted visually, so that:

a. The direction from which an attack may develop may be indicated

b. Fighters may be launched in time if an air attack is imminent

c. Antiaircraft defenses may be brought to the proper degree of readiness in sufficient time

2. Allow constant observation of movements of enemy aircraft, once detected, and control Combat Air Patrol (CAP) to a position suitable for interception

3. Provide security against night attack and attacks during conditions of poor visibility

4. Provide a means of aircraft control when it is necessary for them to be on a specific geographic track (such as an antisubmarine barrier or search and rescue pattern)

Height-Finding Radars

The primary functions of height-finding radars (sometimes referred to as three-coordinate or 3D radars) are those of computing accurate ranges, bearings, and altitudes of aircraft targets detected by the air search radar. Height-finding radars are also used by the ship's air controllers to direct fighter aircraft during interception of air targets.

The main differences between the air-search radar and the height-finding radar are that the height-finding radar has a higher transmitting frequency, higher power output, a much narrower vertical beam width, and requires a stabilized antenna for altitude accuracy.

Applications of height-finding radar include the following:

- Obtaining range, bearing, and altitude data on enemy aircraft and missiles to assist in the control of CAP to a suitable intercept position
- May be used to detect low-flying aircraft
- Determining range to a distant land
- Tracking aircraft over land
- Detecting certain weather phenomena
- Tracking weather balloons

Providing input to fire control for director control

Weapon Control Radars

Although electronics division (ET) personnel do not maintain fire control radars, characteristics and limitations of those radars are included here.

Fire control radars use a dish-shaped antenna and a higher frequency than nonfire control radars to produce a narrow circular beam. They have two modes of operation, search and track. When operating in the search mode, a spiral scan may be employed. A spiral scan is one in which the beam rotates in a circular manner, with the beam axis being continually varied to form a spiral pattern. Once the target is acquired, the radar switches automatically to a conical scan for tracking. In a conical scan, the beam rotates in a circular manner about a fixed axis.

Typical fire control radar characteristics include a very high prf, a very narrow pw, and a very narrow beam. These characteristics, while providing extreme accuracy, limit the radar's range and make target detection difficult.

Applications of fire control radars for other than gun and missile control include:

- Detecting low-flying aircraft
- Assisting in radar navigation
- Tracking weather balloons
- Furnishing range and bearing data for calibrating search radars

Indicators

The purpose of a radar indicator (repeater) is to act as the master-timing device in analyzing the return radar system video, and provide that information to various locations physically remote from the radar set. Each indicator should have the ability to select the outputs from any desired radar aboard the ship. This is accomplished by the use of a radar distribution switchboard. The switchboard contains a switching arrangement which has inputs from each radar (and associated IFF system) aboard ship and provides outputs to each repeater. The radar desired is selected by means of a selection switch on the repeater. In order for the repeater to present correct target position data, it must have the three following inputs from the radar selected:

1. Trigger pulses—The trigger (timing) pulses from the radar ensure that the sweep on the repeater starts from its point of origin each time the radar transmits. As discussed earlier, the repeater displays all targets at their actual range from the ship based on the time lapse between the instant of transmission and the instant a target echo is received
2. Video—The returning echo is applied to the repeaters from the radar receiver
3. Antenna information—The angular sweep position of a plan position indicator (ppi) repeater must be synchronized to the angular position of the radar antenna in order to display contact bearing (azimuth) information

The three most common types of displays are:

1. "A" scope, range-only indicator
2. PPI scope, range-azimuth indicator
3. RHI scope, range-height indicator

The "A" scope (fig. 7-8) is not normally considered a radar repeater, but rather an auxiliary display. Its use is limited because of range-only capability.

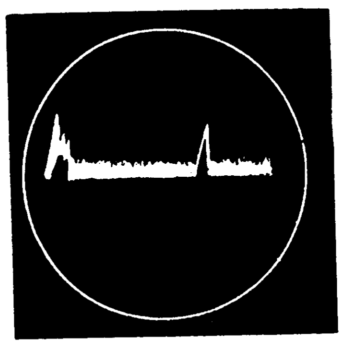

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Figure 7-8.—Presentation of the "A" scope.

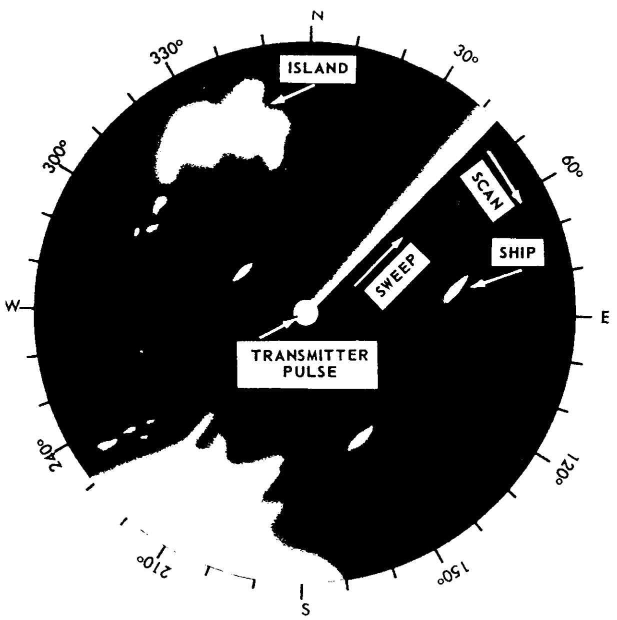

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Figure 7-9.—Presentation on the ppi scope.

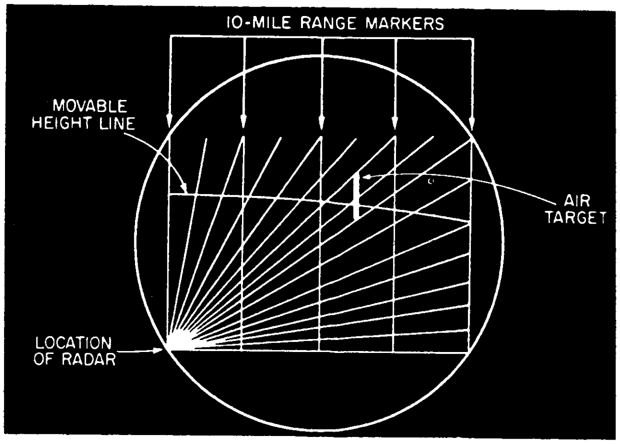

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Figure 7-10.—RHI presentation.

The ppi scope (fig. 7-9) is by far the most used radar repeater. It is a polar coordinate display of the surrounding area, with ownship represented by the origin of the sweep, which is normally located in the center of the scope, but may be offset from center on some sets. The ppi uses a radial sweep pivoting about the center of the presentation, resulting in a maplike picture of the area covered by the radar beam. A relatively long-persistence screen is used so that targets remain visible until the sweep passes again.

Bearing is indicated by the target's angular position in relation to an imaginary line extending vertically from the sweep origin to the top of the scope. The top of the scope is either true North (when the radar is operating in true bearing), or ship's head (when the radar is operating in relative bearing).

The range-height indicator (rhi) scope (fig. 7-10) is used in conjunction with height-finding radars to obtain altitude information. The rhi is a two-dimension presentation indicating target range and altitude. The sweep of an rhi originates in the lower left side of the scope and moves across the scope, to the right, at an angle that is the same as the angle of transmission of the height-finding radar. The line of sight to the horizon is indicated by the bottom horizontal line, and zenith is straight up the left side of the scope (fig. 7-10). Targets are displayed as vertical blips. The operator determines altitude by adjusting the movable height line to the point where it bisects the center of the target blip. Target height is then read directly from the altitude dials (counters).

Vertical range markers (fig. 7-10) are provided to estimate target range.

IDENTIFICATION, FRIEND OR FOE (IFF) EQUIPMENT

IFF equipment is used with search radars to permit a friendly craft to automatically identify itself before approaching near enough to threaten the security of other friendly craft. The basic steps of this identification are CHALLENGE, REPLY, and RECOGNITION. To perform the identification process, two sets of IFF equipment are used. These are the interrogator (recognition) and transponder (identification) sets.

The interrogator transmits a coded challenge in the form of a pulse pair. The spacing between the pulses is determined by the mode of operation. The transponder is a receiver-transmitter combination that automatically replies to a coded challenge. The reply is a series of coded pulses which are transmitted omnidirectionally at a slightly different frequency than the interrogator frequency.

The receiver section of the transponder receives and amplifies signals within its bandpass, decodes correctly coded signals, and automatically keys the transmitter to send certain prearranged reply signals on a different frequency. The receiver section of the interrogator receives the coded reply signals from the transponder of the target craft and processes the reply for display on an indicator. The coded reply from a friendly craft is normally displayed on the ppi scope just beyond the radar blip as a dashed line, as shown in figure 7-11.

Naval Tactical Data System (NTDS) display consoles differ in method of display in that symbology and numerics are utilized. The interrogator operates in a manner similar to a radar transmitter and receiver. Bearing information is obtained by using a small directional antenna attached to and/or rotated in synchronization with the air-search radar antenna. Range information is obtained by determining the time lapse between the transmission and the reception of a reply. IFF synchronization triggers are normally received from the modulator of the radar set with which the IFF equipment is being used.

The IFF interrogator operates at fairly low peak power (1 to 2 kilowatts). High output power is not required, as the pulses transmitted by the interrogator do not have to return to the transmitting unit. Instead, they are transmitted on a one-way trip to the target. After the transmitted pulses are detected by the friendly target's transponder, a different set of pulses is transmitted by the target's transponder for the return trip.

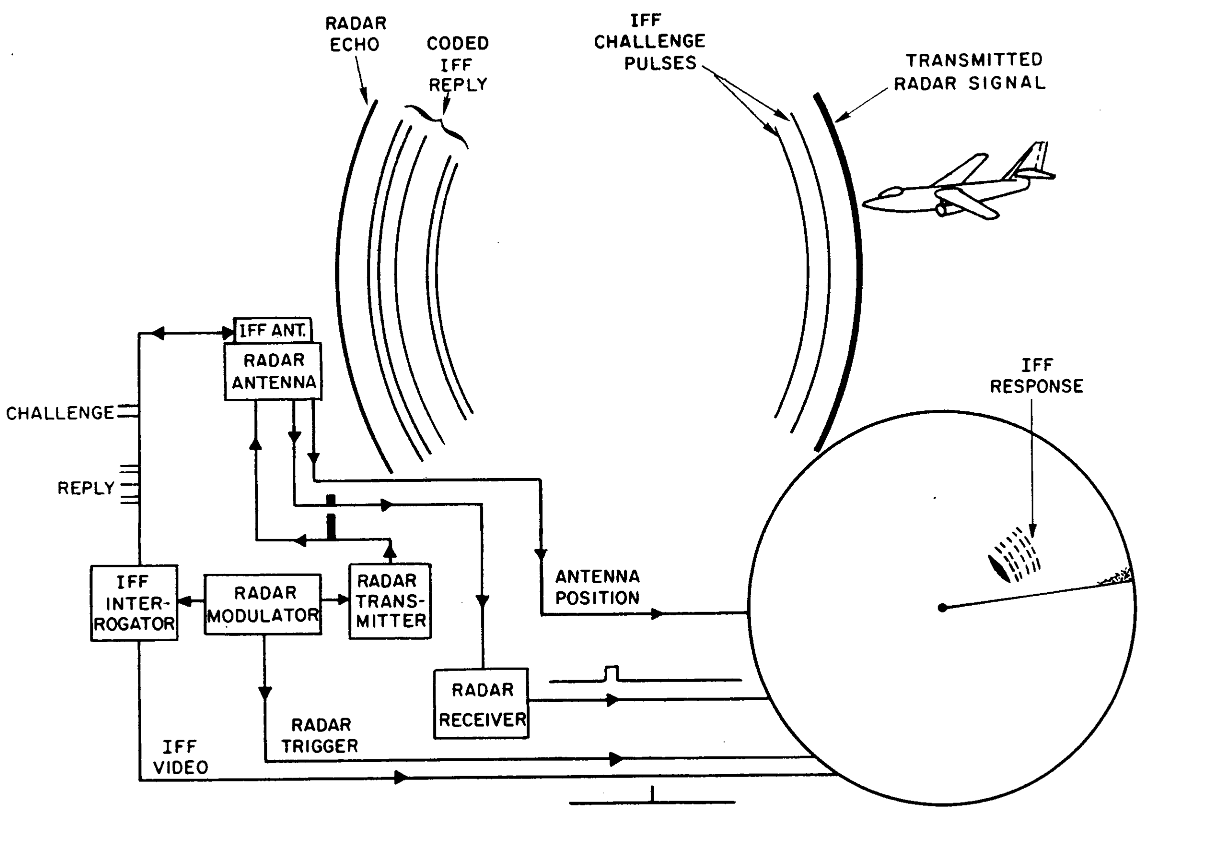

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Figure 7-11.—Fundamentals of IFF operation.

A ship may have one or more interrogator sets, but will have only one transponder. Normally, interrogators and transponders aboard ship function independently, with the only interconnection between the two being a suppression (blanking) signal to inhibit the transponder from replying to the ship's own interrogators. Current IFF systems will be discussed in greater detail later in this text.

RADAR DISTRIBUTION SWITCHBOARD

The radar distribution switchboard provides a method of selecting and connecting the radar and IFF data to the various indicators. The switchboard inputs are connected to the remote indicators through rotary switch assemblies. It also contains amplifier assemblies that ensure sufficient video gain to drive the indicators.

RADAR EQUIPMENT

As stated previously, the modern warship has several radars. Each radar is designed to fulfill a particular need, but it also may be capable of performing other functions. For example, most height-finding radars can be utilized as secondary air-search radars; in emergencies, fire control radars have served as surface-search radars.

Because there are so many different models of radar equipment, the radars and accessories described herein are limited to those common to a large number of ships in the active fleet, and to those that are replacing older equipment currently installed in the fleet.

SURFACE-SEARCH RADAR

As mentioned earlier, the principal function of surface-search radars is the detection of surface targets and low-flying aircraft and the determination of their range and bearing. A surface-search radar in use today is the AN/SPS-10( ) (figure 7-12).

The AN/SPS-67(V) is to replace the AN/SPS-10( ) systems commencing in FY-83. In view of the similarity in characteristics and functions of the two radars, the AN/SPS-67(V) will be discussed here for introductory purposes.

Radar Set AN/SPS-67(V)

The AN/SPS-67(V) Radar (figure 7-13) is a two-dimensional (azimuth and range) pulsed radar set primarily designed for surface operations with a secondary capability of anti-ship-missile (asm) and low-flyer detection. The radar set operates in the 5450 to 5825 MHz frequency range, using a coaxial magnetron as the transmitter output tube. The transmitter/receiver is capable of operation in a long (1.0 μsec), medium (0.25), or short (0.10 μsec) pulse mode to enhance radar performance for specific operational or tactical situations. Pulse repetition frequencies (prf) of 750, 1200, and 2400 pulses per second are used for the long, medium, and short pulse modes respectively. An option to include Digital Moving Target Indicator (DMTI) is under consideration. Special features/processing circuits incorporated in the radar include:

- Automatic Frequency Control (AFC)
- Automatic Tuning
- Fast Time Constant (FTC)
- Interference Suppression (IS)
- Anti-Log Circuit (ALC)
- Main Bang Suppression (MBS)
- Sensitivity Time Control (STC)
- Video Clutter Suppression (VCS)
- Built-in-Test Equipment (BITE)
- Sector Radiate (SR)
- Ships Head Marker (SHM)
- Video Gain Control (VGC)

The AN/SPS-67(V) Radar will be the primary surface search and navigation radar with limited air search capability, and will

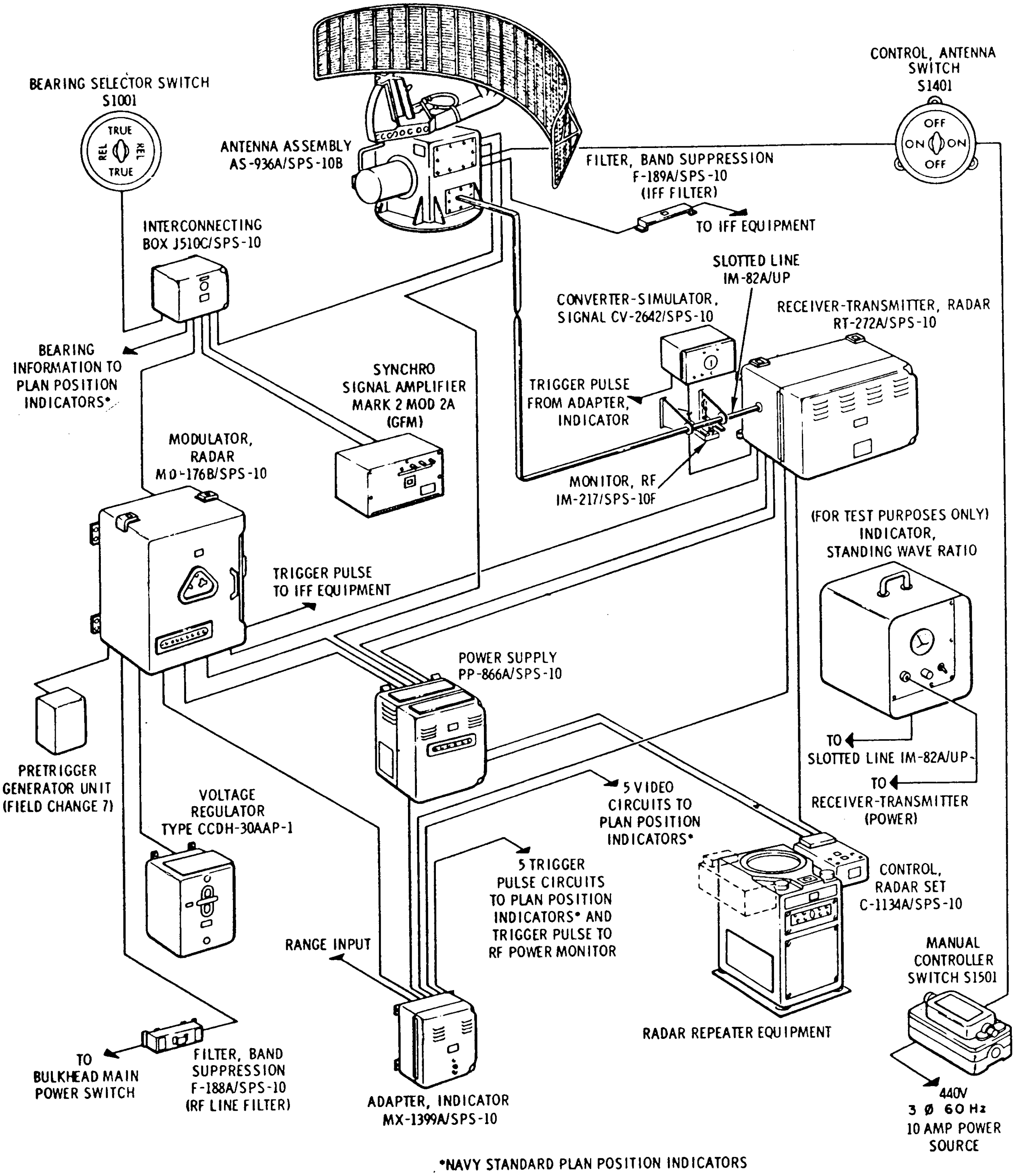

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Figure 7-12.—Radar Set AN/SPS-10F with TEAMS capability.

replace the existing AN/SPS-10 series radars in the following ship classes:

AD	ARS	CV	LHA
AE	AS	CVN	LKA
AFS	AVM	DD	LPD
AGF	AVT	DDG	LPH
AOE	CG	FF	LSD
AOR	CGN	FFG	LST

MAJOR COMPONENTS.—The major units of the radar set are shown in figure 7-13. The Receiver-Transmitter and Video-Processor will have the identical mounting and will not exceed the dimensions of the present AN/SPS-10 series receiver transmitter and modulator cabinets respectively. The Radar Set Control, the Antenna Controller, and the Antenna Safety Switch will mount in the same area as the units they replace, but are not required to have the same form factor or mounting. The dummy load will be mounted on the output of the Receiver-Transmitter unit. The combined weight of the below-deck equipment will be 575 pounds or less.

INTERFACE AND IMPACT ON OTHER SYSTEMS/SUBSYSTEMS.—The radar set will be compatible with the following equipment:

Electronic Synchronizer AN/SPA-42/A or AN/SPG-55B

Blanker/Video Mixer Group AN/SLA-10

IFF Equipment

Indicator Group AN/SPA-25( ), or equivalent

Mk 27 Synchro Signal Amplifier or equivalent

Multiplexed Unit for Transmission Elimination (MUTE)

FEATURES, CONFIGURATION, MATERIAL.—The construction of the radar set is primarily solid-state, with the exception of the transmitter magnetron and the receiver tr device. Miniature and microminiature technology are used extensively throughout the radar set. Standard Electronic Module (SEM) architecture is incorporated in the set design to the maximum extent possible. (The SEM program has been established within the Navy Material Commands to provide standardization of modular plug-in cards for all electronic systems.) The radar set includes a Built-In Test Equipment (BITE) subsystem which will locate 95 percent of the failures to a maximum of four modules or less within the Video-Processor, or four modules or less within the Receiver-Transmitter. The location of the faults is indicated on Light Emitting Diode (LED) index indicators, and the condition of each indexed test point is displayed on readout indicators as GO, MARGINAL, or NO-GO. In addition, the BITE subsystem provides the maintenance operator with an interactive test mode which permits the selection of a series of sensor test points for monitoring purposes, while making level or timing event adjustments. Power and VSWR are monitored on an on-line basis. The BITE subsystem is designed to have its own self-check mode which is performed automatically on a periodic basis. The BITE circuitry will not degrade the performance of the system during normal operation, or in the event of a failure in the BITE circuitry.

Radar Set AN/SPS-55

Radar Set AN/SPS-55 is a solid-state, surface search and navigation radar capable of detecting targets from as close in as 50 yards, out to 50 miles and beyond, with good target resolution. Figure 7-14 illustrates the major assemblies of the radar and their relationship to each other.

The system generates two pulse widths (selectable), a 0.12 microsecond pulse at a pulse repetition rate of 2250 pulses per second, or a 1.0 microsecond pulse at a pulse repetition rate of 750 pulses per second which is variable in the swept mode of operation by ±5%. Rf frequency is tunable from 9.05 to 10.0 GHz with a minimum peak power out of 130 kilowatts (measured at the magnetron). The antenna, rotating in azimuth at 16 rpm, forms a beam narrow in azimuth (1.5°) and broad in elevation (−10° to +10° centered on horizon). Return

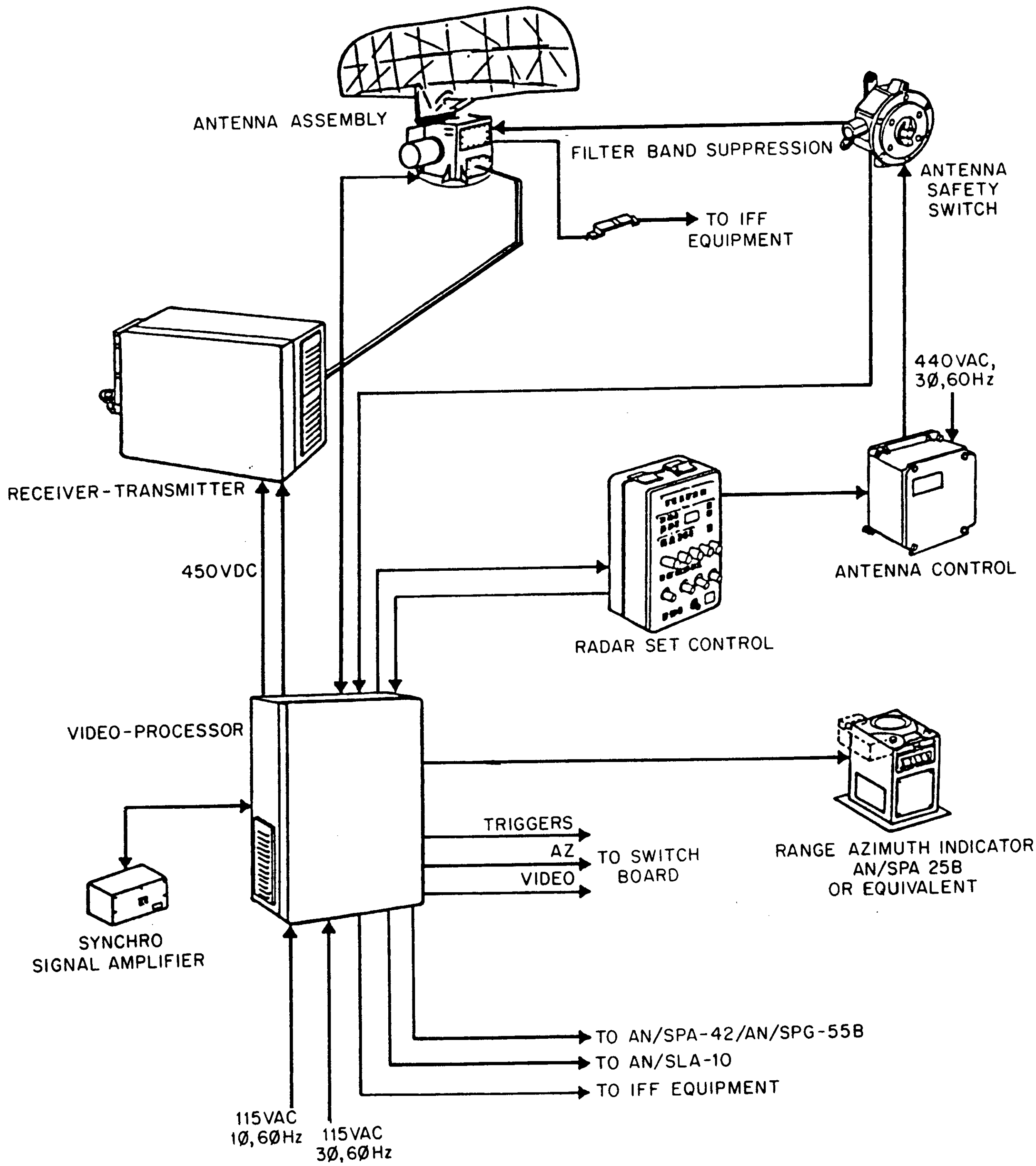

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Figure 7-13.—AN/SPS-67(V) functional diagram.

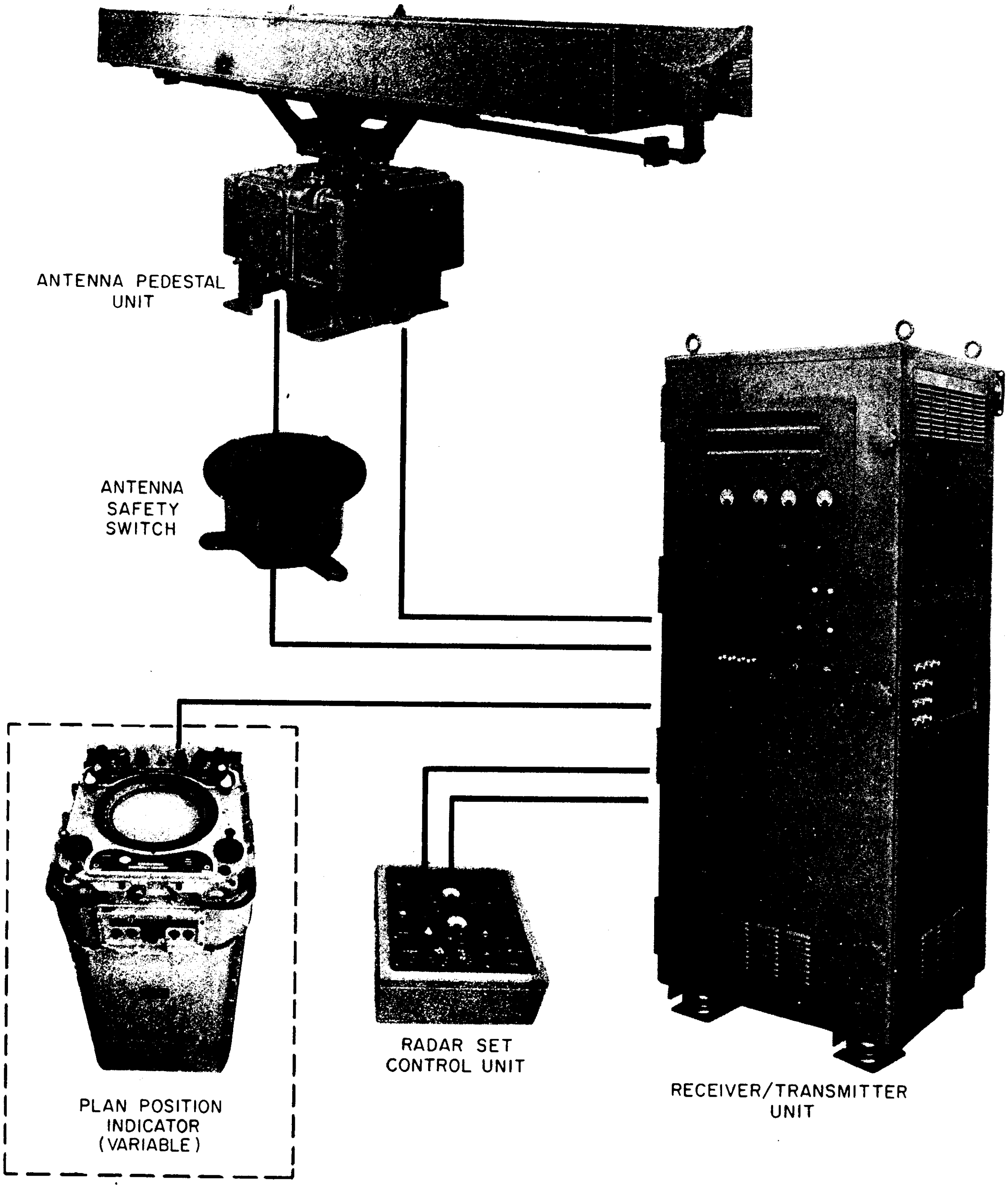

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Figure 7-14.—Surface Search and Navigation Radar System AN/SPS-55.

target echoes are amplified and detected by the receiver and applied to a ppi indicator where range and azimuth information is easily determined.

The target information can be displayed in either of two modes, a "relative" mode where zero degrees bearing on the ppi represents the heading of the ship or a "true" mode where zero degrees bearing represents true North. A ship's heading marker is provided which indicates the bow of the ship in either case.

The Radar Set uses several signal processing circuits which can be used to improve operation under certain prevailing conditions. These are:

- Fast Time Constant (FTC) circuit to reduce clutter by displaying the leading edge of the echo returns only

- Sensitivity Time Control (STC) circuit to reduce receiver gain at close-in ranges where clutter is strong, while allowing a gradual return to normal gain at longer ranges where clutter is less

- Logarithmic amplifier for increasing the system's dynamic range (ability to handle very weak to very strong signal returns)

- Sector radiate capability to allow operator limitation of radiation to a selectable azimuth segment for mutual interference or ECM reasons

Radar Set AN/SPS-55 consists of four major units: Antenna Group; Radar Receiver/Transmitter; Radar Set Control; and Box Switch.

Miscellaneous Small Surface Radars

There are a variety of small radar sets which are used for relatively short-range surface search and navigation purposes. The maximum range of these sets is generally 36 miles or less. The low power consumption and small size make them ideal for small craft where space and generator capacity are limited; however, they may also be found installed aboard large ships such as carriers. The indicating units of these radars are normally located on the bridge or in the pilot house depending upon the vessel in which they are installed. Some of these radars are: CRP-1500, CRP-1900, AN/SPS-53 and the LN-66.

AIR-SEARCH RADARS

The primary function of air-search radars is the long range detection and determination of ranges and bearings of aircraft targets. Some of the most widely used two-coordinate radars in the fleet are: AN/SPS-37A; AN/SPS-43; AN/SPS-43A; AN/SPS-40 B/C/D; and the AN/SPS-49. These radar sets use the ppi display indicators for determining range and bearing.

The main design features of the two-coordinate air-search radars are basically the same. They may, however, vary in frequency, range, type of antenna, and in design detail. All of these radar sets use a moving target indicator (mti) to discriminate between stationary objects and moving targets.

All of the above two-coordinate radars, transmit long pulses from a generated narrow pulse, and then receive and compress the long pulse back into a narrow pulse. This minimizes the peak power requirements of the radar set without impairing the range resolution. These modified shaped pulses also reduce interference with other shipboard electronic equipment.

The AN/SPS-40B will be described as an example of the air-search radars.

Radar Set AN/SPS-40 B/C/D (Long Range)

The AN/SPS-40 B/C/D (figure 7-15) radars are long range, two-dimensional (2D), early warning air search sets designed for use aboard destroyer escort size or larger Navy ships. The systems have a ten-channel (some channels are not presently used) operating capability with an improved Moving Target Indicator (MTI) mode and a Low Flyer Detection Mode (LFDM) for use in detecting small, low altitude close-in targets. The Automation Module includes Automatic Target Detection (ATD) and Digital Moving Target Indication (DMTI) to provide the AN/SPS-40 B/C/D radars with high probability detection of targets over land or water and the capability to generate clutter-free target data.

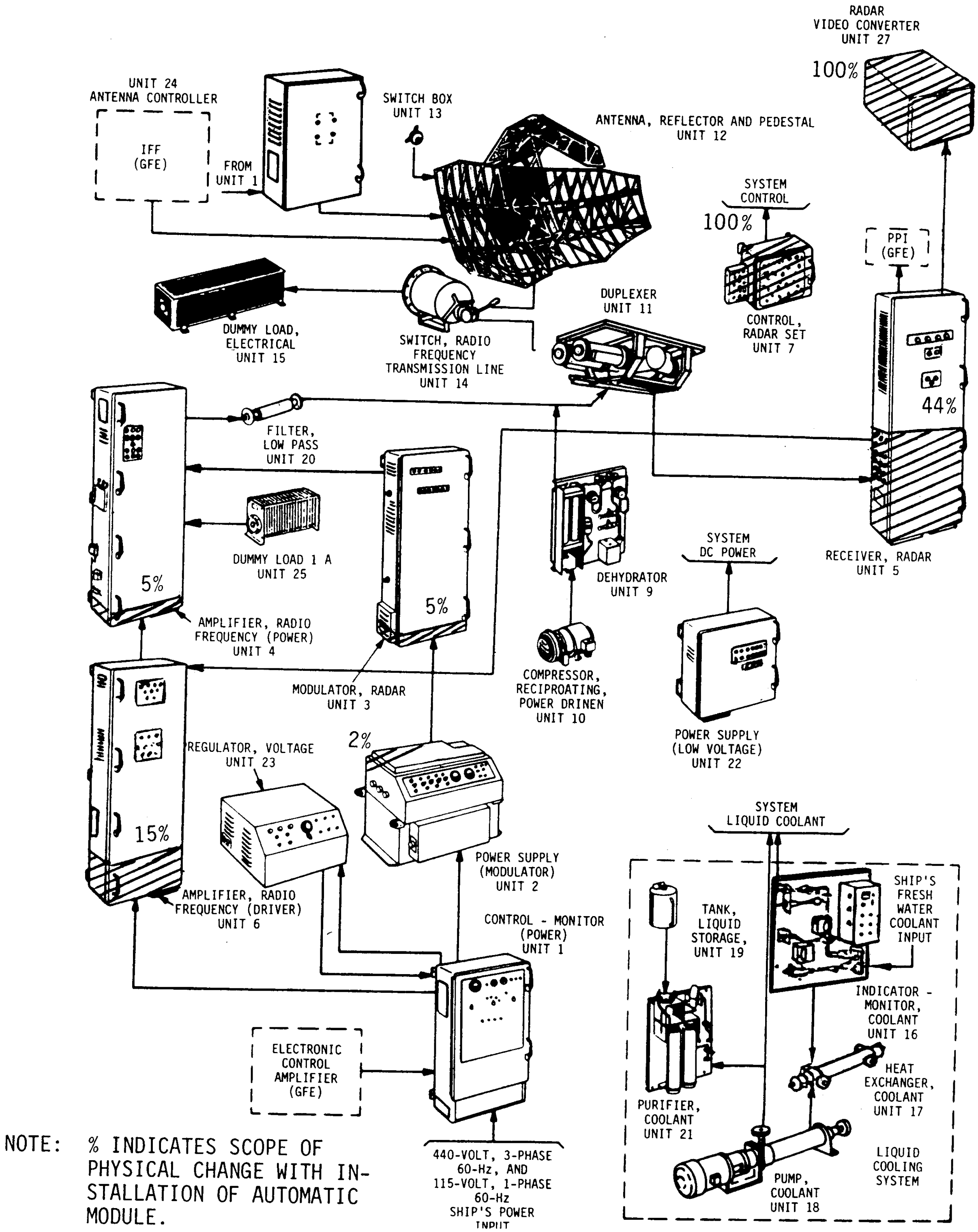

Figure 7-15.—Radar Set AN/SPS-40B (with automation module).

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Figure 7-15 illustrates the AN/SPS-40B with Automation Module radar system. The AN/SPS-40B is installed on all LHAs, CGNs, and DD 963 class ships. In addition, the existing AN/SPS-40/40As on certain destroyers, frigates and amphibious ships have been modified to AN/SPS-40 C/D configuration. The Automation Module is planned for installation in the DDG 2-24, 31-34, LCC 19-20, LHA 1-5, and selected CGs and CGNs. Additional installations to include the majority of AN/SPS-40 B/C/D series radars are anticipated in the mid 1980s.

NEW FEATURES/CONFIGURATIONS.—AN/SPS-40 B/C/D (without Automation Module) provides the following improvements over previous models:

- Transmitter: Increased use of solid state design and modular construction result in a longer Mean Time Between Failures (MTBF) and a shorter Mean Time to Repair (MTTR); high power-amplifier tubes have been improved to provide a better cooling structure, thus increasing tube life under operating conditions.

- Cooling System: Improvements in the pump and heat exchanger area have provided greater cooling flow to the high power transmitter components.

- Receiver: Solid state improvements provide more stable operation and improved maintainability. The new receiver and MTI utilize built-in test equipment to facilitate alignment and trouble shooting.

- LFDM: The Low Flyer Detection Mode (LFDM) has been provided through modification of the timing circuits, and rf system, and increasing the antenna speed to 15 rpm resulting in high data rate capabilities. A two-speed drive motor also produces the normal 7.5 rpm speed for Long Range Mode (LRM) operation.

An/SPS-40 B/C/D with Automation Module provides these additional improvements:

- Radar Video Converter: The RVC provides automatic detection of targets and converts the detected target position data to digital information.

- Digital Moving Target Indication: Replaces existing analog MTI and provides clutter free video to the RVC. Detection of small aircraft and cruise missiles over land and sea clutter is improved.

- Mode Changes: Long Range, Long Range/Chaff and Short Range modes are available instead of Long Range and Low Flyer Detection modes.

- PRF: A four-pulse staggered prf may be utilized in any mode to eliminate MTI blind speeds.

- Antenna Speed Control: Operator selectable antenna scan rate of 15 rpm or 7.5 rpm is provided vice having the scan rate slaved to the mode switch.

- Sensitivity Time Control: Operator adjustable stc is added.

Radar Set AN/SPS-49(V)
(Very Long Range Radar)

The AN/SPS-49(V) Radar (fig. 7-16) is a narrow beam, very long range, two-dimensional (2D), air search radar that primarily supports the AAW mission area in surface ships. The radar is used to provide long range air surveillance in severe clutter and jamming environments. Collateral functions include air traffic control (atc), air intercept control (aic) and anti-submarine aircraft control (asac). It provides backup to the three-dimensional (3D) weapon system designation radar. The AN/SPS-49(V) Radar is or will be installed in the following ships.

BB-61 and 62	(2)
CG-16 through 24, 26 through 34	(18)
CG-47 Class through 64 (REGIS)	(18)
CGN-9, 25, 35, through 41	(9)
CV-41, 59 through 64, 66, 67	(9)
CVN-65, 68 through 71	(5)
DD-997	(1)
DDG-37 through 46, 993 through 996	(14)
FFG-7 through 69	(63)

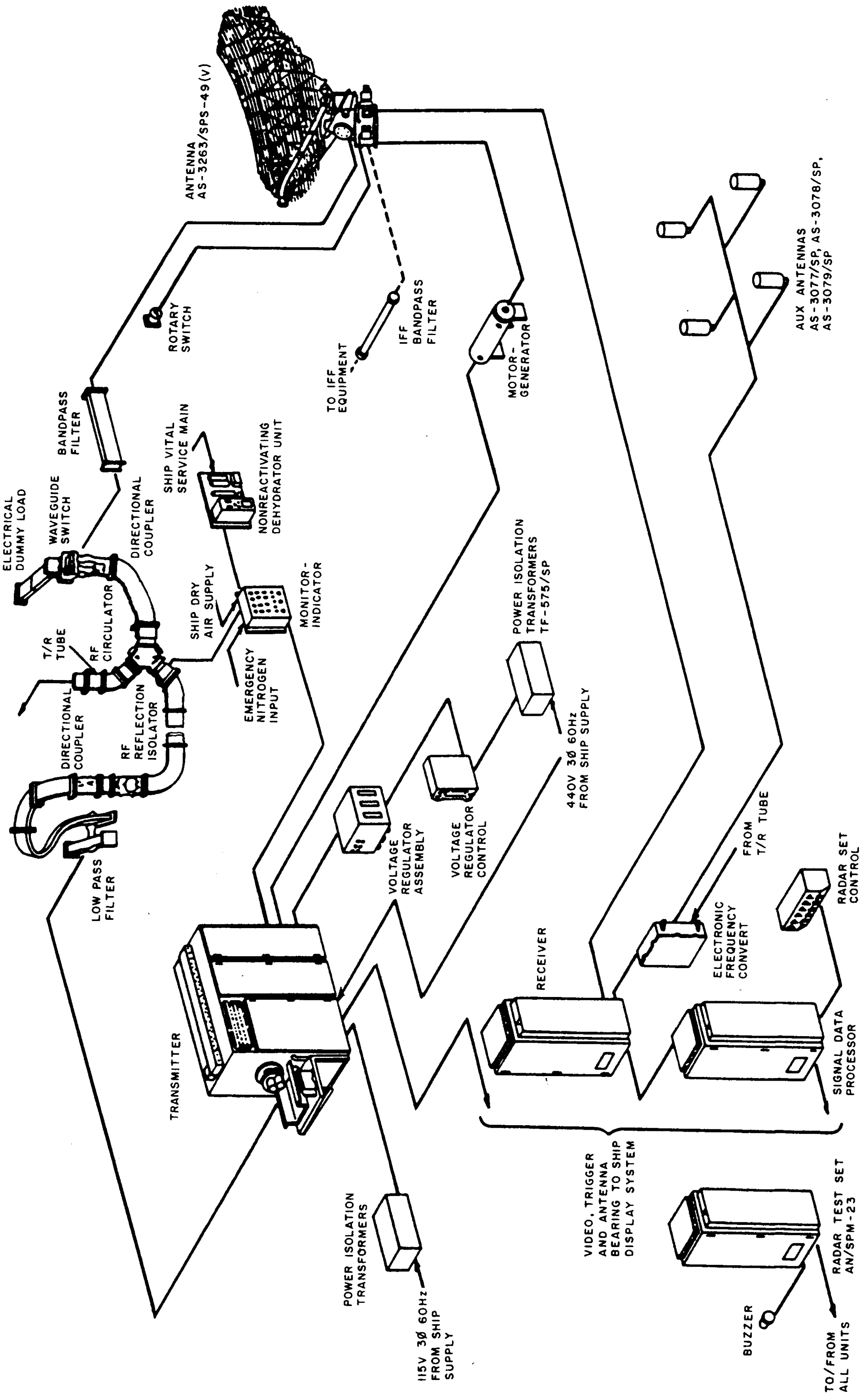

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Figure 7-16.—Radar Set AN/SPS-49(V) relationship of units.

CAPABILITY.—The AN/SPS-49(V) Radar provides the capability to conduct air search operations on a previously unused frequency, thus minimizing electronic interference between ships and imposing an additional burden on hostile electronic countermeasures. It provides good bearing measurement to back-up the 3D radar weapons designation system and its narrow beam width substantially improves resistance to jamming. The addition of Coherent Side Lobe Canceller (CSLC) capability in some AN/SPS-49(V) radars also provides resistance to jamming/interference by cancelling the jamming/interference signals. The Moving Target Indicator (MTI) capability incorporated in the AN/SPS-49(V) Radar enhances target detection of low-flying high speed targets through the cancellation of ground/sea return (clutter), weather and similar stationary targets.

NEW FEATURES/CONFIGURATION.—New features of this set are:

- Technology: Solid state technology with modular construction is used throughout the radar with the exception of the klystron power amplifier and high power modulator tubes. Digital processing techniques are used extensively in the Automatic Target Detection (ATD) modification.

- Built-in test features: Performance monitors, automatic fault detectors and Built-In-Test Equipment (BITE) have been incorporated in the design of the AN/SPS-49(V) Radar to enhance the availability and maintainability of the radar. Automatic on-line self-test features will be included in the ATD modification.

- Standard Electronic Modules (SEM) Program: The requirements of NAVMAT Policy No. 40, Standard Electronic Modules (SEMS), will be strictly adhered to when approved SEMS are available in all new developments for the AN/SPS-49(V) Radar.

Radar Sets AN/SPS-37A and AN/SPS-43 or 43A

These radar sets are high-power, very long range, two-coordinate air search radars used on large ships. They are used for early warning and are capable of detecting fast moving targets at very long ranges.

AIR-SEARCH THREE-COORDINATE RADARS

Among the height-finding radars currently installed aboard Navy ships, some of the most common are the AN/SPS-30, AN/SPS-39A, AN/SPS-52( ), and AN/SPS-48( ).

The three-coordinate radar functions much like the two-coordinate system, but will provide elevation, in addition to a horizontal search pattern, and a vertical search pattern.

Most radars present only range and bearing, so their beams are narrow in azimuth and broad in the vertical plane. The beams of height-finding radars are quite narrow vertically, as well as in the horizontal plane.

Azimuth is provided as the antenna rotates continuously at speeds varying up to 15 rpm. The antenna may be controlled by the operator for searching in a target sector.

As mentioned earlier, the air-search, three-coordinate radars determine altitude by scanning the vertical plane in discrete increments (steps). This may be done mechanically or electronically (the most frequently utilized method). In electronic scanning the radiated frequency is changed in discrete increments, causing the radar beam to be radiated at different elevation angles (fig. 7-3). Each elevation angle or step has its own particular scan frequency. A computer can then electronically synchronize the radiated frequency with the associated scan angle to produce the vertical height of a given target.

The three-coordinate radars also employ a range height indicator (rhi) in addition to the ppi used with the two-coordinate radars.

Radar Set AN/SPS-30

The AN/SPS-30 (fig. 7-17) is a high-power long-range shipboard radar system for air search and interceptor direction of aircraft. It provides information for individual and multiple targets at a fast data rate and presents the information on ppi and rhi indicators. The AN/SPS-30 uses a stabilizing servosystem and a mechanical scanning head.

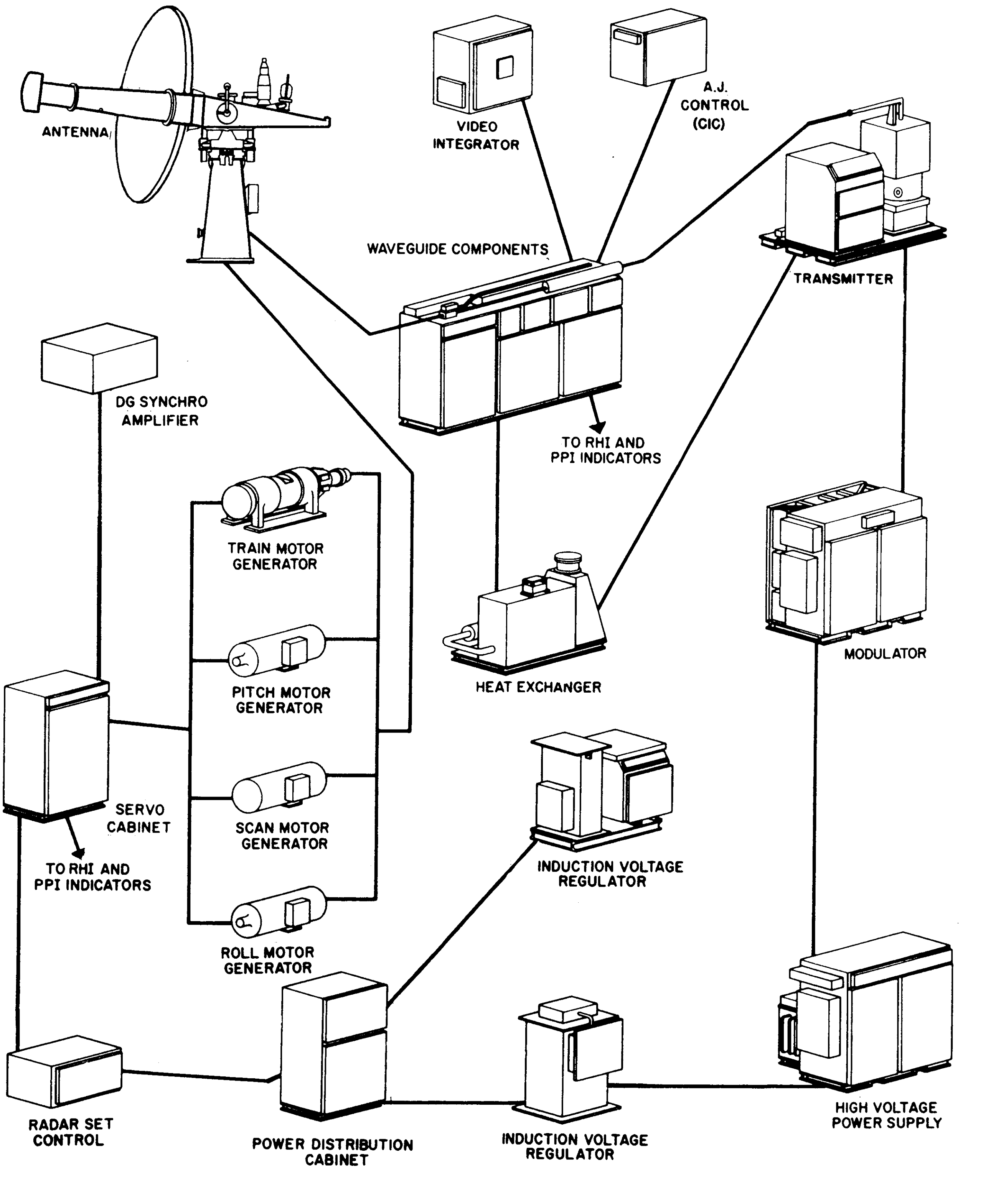

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Figure 7-17.—Air-search Height-finding Radar Set AN/SPS-30 system.

Radar Set AN/SPS-39A

The AN/SPS-39A three-coordinate radar set provides three-dimensional position data under all weather conditions on surface and airborne targets. The radar set provides a means for detecting moving targets in the presence of obscuring echoes and for detecting targets that would be obscure due to large antenna side lobe return. The main functional sections are: the synchronizing, transmitting, receiving, side lobe suppression, antenna positioning, indicating, power distribution, waveform converting, and testing sections.

Radar Set AN/SPS-52 ( )

The AN/SPS-52 (fig. 7-18) is a long-range and short-range radar. It is widely installed on guided missile frigates and LHAs. It provides the target input data required to support the missile system and employs air intercept control techniques.

The AN/SPS-52 ( ) radar utilizes a general-purpose digital computer with both automatic and off-line diagnostic test routines. In addition, it is possible to change the radar programs by use of the input/output radar printer. To enhance detection and accuracy, a digital display indicator is furnished with the radar set.

The radar set employs a high-gain antenna with the radar system.

Radar Set AN/SPS-48( )

The AN/SPS-48( ) is a very versatile radar with many modes of operation. It provides the necessary target input data required to support the Navy surface missile systems, and also fills the requirement for air intercept control. The system is installed on guided missile destroyers, frigates, cruisers, and aircraft carriers.

The radar is composed of six major units: antenna, transmitter, receiver, two computers and frequency control group, plus a number of small auxiliary power units, data converter, and a control console.

The equipment uses solid state, modular construction techniques extensively and operates on 400-hertz primary power.

CARRIER CONTROLLED APPROACH (CCA) EQUIPMENT

Carrier Controlled Approach (CCA) equipment guides aircraft to safe landings under conditions approaching zero visibility. By means of radar, aircraft are detected and observed during the final approach and landing sequence. Guidance information is supplied to the pilot in the form of verbal radio instructions, or to the automatic pilot (autopilot) in the form of pulsed control signals.

Five CCA systems currently are installed aboard carriers in the active fleet. They are models AN/SPN-6, AN/SPN-35A, AN/SPN-42, AN/SPN-43, and AN/SPN-44.

Radar Set AN/SPN-6 (Being phased out)

The AN/SPN-6 CCA system displays an aircraft's position relative to an ideal approach path on offset sector ppi's or the position of aircraft in marshall positions on a centered ppi. The approach presentations are viewed by an aircraft final controller, who transmits verbal landing instructions to the pilot. The aircraft is directed along an ideal approach path to a point where it is visible to the landing signal officer (LSO). When the aircraft is visible, the LSO informs the controller that contact has been made and that the aircraft is being brought aboard by visual means. If the aircraft approaches CCA minimums without the LSO indicating that contact has been made, it is given a waveoff.

Radar Set AN/SPN-42

The AN/SPN-42 is a computerized Automatic Carrier Landing System (ACLS) system that provides precise control of aircraft during their final approach and landing. The equipment automatically acquires, controls, and lands a suitably equipped aircraft on aircraft carriers under severe ship motion or weather conditions.

Aircraft returning to the carrier are assigned to the AN/SPN-42 system by means of an air traffic control computer. On receipt of an assignment, the system programs an optimum flight path for the aircraft. It also establishes a radar acquisition window (search area). When

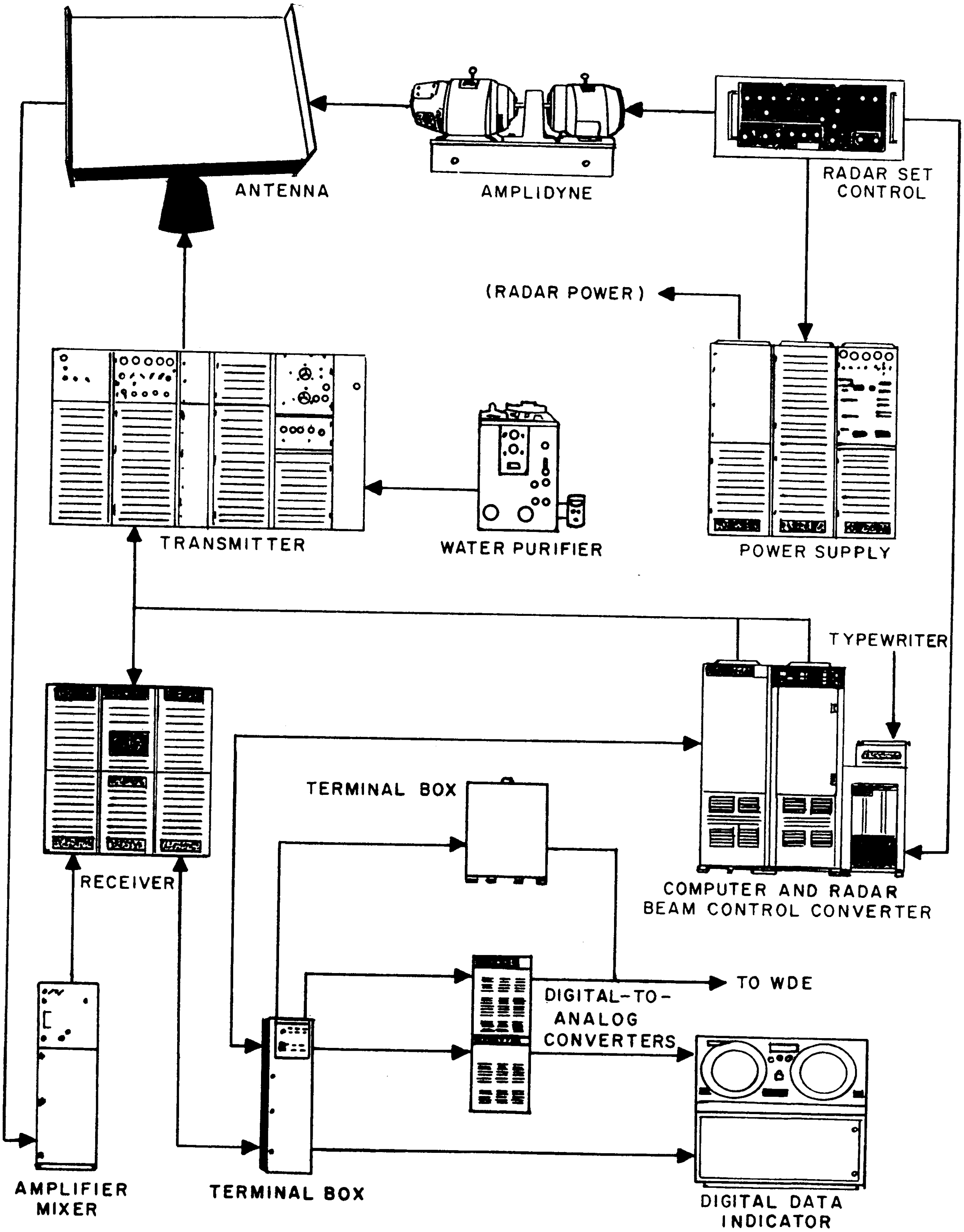

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Figure 7-18.—Air-search Height-finding Radar Set AN/SPS-52 system.

the assigned aircraft enters the window, it is automatically detected, locked onto, and traced by the precision radar subsystem. The radar-derived data of the aircraft's position (flight path) is compared with the optimum flight path. As a result of this comparison, correction signals are generated to control the aircraft along the optimum flight path to touchdown.

If an unsafe flight or landing condition is indicated, the AN/SPN-42 signals a waveoff and returns control of the aircraft to the air traffic control computer. In addition, the LSO or equipment operator may initiate a waveoff sequence when a judgment is made that a safe landing cannot be accomplished. The automatic landing can be terminated at any time at the pilot's discretion.

The AN/SPN-42 has two identical control channels. These channels, operating independently, provide an overall maximum system landing rate capable of challenging the after-landing action requirements of the most efficient flight deck crews. Each channel has three modes of operation: automatic, semiautomatic, and manual (voice talkdown). In instances where both the ship and aircraft are capable of operating in three modes, the mode of operation is determined by the pilot of the landing aircraft, after which the operator will take the appropriate action to furnish the pilot with the desired control guidance.

The AN/SPN-42 offers great reliability and maintainability. It employs digital computers and solid state circuitry, resulting in a mean time between failures of approximately 250 hours in Mode I; whereas, previous equipment had mean time between failures of 35 hours in Mode I.

Radar Set AN/SPN-44

The AN/SPN-44 is a range-rate radar set that computes, indicates, and records the speed of aircraft making a landing approach to the carrier. Both true air speed and relative speed are indicated. Thus, the LSO is supplied with accurate information on the speed of the approaching aircraft, and can wave off those attempting to land at an unsafe speed.

Radar Set AN/SPN-35A (Being phased out)

The AN/SPN-35A is a lightweight carrier-controlled approach radar designed to provide precision range, azimuth, and elevation information for aircraft during the final approach phase of flight onto aircraft carriers. Two antennas are employed, one for azimuth search and one for elevation.

Aircraft normally enter AN/SPN-35A control approximately ten miles from touchdown. Under optimum weather conditions, aircraft may enter AN/SPN-35A control approximately twenty-five miles from touchdown. Information presented on the indicators provides the final approach controllers with precision information as to relative azimuth, range, and elevation of the aircraft. This enables the operator to direct the pilot along a predetermined glide-slope path and azimuth course line. All aircraft on the glide-slope and azimuth course line are displayed and can be controlled.

The three major modes of operation for the AN/SPN-35A are as follows:

1. Normal Mode—For normal precision approach operation, the azimuth antenna scans a 30-degree sector, and the elevation antenna scans 11 degrees vertically.
2. 35-Degree Elevation Mode—The azimuth antenna scans a 30-degree sector, and the elevation antenna scans 35 degrees vertically.
3. 60-Degree Azimuth Mode—The azimuth antenna scans a 60-degree sector, and the elevation antenna scans 11 degrees vertically.

The AN/SPN-35A employs a more reliable stabilization system to compensate for pitch and roll of the carrier in order to maintain precision azimuth and elevation coverage. It employs an electromechanical stabilization system, whereas the previous stabilization system was the modified mechanical-hydraulic stabilization system of the AN/SPN-6 radar.

Radar Set AN/SPN-43, -43A

The AN/SPN-43 (fig. 7-19, a foldout at the end of this chapter) provides azimuth and range information from fifty miles to a minimum range of 250 yards at altitudes from radar horizon to

30,000 feet. The ship's radar indicators display the information to the operators in the Carrier Air Traffic Control Center. This enables the operator to direct the aircraft along a predetermined azimuth course line to a point approximately one-quarter mile from touchdown. At night or during adverse flying weather, however, control of the aircraft is transferred to the precision approach radar (AN/SPN-35A) or Landing Control Central (AN/SPN-42) for guidance along the glide-path and azimuth course line to the carrier landing ramp.

The AN/SPN-43 modifies and improves the AN/SPN-6 radar air space coverage required for carrier landing operations. The present AN/SPN-6 radar's vertical beamwidth of 2-1/2 degrees is inadequate to simultaneously cover normal carrier approach and bolter/waveoff patterns. Furthermore, the AN/SPN-6 no longer provides adequate range coverage for surveillance of aircraft at high altitudes.

REPEATERS (INDICATORS)

Repeaters provide video information on range and bearing or height at a location remote from the actual radar set. Most repeaters are capable of selecting any one of several radar inputs. Many of the repeaters are being replaced on Navy Tactical Data System (NTDS) equipped ships in favor of multipurpose consoles; however, repeaters are still irreplaceable on ships not equipped with NTDS and as a backup to the consoles on NTDS ships.

Several types of radar repeaters currently installed on Navy ships are described in the following topics.

Remote Indicator AN/SPA-25( )

The Range-Azimuth Indicator AN/SPA-25 (fig. 7-20) is a lightweight transistorized general-purpose plan position indicator with a standard 10-inch screen designed for operation with any standard Navy search radar system having a pulse repetition frequency of 10 to 5000 pps (pulses per second). The indicator can be employed to display radar information from any one of up to seven radar systems, depending on the installation. The AN/SPA-25( ) incorporates continuous range variation from 1 to 300 miles, time sharing of electronic cursor sweep with the video sweep, and a sweep offset capability when a dead reckoning auxiliary unit is employed. Without the dead reckoning unit, the indicator does not have the offset capability.

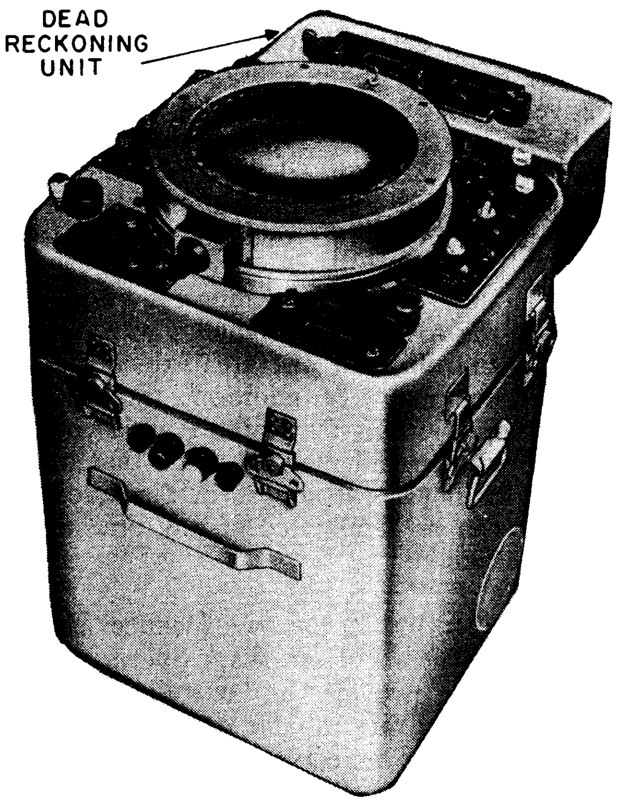

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Figure 7-20.—Range-Azimuth Indicator AN/SPA-25 with dead reckoning auxiliary unit attached.

Range may be determined in two ways: (1) by using the range rings, which occur at 1/2, 1-, 2-, 5-, 10-, 20-, or 50-mile intervals for the operator's selection, or (2) by using the electronic range strobe and a direct-reading mechanical counter. (Some AN/SPA-25 models are equipped with digitalized counters.)

Bearing (azimuth) may be determined in two ways: (1) by using the electronic cursor and azimuth scale or (2) by using the electronic cursor and a direct reading mechanical counter.

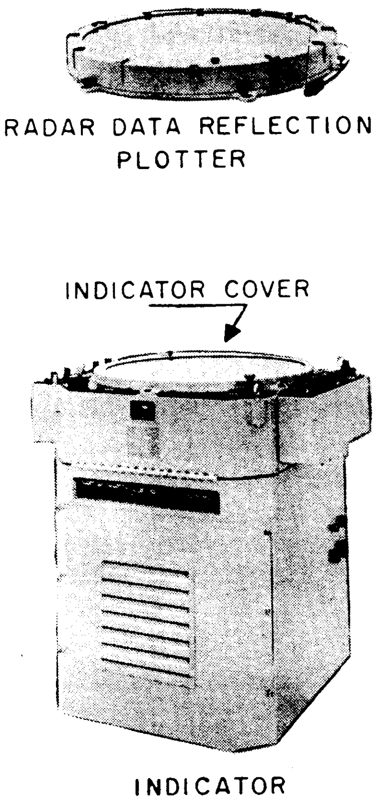

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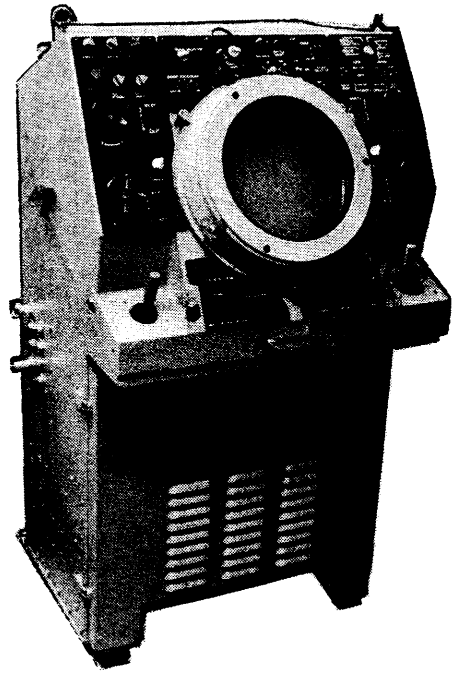
Figure 7-21.—Range-Azimuth Indicator AN/SPA-50A.



120.34B
Figure 7-22.—Range-Azimuth Indicator AN/SPA-66.

Remote Indicator AN/SPA-50A

Range-Azimuth Indicator AN/SPA-50A (fig. 7-21) is a transistorized, direct-view, large-screen (22-inch) ppi designed to display the output of any standard search-radar system having a pulse rate frequency between 15 and 5000 pps. The indicator unit will display the signals from any standard search radar. It normally uses only the electronic bearing cursor, although a mechanical cursor can be installed.

A reflector plotter is shown separately in figure 7-21. A plotting head enables the operator to plot the position and motion of a radar target accurately on a planned position indicator.

The AN/SPA-4, -25, and -50A Remote Indicators are used primarily with surface search radars. Remote Indicators AN/SPA-66, and -41, are used more with air search radars.

Remote Indicator AN/SPA-66

The AN/SPA-66 (fig. 7-22) is very accurate and consists of Azimuth-Range Indicator, Power Supply, Electrical Equipment Cabinet, Writing Shelf, and Indicator Group Accessory Kit. The accessory kit provides storage space for the reflection plotter, four window assemblies, four unmounted windows, a chart, and a cursor holder. One of the window assemblies and the cursor holder are attached to the indicator when shipped, but storage space for them is available in the accessory kit.

The AN/SPA-66 is a general purpose plan position indicator. By means of a front panel function control switch it can be used as an ordinary ppi, as an airborne early warning (AEW) tracking indicator, or as an AEW repeat (final) indicator. In addition, as an ordinary ppi, the indicator can accept azimuth information in the form of two rectangular coordinate voltages instead of synchro voltages when used with electronic scanning (ELSCAN) radars.

When the indicator is operating as a tracking indicator, either the tracking strobe or the cursor origin can be moved by the operator to follow the position of any selected point on the display. This point may be ownship, any selected target, or any other selected reference point. The tracking information is indicated by counters, and it can be transmitted by synchros to another AN/SPA-66 indicator which is operating as a repeat indicator. In the repeat indicator the tracking information displaces the display from center by an amount equal to, and in the direction opposite to, that of the off-centering in the tracking indicator. Thus, the point of reference selected for the tracking strobe or cursor origin as applicable in the tracking indicator becomes the center of the display in the repeat indicator. With ownship at the origin of the cursor, the operator of the repeat indicator can read range and bearings of targets directly in relation to ownship.

The indicator incorporates a selection of fixed range rings, an electronic variable range strobe, and a movable cursor. The fixed-range rings and the electronic variable-range strobe are centered on the position of the radar. The fixed-range rings appear either as range rings on the video sweep or as range markers on the cursor. The cursor and range strobe can be centered on the sweep or unlocked and moved independently for air intercept use. The range indicated by the range strobe and the bearing indicated by the cursor are registered by range and azimuth counters, respectively. In addition, when the cursor is off, the range strobe appears on the sweep as a variable range ring. Sweep range is continuously variable from four miles to 400 miles. The sweep origin can be off-centered as much as five radii depending on range in use, but not more than 400 miles either locally by the manual off-centering controls or remotely by the ship's dead reckoning analyzer. The movement of the sweep origin is registered on counters and direction indicators in terms of range and direction.

The indicator is equipped with a 10-inch, low video drive, long-persistence cathode-ray tube which uses electromagnetic deflection and focusing. An automatic intensity compensation circuit is incorporated in the indicator. This circuit keeps the display brightness substantially constant throughout changes in sweep length. All operating voltages required by the indicator are supplied by internal low-voltage and high-voltage power supplies. External power is supplied from the ship's 115-volt, 60 Hz, single-phase power source.

Remote Indicator AN/SPA-40

Although the AN/SPA-40 is no longer in use in the fleet, it is used for purposes of introduction here due to its unclassified nature. The AN/SPA-40 was a shipboard equipment used with various height-finding radar systems (fig. 7-23). The range-height indicator (rhi) displayed target information by the sweep trace on the screen. The height of the radar beam was presented vertically to a maximum of 150,000 feet. The range was presented horizontally to a

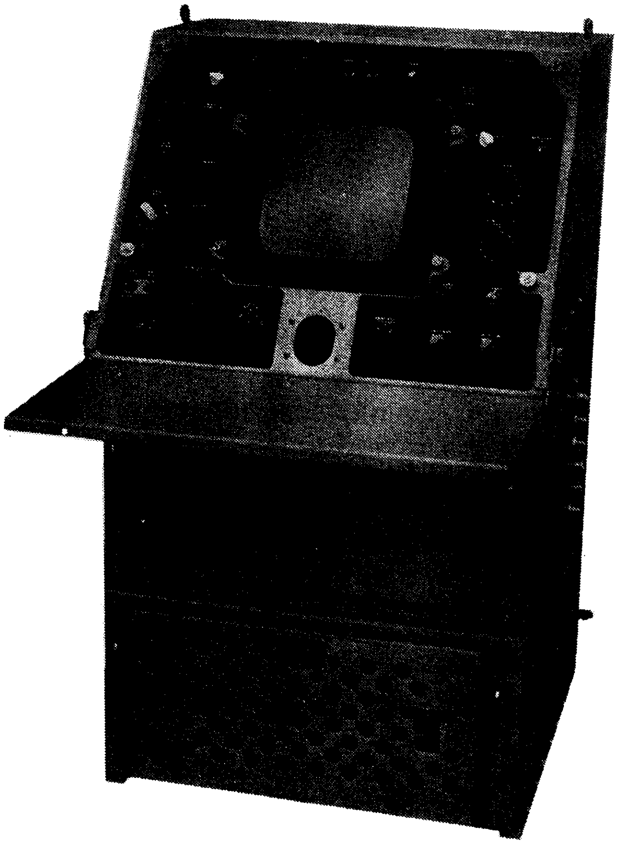


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Figure 7-23.—Height-Finding Indicator AN/SPA-40.

maximum of 300 nautical miles. The rhi supplied the third dimension for a ppi's two-dimension target range and azimuth.

The general-purpose indicator AN/SPA-40 displayed a height-line cursor. This cursor was a straight line painted across the width of the screen. The vertical position of the cursor was controlled by the joystick which was centrally located a few inches below the bottom of the screen. The indicator provided an angle mark cursor used to determine the elevation angle of the target.

The operator could select a delayed sweep of a traverse 30-mile range segment to heights (above sea level) of 0 to 150,000 feet, 50,000 to 150,000 feet, or 0 to 70,000 feet. The center of the range segment could be adjusted anywhere between 15 and 285 miles.

The height-determining capabilities of the indicator were produced by an analog computer. After calibration, this computer solved equations to provide the target height above sea level which was accurate within ±200 feet. The errors due to earth curvature and refraction of the radar beam were adequately corrected.

Remote Indicator AN/SPA-41

The height-finding Indicator AN/SPA-41 has replaced the AN/SPA-40. For characteristics and capabilities of the AN/SPA-41, refer to the applicable technical manual (which is classified).

IFF SYSTEMS

As stated previously, IFF (Identification, Friend, or Foe) systems allow friendly craft to identify themselves when challenged. In addition to "friendly" identification, modern IFF systems may also be used to provide other information, such as type of craft, squadron, side number, mission, and aircraft altitude. This section will discuss the Mark XII IFF system.

AIMS MARK XII IFF SYSTEM

AIMS is an acronym for air traffic control radar beacon and Identification Friend or Foe Mark XII Systems. The Mark XII system is capable of challenging in five different modes (1, 2, 3/A, 4 and C). Each mode is assigned a specific function. Modes 1, 2, and 4 are assigned for military use only. Modes 3/A and C are assigned for civilian and military use. The replies in modes 1 and 3/A are set in at the control box C-6280. Mode 2 is set in at the transponder unit. The reply in mode C indicates aircraft altitude and is automatically derived from the aircraft's barometric altimeter. The reply in mode 4 is generated automatically according to a preset crypto key list.

The Mark XII IFF system includes all of the Mark X equipment such as interrogators, transponders, and decoders, plus additional equipment such as Interrogator Side Lobe Suppression (ISLS) switches and drivers, defruiters, and crypto computers. New features in the Mark XII system include mode C for altitude reporting, mode 4 for secure identification, Interrogator Side Lobe Suppression (ISLS) to reduce "ring-around" targets (explained later), and increased active readout capabilities. Other additions include random nonsynchronous replies (fruit) removal, greater range, and increased decoding capabilities.

Interrogations and Replies

Air traffic control and code monitoring for friendly aircraft and surface craft are accomplished by the use of the sif modes (modes 1, 2, and 3/A). These modes (and mode C) interrogations consist of two pulses spaced at a characteristic interval for each pulse, with a third pulse added for ISLS operation, as shown in figure 7-24.

Each mode 1, 2, or 3/A transponder reply (fig. 7-24) is a binary code contained between two bracket (framing) pulses which are present in every reply, regardless of code content. Each reply code corresponds to a unique four-digit decimal code. The desired reply code for each mode is dialed into the transponder by means of thumbwheel switches. For mode 1 replies, the first digit may be any number from 0 to 7, inclusive, and the second digit any number from 0 to 3, inclusive, with the remaining two digits normally 0. For mode 2 and 3/A reply codes, each of the four reply digits may assume any value from 0 to 7, inclusive.

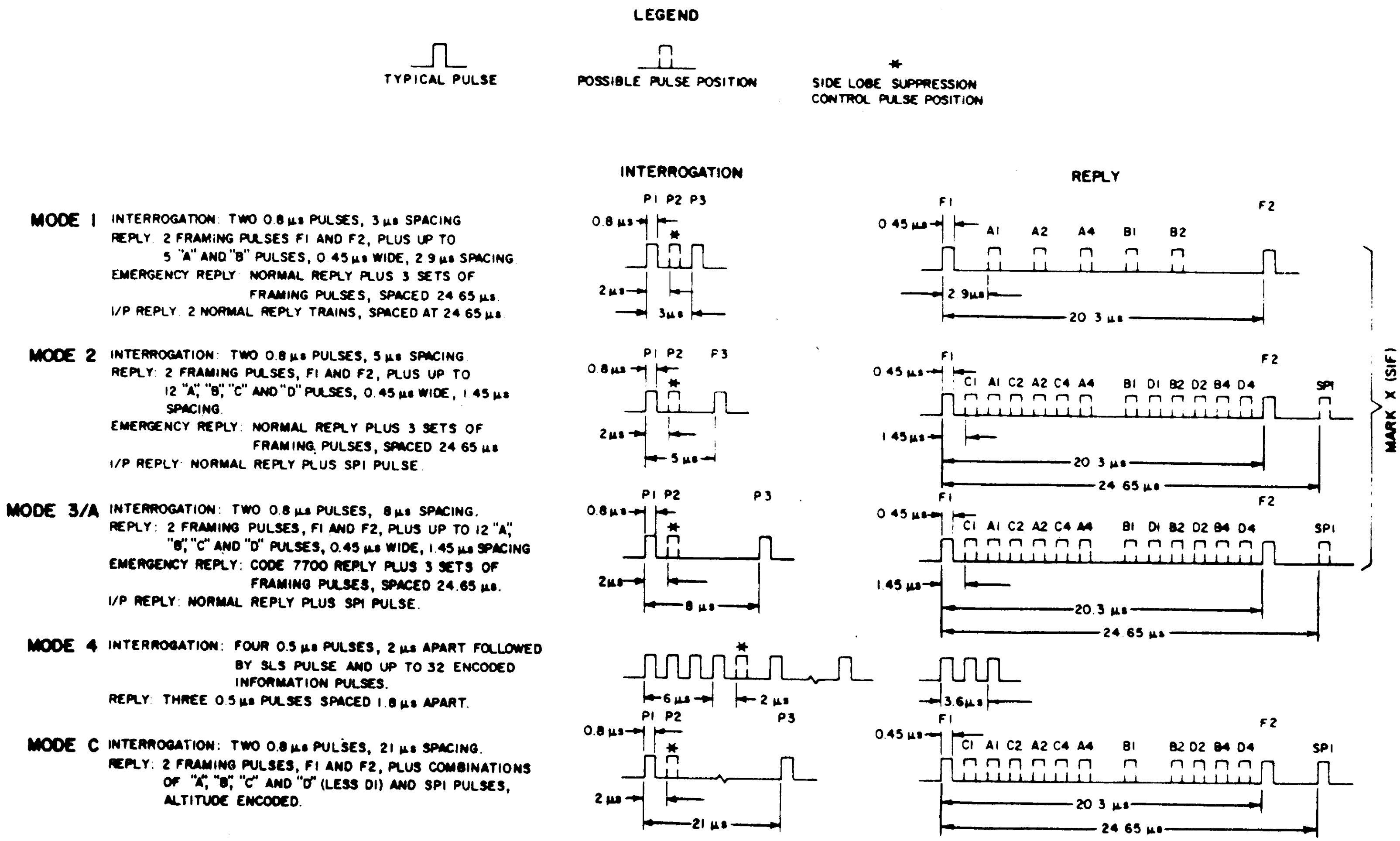

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Figure 7-24.—Mark XII interrogations and replies.

Mode C replies are also binary codes contained between bracket pulses similar to those for the sif modes. Mode C replies may represent any altitude from −1000 feet to +126,700 feet in 100 foot increments, the mode C reply being derived from an encoder linked to the aircraft altimeter. Shipboard transponders are wired to reply to mode C interrogations with bracket pulses only (Code 0000). Modes 1, 2, 3/A and C replies cannot in themselves be separated according to mode. The fact that the interrogator "knows" which mode it has interrogated allows replies to be separated and identified with the proper mode.

Secure identification of friendly aircraft and surface vessels by the Mark XII system is provided through the use of mode 4. Referring to figure 7-24, mode 4 interrogations are encoded multipulse trains which consist of four (sync) pulses and an ISLS pulse, followed by up to 32 information pulses. Upon receipt of a valid mode 4 interrogation, the transponder section processes the interrogation and sends out a time coded three-pulse reply. The interrogator section, in turn, receives the reply, converts it to one pulse, and time decodes it for presentation on the indicators if it is a valid reply.

Figure 7-24 also shows mode 2 and 3/A emergency replies. Military emergencies for modes 1 and 2 are called 4X (four train) emergencies. Mode 3/A military emergency replies consist of a combined 4X and 7700 code. A mode 3/A civilian emergency reply is simply a 7700 code, without the 4X code. In addition, a mode 3/A, 7600 reply code designates a radio communications failure for both civilian and military replies. There are no emergency replies for mode C or mode 4.

When desired, a transponder can be made to transmit an identification of position (I/P) reply to mode 1, 2, or 3/A interrogations. This reply is decoded to mark on an indicator a particular aircraft with which the interrogator system operator has voice communication. A pilotless aircraft containing a transponder will transmit an X-pulse reply to mode 1, 2, or 3/A interrogations. The X-pulse reply consists of a normal mode reply code plus an additional pulse occupying the center position of a reply train. X-pulse replies are unique to pilotless aircraft. (Mode C replies will not contain an X-pulse.)

Interrogator Section

A simplified block diagram of the interrogator section of a representative Mark XII IFF system is shown in figure 7-25. The major units of the interrogator section (with the exception of the video decoder group) are usually mounted in a rack, as shown in figure 7-26, and located in the radar equipment room.

INTERROGATOR SET AN/UPX-23.—Interrogator Set AN/UPX-23 (shown in figure 7-26) provides rf interrogations for the various modes, receives the transponder replies to these interrogations, and processes them into proper video signals for application to the decoders and indicators.

COMPUTER.—The Computer (fig. 7-25) encodes the mode 4 challenges for transmission by the interrogator, and decodes the mode 4 transponder replies received by the interrogator in response to these interrogations. Code Changer Key KIK-18 is used to insert the mode 4 code into the computer.

DEFRUITER.—The defruiter (Interference Blanker MX-8757/UPX or MX-8758/UPX, fig. 7-26) functions to remove nonsynchronous transponder replies and receiver noise from the IFF video. The nonsynchronous replies (termed "fruit") are generated by omnidirectional transmissions from transponders answering to interrogators other than the one receiving the reply, and as such are not legitimate replies. The Interference Blanker, MX-8757/UPX, is a four-channel type (one channel used for each sif mode and mode C), and the MX-8758/UPX is a one-channel type (one channel used for all modes). A given system may contain either type of defruiter.

PULSE GENERATOR.—The Pulse Generator provides the IFF system pretriggers which initiate IFF challenges for the enabled modes. For "slaved IFF" systems, the pretrigger generator synchronizes IFF interrogations with the associated radar, and for "black IFF" systems, the pretrigger generator produces triggers internally. (Slaved IFF systems are IFF systems that are associated with radar systems,

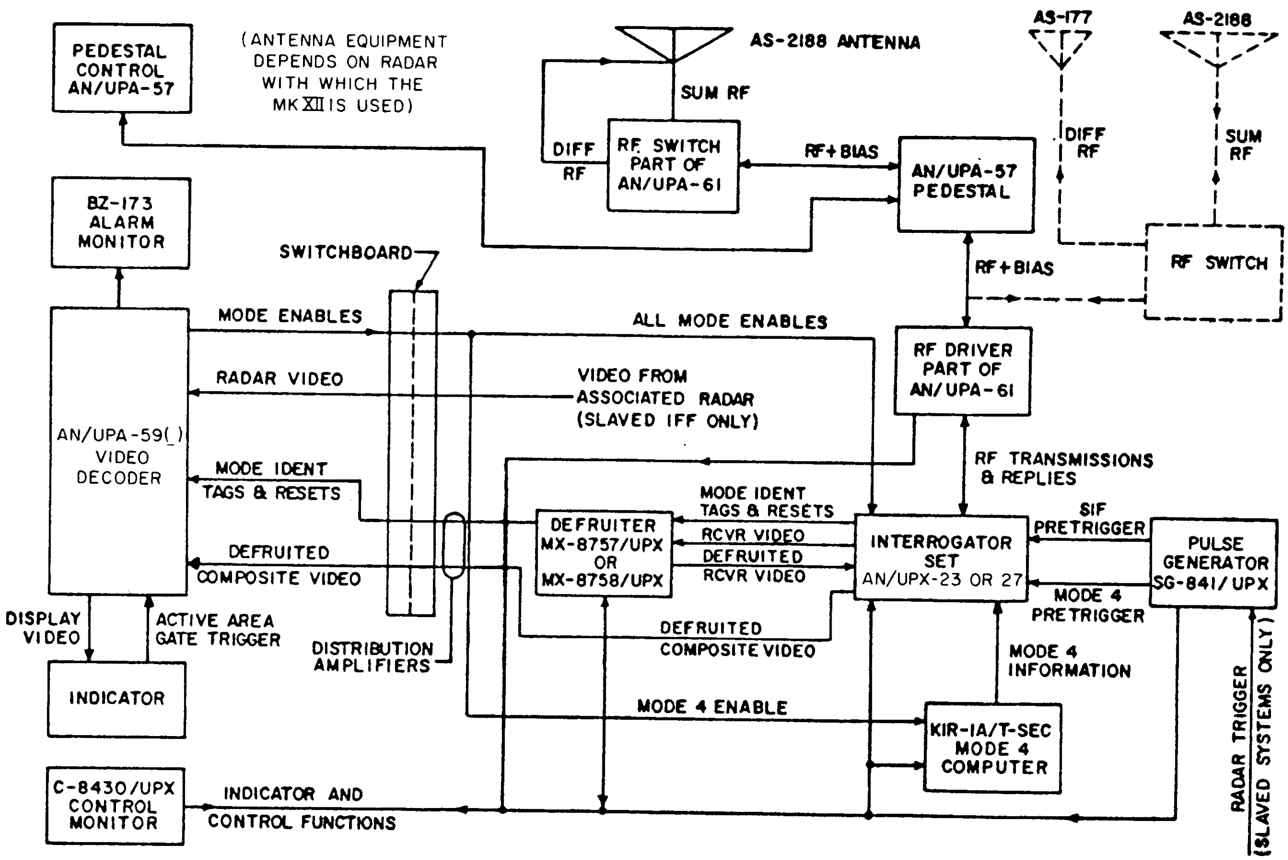

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Figure 7-25.—Mark XII IFF system interrogator section.

and black IFF systems are those systems not associated with radar systems.)

AN/UPA-61 SWITCH AND DRIVER.—The AN/UPA-61 Switch and Driver functions to provide the ISLS operation for the Mark XII system. Targets at close ranges to an interrogator set will reply to side and back lobes of the antenna as well as the main antenna beam. This causes the target to appear for nearly 360° close to the origin of display (ring around).

The function of ISLS is to prevent ring-around by inhibiting transponder replies to interrogations from the side lobes of the IFF antenna. The rf driver mixes a switching bias and the transmitted rf on a single line for routing to the rf switch. The rf switch (usually mounted on the antenna) separates the transmitted rf into sum and difference signals (fig. 7-25) which are applied to the antenna(s) to obtain proper ISLS transmissions.

CONTROL MONITOR.—The Control Monitor (fig. 7-25) functions as a remote control and a remote monitor for the interrogator section. The front panel of the control monitor is shown in figure 7-27.

VIDEO DECODER AN/UPA-59( ).—Video Decoder AN/UPA-59( ) processes the pulse coded replies received by the interrogator set, and provides video output to the indicator. The AN/UPA-59( ) is of variable configuration. The most common configuration uses a Video Decoder, an Intratarget Data Indicator, and an Alarm Monitor.

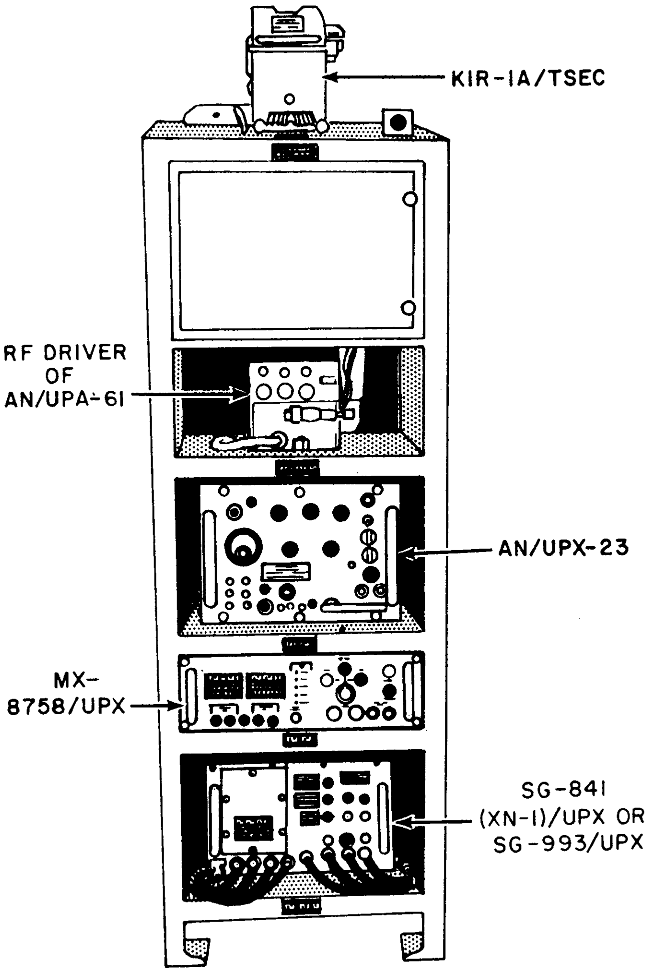

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Figure 7-26.—Mark XII IFF interrogator equipment.

The Video Decoder provides control signals for the interrogator to indicate challenges in the various modes, and accepts reply video for decoding and processing. (Mode 4 reply video is fed directly through the decoder with no processing). The decoder also accepts radar video from an associated radar, and routes this video directly to the indicator, or mixes it with IFF video for display. In addition, the decoder contains active decoding circuitry to display information for the intratarget data indicator.

The Intratarget Data Indicator inserts into a receptacle in the decoder front panel to provide readouts of codes for modes 1, 2, and 3/A replies, plus direct altitude readouts for mode C replies. The Alarm Monitor BZ-173/UPA-59(V) contains a loudspeaker and indicator lights for producing audible and visual alarms when IFF emergency signals are decoded.

ANTENNAS.—The standard Mark XII IFF system antenna is the AS-2188( )/UPX. This antenna has both sum and difference input jacks for radiating rf (from the AN/UPA-61 switch and driver) into the proper patterns for ISLS operation. In installations where the antenna rotary joint will not pass the switching bias, the AS-2188( )/UPX will transmit a sum pattern only, with a separate AS-177( )/UPX omnidirectional antenna transmitting the difference rf. Some installations use an integral antenna to transmit and receive both radar and IFF, with difference IFF being transmitted on a separate AS-177( )/UPX.

ANTENNA PEDESTAL GROUP AN/UPA-57.—Antenna Pedestal Group AN/UPA-57 (fig. 7-25) is capable of self-synchronous operation at rotation rates variable up to 15 rpm. It is also capable of manual operation whereby an operator (at a ppi) can rotate the antenna to any desired position. In addition, the pedestal group may be slaved to a radar system antenna. This application is used for radars which cannot have the IFF antenna mounted on the radar antenna, but are otherwise compatible with the IFF system. The pedestal group consists of a control power supply unit, a manual pedestal control unit, an antenna pedestal assembly, and a pedestal disconnect mast switch.

The control supply unit is located belowdeck and develops all of the power required for the pedestal group. When slaved to a primary radar, the control power supply unit accepts the radar synchro information (via the radar switchboard) and is capable of being slaved to rotation rates of 2 to 30 rpm. When free run operation is selected (on the front panel), the unit drives the pedestal assembly to a variable rate of up to 15 rpm. In conjunction with the manual pedestal control, the unit is also capable of positioning the antenna to any azimuth from a remote position.

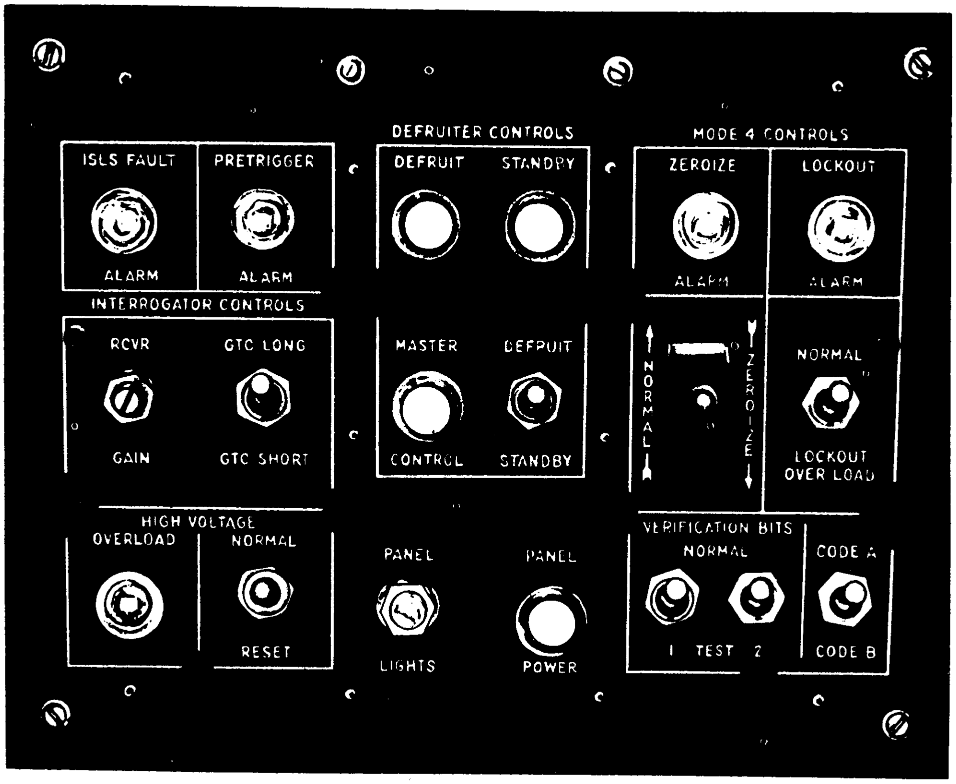

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Figure 7-27.—Control monitor front panel.

The manual pedestal control is usually located at the ppi. Front panel controls provide for selection of slave, free run, and manual operation. The antenna pedestal assembly is capable of mounting the AS-2188( )/UPX or any other 10 foot antenna designed to mount on the same platform. The pedestal disconnect mast switch is located above-deck and functions to remove all power from the pedestal assembly when activated.

Transponder Section

The transponder section receives interrogation pulses, and in turn generates the proper reply pulses. A simplified block diagram of a typical shipboard transponder section installation is shown in figure 7-28.

AUXILIARY EQUIPMENT.—As shown in figure 7-25, the interrogator system must interface with a radar switchboard. Also, for some installations the outputs of the interrogator and defruiter are fed to a distribution amplifier to compensate for multiple cable runs to the switchboard(s). In addition, installations will include a mode enable multiplexer to reduce the number of mode enable lines which are run through the switchboard. The multiplexing unit permits independent use of two mode enable functions wires through one control lead.

Radar Signal Distribution Switchboard.—The switchboard expands the shipboard radar indicator facilities. The SB-1505/SP (figure 7-29) enables any one of ten remote radar indicators to receive radar data from any one of eleven radar receivers. The data from one radar may be fed simultaneously to any number of channels and all channels may be in operation at the same time.

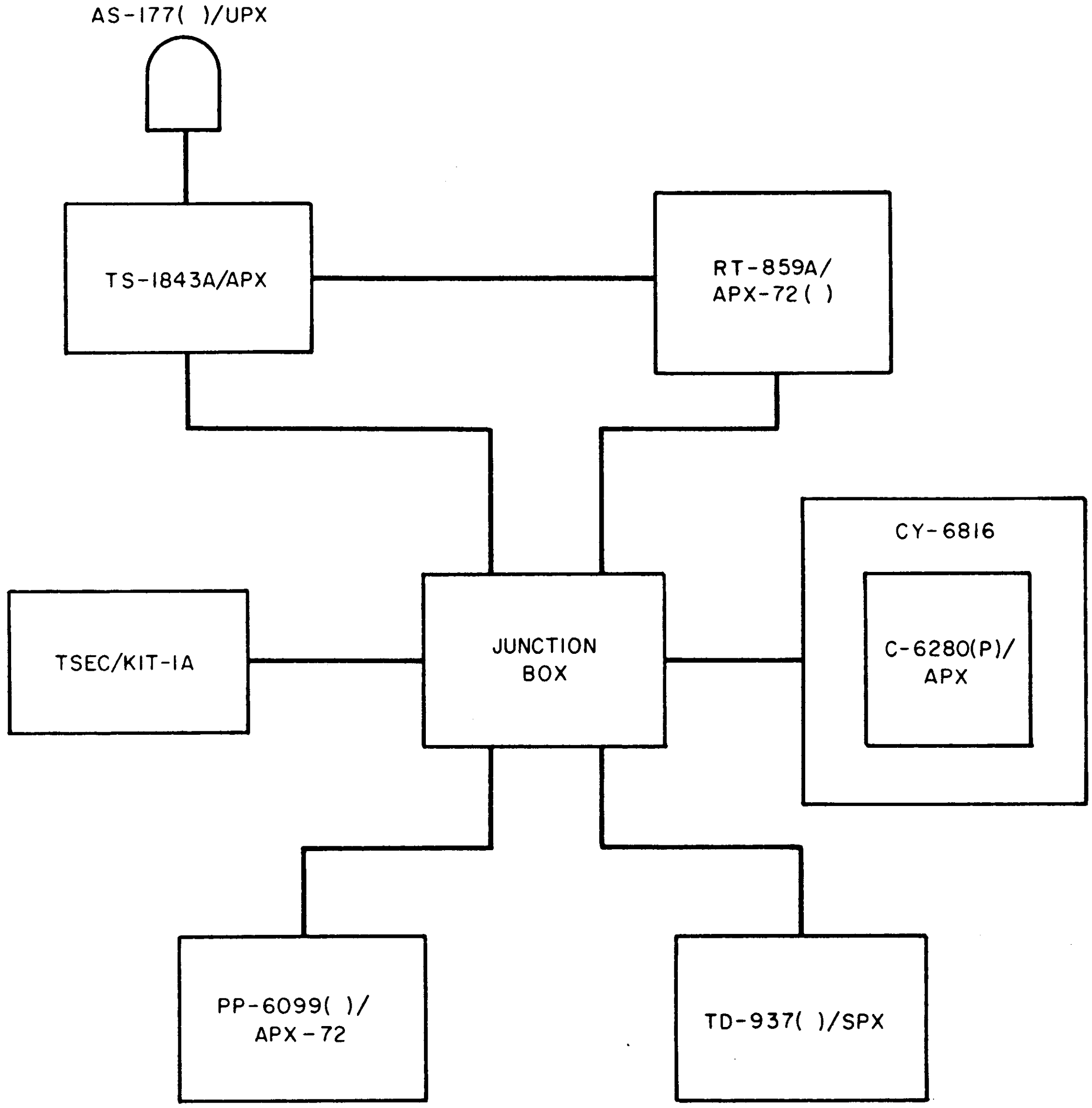

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Figure 7-28.—Typical Shipboard Mk XII Transponder section.

All channels function identically; therefore, to avoid repetition, only one channel is described in this section. Each channel consists of one rotary selector switch; one video and four IFF amplifiers; three trigger regenerators; two dc amplifiers; one stabilizer subassembly; one amplifier power supply (which provides dc power for the video and IFF amplifiers, trigger regenerators and dc amplifiers); and a solenoid power supply. The input terminal boards (located on the inside) and coaxial connectors for eleven radar receivers are mounted on the right side (facing the equipment) of the switchboard. The output from each radar receiver is coupled to all rotary selector switches. The channel outputs are located on the left side of the switchboard enclosure. Each channel has two output terminal boards (located on the inside) and twelve output coaxial connectors.

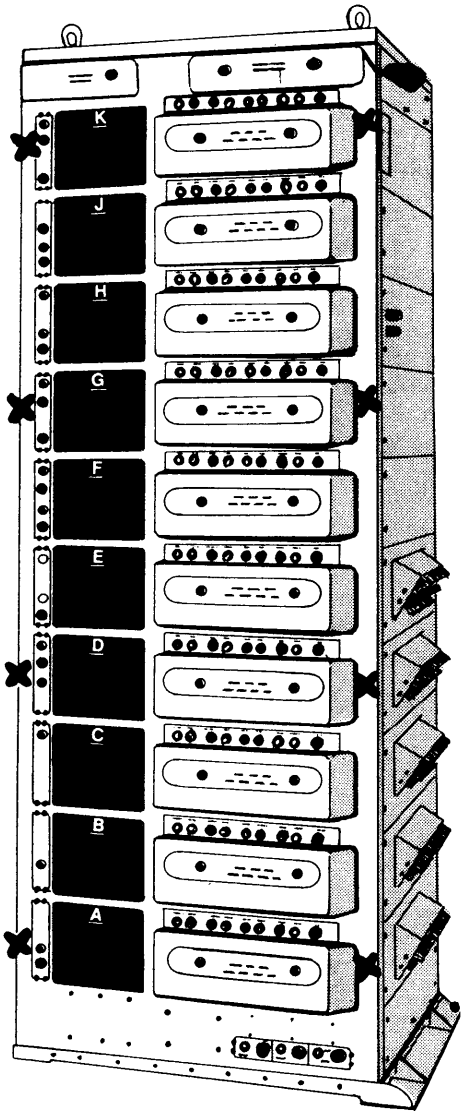

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Figure 7-29.—Radar Signal Distribution Switchboard SB-1505/SP.

Each radar indicator in the system is associated with a specific channel in the switchboard. Two selector switches for remote switchboard control are located at each radar indicator (ppi). One remote switch controls the signal input level for one switchboard video amplifier. The other remote switch controls the position of the rotary-selector switch in the switchboard channel through a five-wire, two-wafer, switch-position sensing system. This system orients the rotary selector switch to any one of twelve positions (there are 11 radar receiver input signal positions and an OFF position on each switch). When the remote radar selector switch and the rotary selector switch are in corresponding positions, the rotors and contacts of the switch wafers interrupt the power source to a rotary solenoid. The rotary selector switch is thus positioned to couple the selected radar signals to the remote indicator unit. Synchro and IFF control information is coupled through the rotary selector switch directly from the selected input terminal board to the output terminal board. The video, IFF, trigger, and scan signals are coupled through the rotary selector switch from the input coaxial connectors to their respective amplifier stages. The amplifier outputs are wired directly to the output coaxial connectors. The output terminal boards and connectors for each switchboard channel are identical. The switchboard input terminal boards are wired for specific radar receivers.