

CDC 1C853A

Radar, Airfield & Weather Systems Journeyman

Volume 2. Introduction to Radar Systems



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THIS SECOND volume of CDC 1C853A is divided into two units that introduce you to the radar system fundamentals and support systems.

Unit 1 covers radar fundamentals and is divided into two sections. The first section covers basic radar systems, focusing on radar principles and characteristics, and an overview of different radar components. The second section covers radio frequency signal propagation with emphasis on radar-signal radiation patterns and possible anomalies.

Unit 2 discusses radar support systems and is divided into three sections. The first section describes radar indicator fundamentals. The second section covers identification friend or foe/selective identification features (IFF/SIF) as they apply to radar systems in general. The last section discusses the radar waveguide system and system support functions.

A glossary is included for your use.

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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

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Unit 1. Radar Fundamentals

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TO BEGIN THIS UNIT, let’s find out exactly what radar is. A very basic definition is “an electronic device used to detect and locate objects on or above the Earth’s surface.” The term “radar” is an acronym formed from the underlined letters in “radio detection and ranging.”

1–1. Basic Radar Systems

The development of radar began with experiments by Heinrich Hertz in the late 19th century. Hertz was able to prove that metallic objects reflect radio waves. It wasn’t until the early 20th century that systems using this principal became widely available. Since that time, radar systems have advanced dramatically and are used throughout the world.

201. Roles in operational theater

Radar has many uses both military and civilian. The best known is surveillance radar used to detect airborne objects within a particular area. Air traffic controllers use this type of radar to monitor and control commercial air traffic near airports and in the air lanes that crisscross our nation. Our air defense system also uses surveillance radars. Aircraft Control and Warning (AC&W) radars provide vital information that allows air battle managers to control friendly aircraft, detect hostile aircraft, and control interceptors.

Military and commercial aircraft make extensive use of radar for navigational purposes. A good example is the radar altimeter, which measures an aircraft’s height above the ground. Most modern aircraft are also equipped with weather avoidance radar, which aids in navigating around storms. Beyond navigation, the military also uses radar to guide missiles to targets and direct the firing of gun systems.

Land-based weather radars track weather disturbances such as tornadoes, hurricanes, and thunderstorms. Weather radars provide critical information to provide ample time for preparations or evacuation. Another type of land-based radar is the precision approach radar (PAR). Controllers use a PAR to assist aircraft in making safe landings during poor weather conditions and it is a key part of the deployable air traffic control and landing systems (DATCALs).

Radars can track satellites and measures distance on land and in outer space. Because of its accuracy, the use of radar in land surveying has greatly enhanced mapmaking precision.

The joint-service standardized classification system further divides these broad categories for more precise identification. The table below is a list of equipment identification indicators; using the table to identify a particular radar system is illustrated in figure 1–1.

NOTE: That for simplicity, only a portion of the table has been listed.

TABLE OF EQUIPMENT INDICATORS		
Installation (1st letter)	Type of Equipment (2d letter)	Purpose (3rd letter)
A - Piloted Aircraft	A - invisible light, heat radiation	B - Bombing
B - Underwater mobile, submarine	C - Carrier	C - Communications
D - Pilotless carrier	D - Radiac	D - Direction finding reconnaissance and/or surveillance
F - Fixed ground	G - Telegraph or Teletype	G - Fire control, or searchlight directing
G - General ground use	I - Interphone and public address	H - Recording and/or reproducing
K - Amphibious	J - Electromechanical or inertial wire covered	K - Computing
M - Ground, mobile	K - Telemetry	M - Maintenance and/or test assemblies
P - Portable	L - Countermeasures	N - Navigational aids
S - Ship	M - Meteorological	Q - Special, or combination of purposes
T - Ground, transportable	N - Sound in air	R - Receiving, passive detecting
U - General, utility	P - Radar	S - Detecting and/or range and azimuth (bearing), search
V - Ground, vehicular	Q - Sonar and underwater sound	T - Transmitting
W - Water surface and underwater combination	R - Radio	X - Identification and recognition
Z - Piloted and pilotless airborne vehicle combination	S - Special types, magnetic, etc.	Y - Surveillance

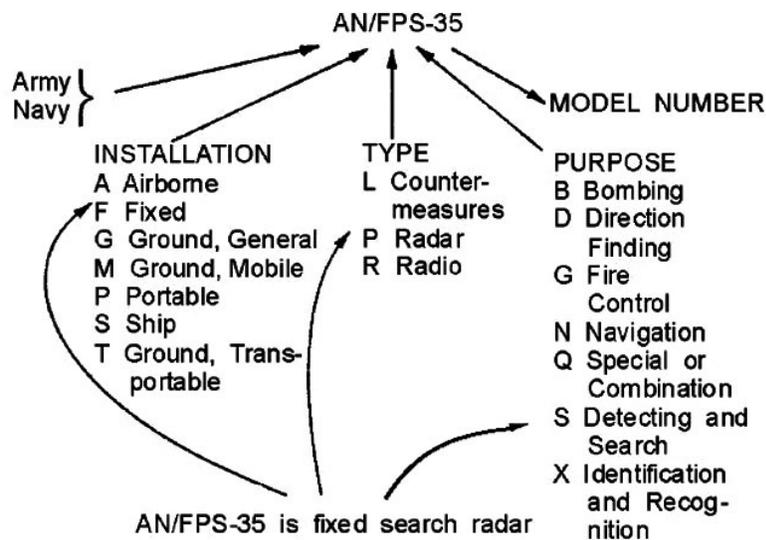


Figure 1-1. Joint service classification system.

Over the years, radar has become a household word. The contributions of radar technology to our society are too numerous to list. They vary from weather surveillance to law enforcement to parking your car. The next lesson of this unit will familiarize you with the basic principles of radar.

202. Principles and frequency characteristics

Radar operates on the echo principal. This is because radar transmits radio frequency (RF) energy into space, and receives and displays reflections (echoes) of that energy. There are two basic types of radar: continuous wave (CW) radar and pulse radar. The simplest is continuous wave radar, which transmits a steady wave of RF energy; the other type, called pulse radar, transmits short bursts of energy called pulses.

Basic principles of radar

When radio waves strike an object, some of the energy is reflected. If the object consists of the proper material, configuration, and attitude, some of the energy reflects back to the source. In this respect, light behaves the same way.

Figure 1-2, shows how light reflects from a mirror. Notice that in figure 1-2, view A the light reflects back to the source. In figures 1-2 view A and 1-2 view C the light reflects, but not back to the source. Angle A in all three illustrations is the angle of incidence. It is obvious that the angle of incidence must be 90 degrees in order to get a reflection back to the light source. Even a sphere provides a 90-degree angle of incidence, although the area is very small, as seen in the bottom of figure 1-2.

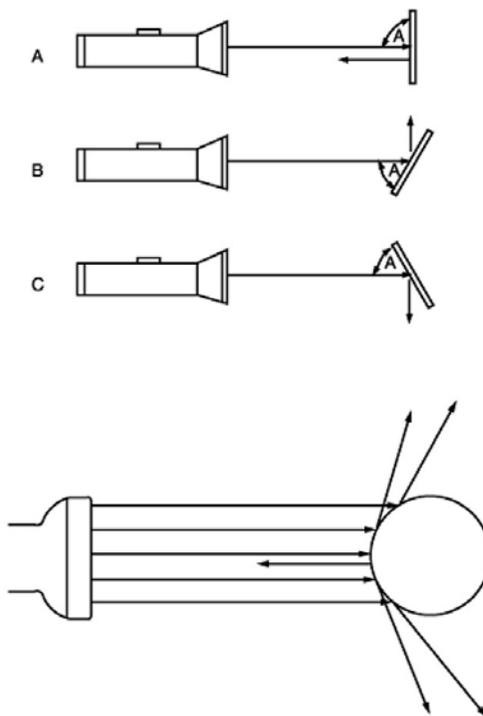


Figure 1-2. Light reflections from a mirror and a sphere.

Radar uses radio waves rather than light. The principle concerning reflection and the angle of incidence is basically the same. The physical configuration and the three-dimensional attitude of most objects provide some areas of 90-degree incidence when struck by light or radio waves; therefore, there is a reflection from them toward the source of the energy. If the reflections are strong enough, they return to the source.

Some materials, when struck by radio waves, will actually break into oscillation and act similarly to a transmitter, radiating the radio waves in all directions. Therefore, some of the waves will travel toward the origin of the original waves, reinforcing the reflected waves. If the energy is great enough and strikes an object with good reflective qualities, some of the energy will return to the origin. Using

proper receiving equipment, you can detect the presence of a distant object by using the reflected energy.

Radio frequency energy principles

Radio waves travel at the speed of light; 162,000 nautical miles (nm) per second. The nautical mile is the unit of measure applied in radar ranging. It is an international unit of measure and is equal to approximately 6076 feet, 2025 yards, or 1852 meters. When a pulse of RF energy is transmitted, it travels at the speed of light. Reflected light from a target (object), returns at the same rate of speed.

Based on the preceding facts, range can be determined by measuring the time it takes for an RF pulse to travel to the target and return. Determine the distance to the target using the following information.

Mathematically, it takes approximately 6.18 microseconds (μs) for the RF energy to travel 1 nm to a target. Obviously, it will take twice that time to make the round trip. Very simply, the round trip constitutes 2 nm (6.18 μs multiplied by 2) or approximately 12.36 μs of time. The 12.36 μs , roundtrip, is called a radar mile. If a target is 2 nm away, it would take 24.72 μs (12.36 $\mu\text{s} \times 2$) for the RF energy to make the round trip.

This mathematical relationship or ratio is the same at any range. A simple formula is:

$$\text{Range of target in nautical miles} = \text{total elapsed time} \div 12.36 \mu\text{s}$$

Remember, the abbreviation radar represents radio detection and ranging. The fact that echoes are actually present accounts for the detection aspect of radar. Ranging is accomplished by measuring the time required for radio waves to travel to target and return to the radar.

The radar sends out a pulse of RF energy and then “listens” or waits for an echo (target return). It listens for a definite period, then transmits another pulse and listens again. Thus, a time base determines the range of targets in radar.

The width of the pulses that the radar sends out is very narrow and varies for different types of radar. This time is the radar’s pulse width (PW). Relating the PW to a radar mile (12.36 μs), we see that a typical pulse width of 0.5 to 6.5 μs is less than 1/2 of one radar mile’s worth of time.

The time from one pulse to the next that the radar sends out is the pulse recurrence time (PRT) or pulse recurrence interval (PRI). The rate or frequency that these pulses occur is the pulse repetition frequency (PRF). A radar that sends out 250 pulses or short bursts of RF energy per second has a PRF of 250 pulses per second (pps). To find the time between each of these 250 pulses sent out in one second, we use this simple formula:

$$\text{PRT} = (1 \div \text{PRF}) = (1 \div 250 \text{ pps}) = 4,000 \mu\text{s}$$

If the time between the pulses PRT is known and you want to know the frequency of them, simply transpose the above formula to read:

$$\text{PRF} = (1 \div \text{PRT}) = (1 \div 4,000 \mu\text{s}) = 250 \text{ pps}$$

To determine the maximum range or distance that a radar can detect a target, recall that the time for the energy to travel from the radar to a target 1 mile away and return to the radar is 12.36 μs or 1 radar mile. You find the maximum detection range of the radar then by dividing the time of 1 radar mile into the time between the pulses leaving the radar (PRT) as shown below.

$$\text{Range} = (\text{PRT} \div 12.36 \mu\text{s})$$

With a 250 pps PRF which equals a 4,000 μs PRT:

$$\text{Range} = (4,000 \mu\text{s} \div 12.36 \mu\text{s}) = 323 \text{ nautical miles}$$

To clarify the time relationship of “transmit time” the time during which the RF burst is sent into space and one given PRT, we find that the radar transmitter is turned on for 0.5 to 6.5 μs .

For the rest of the PRT, the transmitter is off and the radar's receiver listens for an echo of that RF burst. Therefore, the radar time base PRT is from the beginning of one transmit time, through receiver listening time which ends at the beginning of the next transmit time. Notice that although transmitter power, radar frequency, and receiver sensitivity all affect radar range, PRT is actually the primary limiting factor for maximum radar range.

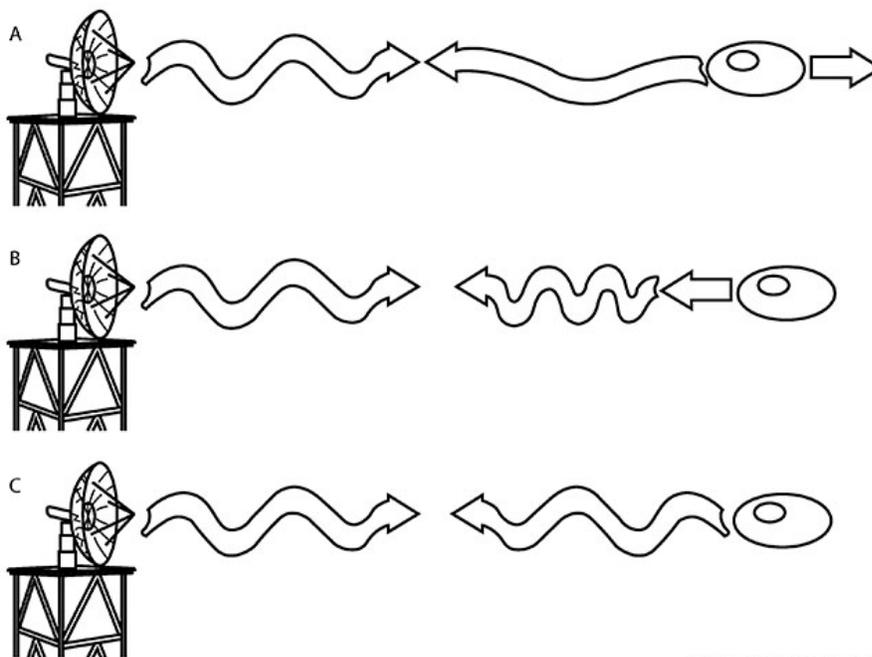
Range and frequency

The frequency of the RF energy in the pulse radiated by a radar is the carrier frequency of the radar system. The carrier frequency is often a limiting factor in the maximum range capability of a radar system because the atmosphere rapidly attenuates radio frequency energy above 3,000 megahertz (MHz). This decreases the usable range of radio-frequency energy. Therefore, as the carrier frequency is increased, the transmitted power must be increased to cover the same range. Long-range coverage is easier to achieve at lower frequencies because atmospheric conditions have less effect on low-frequency energy.

Particles suspended in the air also affect radar performance. Water droplets and dust particles diffuse radar energy through absorption, reflection, and scattering so less energy strikes the target. Consequently, the return echo is smaller. The overall effect is a reduction in usable range that varies widely with weather conditions. The higher the frequency of a radar system, the more weather conditions such as rain or clouds affect radar performance. In some parts of the world, dust suspended in the air can greatly decrease the normal range of high-frequency radar.

Doppler effect

Energy reflected by a target moving away from the radar returns at a lower frequency than the original broadcast. View A of figure 1-3 illustrates this. The faster the target is moving away, the lower the returned frequency. Similarly, energy reflected from a target moving toward the radar has a higher frequency than the original broadcast, as shown in view B of the figure. The faster the target is moving toward the radar, the higher the returned frequency. Energy returning to the radar from a stationary target, however, does not exhibit any frequency change compared to what was broadcast, as you can see in view C. These three relationships collectively summarize the Doppler effect.



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Figure 1-3. The Doppler effect.

Major radar subassemblies

Radar systems, like other complex electronics systems, are composed of several major assemblies, or subsystems, as well as many subassemblies and individual circuits. In this portion of the lesson, you will learn about the major assemblies that are common to most radar sets with a brief functional description of subsystem principles of operation.

Since most radar systems in use today are some variation of the pulse radar system, the units discussed here will be those used in pulse radar.

Typical radar components

Figure 1-4 shows the six functional components that make up a pulse radar system:

1. The synchronizer (also referred to as the timing system) supplies the timing signals that time the transmitted pulses, the indicator, and other associated circuits.
2. The transmitter generates electromagnetic energy in the form of short, powerful pulses.
3. The duplexer allows the same antenna to be used for transmitting and receiving.
4. The antenna system routes the electromagnetic energy from the transmitter, radiates it in a directional beam, receives any returning echoes, and routes those echoes to the receiver.
5. The receiver amplifies the weak, electromagnetic pulses returned from the reflecting object and reproduces them as video pulses
6. The indicator produces a visual indication of the echo pulses in a manner that, at a minimum, furnishes range and azimuth information.

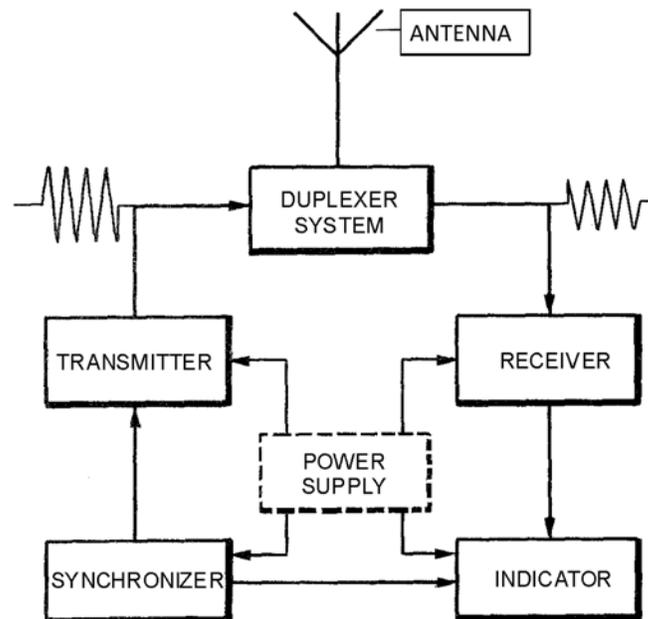


Figure 1-4. Functional block diagram of a basic radar system.

While the physical configuration of radar systems differs, the functional block diagram in figure 1-4 can represent any radar system. An actual radar set may have several of these functional components within one physical unit, or a single one of these functions may require several physical units. However, the functional block diagram of a basic radar set may be used to analyze the operation of almost any radar set. In the following paragraphs, we will briefly discuss the operation of each of the major components.

Synchronizer

The synchronizer ensures all circuits connected with the radar system operate in a definite timed relationship. It also times the interval between transmitted pulses to make sure that the interval is the proper length. Timing pulses ensure synchronous circuit operation and are related to the PRF. Any stable oscillator, such as a sine-wave oscillator, multivibrator, or a blocking oscillator, can set the PRF. That output is then applied to pulse-shaping circuits to produce timing pulses. Associated components may be timed by the output of the synchronizer or by a timing signal from the transmitter as it is turned on.

In today's more advanced radar systems the synchronizer is not a stand-alone unit. Current radar systems have a processor that accepts returns from the receiver and extracts information from the signals. The processor also handles most, if not all, of the system timing normally performed by the synchronizer. Therefore, in most systems today you will not have a unit call the synchronizer because its functions and components have been included in the processor. A more detailed look at the processor is included in a later section of this unit.

Transmitter

The transmitter generates powerful pulses of electromagnetic energy at precise intervals. High-power microwave oscillators, such as a magnetron, or a microwave amplifier, such as a klystron provide the required power. The high-power generator, whether an oscillator or amplifier, requires operating power in the form of a properly-timed, high-amplitude, rectangular pulse. This pulse is supplied by a transmitter subassembly called the modulator. When a high-power oscillator is used, the modulator high-voltage pulse switches the oscillator on and off to supply high-power electromagnetic energy. When a microwave power amplifier is used, the modulator pulse activates the amplifier just before the arrival of an electromagnetic pulse from a preceding stage or a frequency-generation source. Normally, because of the extremely high voltage involved, the modulator pulse is supplied to the cathode of the power tube and the plate is at ground potential to shield personnel from shock hazards. The modulator pulse may be more than 100,000 volts in high-power radar transmitters. In any case, radar transmitters produce voltages, currents, and radiation hazards that are extremely dangerous to personnel. You must always observe safety precautions when working in or around a radar transmitter.

Duplexer

A duplexer is essentially an electronic switch that permits a radar system to use a single antenna to both transmit and receive. The duplexer must connect the antenna to the transmitter and disconnect the antenna from the receiver for the duration of the transmitted pulse. The receiver must be completely isolated from the transmitted pulse to avoid damage to the extremely sensitive receiver input circuitry. After the transmitter pulse has ended, the duplexer must rapidly disconnect the transmitter and connect the receiver to the antenna. As mentioned previously, the switching time is called receiver recovery time and must be very fast if close-in targets are to be detected. Additionally, the duplexer should absorb very little power during either phase of operation. Low-loss characteristics are particularly important during the receive period of duplexer operation. This is because the received signals are of extremely low amplitude.

Antenna system

The antenna system routes the pulse from the transmitter, radiates it in a directional beam, picks up the returning echo, and passes it to the receiver with minimum loss. The antenna system includes the antenna, transmission lines and waveguide from the transmitter to the antenna, and the transmission line and waveguide from the antenna to the receiver. In some publications, the duplexer is included as a component of the antenna system.

Receiver

The receiver accepts the weak echo signals from the antenna system, amplifies them, detects the pulse envelope, amplifies the pulses, and then routes them to the indicator. One of the primary functions of the radar receiver is to convert the frequency of the received echo signal to a lower frequency that is easier to amplify. This is because radar frequencies are very high and difficult to amplify. This lower frequency is called the intermediate frequency (IF). The type of receiver that uses this frequency conversion technique is the superheterodyne receiver. Superheterodyne receivers used in radar systems must have good stability and extreme sensitivity. Stability is ensured by careful design and the overall sensitivity is greatly increased by the use of many IF stages.

Indicator

The indicator uses the received signals routed from the radar receiver to produce a visual indication of target information. The cathode-ray oscilloscope is an ideal instrument for the presentation of radar data. This is because it not only shows a variation of a single quantity, such as voltage, but also gives an indication of the relative values of two or more quantities. The pulse-repetition frequency of the radar system determines the sweep frequency of the radar indicator. Sweep duration is determined by setting the range-selector switch. Since the indicator is so similar to an oscilloscope, the term radar scope is commonly used when referring to radar indicators.

203. Transmitter

The transmitter produces the short-duration high-power RF pulses of energy that are radiated into space by the antenna. Two main types of transmitters are now in common use. The first is the keyed-oscillator type. In this transmitter one stage or tube, usually a magnetron, produces the RF pulse. A high-power direct current (DC) pulse of energy generated by a separate unit called the modulator (discussed next) keys the oscillator tube. The second type of transmitter consists of a power-amplifier chain. This transmitter system begins with an RF pulse of very low power. This low-level pulse is then amplified by a series (chain) of power amplifiers to the high level of power desired in a transmitter pulse. In most power-amplifier transmitters, each of the power-amplifier stages are pulse modulated in a manner similar to the oscillator in the keyed-oscillator type. Because the modulator is common to both types of transmitter systems, the operation of a typical modulator will be discussed first.

Radar modulator

The modulator controls the radar pulse width by means of a rectangular DC pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted RF pulse depends on the amplitude of the modulator pulse. Figure 1-5 shows the waveforms of the trigger pulse applied by the synchronizer to the modulator, the modulator pulse applied to the radar transmitter, and the transmitted RF pulse.

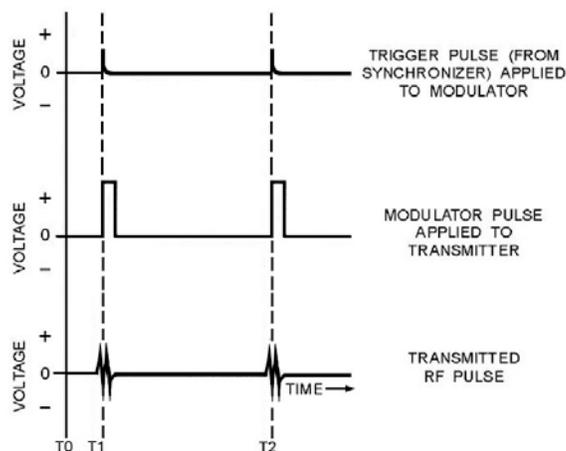


Figure 1-5. Transmitter waveforms.

As you can see in the figure, the modulator pulse is applied to the transmitter the instant the modulator receives the trigger pulse from the synchronizer (T1 and T2). The modulator pulse is flat on top and has very steep leading and trailing edges. These pulse characteristics are necessary for the proper operation of the transmitter and for the accurate determination of target range. The range timing circuits must be triggered the instant the leading edge of the transmitted RF pulse leaves the transmitter. In this way, the trigger pulse that controls the operation of the modulator also synchronizes the cathode-ray tube sweep circuits and range measuring circuits.

Magnetron oscillators are capable of generating RF pulses with very high peak power at frequencies ranging from 600 to 30,000 MHz. However, if its cathode voltage changes, the magnetron oscillator shifts in frequency. To avoid such a frequency change, you must make sure the amplitude of the modulator DC pulse remains constant for the duration of the transmitted RF pulse. That is, the modulator pulse must have a flat top. The range of cathode voltages over which a magnetron oscillates in the desired frequency spectrum is relatively small.

When a low voltage is applied to a magnetron, the magnetron produces a noise voltage output instead of oscillations. If this noise enters the receiver, it can completely mask the returning echoes. If a modulator pulse builds up and decays slowly, noise is produced at both the beginning and end of the pulse. Therefore, for efficient radar operation, a magnetron requires a modulator pulse that has a flat top and steep leading and trailing edges. An effective modulator pulse must perform in the following manner:

- Fall from its maximum value to zero almost instantaneously.
- Rise from zero to its maximum value almost instantaneously.
- Remain at its maximum value for the duration of the transmitted RF pulse.

In radars that require accurate range measurement, the transmitted RF pulse must have a steep leading edge. The leading edge of the echo is used for range measurement. If the leading edge of the echo is not steep and clearly defined, accurate range measurement is not possible. The leading and trailing edges of echoes have the same shape as the leading and trailing edges of the transmitted RF pulse.

Types of modulators

The two types of modulators are the line pulsing modulator and the hard tube modulator (a hard tube is a high-vacuum electron tube). The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse-forming network. The hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. In most cases, the hard-tube modulator has been replaced by the line-pulsed modulator. This is because the hard-tube modulator has lower efficiency, its circuits are more complex, a higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsing modulator is easier to maintain because of its less complex circuitry. Also, for a given amount of power output, it is lighter and more compact. Because it is the most used modulator in modern radar, it is the only type we discuss here. Figure 1-6 shows the basic sections of a radar modulator.

- The power supply.
- The storage element (a circuit element or network used to store energy).
- The charging impedance (used to control the charge time of the storage element and to prevent short-circuiting of the power supply during the modulator pulse).
- The modulator switch (used to discharge the energy stored by the storage element through the transmitter oscillator during the modulator pulse).

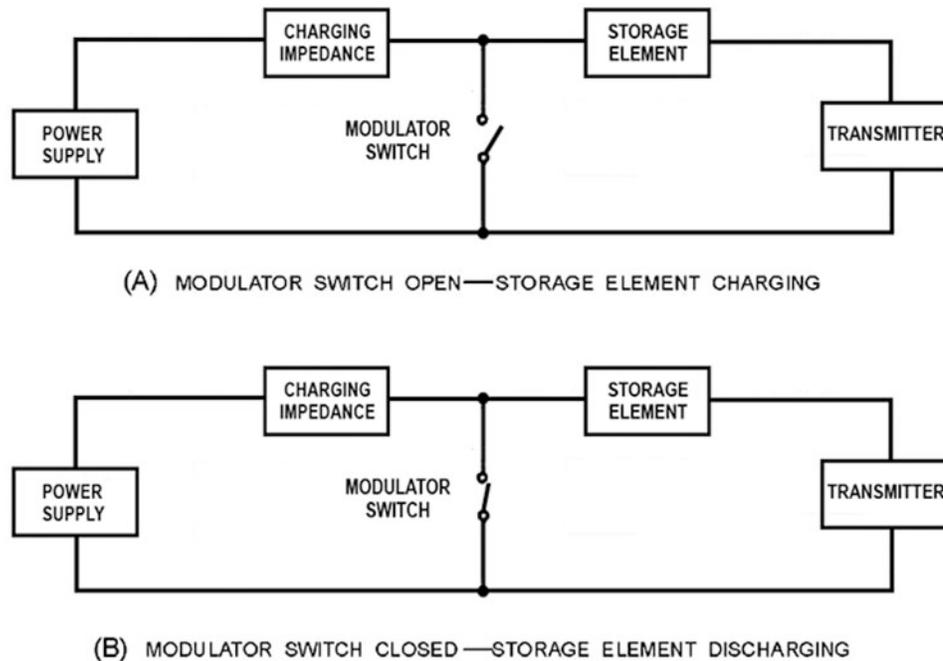


Figure 1-6. Basic line-pulsing modulator block diagram.

View A of figure 1-6 shows the modulator switch open and the storage element charging. With the modulator switch open, the transmitter produces no power output, but the storage element stores a large amount of energy. View B shows the modulator switch closed and the storage element discharging through the transmitter. The energy stored by the storage element is released in the form of a high-power, DC modulator pulse. The transmitter converts the DC modulator pulse to an RF pulse, which is radiated into space by the radar antenna. Thus, the modulator switch is closed for the duration of a transmitted RF pulse, but open between pulses.

Many different kinds of components are used in radar modulators. The power supply generally produces a high-voltage output, either alternating or direct current. The charging impedance may be a resistor or an inductor. The storage element is generally a capacitor, an artificial transmission line, or a pulse-forming network. The modulator switch is usually a thyatron.

Modulator-storage element

Capacitor-storage elements are used only in modulators that have a DC power supply and an electron-tube modulator switch. The capacitor-storage element is charged to a high voltage by the DC power supply. It releases only a small part of its stored energy to the transmitter. The electron-tube modulator switch controls the charging and discharging of the capacitor storage element.

The artificial transmission line storage element, shown in view A of figure 1-6, consists of identical capacitors (C) and inductors (L) arranged to simulate sections of a transmission line. The artificial transmission line serves two purposes:

1. To store energy when the modulator switch is open (between transmitted RF pulses).
2. To discharge and form a rectangular DC pulse (modulator pulse) of the required duration when the modulator switch is closed.

Artificial transmission lines, pulse-forming networks, and capacitor-type are the three storage elements most often used in modulators. In modern radar, artificial transmission lines and pulse-forming networks are used more often than capacitor-type storage elements.

Modulator-switching devices

The voltage stored in a storage-element capacitor, artificial transmission line, or pulse-forming network must be discharged through a modulator-switching device. The modulator-switching device conducts for the duration of the modulator pulse and is an open circuit between pulses. Thus, the modulator switch must perform the following four functions:

1. Close very quickly and then reach full conduction in a small fraction of a μs .
2. Conduct large currents (tens or hundreds of amperes) and withstand large voltages (thousands of volts).
3. Cease conducting (become an open circuit) with the same speed that it starts to conduct.
4. Consume only a very small fraction of the power that passes through it.

These switching and conducting requirements are met best by the thyratron tube. The thyratron tube is normally held below cutoff by a negative grid voltage and conducts when a positive trigger pulse is applied to its grid. Once fired, the thyratron tube continues to conduct as long as the storage element (artificial transmission line or pulse-forming network) is discharging.

During discharge of the storage element, the gas in the thyratron tube is highly ionized. While the storage element discharges, the plate-to-cathode resistance of the thyratron is practically zero. When the storage element is completely discharged, current ceases to flow through the thyratron and the gases become deionized; the negative grid bias regains control, and the thyratron is cut off (the modulator switch opens).

Most radar modulators use a high-voltage, DC power supply. Typical DC power supplies for radar modulators use a half-wave rectifier, a full-wave rectifier, or a bridge rectifier.

The modulator charging impedance, shown in figure 1-7, prevents the DC power supply from becoming short-circuited when the modulator switch closes. When the modulator switch is open, the charging impedance also controls the rate at which the storage element charges. When the charging impedance is small, the storage element charges rapidly.

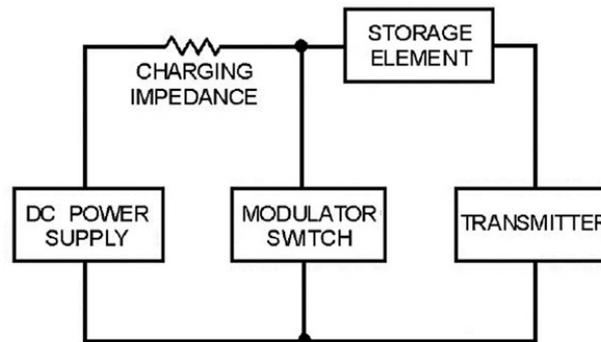


Figure 1-7. Modulator charging impedance.

Many different kinds of charging impedance and charging circuits are used in radar modulators. The type of charging impedance and charging circuit used depends on the following five elements:

1. The type of power supply (alternating current [AC] or DC).
2. The frequency of the available AC supply voltage.
3. The amount of modulator pulse voltage required.
4. The type of storage element.
5. The pulse-repetition rate.

Keyed-oscillator transmitter

The keyed-oscillator transmitter most often uses a magnetron as the power oscillator. The following discussion is a description of a magnetron used as a keyed-oscillator radar transmitter.

Figure 1-8 shows the typical transmitter system that uses a magnetron oscillator, waveguide transmission line, and microwave antenna. The magnetron at the bottom of the figure is connected to the waveguide by a coaxial connector. High-power magnetrons, however, are usually coupled directly to the waveguide. A cutaway view of a typical waveguide-coupled magnetron is shown in figure 1-9.

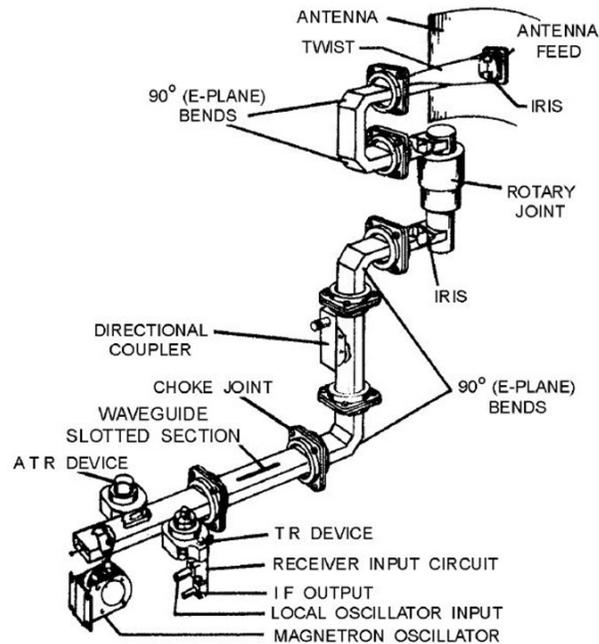


Figure 1-8. Keyed oscillator transmitter physical layout.

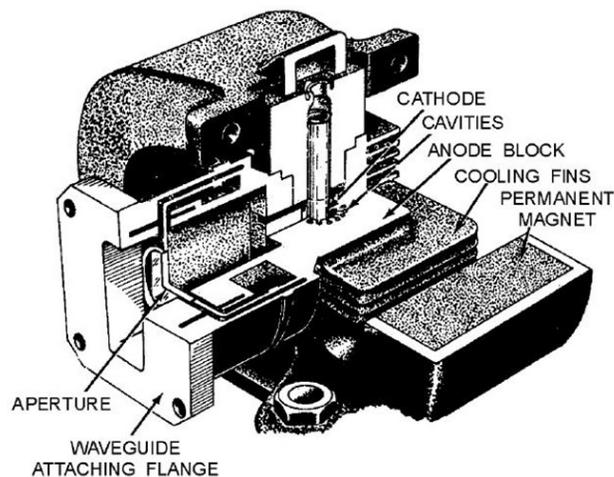


Figure 1-9. Typical magnetron.

The magnetron is an electron tube in which a magnetic (H) field between the cathode and plate is perpendicular to an electric (E) field. Tuned circuits, in the form of cylindrical cavities in the plate, produce RF electric fields. Electrons interact with these fields in the space between the cathode and plate to produce an AC power output. Magnetrons function as self-excited microwave oscillators. These multicavity devices may be used in radar transmitters as either pulsed or CW oscillators at frequencies ranging from approximately 600 to 30,000 MHz.

Let's examine the following characteristics of a magnetron used as a pulse radar transmitter oscillator stage:

- Stability.
- The magnet.
- Output coupling.
- Pulse characteristics.

Stability

In speaking of a magnetron oscillator, stability usually refers to the stability of the mode of operation of the magnetron. The two main types of mode instability are mode skipping and mode shifting.

Mode skipping (or misfiring) is a condition in which the magnetron fires randomly in an undesired, interfering mode during some pulse times, but not in others. Pulse characteristics and tube noises are factors in mode skipping.

Mode shifting is a condition in which the magnetron changes from one mode to another during pulse time. This is highly undesirable and usually does not occur if the modulator pulse is of the proper shape. However, it can also occur if the cathode of the magnetron is in very poor condition.

Pulse characteristics

Pulse characteristics are the makeup of the high-voltage modulator pulse that is applied to the magnetron. The pulse should have a steep leading edge, a flat top, and a steep trailing edge. If the leading edge is not steep, the magnetron may begin to oscillate before the pulse reaches its maximum level. Since these low-power oscillations will occur in a different mode, the mode of the magnetron will be shifted as the pulse reaches maximum power. This mode shifting will result in an undesirable magnetron output. For the same reason (to prevent mode shifting), the top of the modulator pulse should be as flat as possible. Variations in the applied operating power will cause variations in the mode of operation. The trailing edge of the pulse should also be steep for the same reason—to prevent mode shifting.

Magnet

The purpose of the magnet is to produce a uniform magnetic field of the desired value over the interaction space between the cathode and plate of the magnetron. The strength of the magnet is critical to operate properly. If the magnetic field strength is too high, the magnetron will not oscillate. If the magnetic field strength is too low, the plate current will be excessive and power output will be low; frequency of operation will also be affected.

Since the strength of the magnet is critical, you should be careful when handling the magnet. Striking the magnet, especially with a ferromagnetic object, will misalign the molecular structure of the magnet and decrease the field strength.

Output coupling

The output coupling transfers the RF energy from the magnetron to the output transmission line (coaxial line or waveguide). A number of considerations impose restrictions upon the output circuit. The wavelength (frequency) and the power level of the magnetron output energy determine whether the transmission line to the antenna will be waveguide or coaxial line.

The coaxial output circuit consists of a length of coaxial line in which the center conductor is shaped into a loop and inserted into one of the magnetron cavities for magnetic coupling. The load side of the coupling line may feed either an external coaxial line or a waveguide. If the external line is coaxial, the connection may be direct or by means of choke joints. If the external line is a waveguide, the output circuit must include a satisfactory junction from the coaxial line to the waveguide. One type of

junction used quite often is the probe coupler. The probe coupler acts as an antenna radiating into the waveguide.

The waveguide output may be fed directly by an opening (slot) into one of the magnetron cavities, as shown in figure 1-9. This opening must be covered by an iris window to maintain the vacuum seal.

The peak power ratings of magnetrons range from a few thousand watts (kilowatts) to several million watts (megawatts). The average power ratings are much lower; however, ratings vary from a few watts to several kilowatts. Additionally, many of the magnetrons used in modern radar systems are tunable in frequency. Typically, a tunable magnetron can vary the output frequency ± 5 percent around the center of its frequency band. Thus, the carrier frequency of radar can be changed to obtain the best operation or avoid electronic jamming on a particular frequency.

Modulator signals of many thousands of volts are applied to the magnetron cathode during operation. These high voltage levels require large glass posts to insulate the cathode and filaments from the anode block. In some high-power magnetrons, the cathode is completely enclosed in a container filled with insulating oil. Remember, all radar transmitters contain lethal voltages. Extreme care and strict observance of all posted safety precautions are essential when working on a radar transmitter.

Power-amplifier transmitter

Power-amplifier transmitters are used in many recently developed radar sets. This type of transmitter was developed because of the need for more stable operation of the moving target indicator (MTI). In a magnetron transmitting system, the high-power magnetron oscillator has a tendency to drift in frequency because of temperature variations, changes in the modulating pulse, and various other effects. Frequency drift is compensated for, in part, by the use of automatic frequency control (AFC) circuits designed to control the frequency of the local oscillator in the receiver system. This, however, does not completely eliminate the undesirable effects of frequency drift on MTI operation.

The power-amplifier transmitter system does the same thing as the keyed-oscillator transmitter but with fewer frequency stability problems. It generates, shapes, and amplifies pulses of RF energy for transmission. Figure 1-10 is a block diagram of a typical power-amplifier transmitter system. In this transmitter system, a multi-cavity klystron tube amplifies lower-powered RF pulses that have been generated and shaped in other stages. Crossed-field amplifiers also called amplitrons are used in radar systems with a wide band of transmitted frequencies because they are stable over a wider frequency range. A crossed-field amplifier transmitter is discussed later in this section.

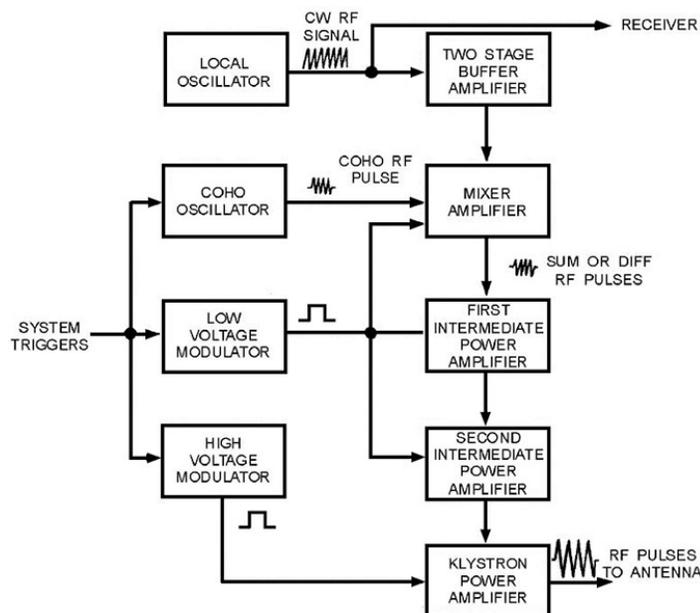


Figure 1-10. Power amplifier transmitter block diagram.

In figure 1-10, the power-amplifier chain input signals are generated by heterodyning (mixing) two frequencies. That is, two different frequencies are fed to a mixer stage (mixer amplifier) and the resultant, either the sum or difference frequency, may be selected as the output. (The operation of mixer circuits is explained in more detail in the area on receivers). The low-power pulse is then amplified by intermediate power amplifier stages and applied to the klystron power amplifier. The klystron power amplifier concentrates the RF output energy into a very narrow frequency spectrum. This concentration makes the system more sensitive to smaller targets. In addition, the detection range of all targets is increased.

To examine the operation of the transmitter, we will trace the signal through the entire circuit. The local oscillator shown at the left of figure 1-10 is a very stable RF oscillator that produces two CW RF outputs. As shown, the CW output is sent to the receiver system; the CW output is also one of the two RF signals fed to the mixer amplifier by way of the two buffer amplifier stages. The buffer amplifiers raise the power level of the signal and isolate the local oscillator.

The coherent oscillator (COHO) is triggered by the system trigger and produces an RF pulse output. This RF pulse is fed directly to the mixer amplifier. The mixer-amplifier stage receives three signals: the coherent RF pulse, the local oscillator CW RF signal, and a DC modulating pulse from the low-voltage modulator. The coherent and local oscillator signals are mixed to produce sum and difference frequency signals. Either of these may be selected as the output. The modulator pulse serves the same purpose as in the keyed-oscillator transmitter, because it determines the pulse width and power level. The mixer stage functions only during the modulator pulse time. Thus, the mixer amplifier produces an output of RF pulses in which the frequency may be either the sum or difference of the coherent and local oscillator signals.

The mixer-amplifier feeds the pulses of RF energy to an intermediate power amplifier. This amplifier stage is similar to the buffer-amplifier stage except that it is a pulsed amplifier. That is, the pulsed amplifier has operating power only during the time the modulator pulse from the low-voltage modulator is applied to the stage. The amplified output signal is fed to a second intermediate power amplifier that operates in the same manner as the first.

From the second intermediate power amplifier, the signal is fed to the klystron power amplifier. This final stage of amplification uses a multi-cavity klystron. The input RF signal is used as the exciter signal for the first cavity. High-voltage modulating pulses from the high-voltage modulator are also applied to the klystron power amplifier. These high-voltage modulating pulses are stepped up across a pulse transformer before being applied to the klystron. All cavities of the klystron are tunable and are tuned for maximum output at the desired frequency.

Provisions are made in this type of transmitter to adjust the starting time of the modulating pulses applied to the coherent oscillator, mixer amplifier, intermediate power amplifiers, and klystron power amplifier. By this means, the various modulator pulses are made to occur at the same time.

This transmitter produces output RF pulses of constant power and minimum frequency modulation and ensures good performance.

Figure 1-11 is a block diagram of a power-amplifier transmitter that uses a frequency synthesizer to produce the transmitted frequency rather than the heterodyning mixer. The frequency synthesizer allows the transmitter to radiate a large number of discrete frequencies over a relatively wide band. Such a system is commonly used with frequency-scan search radars that must transmit many different frequencies to achieve elevation coverage and to compensate for the roll and pitch of a ship.

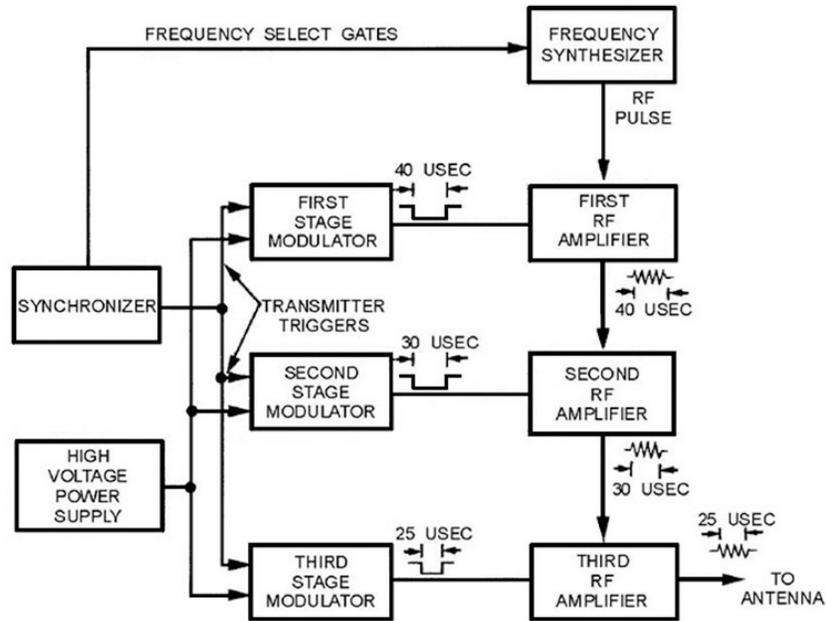


Figure 1-11. Power amplifier transmitter using crossed-field amplifiers.

A typical frequency synthesizer consists of a bank of oscillators producing different fixed frequencies. The outputs of a relatively few fixed oscillators can be mixed in various combinations to produce a wide range of frequencies. In MTI systems, the selected oscillator frequencies are mixed with a coherent oscillator frequency to provide a stable reference for the MTI circuits. The frequency synthesizer also produces the local oscillator signals for the receiver system. Because the transmitted pulse changes frequency on each transmission, the local oscillator signal to the receiver must also change and be included in the transmitted frequency. A system of this type is frequency-programmed by select gates from the synchronizer. The detailed operation of frequency synthesizers is beyond the scope of this lesson but may be found in the technical manuals for most frequency scan radar systems.

The first RF amplifier receives the pulses of the selected frequency from the synthesizer and a modulator pulse (from the first stage modulator) at the same time. The RF pulse is usually slightly wider than the modulator pulse, which prevents the amplifier tube from pulsing when no RF energy is present. Most pulsed RF amplifiers will oscillate at an undesired frequency if pulsed without an RF input. The output of the first RF amplifier is an amplified RF pulse that is the same width as the first stage modulator pulse. The second stage modulator is designed to produce a pulse slightly narrower than the first stage modulator pulse; this also prevents the amplifier from pulsing when no RF is present. Therefore, the second stage amplifier receives a modulator pulse a short time after the first stage RF arrives at the input. As shown in figure 1-11, the same procedure is repeated in the third and final stage.

The amplifiers in this type of power-amplifier transmitter must be broadband microwave amplifiers that amplify the input signals without frequency distortion. Typically, the first stage and the second stage are traveling-wave tubes (TWT) and the final stage is a crossed-field amplifier. Recent technological advances in the field of solid-state microwave amplifiers have produced solid-state amplifiers with enough output power to be used as the first stage in some systems. Transmitters with more than three stages usually use crossed-field amplifiers in the third and any additional stages. Both traveling-wave tubes and crossed-field amplifiers have a very flat amplification response over a relatively wide frequency range.

Crossed-field amplifiers have another advantage when used as the final stages of a transmitter; that is, the design of the crossed-field amplifier allows RF energy to pass through the tube virtually unaffected when the tube is not pulsed. When no pulse is present, the tube acts as a section of

waveguide. Therefore, if less than maximum output power is desired, the final and preceding crossed-field amplifier stages can be shut off as needed. This feature also allows a transmitter to operate at reduced power, even when the final crossed-field amplifier is defective.

204. Antennas

A tremendous amount of knowledge and information has been gained about the design of antennas and radio-wave propagation. Still, many old-time technicians will tell you that when it comes to designing the length of an antenna, the best procedure is to perform all calculations and operationally check the antenna. If it does not work correctly, use a cut-and-try method until it does. Fortunately, enough information has been collected over the last few decades that it is now possible to predict the behavior of antennas. In this lesson, we will review the requirements of radar antennas.

Principles of antenna radiation

Antennas fall into two general classes, omnidirectional and directional. Omnidirectional antennas radiate RF energy in all directions simultaneously. They are seldom used with modern radars, but are commonly used in radio equipment, in IFF (identification friend or foe) equipment, and in countermeasure receivers for the detection of enemy radar signals. Directional antennas radiate RF energy in patterns of lobes or beams that extend outward from the antenna in one direction for a given antenna position. The radiation pattern also contains minor lobes, but these lobes are weak and normally have little effect on the main radiation pattern. The main lobe may vary in angular width—from one or two degrees in some radars to 15 to 20 degrees in other radars. The width depends on the system's purpose and the degree of accuracy required.

Directional antennas have two important characteristics: directivity and power gain. The directivity of an antenna refers to the degree of sharpness of its beam. If the beam is narrow in either the horizontal or vertical plane, the antenna is said to have high directivity in that plane. Conversely, if the beam is broad in either plane, the directivity of the antenna in that plane is low. Thus, if an antenna has a narrow horizontal beam and a wide vertical beam, the horizontal directivity is high and the vertical directivity is low.

When the directivity of an antenna is increased, that is, when the beam is narrowed, less power is required to cover the same range because the power is concentrated. Thus, the other characteristic of an antenna, power gain, is introduced. This characteristic is directly related to directivity.

Power gain of an antenna is the ratio of its radiated power to that of a reference (basic) dipole. Both antennas must have been excited or fed in the same manner and each must have radiated from the same position. A single point of measurement for the power-gain ratio must lie within the radiation field of each antenna. An antenna with high directivity has a high power gain, and vice versa. The power gain of a single dipole with no reflector is unity (1), which is the dielectric constant of free space. An array of several dipoles in the same position as the single dipole and fed from the same line would have a power gain of more than one; the exact figure would depend on the directivity of the array.

The measurement of the azimuth of a target, as detected by the radar, is usually given as an angular position. The angle may be measured either from true north (true azimuth), or with respect to the bow of a ship or nose of an aircraft containing the radar set (relative azimuth). The angle at which the echo signal returns is measured by using the directional characteristics of the radar antenna system. Radar antennas consist of radiating elements, reflectors, and directors to produce a narrow, unidirectional beam of RF energy. A pattern produced in this manner permits the beaming of maximum energy in a desired direction. The transmitting pattern of an antenna system is also its receiving pattern. An antenna can therefore be used to transmit energy, receive energy, or both. The simplest form of antenna for measuring azimuth is a rotating antenna that produces a single-lobe pattern.

The remaining coordinate necessary to locate a target in space may be expressed either as elevation angle or as altitude. If one is known, the other can be calculated from basic trigonometric functions. A

method of determining the angle of elevation or the altitude is shown in figure 1-12. The slant range is obtained from the radar scope as the distance to the target. The angle of elevation is the angle between the axis of the radar beam and the earth's surface. The altitude in feet is equal to the slant range in feet multiplied by the sine of the angle of elevation. For example if the slant range in figure 1-12 is 2,000 feet and the angle of elevation is 45 degrees, the altitude is 1,414.2 feet ($2,000 \times .7071$). In some radar equipment that use antennas that may be moved in elevation, altitude determination is automatically computed.

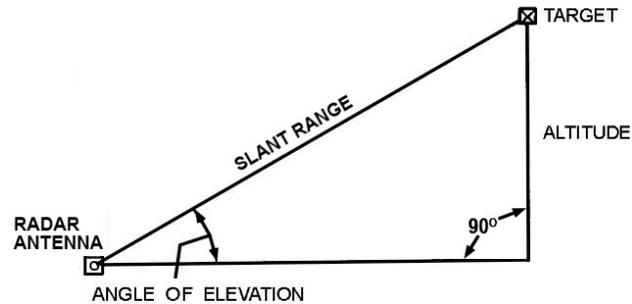


Figure 1-12. Radar determination of altitude.

Parabolic reflectors

A spherical wave front spreads out as it travels and produces a pattern that is neither too sharp nor too directive. On the other hand, a plane wave front does not spread out because all of the wave front moves forward in the same direction. For a sharply defined radar beam, the need exists to change the spherical wave front from the antenna into a plane wave front. A parabolic reflector is one means of accomplishing this.

Radio waves behave similarly to light waves. Microwaves travel in straight lines as do light rays. They may be focused and/or reflected just as light rays can. In figure 1-13, a point-radiation source is placed at the focal point F. The field leaves this antenna with a spherical wave front. As each part of the wave front reaches the reflecting surface, it is shifted 180 degrees in phase and sent outward at angles that cause all parts of the field to travel in parallel paths. Because of the shape of a parabolic surface, all paths from F to the reflector and back to line XY are the same length. Therefore, all parts of the field arrive at line XY the same time after reflection.

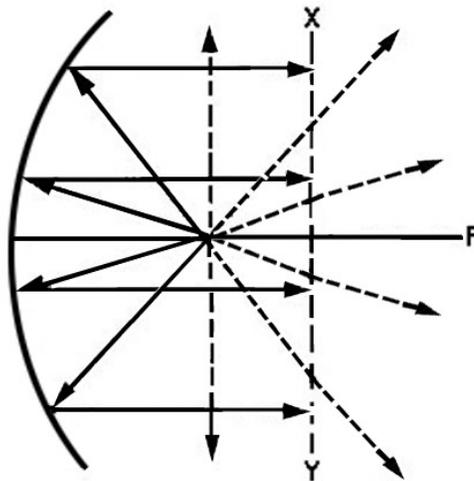


Figure 1-13. Parabolic reflector radiation.

If a dipole is used as the source of radiation, there will be radiation from the antenna into space (dotted lines in figure 1-13) as well as toward the reflector. Energy that is not directed toward the

paraboloid has a wide-beam characteristic that would destroy the narrow pattern from the parabolic reflector. This occurrence is prevented by the use of a hemispherical shield (not shown) that directs most radiation toward the parabolic surface. By this means, direct radiation is eliminated, the beam is made sharper, and power is concentrated in the beam. Without the shield, some of the radiated field would leave the radiator directly. Since it would not be reflected, it would not become a part of the main beam and thus could serve no useful purpose. The same end can be accomplished by using a parasitic array, which directs the radiated field back to the reflector, or by using a feedhorn pointed at the paraboloid.

The radiation pattern of a parabola contains a major lobe, which is directed along the axis of revolution, and several minor lobes, as shown in figure 1-14. Very narrow beams are possible with this type of reflector. View A of figure 1-15 illustrates the parabolic reflector.

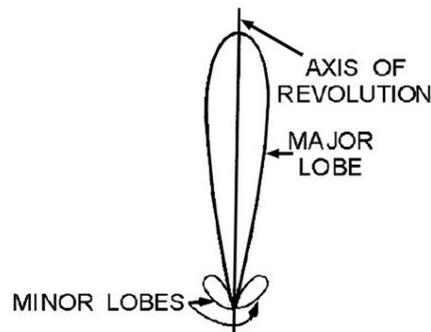


Figure 1-14. Parabolic radiation pattern.

Truncated paraboloid

View B of figure 1-15 shows a horizontally truncated paraboloid. Since the reflector is parabolic in the horizontal plane, the energy is focused into a narrow horizontal beam. With the reflector truncated, or cut, so that it is shortened vertically, the beam spreads out vertically instead of being focused. Since the beam is wide vertically, it will detect aircraft at different altitudes without changing the tilt of the antenna. It also works well for surface search radars to overcome the pitch and roll of the ship.

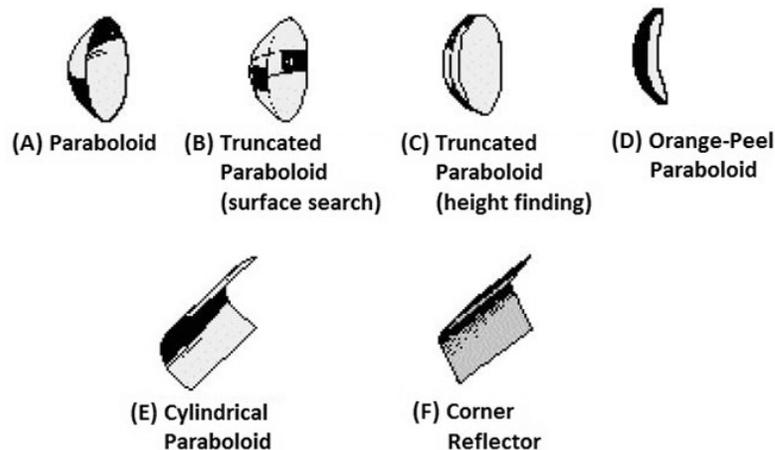


Figure 1-15. Reflector shapes.

The truncated paraboloid reflector may be used in height-finding systems if the reflector is rotated 90 degrees, as shown in view C. Because the reflector is now parabolic in the vertical plane, the energy is focused into a narrow beam vertically. With the reflector truncated, or cut, so that it is shortened

horizontally, the beam spreads out horizontally instead of being focused. Such a fan-shaped beam is used to determine elevation very accurately.

Orange-peel paraboloid

A section of a complete circular paraboloid, often called an orange-peel reflector because of its shape, is shown in view D of figure 1-15. Since the reflector is narrow in the horizontal plane and wide in the vertical, it produces a beam that is wide in the horizontal plane and narrow in the vertical. In shape, the beam resembles a huge beaver tail. This type of antenna system is generally used in height-finding equipment.

Cylindrical paraboloid

When a beam of radiated energy noticeably wider in one cross-sectional dimension than in the other is desired, a cylindrical paraboloidal section approximating a rectangle can be used. View E of figure 1-15 illustrates this antenna. A parabolic cross section is in one dimension only; therefore, the reflector is directive in one plane only. The cylindrical paraboloid reflector is fed either by a linear array of dipoles, a slit in the side of a waveguide, or by a thin waveguide radiator. Rather than a single focal point, this type of reflector has a series of focal points forming a straight line. Placing the radiator, or radiators, along this focal line produces a directed beam of energy. As the width of the parabolic section is changed, different beam shapes are obtained. This type of antenna system is used in search and in ground control approach (GCA) systems.

Corner reflector

A corner reflector consists of two or three electrically conductive surfaces that are mounted crosswise (at an angle of exactly 90 degrees). They are used to generate a particularly strong radar echo from objects that would otherwise have only a very low radar cross section. Corner reflectors are commonly used as a known location to verify radar operation.

Horn radiators

Horn radiators, like parabolic reflectors, may be used to obtain directive radiation at microwave frequencies. Because they do not involve resonant elements, horns have the advantage of being usable over a wide frequency band.

The operation of a horn as an electromagnetic directing device is analogous to that of acoustic horns. However, the throat of an acoustic horn usually has dimensions much smaller than the sound wavelengths for which it is used, while the throat of the electromagnetic horn has dimensions that are comparable to the wavelength being used.

Horn radiators are readily adaptable for use with waveguides because they serve both as an impedance-matching device and as a directional radiator. Horn radiators may be fed by coaxial or other types of lines.

Horns are constructed in a variety of shapes as illustrated in figure 1-16. The shape of the horn, along with the dimensions of the length and mouth, largely determines the field-pattern shape. The ratio of the horn length to mouth opening size determines the beam angle and thus the directivity. In general, the larger the opening of the horn, the more directive is the resulting field pattern.

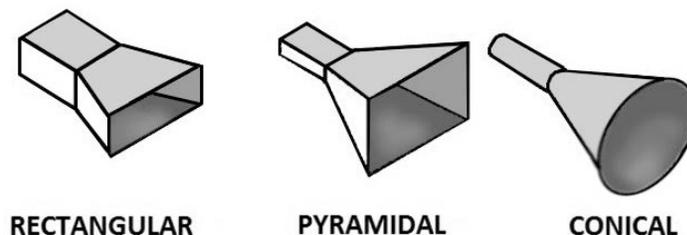


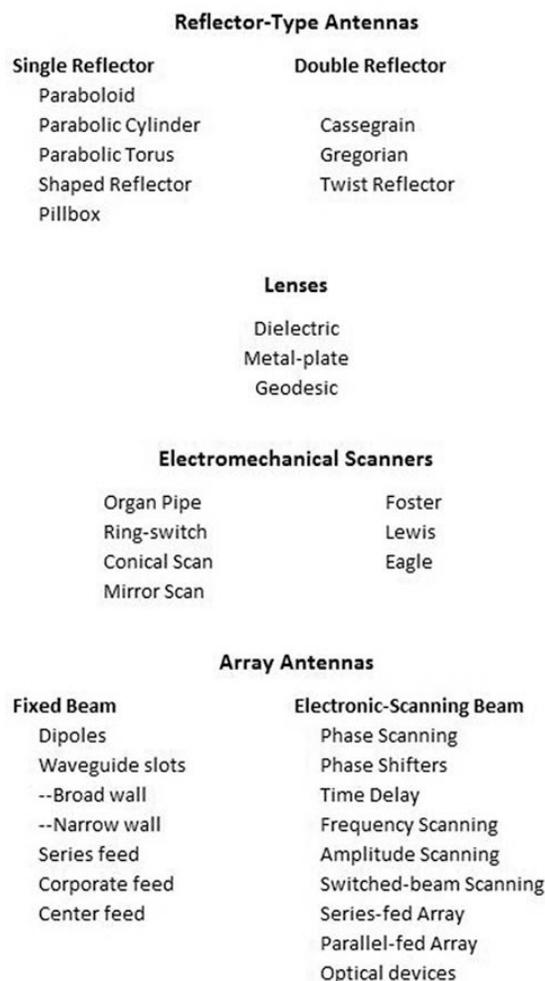
Figure 1-16. Horn radiators.

Antenna types

Radar antennas are a crucial system design assembly, because they are where the radar interacts with the world by sending and receiving RF signals from the atmosphere. Radar antennas typically are required to have narrow beams (at least in one plane) and relatively low side-lobe levels, and are usually scanned by mechanical movement of the entire antenna structure, by an electromechanical or electronic scanning feed mechanism, or by electronically scanning an array of elements. Although, the first radar antennas used fixed arrays of dipole-type elements because of the low frequencies involved, the paraboloidal reflector antenna has been used in some form in the majority of radar applications. The lens antenna has also seen favor in certain instances, and recently great progress has been made in the development of electronic-scanning phased arrays.

The type of antenna selected for a certain application depends not only on the electrical and mechanical requirements dictated by the radar design specifications but also on cost and risk trade-offs. For example, the antenna requirements for tracking radar typically call for a pencil-shaped beam with parallel-polarized and cross-polarized sidelobes commensurate with the clutter and jamming environment. The selection of a paraboloidal reflector antenna versus a scanning phased array, however, depends on cost versus performance and the risk associated with implementing a phased array at the required frequency.

Radar systems can use a wide variety of radar antennas. Figure 1-17 displays a partial list of antennas and figure 1-18 lists some of the parameters for evaluating an antenna's suitability for a particular application.



Transmission lines to the antenna send energy from the radar transmitter. The functions of the antenna on transmit are to concentrate the energy in a predetermined beam shape and to point this beam in a predetermined direction. On receive, the antenna again forms a beam in a particular direction to gather selectively transmitted energy that has been reflected from various targets. Received energy is sent via transmission lines to the receiver. The transmit and receive patterns of the antenna are usually identical; if they are, the antenna is said to be reciprocal. Only one pattern, usually the transmit, is specified and measured for a reciprocal antenna. If the antenna is not reciprocal (e.g., if it contains ferrite devices) or is nonlinear, then the transmit and receive patterns may be different. In this case, both transmit and receive patterns are specified and measured.

Figure 1-17. Antennas.

Electrical	
Frequency (and bandwidth)	Impedance (or VSWR)
Gain (and efficiency)	Power-handling capability
Polarization	Scan sector
Beamwidths (and beam shape)	Scan modes and rates
Sidelobes	Electronic counter-countermeasures (ECCM)

Mechanical	
Size	Operating Conditions
Weight	Temperature
Reliability	Humidity
Maintainability	Wind Loads
Stabilization	Shock loads and vibration
Tolerances	Icing
Manufacturing methods	Dust
	Rain

Figure 1–18. Parameters.

Reflector antennas are extremely important and practical devices for use in radar systems. They offer an economical method of distributing energy over a large aperture area and can produce shaped or pencil beams with high gain. In general, the reflector redirects and reshapes energy from one or more point sources located near the focal point into a desired far-field pattern.

The most common reflector shape is the paraboloid formed by rotating a two-dimensional parabola about its focal axis. This shape is particularly useful, since all rays leaving the focal point and striking the reflector are reflected along a path parallel to the focal axis.

Additionally, the fields transversing all of these reflected ray paths will be in phase over any plane perpendicular to the axis, since these planes are equidistant from the focal point. Consequently, a spherical wave front leaving a primary feedhorn is mapped into a uniform (plane) wave front by a paraboloid. This constant path length feature indicates that the paraboloid is inherently a broadband device. The paraboloid is reciprocal in that it intercepts an electromagnetic plane wave traveling parallel to its axis and redirects it so that all of the energy passes to the focal point, where it may be collected.

Multiple feedhorn systems

The feedhorn is the component that allows RF to transition from the antenna waveguide to free space. Many systems have a single feedhorn that transmits the complete radar signal, but for some applications, multiple feedhorns are required.

Dual feedhorn

Changing the physical shape of the antenna gives you a fixed change to the radiated beam pattern, but does not give us any way to continuously control or vary the beam pattern. One way to provide an amount of control over the received beam pattern is to use two feedhorns: one active (low beam) and one passive (high beam). The active feedhorn is the horn normally used for transmitting and receiving.

In a single-feedhorn system, the active horn would be the single feedhorn. The passive feedhorn is used only for receiving; it is gated to the receiver only when the signal received by that horn is

desired over the signal from the normal horn. Figure 1-19 illustrates the reason for using a two-feedhorn system.

The beam pattern of the normal feedhorn has to go below ground level coverage at maximum range. This causes reflections and a lot of ground clutter up close, especially if there are large blocks of video above the horizon. This also causes screening objects behind mountains or other tall structures. MTI can be used to reduce the clutter, but MTI also reduces system sensitivity, and cannot do anything about low-level moving clutter, such as birds.

By selecting the signal received by the passive horn over high-clutter areas, the elevation beam pattern is raised approximately 3.5 degrees. This significantly reduces the returns from any ground targets below 3.5 degrees, while also enhancing the targets at higher elevation angles. The passive received signal is coupled to the receiver until the clutter areas were passed, and then the normal returns would again be used so we would not lose low-level coverage at long range.

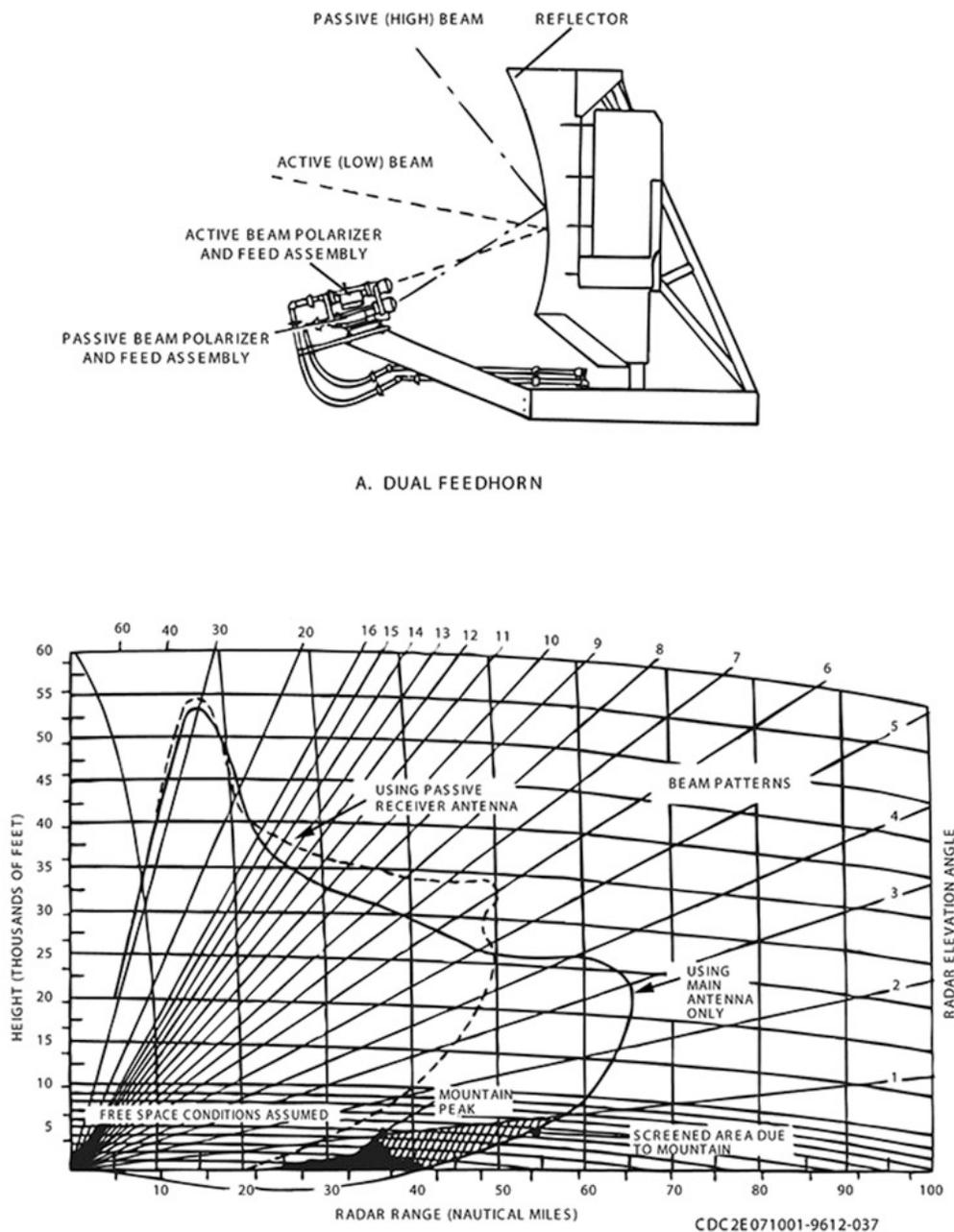
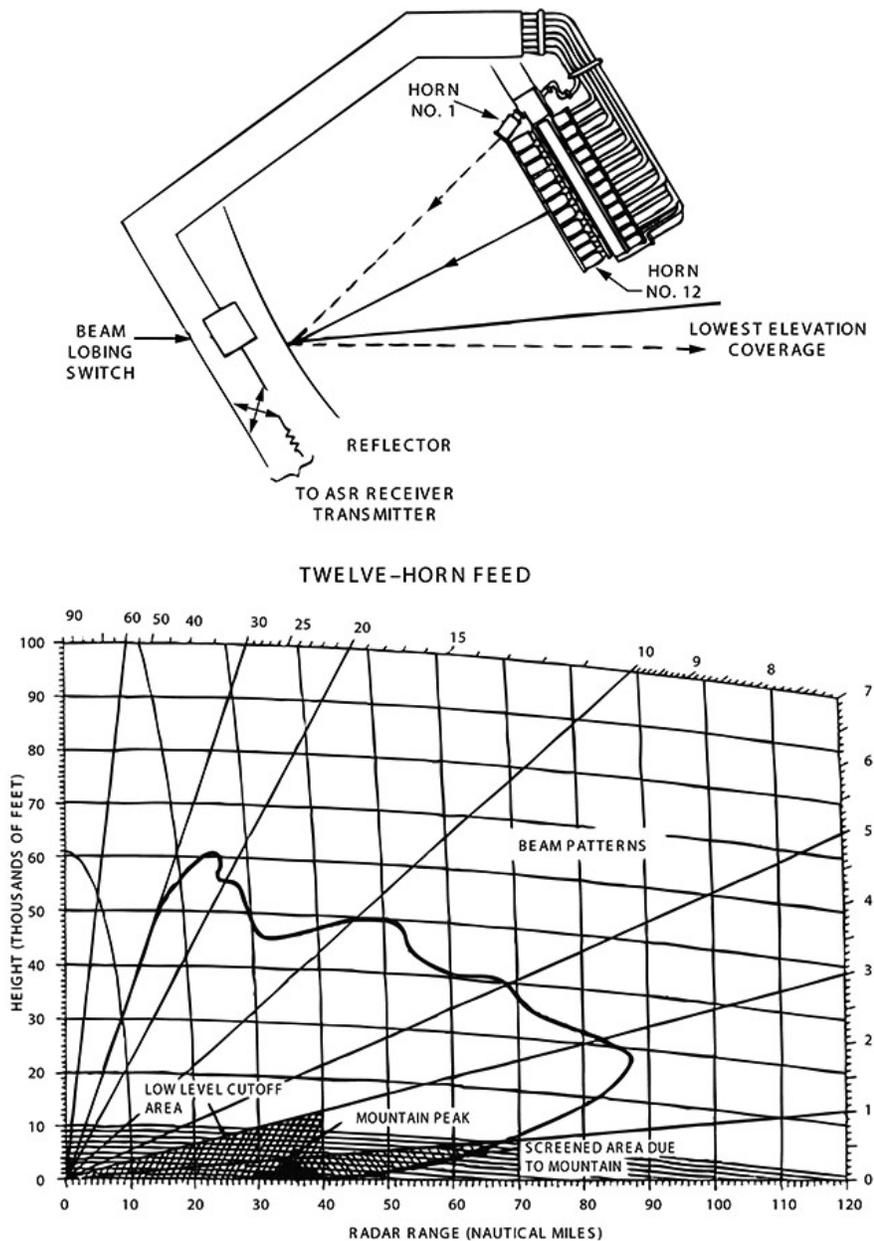


Figure 1-19. Dual feedhorn beam pattern.

Twelve-horn feed

The normal transmitted beam pattern of the single-and-dual feedhorn systems causes a problem of multipath reflections, but a twelve-horn feed system (fig. 1-20) practically eliminates this problem. Multipath reflections refer to secondary reflections from ground targets (a major cause of holes in high-altitude coverage), or forward reflections, causing nulls in coverage along the horizon. The twelve-feedhorn system produces a sharp low-beam cutoff while still providing low-angle coverage at long range. If you compare figures 1-19 and 1-20, beam patterns, you can see that the multi-feedhorn's transmitted pattern has a flatter base and does not need to go below ground level to provide coverage at long range.



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Figure 1-20. Twelve-feedhorn beam pattern.

Although the sharper low-beam cutoff reduces ground returns, there will be clutter from high-ground targets. This can be reduced below 3 degrees elevation by gating off the low-level returns entering feedhorn number one (fig. 1-20, bottom). Unlike the dual-feedhorn system, there is no passive horn

for low-level coverage. The beam-lobing switch can be gated to route the low-level returns from number one feedhorn to the dummy load. Actually, the returns are attenuated and only the residue gets to the dummy load. Ground clutter reduction by means of antenna beam switching during each radar receiving interval is instrumented by providing the operator with controls for accommodating the clutter at the radar site. The controls will permit cutout of the low-angle radar beam from zero to any operator-selected range up to maximum range. This range gating will be individually adjustable in each of four azimuth quadrants, relative to the north reference. The quadrants can be rotated by 45 degrees to further aid in aligning them with the clutter contours of the locale.

Array antennas

The single most noticeable change between older radar systems and the AN/TPS-75 AC&W radar is the antenna. Physically, it is flat (planar) rather than parabolic. Electrically, it uses electronic phasing to develop the desired beam pattern. These two differences, in turn, require many significant changes in the system. For example, the antenna now requires a very refined tilt sensing system to compensate for the increased effects of wind on the large flat surface. Extensive new technology is also required to provide the proper phasing for an antenna beam with minimal sidelobes, which is the primary purpose for the new antenna.

Multiple elevation (stacked) beams

Stacked beam radars, or contiguous beams stacked in elevation, are used for 3D radar (see fig. 1-21). Fundamentally, it is a good technique, because it uses simultaneous pencil-beam radiation patterns from a single aperture to cover the elevation angles of interest. Each beam is considered a separate radar, making the system costly and complex. The transmitter radiates a fan beam from the summation of all overlapping pencil beams to give the desired elevation coverage. To refine the angle measurement, there is a separate receiver for each pencil beam and some means of interpolation is used between the beams. If automatic detection, sidelobe cancellation, or MTI is needed in the radar, they are used separately in each receiving channel, again adding to the radar's cost and complexity. The individual pencil beams offer an advantage in handling rain clutter or chaff, because it limits the volume of space observed. The MTI in the lower beams can be optimized for surface clutter and MTI in the upper beams can be optimized for rain and chaff. The individual pencil beams have a higher gain than a fan-beam antenna. This can provide a larger number of hits at a higher data rate than a 3D radar can with a single scanning beam in elevation.

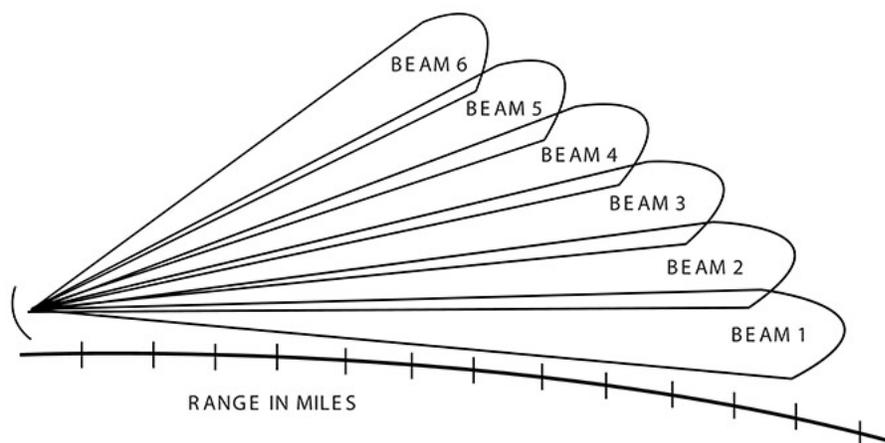


Figure 1-21. Stacked beam.

Phased-array antennas

The phased-array antenna is particularly attractive for radar applications because of its inherent ability to steer a beam without the necessity of moving a large mechanical structure. This ability is an important advantage if the required antenna is large. Other attractive features of the phased-array

antenna include the capability to generate more than one beam with the same array and flexibility in the control of the aperture illumination. On the other hand, phased arrays have been slow to be widely accepted because of their high cost and complexity. The two-dimensional planar array is particularly useful in radar applications. In a rectangular aperture form, it can generate fan beams; in a circular aperture form, it can generate pencil beams. Such an array can also be used to generate multiple beams simultaneously for search and track functions.

Array elements

Almost any type of radiating antenna element can be considered for use in an array antenna, but be aware that a radiating element's properties in an array can differ significantly from its properties in free space. There have been many different kinds of radiators used in phased arrays. The dipole, the open-ended waveguide, and the slotted waveguide probably have been used more than others have. The dipole with its arm bent back (like an arrowhead) has been used for wide-angle coverage in addition to the conventional dipole. For reducing mutual coupling, use the thick dipole. For broad bandwidth (a dipole with a director rod also reduces mutual coupling), crossed dipoles are used for operation with dual orthogonal polarization, and printed-circuit dipoles for simplification of fabrication. In order to confine the main beam radiation to the forward direction, the dipole or its equivalent is always used over a reflecting ground plane.

At higher microwave frequencies, a slot array is generally easier to build than an array of dipoles. The narrow wall is generally preferred (edge slots), although the slots may be in either the broad or the narrow wall of the waveguide. This is so that the waveguides may be stacked close enough to get wide-angle scan without grating lobes. The waveguide slot array antenna is more suited for one-dimensional scanning than scanning in two coordinates. This type of construction is also suitable for mechanically rotating antennas. For forming a beam that is frequency-scanned in elevation, a stack of slotted waveguides is used. The slotted guides, or sticks, form the rows of the antenna. The power coupled out of the guide by the slots is fed in a series fashion, as the field inside the guide changes phase by 180 degrees between elements. In order to output the radiated energy in phase, the phases of every other slot is reversed. This is done in a slotted waveguide by altering the direction of tilts of adjacent elements. In a dipole array, the phase is reversed by reversing every other dipole.

205. Receiver

The energy that a distant object reflects back to the antenna in a radar system is a very small fraction of the original transmitted energy. The echoes return as pulses of RF energy of the same nature as those sent out by the transmitter. However, the power of a return pulse is measured in fractions of microwatts instead of in kilowatts, and the voltage arriving at the antenna is in the range of microvolts instead of kilovolts. The radar receiver collects those pulses and provides a visual display of object information.

Information about the position of the object is present visually when the reception of an echo causes the movement or appearance of a spot of light on a cathode ray tube (CRT). The CRT requires a signal on the order of at least several volts for proper operation and will not respond to the high frequencies within a return pulse. Therefore, a receiver amplifier and detector must be used that are capable of producing a visible indication on the CRT under the following conditions:

1. The input signal to the amplifier is in the form of pulses of extremely high frequency.
2. The amplitude of the pulses is in the microvolt range.
3. The pulses last for only a few μs .

The radar receiver evolved directly from the simple radio receiver. The radar receiver operates on exactly the same principles as the radio receiver. However, the overall requirements and limitations of a radar receiver differ somewhat from those of a radio receiver because of the higher frequencies involved and the greater sensitivity desired.

In studying the radar receiver, we will first examine its overall requirements. Second, we will examine a typical radar receiver that satisfies these requirements. Finally, we will discuss the individual components of the receiver.

Radar receiver requirements

The following characteristics determine the design requirements of an effective radar receiver: noise, gain, tuning, distortion, and blocking. Let's look at each one of them.

Noise

The word noise is a carryover from sound-communications equipment terminology. Noise voltages in sound equipment produce actual noise in the loudspeaker output. In radar, noise voltages result in erratic, random deflection or intensity of the indicator sweep that can mask small return signals.

Noise is the greatest limiting factor in a receiver's detectable range. Were it not for noise, the maximum range at which an object would be detectable by radar could be extended almost infinitely. Objects at great range return exceedingly small echoes. However, without noise, almost any signal could be amplified to a usable level if enough stages were added to the receiver. Because of noise, the signal detection limit or sensitivity level of a receiver is reached when the signal level falls below the noise level to such an extent as to be obscured. A simple increase of amplification is of no help because both signal and noise are amplified at the same rate.

In the radar portion of the RF spectrum, external sources of noise interference are usually negligible; consequently, the sensitivity that can be achieved in a radar receiver is usually determined by the noise produced in the receiver. Not only must noise be kept down, but everything possible must be done to minimize attenuation of the video signal (echo) before it is amplified.

Gain

The gain of a radar receiver must be very high. This is because the strength of the signal at the antenna is at a level of microvolts and the required output to the indicator is several volts. The gain of a radar receiver is roughly in the range of 10^6 to 10^8 . Feedback, or regeneration, is one of the most serious difficulties in the design of an amplifier with such high gain. Special precautions must be taken to avoid feedback. Such precautions include careful shielding, decoupling (isolation) between voltage supplies for the different tubes, and amplification at different frequencies in separate groups of stages.

Tuning

The radar receiver requires a limited tuning range to compensate for transmitter and local oscillator frequency changes because of variations in temperature and loading. Microwave radar receivers usually use automatic AFC for this purpose.

Distortion

If distortion occurs in the receiver, the time interval between the transmitted pulse and the received pulse changes, thereby affecting range accuracy.

Blocking

Blocking refers to a condition of the receiver in which the voltage pulse at the receiver input is too large. As a result, for a short time after the pulse, the receiver is insensitive or blocked to signals below a certain level. This condition results from one or more of the amplifier stages in the receiver being overdriven. After a strong pulse, the receiver may be biased to a point at which it will not amplify small signals. Recovery after blocking may be only a fraction of a μs , or it may take several hundred μs , depending upon the point in the receiver at which blocking occurs. To detect a weak echo immediately following a strong one, the receiver must have a short blocking recovery time. The blocking itself must be minimized as much as possible. If a portion of the transmitted pulse leaks into the receiver input, then the receiver may be blocked and not show small, nearby objects. In most

receivers, blocking is minimized from this cause by a duplexer. The duplexer protects the receiver by isolating it during the transmitted pulse.

Receiver block diagram

The superheterodyne receiver is most commonly used in microwave radar systems. A typical superheterodyne radar receiver is shown in figure 1-22. A receiver of this type meets all the requirements listed above. Signals from the antenna enter the receiver via the duplexer. A low-noise RF amplifier is usually the first stage of modern radar receivers. Some receivers, however, send the antenna signal directly to the mixer, as shown by the dashed path. The low-noise amplifiers used in modern systems are usually solid-state devices, such as tunnel-diode, parametric, or microwave transistor amplifiers.

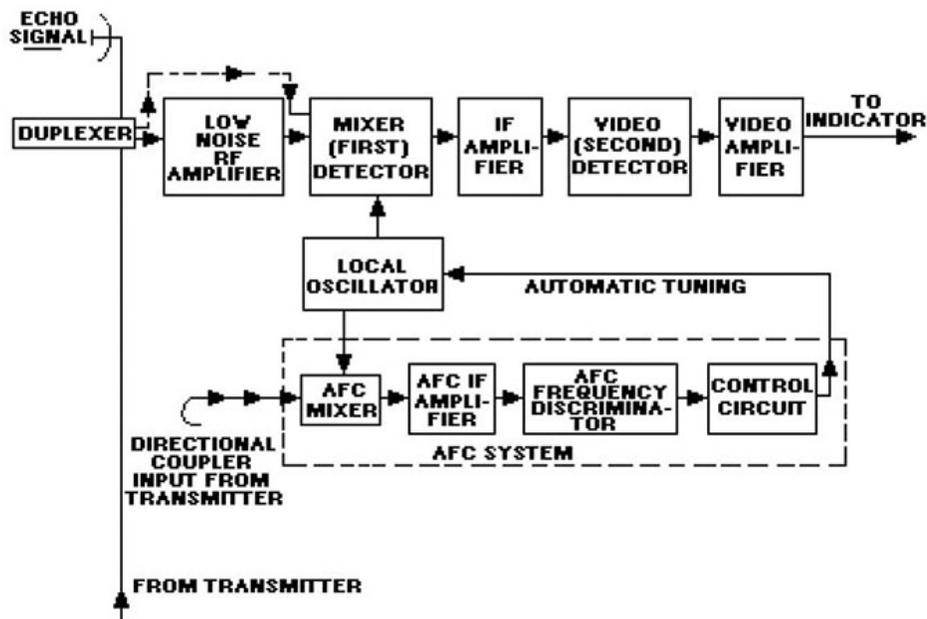


Figure 1-22. Typical superheterodyne radar receiver.

The mixer stage is often called the first detector. The function of this stage is to convert the received RF energy to a lower, IF that is easier to amplify and manipulate electronically. The intermediate frequency is usually 30 or 60 MHz. It is obtained by heterodyning the received signal with a local-oscillator signal in the mixer stage. The mixer stage converts the received signal to the lower IF signal without distorting the data on the received signal.

After conversion to the intermediate frequency, the signal is amplified in several IF amplifier stages. Most of the gain of the receiver is developed in the IF amplifier stages. The overall bandwidth of the receiver is often determined by the bandwidth of the IF stages.

The output of the IF amplifiers is applied to the second detector. It is then rectified and passed through one or more stages of amplification in the video amplifier(s). The output stage of the receiver is normally an emitter follower. The low-impedance output of the emitter follower matches the impedance of the cable. The video pulses are coupled through the cable to the indicator for video display on the CRT.

Controlling the frequency of the local oscillator, as in all superheterodyne receivers, keeps the receiver tuned. Since this tuning is critical, some form of AFC is essential to avoid constant manual tuning. AFC circuits mix an attenuated portion of the transmitted signal with the local oscillator signal to form an IF signal. This signal is applied to a frequency-sensitive discriminator that produces an output voltage proportional in amplitude and polarity to any change in IF frequency. If the IF signal is at the discriminator center frequency, no discriminator output occurs. The center frequency

of the discriminator is essentially a reference frequency for the IF signal. The output of the discriminator provides a control voltage to maintain the local oscillator at the correct frequency.

Different receiving systems may vary in the type of coupling between stages, the type of mixer, the detector, the local oscillator, and the number of stages of amplification at the different frequencies. However, the receiver is always designed to have as little noise as possible. It is also designed to have sufficient gain so that noise, rather than lack of gain, limits the smallest visible signal.

Receiver components

In this area, we will analyze in more detail the operation of the receiver circuits mentioned above. The circuits discussed are usually found, in some form, in all radar superheterodyne receivers.

Low-noise amplifier

Low-noise amplifiers, sometimes called preamps, are found in most modern radar receivers. As previously mentioned, these amplifiers are usually solid-state microwave amplifiers. The most common types are tunnel diode and parametric amplifiers. Some older systems may still use a TWT as a low-noise first stage amplifier. However, the solid-state amplifiers produce lower noise levels and more gain.

Local oscillator

Most radar receivers use a 30 or 60 MHz IF. The IF is produced by mixing a local oscillator signal with the incoming signal in the mixer stage. The local oscillator is, therefore, essential to efficient operation and must be both tunable and very stable. For example, if the local oscillator frequency is 3,000 MHz, a frequency change of 0.1 percent will produce a frequency shift of 3 MHz. This is equal to the bandwidth of most receivers and would greatly decrease receiver gain.

The power output requirement for most local oscillators is small (20 to 50 mW [milliwatts]) because most receivers use crystal mixers that require very little power.

The local oscillator output frequency must be tunable over a range of several MHz in the 4,000- MHz region. The local oscillator must compensate for any changes in the transmitted frequency and maintain a constant 30 or 60 MHz difference between the oscillator and the transmitter frequency. A local oscillator that can be tuned by varying the applied voltage is most desirable.

The reflex klystron is often used as a local oscillator because it meets all the requirements mentioned above. The reflex klystron is a very stable microwave oscillator that can be tuned by changing the repeller voltage.

Most radar systems use an AFC circuit to control the output of the local oscillator. A block diagram of a typical AFC circuit is included in figure 1-22 (typical superheterodyne radar receiver). Note that the AFC circuits form a closed loop. This circuit is, in fact, often called the AFC loop.

A sample of the transmitter energy is fed through the AFC mixer and an IF amplifier to a discriminator. The output of the discriminator is a DC error voltage that indicates the degree of mistuning between the transmitter and the local oscillator. In this particular example, let's assume that the IF is 30 MHz. If the output of the mixer is correct, the discriminator will have no output. If the mixer output is above 30 MHz, the output of the discriminator will be positive DC pulses; if the mixer output is below 30 MHz, the discriminator output will be negative DC pulses. In either case, this output is fed through an amplifier to the control circuit. The control circuit adjusts the operating frequency of the local oscillator so that no mistuning exists and the IF is 30 MHz. In this example, the local oscillator is a reflex klystron and the control circuit provides the repeller plate voltage for the klystron; thus, the klystron directly controls the local oscillator frequency. In this manner, the local oscillator is maintained exactly 30 MHz below the transmitter frequency.

Mixer

Many older radar receivers do not use a low-noise amplifier as the receiver front end; they simply send the echo signal directly to a crystal mixer stage. A crystal is used rather than an electron-tube diode because, at microwave frequencies, the tube would generate excessive noise. Electron tubes are also limited by the effects of transit time at microwave frequencies. The crystal most commonly used is the point-contact crystal diode; however, recent developments in the field of solid-state microwave devices may soon replace the point-contact diode with devices that produce even less noise. The Schottky-Barrier Diode is an example of a relatively recent development that produces less noise than the point-contact crystal.

The simplest type of radar mixer is the single ended or unbalanced crystal mixer, shown in figure 1-23. The mixer illustrated uses a tuned section of coaxial transmission line one-half wavelength long. This section matches the crystal to the signal echo and the local oscillator inputs. Local oscillator injection is accomplished by means of a probe. In the coaxial assembly, the signal is injected by means of a slot. This slot would normally be inserted in the duplexer waveguide assembly and be properly oriented to provide coupling of the returned signal. In this application, the unwanted signals at the output of the mixer (carrier frequency, the local oscillator frequency, and sum of these two signals) are effectively eliminated by a resonant circuit tuned to the intermediate, or difference frequency. One advantage of the unbalanced crystal mixer is its simplicity. It has one major disadvantage; its inability to cancel local oscillator noise. Difficulty in detecting weak signals will exist if noise is allowed to pass through the mixer along with the signal.

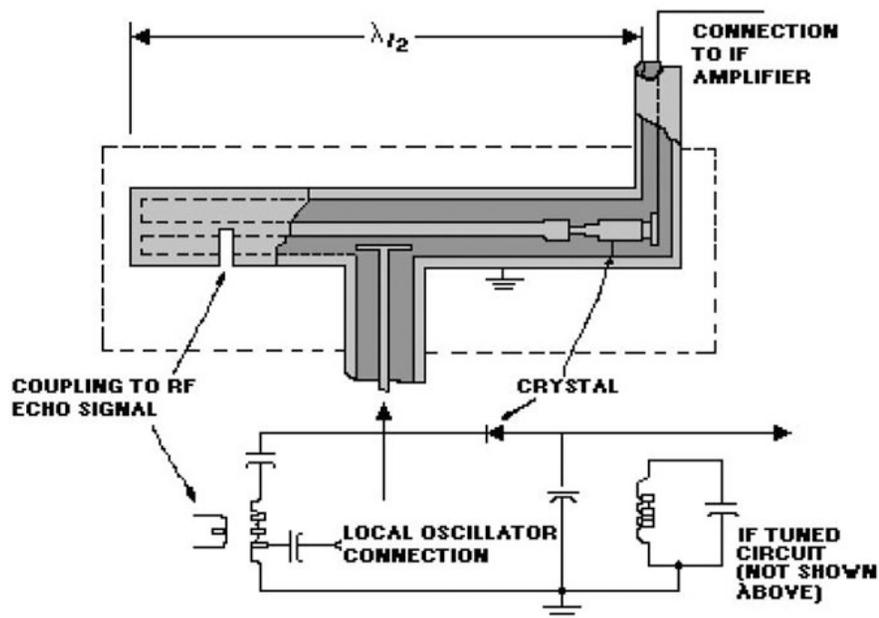


Figure 1-23. Single-ended crystal mixer.

One type of mixer, which cancels local oscillator noise is the balanced, or hybrid, mixer (sometimes called the MAGIC T). Figure 1-24 shows this type of mixer. In hybrid mixers, crystals are inserted directly into the waveguide. The crystals are located one-quarter wavelength from their respective short-circuited waveguide ends (a point of maximum voltage along a tuned line). The crystals are also connected to a balanced transformer, the secondary of which is tuned to the desired IF. The local oscillator signal is introduced into the waveguide local oscillator arm and distributes itself as shown in view A of figure 1-25. Observe that the local oscillator signal is in phase across the crystals. In view B, the echo signal is introduced into the echo signal arm of the waveguide and is out of phase across the crystals. The resulting fields are shown in view C.

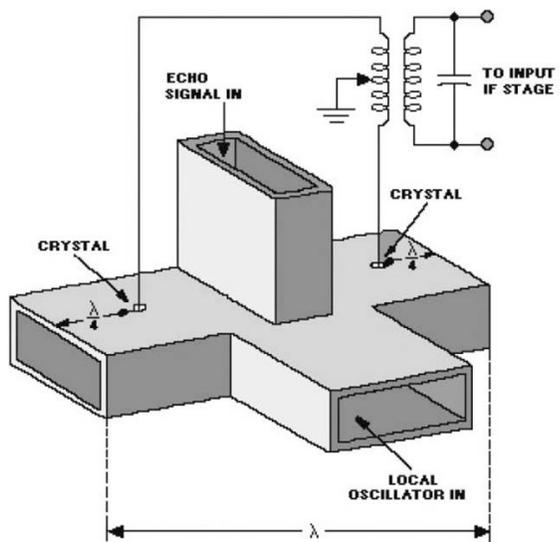
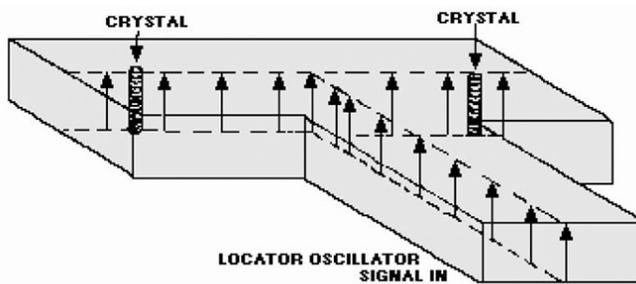
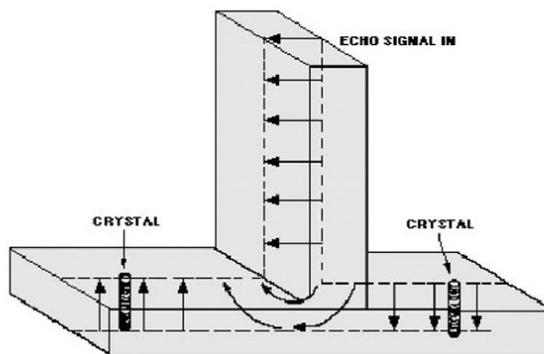


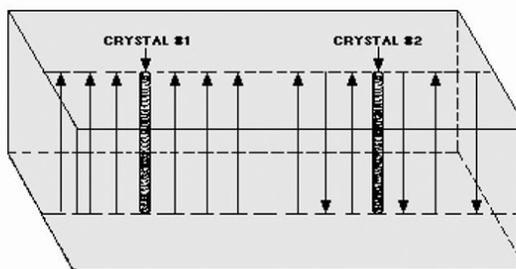
Figure 1-24. Balanced (hybrid) crystal mixer.



(A) Waveguide and local oscillator



(B) Waveguide and echo signal



(C) Waveguide

Figure 1-25. Balanced mixer fields.

A difference in phase exists between echo signals applied across the two crystals. The signal applied to the crystals from the local oscillator is in phase. Therefore, at some point both signals applied to crystal #1 will be in phase, and the signals applied to crystal #2 will be out of phase. This means that an IF signal of one polarity will be produced across crystal #1 and an IF signal of the opposite polarity will be produced across crystal #2. When these two signals are applied to the balanced output transformer (fig. 2-25), they will add. Outputs of the same polarity will cancel across the balanced transformer.

This action eliminates the noise of the local oscillator. Noise components introduced from the local oscillator are in phase across the crystals and are, therefore, cancelled in the balanced transformer. The RF characteristics of the crystals must be nearly equal, or the noise of the local oscillator will not completely cancel. Note that only the noise produced by the local oscillator is canceled. Noise arriving with the echo signal is not affected.

Intermediate frequency amplifier stage

The IF amplifier section of a radar receiver determines the gain, signal-to-noise ratio, and effective bandwidth of the receiver. The typical IF amplifier (commonly called an IF strip) usually contains from three to ten amplifier stages. The IF amplifier has the capability to vary the bandpass and the gain of a receiver. Normally, the bandpass is as narrow as possible without affecting the actual signal energy. When a selection of pulse widths is available, such as short and long pulses, the bandpass must be able to match the bandwidth of the two different signals. Gain must be variable to provide a constant voltage output for input signals of different amplitudes. Figure 2-26 is a block diagram of an IF amplifier that meets these requirements.

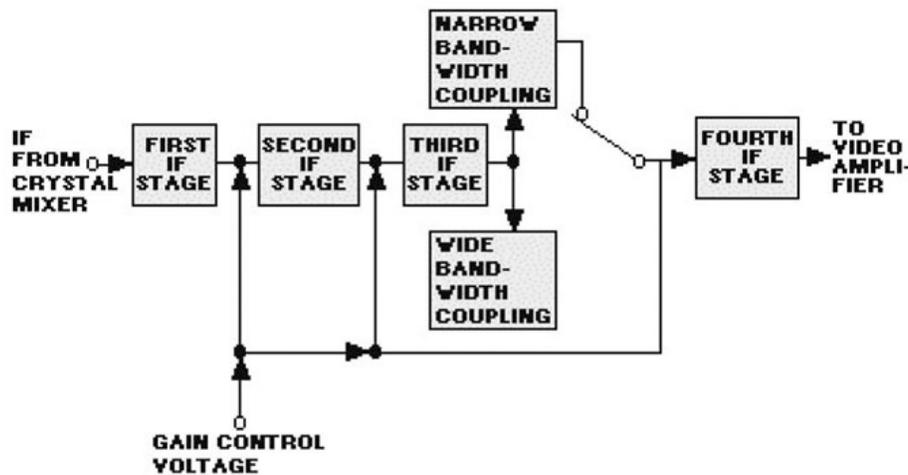


Figure 1-26. IF amplifier block diagram.

The most critical stage of the IF section is the input (first stage). The quality of this stage determines the noise figure of the receiver and the performance of the entire receiving system with respect to detection of small objects at long ranges. Gain and bandwidth are not the only considerations in the design of the first IF stage. A consideration perhaps of more importance is noise generation. Noise generation in this stage must be low. Noise generated in the input IF stage will be amplified by succeeding stages and may exceed the echo signal in strength.

Detectors

The detector in a microwave receiver serves to convert the IF pulses into video pulses. After amplification, these are applied to the indicator. The simplest form of detector, and the one most commonly used in microwave receivers, is the diode detector.

A diode detector circuit is shown in view A of figure 2-27. The secondary of T1 and C1 form a tuned circuit that is resonant at the intermediate frequency. Should an echo pulse of sufficient amplitude be received, the voltage (e_i) developed across the tuned circuit is an IF pulse. Its shape is indicated by the dashed line in view B. Positive excursions of e_i cause no current to flow through the diode. However, negative excursions result in a flow of diode current and a subsequent negative voltage (e_o) to be developed across R1 and C2. Between peak negative voltage excursions of the e_i wave, capacitor C2 discharges through R1. Thus, the e_o waveform is a negative video pulse with sloping edges and superimposed IF ripple, as indicated by the solid line in view B. A negative polarity of the output pulse is ordinarily preferred, but a positive pulse may be obtained by reversing the connections of the diode. In view A, inductance L1, in combination with wiring capacitance and C2, forms a low-pass filter. This filter attenuates the IF components in the e_o waveform but results in a minimum loss of video high-frequency components.

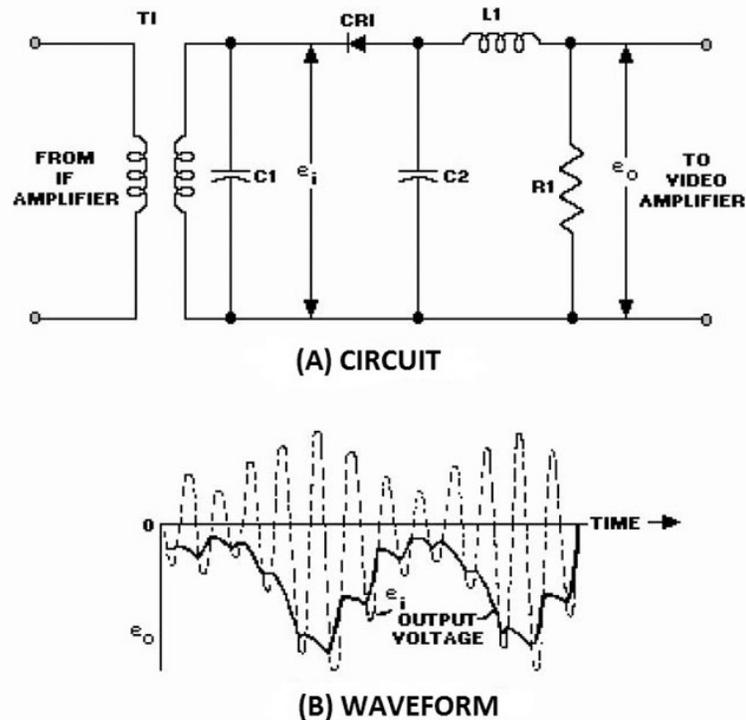


Figure 1-27. Diode detector.

Video amplifiers

The video amplifier receives pulses from the detector and amplifies these pulses for application to the indicating device. A video amplifier is fundamentally an RC coupled amplifier that uses high-gain transistors or pentodes. However, a video amplifier must be capable of a relatively wide frequency response. Stray and interelectrode capacitances reduce the high-frequency response of an amplifier, and the reactance of the coupling capacitor diminishes the low-frequency response. These problems are overcome by the use of frequency compensation networks in the video amplifier.

Receiver special circuits

The performance efficiency of radar receivers is often greatly decreased by interference from one or more of several possible sources. Weather and sea return are the most common of these interference sources, especially for radar systems that operate above 3,000 MHz. Unfavorable weather conditions can completely mask all radar returns and render the system useless. Electromagnetic interference from external sources, such as the deliberate interference by an enemy, called jamming or electronic countermeasures (ECM), can also render a radar system useless. Many special circuits have been

designed to help the radar receiver counteract the effects of external interference. These circuits are called: video enhance features, anti-jamming circuits, or electronic counter-countermeasures (ECCM) circuits. Here we will discuss, in general terms, some of the more common video enhancement features associated with radar receivers.

Automatic gain control

Most radar receivers use some means to control the overall gain. This usually involves the gain of one or more IF amplifier stages. Manual gain control by the operator is the simplest method. Usually, some more complex form of automatic gain control (AGC) or instantaneous automatic gain control (IAGC) is used during normal operation. Gain control is necessary to adjust the receiver sensitivity for the best reception of signals of widely varying amplitudes. AGC and IAGC circuits are designed with, a shut-off feature so that receiver gain may be adjusted manually. In this way, manual gain control can be used to adjust for best reception of a particular signal.

The simplest type of AGC adjusts the IF amplifier bias (and gain) according to the average level of the received signal. AGC is not used as frequently as other types of gain control because of the widely varying amplitudes of radar return signals.

With AGC, gain is controlled by the largest received signals. When several radar signals are being received simultaneously, the weakest signal may be of greatest interest. IAGC is used more frequently because it adjusts receiver gain for each signal.

The IAGC circuit is essentially a wide-band, DC amplifier. It instantaneously controls the gain of the IF amplifier as the radar return signal changes in amplitude. The effect of IAGC is to allow full amplification of weak signals and to decrease the amplification of strong signals. The range of IAGC is limited, however, by the number of IF stages in which gain is controlled. The range of IAGC is limited to approximately 20 decibels (dB) when only one IF stage is controlled. IAGC range can be increased to approximately 40 dB when more than one IF stage is controlled.

Sensitivity time control

In radar receivers, the wide variation in return signal amplitudes make adjustment of the gain difficult. The adjustment of receiver gain for best visibility of nearby target return signals is not the best adjustment for distant target return signals. Circuits used to adjust amplifier gain with time, during a single pulse-repetition period, are called sensitivity time control (STC) circuits.

Sensitivity time-control circuits apply a bias voltage that varies with time to the IF amplifiers to control receiver gain. Figure 1-28 shows a typical STC waveform in relation to the transmitted pulse. When the transmitter fires, the STC circuit decreases the receiver gain to zero to prevent the amplification of any leakage energy from the transmitted pulse. At the end of the transmitted pulse, the STC voltage begins to rise, gradually increasing the receiver gain to maximum. The STC voltage effect on receiver gain is usually limited to approximately 50 miles. This is because close-in targets are most likely to saturate the receiver; beyond 50 miles, STC has no affect and the receiver operates normally.

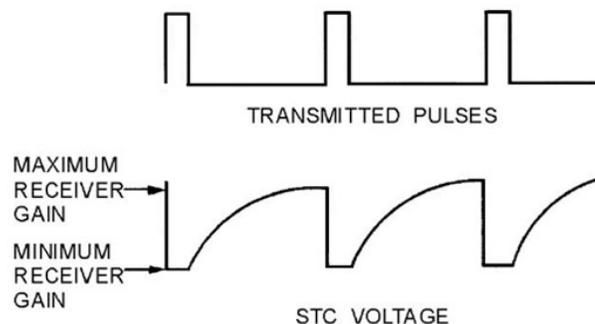


Figure 1-28. STC voltage waveform.

The combination of STC and IAGC circuits results in better overall performance than with either type of gain control alone. STC decreases the amplitude of nearby target return signals, while IAGC decreases the amplitude of larger-than-average return signals. Thus, normal changes of signal amplitudes are adequately compensated for by the combination of IAGC and STC.

Anti-jamming circuits

Among the many circuits used to overcome the effects of jamming, two important ones are gated AGC circuits and fast-time-constant circuits. A gated AGC circuit permits signals that occur only in a very short time interval to develop the AGC. If large-amplitude pulses from a jamming transmitter arrive at the radar receiver at any time other than during the gating period, the AGC does not respond to these jamming pulses.

Without gated AGC, a large jamming signal would cause the automatic gain control to follow the interfering signal. This would decrease the target return signal amplitude to an unusable value. Gated AGC produces an output signal for only short time periods; therefore, the AGC output voltage must be averaged over several cycles to keep the automatic gain control from becoming unstable.

Gated AGC does not respond to signals that arrive at times other than during the time of a target return signal. However, it cannot prevent interference that occurs during the gating period. Neither can gating the AGC prevent the receiver from overloading because of jamming signal amplitudes far in excess of the target return signal. This is because the desired target is gated to set the receiver gain for a signal of that particular amplitude. As an aid in preventing radar receiver circuits from overloading during the reception of jamming signals, fast-time-constant coupling circuits are used. These circuits connect the video detector output to the video amplifier input circuit.

A fast-time-constant (FTC) circuit is a differentiator circuit located at the input of the first video amplifier. When a large block of video is applied to the FTC circuit, only the leading edge will pass. This is because of the short time constant of the differentiator. A small target will produce the same length of signal on the indicator as a large target because only the leading edge is displayed. The FTC circuit has no effect on receiver gain; and, although it does not eliminate jamming signals, FTC greatly reduces the effect of jamming.

Special receivers

The basic receiver of a radar system often does not meet all the requirements of the radar system, nor does it always function very well in unfavorable environments. Several special receivers have been developed to enhance target detection in unfavorable environments or to meet the requirements of special transmission or scanning methods. A radar system with a MTI system or a monopulse scanning system requires a special type of receiver. Other types of special receivers, such as the logarithmic receiver, have been developed to enhance reception during unfavorable conditions. These receivers will be discussed in general terms in this section.

Moving target indicator system

The MTI system effectively cancels clutter (caused by fixed unwanted echoes) and displays only moving target signals. Clutter is the appearance on a radar indicator of confusing, unwanted echoes, which interfere with the clear display of desired echoes. Clutter is the result of echoes from land, water, weather, and so forth. The unwanted echoes can consist of ground clutter (echoes from surrounding landmasses), sea clutter (echoes from the irregular surface of the sea), or echoes from the clouds and rain. The problem is to find the desired echo in the midst of the clutter. To do this, the MTI system must be able to distinguish between fixed and moving targets and then must eliminate only the fixed targets. This is accomplished by phase detection and pulse-to-pulse comparison.

Target echo signals from stationary objects have the same phase relationship from one receiving period to the next. Moving objects produce echo signals that have a different phase relationship from one receiving period to the next. This principle allows the MTI system to discriminate between fixed and moving targets.

Signals received from each transmitted pulse are delayed for a period exactly equal to the pulse-repetition time. The delayed signals are then combined with the signals received from the next transmitted pulse. This is accomplished in such a manner that the amplitudes subtract from each other as shown in figure 1-29, views A and B. Since the fixed targets have approximately the same amplitude on each successive pulse, they will be eliminated. The moving target signals, however, are of different amplitudes on each successive pulse and, therefore, do not cancel. The resulting signal is then amplified and presented on the indicators.

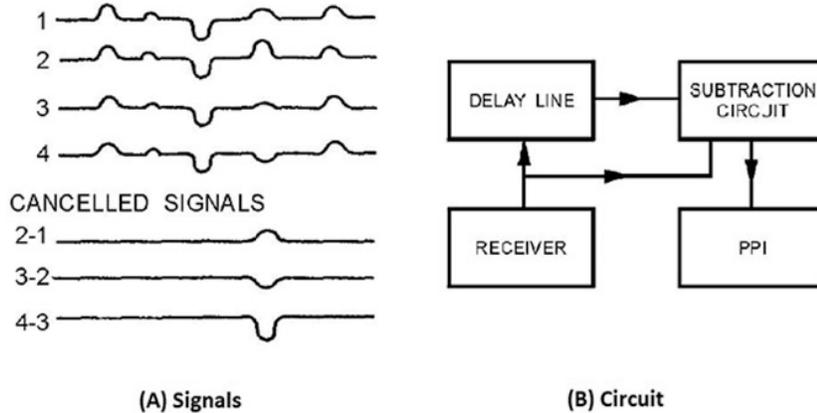


Figure 1-29. Fixed target cancellation.

In figure 1-30, 30 MHz signals from the signal mixer are applied to the 30 MHz amplifier. The signals are then amplified, limited, and fed to the phase detector. Another 30-MHz signal, obtained from the COHO mixer, is applied as a lock pulse to the COHO. The transmitted pulse originates the COHO lock pulse. It is used to synchronize the COHO to a fixed phase relationship with the transmitted frequency at each transmitted pulse. The 30-MHz, CW reference signal output of the COHO is applied, together with the 30-MHz echo signal, to the phase detector.

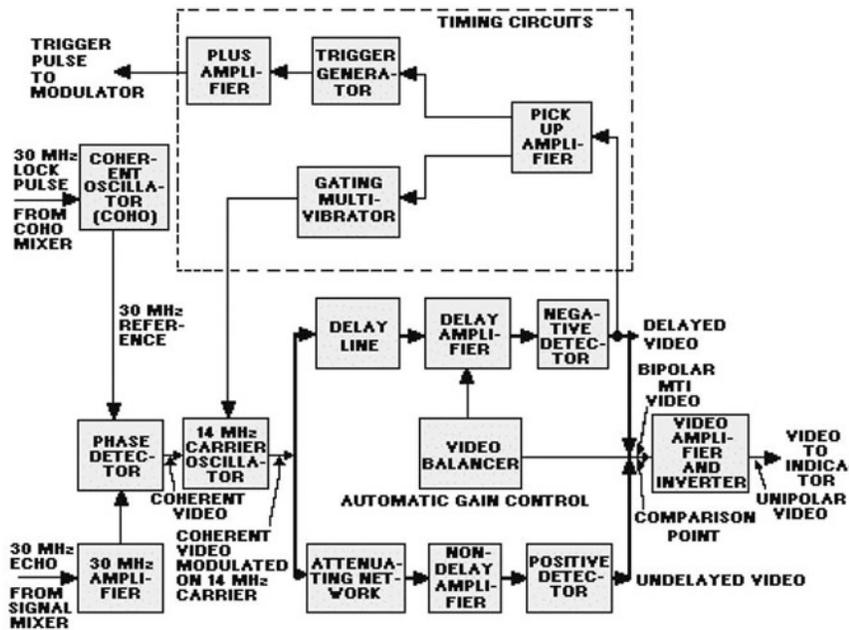


Figure 1-30. MTI block diagram.

The phase detector produces a video signal. The amplitude of the video signal is determined by the phase difference between the COHO reference signal and the IF echo signals. This phase difference is

the same as that between the actual transmitted pulse and its echo. The resultant video signal may be either positive or negative. This video output, called coherent video, is applied to the 14-MHz CW carrier oscillator.

The 14-MHz CW carrier frequency is amplitude modulated by the phase-detected coherent video. The modulated signal is amplified and applied to two channels. One channel delays the 14-MHz signal for a period equal to the time between transmitted pulses. The signal is then amplified and detected. The delay required (the period between transmitted pulses) is obtained by using a mercury delay line or a fused-quartz delay line, which operates ultrasonically at 14 MHz.

The signal to the other channel is amplified and detected with no delay introduced. This channel includes an attenuating network that introduces the same amount of attenuation, as does the delay line in the delayed video channel. The resulting non-delayed video signal is combined in opposite polarity with the delayed signal. The amplitude difference, if any, at the comparison point between the two video signals is amplified; because the signal is bipolar, it is made unipolar. The resultant video signal, which represents only moving targets, is sent to the indicator system for display.

An analysis of the MTI system operation just described, shows that signals from fixed targets produce, in the phase detector, recurring video signals of the same amplitude and polarity. (Fixed targets have an unchanging phase relationship to their respective transmitted pulses). Thus, when one video pulse is combined with the preceding pulse of opposite polarity, the video signals cancel and are not passed on to the indicator system.

Signals from moving targets, however, will have a varying phase relationship with the transmitted pulse. As a result, the signals from successive receiving periods produce signals of different amplitudes in the phase detector. When such signals are combined, the difference in signal amplitude provides a video signal that is sent to the indicator system for display.

The timing circuits, shown in figure 1-30, are used to accurately control the transmitter pulse repetition frequency to ensure that the pulse-repetition time remains constant from pulse to pulse. This is necessary, of course, for the pulses arriving at the comparison point to coincide in time and achieve cancellation of fixed targets.

As shown in figure 1-30, a feedback loop is used from the output of the delay channel, through the pickoff amplifier, to the trigger generator and gating multivibrator circuits. The leading edge of the square wave produced by the detected carrier wave in the delayed video channel is differentiated at the pickoff amplifier. It is used to activate the trigger generator and gating multivibrator. The trigger generator sends an amplified trigger pulse to the modulator, causing the radar set to transmit.

The negative spike from the differentiated square wave also triggers the gating multivibrator. This stage applies a 2,000- μ s negative gate to the 14-MHz oscillator. The oscillator operates for 2,400 μ s and is then cut off. Because the delay line time is 2,500 μ s, the 14-MHz oscillations stop before the initial waves reach the end of the delay line. This wave train, when detected and differentiated, turns the gating multivibrator on, producing another 2,400- μ s wave train. The 100 μ s of the delay line is necessary to ensure that the mechanical waves within the line have time to damp out before the next pulse-repetition time. In this manner, the pulse-repetition time of the radar set is controlled by the delay of the mercury, or quartz delay line. Because this delay line is also common to the video pulses going to the comparison point, the delayed and the undelayed video pulses will arrive at exactly the same time.

Logarithmic receiver

The logarithmic receiver uses a linear logarithmic (LIN-LOG) amplifier, commonly called a LIN-LOG amplifier, instead of a normal IF amplifier. The LIN-LOG amplifier is a non-saturating amplifier that does not ordinarily use any special gain-control circuits. The output voltage of the LIN-LOG amplifier is a linear function of the input voltage for low-amplitude signals. It is a logarithmic function for high-amplitude signals. In other words, the range of linear amplification does not end at a

definite saturation point, as is the case in normal IF amplifiers. The comparison of the response curves for normal IF and LIN-LOG amplifiers is shown in figure 1-31. The curves show that a continued increase in the input to the LIN-LOG amplifier causes a continued increase in the output, but at a reduced rate. Therefore, a large signal does not saturate the LIN-LOG amplifier; rather, it merely reduces the amplification of a simultaneously applied small signal. A small echo signal can often be detected by the LIN-LOG receiver when a normal receiver would be saturated.

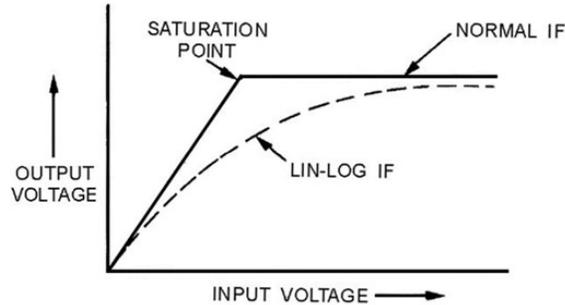


Figure 1-31. LIN-LOG amplifier versus normal IF amplifier.

A typical circuit for obtaining a LIN-LOG response is shown in figure 1-32. If detectors 2 and 3 were not present, the output voltage would be limited by the saturation point of the final IF stage, as it is in a normal IF section. However, when the final stage of the LIN-LOG is saturated, larger signals cause an increase in the output of the next to last stage. This increase is detected by detector 2 and summed with the output of detector 1. This sum produces an increase in the output even though the final stage is saturated. Detector 3 causes the output to continue to increase after the second stage saturates. The overall gain becomes less and less as each stage saturates, but some degree of amplification is still available. The proper choice of IF stage gains and saturation points produces an approximately logarithmic response curve.

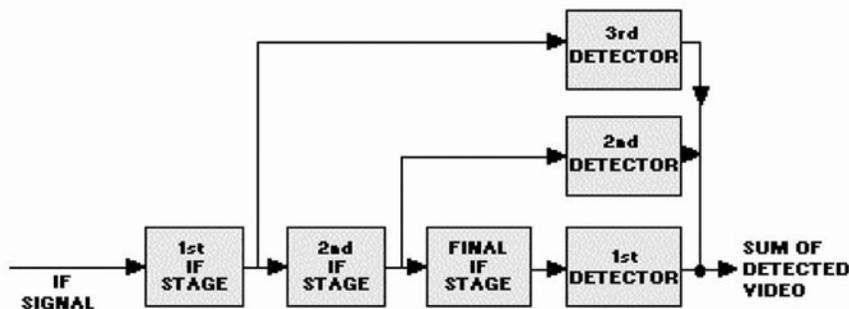


Figure 1-32. LIN-LOG receiver block diagram.

Figure 1-33, shows the response curves of the three IF stages in the LIN-LOG amplifier shown in figure 1-32. The responses of the individual stages produce a segmented overall response curve for the receiver.

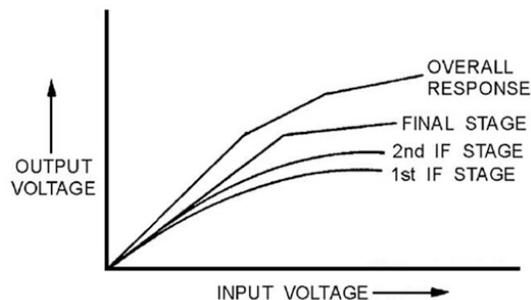


Figure 1-33. LIN-LOG amplifier stage response curves.

Monopulse receiver

The most common of the automatic tracking radars is the monopulse radar. The monopulse radar obtains the three target position coordinates of range, azimuth, and elevation from a single pulse. The receiver for a monopulse radar must have three separate channels to process range, azimuth, and elevation information. The block diagram of a simplified monopulse receiver is shown in figure 1-34.

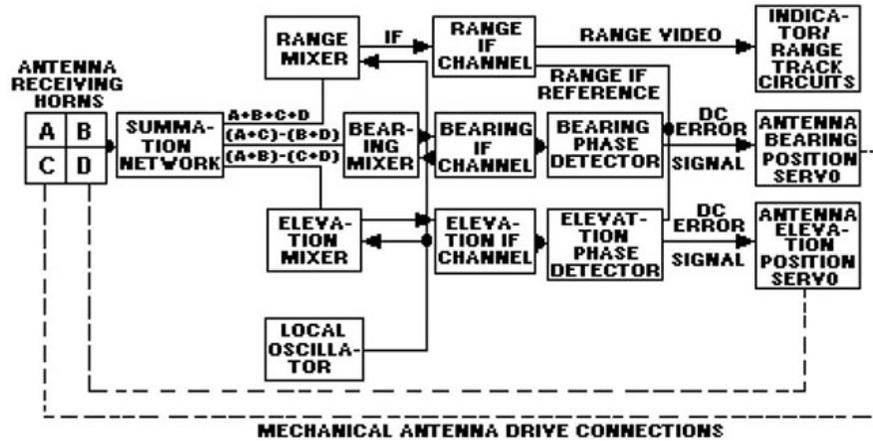


Figure 1-34. Monopulse receiver block diagram.

As in a conventional receiver, each channel of the monopulse receiver converts the return echo to an IF frequency by mixing the returned signal with a common local oscillator signal. The sum of the energy from all four return signals is mixed with the local oscillator signal to produce range IF information. Azimuth information is obtained by subtracting the energy from horns B and D from the energy from horns A and C:

$$(A + C) - (B + D)$$

The difference is then mixed with the local oscillator signal. The result is an azimuth IF signal. Elevation information is obtained in the same way, except the energy from horns C and D is subtracted from the energy from horns A and B:

$$(A + B) - (C + D)$$

If the target is on the elevation and azimuth axis, the summations will both be zero; therefore, neither the azimuth nor the elevation channels will receive an input signal. If either of the azimuth or elevation signals is off the axis, an input to the IF channel is produced. This input is subsequently converted to an IF signal in the appropriate channel.

The major difference between the monopulse receiver and the conventional receiver is the requirement for a DC error voltage output from the azimuth and elevation channels. The range channel of a monopulse receiver is sent to a conventional ranging circuit for presentation on an indicator or for use by a range-tracking circuit. However, since most monopulse radars are automatic tracking radars, the outputs of the azimuth and elevation channels must be converted to DC error signals for use by automatic azimuth and elevation tracking systems. The DC error voltages are applied to the antenna azimuth and elevation positioning servos. These servos reposition the antenna until the errors are nulled.

The phase detectors compare the phase of the azimuth and elevation IF with a reference IF from the range channels. This comparison produces the DC error pulses needed to drive the antenna servos. The signals from both the azimuth and elevation channels are the result of a summation process. They can be either positive (in-phase) or negative (180-degrees out of phase) when compared to the reference IF signal. For example, if the output of horns A and C is smaller than the output of horns B and D, a negative or 180-degree-out-of-phase signal is produced by the azimuth channel $(A + C) - (B + D)$. If output $A + C$ is greater than output $B + D$, a positive or in-phase signal is produced by the

azimuth channel. The phase of the azimuth and elevation output signals determines the direction in which the antenna moves; the magnitude of the signal determines the amount of movement. Since two signals must be present at the phase detector to produce an output, an error signal occurs only when a return echo is not on the antenna beam axis.

This technique produces an error signal when the target moves off the radiated beam axis in either azimuth or elevation. The error signal causes the antenna to move in the proper direction and for the proper duration to cancel the error signal. This method of automatic tracking is commonly used by weapons-control tracking radar systems.

206. Processor

The radar processor comes in many shapes and sizes. For this section we will discuss the advanced signal/data processor (ASDP) in the ASR-11 (fig. 1-35). The ASR-11 or digital air surveillance radar (DASR) is the primary fixed radar system used in aviation today. The DASR uses cutting edge technology that will be around many years and is most likely what you will see in the field.

The ASDP provides synchronization, receiver/exciter (REX) control, digital pulse compression, target processing, and weather processing for the receiver channel in which it resides. Pulse compression is supplied for both the target and weather input signals. Target processing consists of Doppler filtering, constant false alarm rate (CFAR) detection thresholding, sliding dwell binary integration, plot extraction, and scan-to-scan tracking. Weather processing consists of clutter rejection, map generation, and contour thresholding.

Signal processing of the radar returns is carried out in the ASDP software, which is under control of the REX/ASDP control software. The digital signal processor (DSP) uses a combination of several techniques to discriminate between wanted target and unwanted target returns and clutter. The most significant of these techniques are the use of Doppler filters to separate returns by their velocity and an adaptive clutter map to optimize the radar response and minimize false alarms. The weather channel can be configured to provide weather returns, a weather map and multiple weather thresholds.

The signal outputs of the DSP are passed to the plot extraction and track processing in a single board computer (SBC), which calculates the centroids for clusters of detections, establishes track files, and correlates new plots to existing tracks. The dual output of these processors is routed through the Ethernet to a combiner in a workstation, which combines and formats primary and secondary radar plots (or tracks) and transmits the combined data to the Air Traffic Display Site.

Target/weather processor

The target/weather processor executes the following five main functions:

- Pulse compression.
- Weather processing.
- System synchronizing.
- Moving target detection (MTD).
- Interfaces to the REX for receipt of radar data and for beam STC switching control.

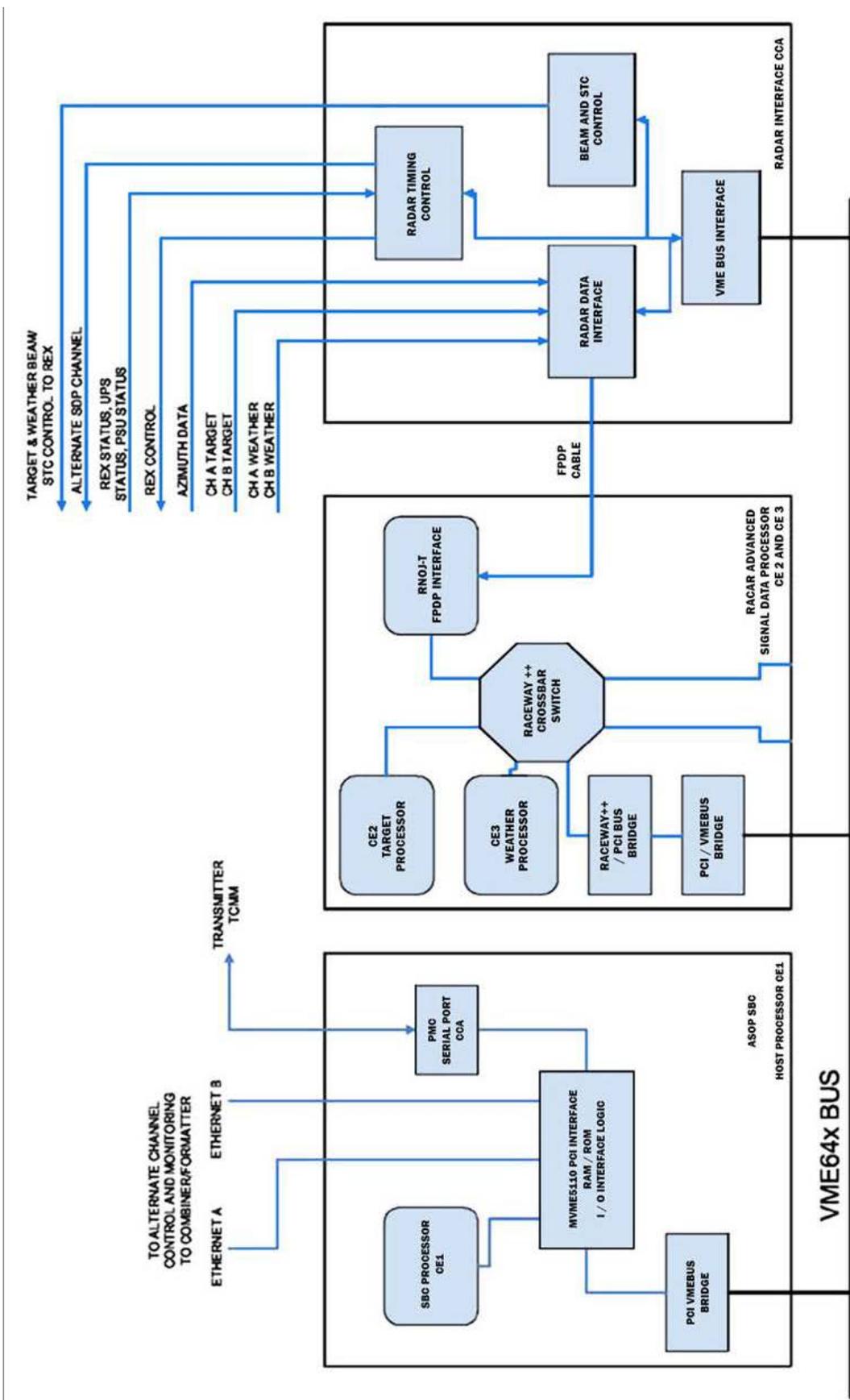


Figure 1-35. ASDP simplified block diagram.

Azimuth beam/sensitivity time control interface

Target and weather channel signals interface to the signal processor through the azimuth beam/sensitivity time control interface. The 16-bit Parallel Receiver data from the REX Downconverters is clocked in at a 2.59 MHz rate using the clock from the Online Local Oscillator. During reception from the short pulse transmission, the parallel input data is routed directly to the input bus to the DSP. During long pulse transmission, the input data is rerouted to the pulse compression function. The radar interface card (RIC) controls routing of the signals.

The Beam/STC function provides the controls for high/low beam switching and STC circuits in the target and weather receivers. These controls resolve the coverage to the full-instrumented range into cells.

Radar interface suppressor

The radar interface suppressor's (RIS) purpose is to suppress large in-band interference returns produced by other radar sources. The RIS processing is performed on DSP processor node CE2 on the DSP circuit card assembly (CCA).

Pulse compression

The pulse compression function is used to recover the radar range resolution when long pulse transmissions are used. The nominal 89:1 pulse compression function is applied to the non-linear frequency modulated (FM) long pulse to compress the pulse length from 89 μ s to 1 μ s. This compression function results in a 19.5 dB signal gain. The compressed returns are routed to the DSP.

Moving target detection

The primary function of the target processor is to accept the output of the REX, and decide, for every range and azimuth cell in the radar coverage area, whether a moving target is present or not. It passes these target detections on to the plot processor. The MTD function is exercised in the DSP.

The MTD uses a combination of several techniques for detecting wanted targets and rejecting unwanted targets and clutter. There are four key components. Doppler filters separate returns according to their radial velocities. CFAR processing develops thresholds to control false alarms from fixed and moving clutter as well as system noise. A Binary Integrator eliminates nonsynchronous interference and random noise. Finally, an Adaptive Clutter Map maintains data on the zero Doppler clutter environments.

Doppler filtering

The Doppler filtering operations are performed by the coherent processing interval (CPI) DSP bank. The input data is directed to the DSP. The DSP receives uncompressed data in the short-pulse receive interval, and compressed data in the long-pulse receive interval.

The five-pulse MTD uses five finite impulse response (FIR) filters operating in parallel to separate moving target returns from stationary clutter. Each filter processes input data on a CPI basis; that is, a batch of all returns from five transmissions. Each filter uses an integrate and dump approach where the output is only valid at the end of a CPI. For example, in a five-pulse MTD, the filter output is not valid until the end of the fifth pulse receive interval.

The Doppler filtering operations are performed using floating-point numbers to maintain the dynamic range of the MTD. See figure 1-36 for the basic five-pulse MTD frequency response curves.

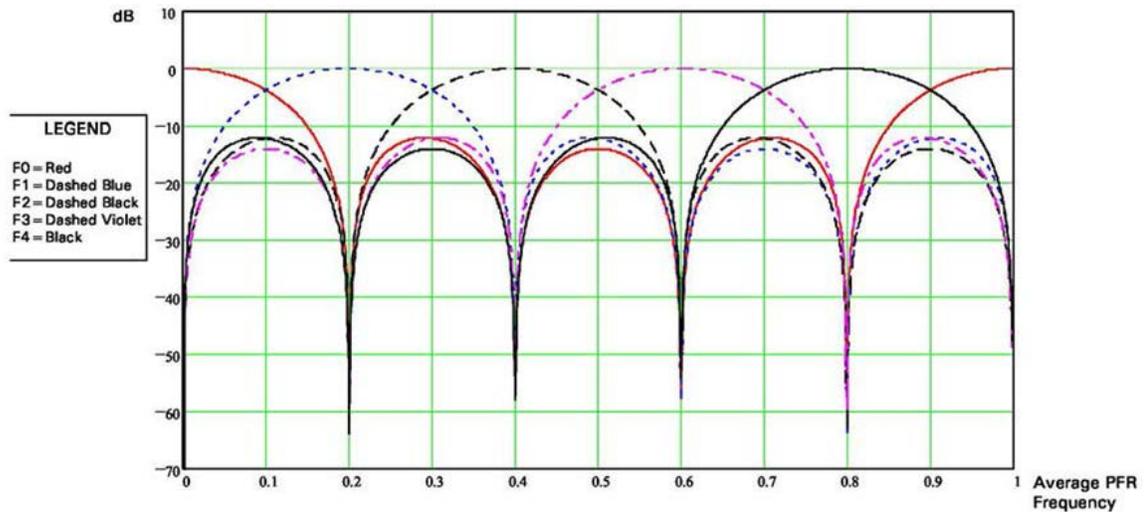


Figure 1-36. Five-pulse MTD frequency response in clear.

Input signals pass through the five filters in parallel, see figure 1-36, Filter 0's response is centered at 0 Doppler; that is, FM/PRF is zero. The F1, F2, F3, and F4 filter responses are centered at 0.2, 0.4, 0.6, and 0.8 of the first blind speed of the filter set for the particular PRF; that is, FM/PRF equals one.

The F0 (red) filter detects fixed clutter with zero Doppler frequency. The response of the other four filters to the fixed clutter returns is down more than 40 dB (see fig. 1-37). Moving targets will be detected based on the response of each filter to the Doppler frequency of the target relative to the response of the filter to the zero Doppler signal from the clutter. If the target signal amplitude is greater than the clutter signal amplitude in the particular filter, target detection may be declared. This signal comparison is one component of the CFAR thresholding, which takes place following the filters.

Some filter responses are adaptive in both range and azimuth. Range adaptation uses two coefficient sets (clear and clutter) for each sector in azimuth, one for short range and another for long range. The transition range is determined by contouring the clutter level in the clutter map. In the region in which the clutter is greatest, the clutter coefficient set is chosen which reduces the effect of zero Doppler data on the filter output. In the region in which the clutter level is low, a clear coefficient set is chosen.

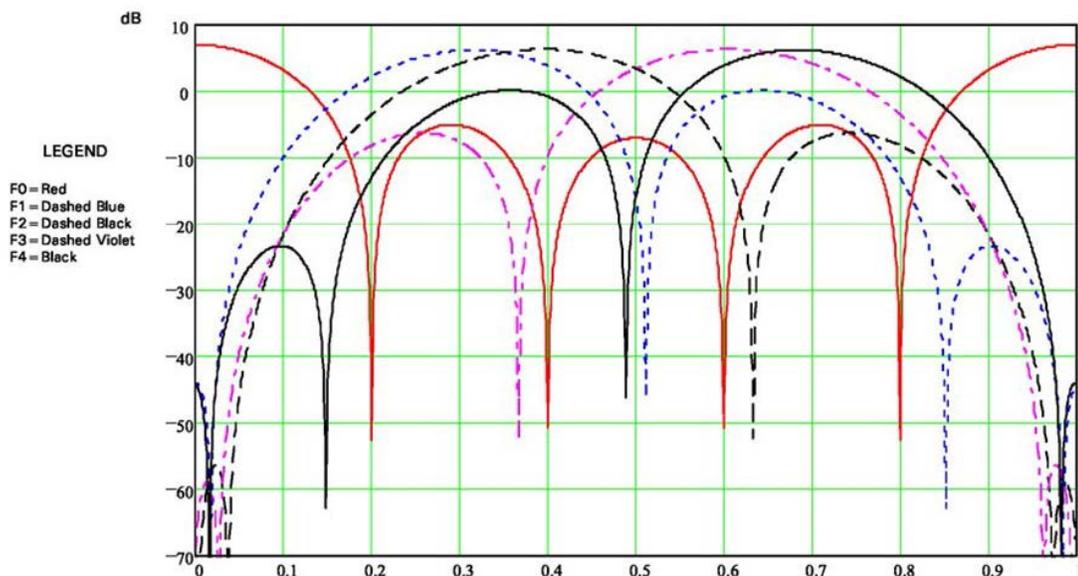


Figure 1-37. Five-pulse MTD frequency response in clutter.

Azimuth adaptation of filters involves selection of different filter coefficients as a function of azimuth. The area of coverage is divided into 256, 1.4-degree azimuth sectors. For each azimuth sector, there are two sets of site-programmable coefficients for range adaptation, or two sets of coefficients which are adaptively calculated to eliminate second, third, and fourth time returns because of anomalous propagation (AP). In this case, the filter coefficient selections are based on the level of clutter at a site-programmable reference point.

The output of each Doppler filter is converted to logarithmic form by taking the logarithm of the magnitude of the complex filter output. The log-magnitude outputs of non-zero filters are then fed into a CFAR process to minimize the number of false alarms. The zero Doppler filter outputs are fed to a clutter map generation process, which generates a range-azimuth map of the clutter.

Constant false alarm rate

The output of each Doppler filter is passed to the CFAR to remove clutter and weather returns correlated in range. The CFAR applies a detection threshold to the output of each filter that adapts to the radar environment in addition to a pre-determined minimum value. The CFAR threshold for each filter is based on three processes (as follows); the composite threshold applied to the filter outputs is the greatest of the three:

1. The CFAR minimum threshold varies as a function of range in the short pulse region. The minimum CFAR threshold map is produced by the second level engineering utility that prepares the STC map used by the ASR-11 primary surveillance radar (PSR).
2. The adaptive clutter map is used as an input to allow the CFAR to adapt to higher levels in areas where clutter is detected. This allows the CFAR to suppress clutter as it breaks through in the Doppler filters. The amount of adaptive contribution from the clutter map is scaled for each individual filter output in proportion to the filter response to near-zero Doppler clutter returns.
3. Each range cell (1/16 nautical miles [nmi]) of data is given an adaptive threshold value. This adaptive threshold is based on the greater of the computed averages of the detection amplitude in each filter for the 16 range cells before and after the current range cell. This process provides additional clutter rejection, and suppresses weather returns and long pulse sidelobes from close in targets and clutter.

The detection amplitudes in each filter are compared against their CFAR thresholds. These are output as detections only, if the amplitudes exceed the threshold by a predetermined visibility factor, which provides the desired probability of detection while minimizing the false alarm rate. Clutter residue is thereby removed from each CFAR output for the corresponding filter, and the filter outputs are merged to provide the highest detection amplitude to the binary integrator.

Binary integrator

The binary integrator outputs a detection when two or more detections at the same range have occurred in four successive CPIs, but rejects returns that are not correlated between CPIs. For example, during second-time-around targets and single pulse interference.

The binary integrator consequently increases the probability of detection while reducing the false alarm rate. The binary integrator output is formatted and fed to the plot processor.

Adaptive clutter map

The output of the zero Doppler filter (F0) is applied to a scan-to-scan adaptive clutter map in the SBC. The clutter map resolves the coverage area into cells (fig. 1-38). Each cell is 1.4 degrees in azimuth and 0.0625 nmi (1/16 of a nautical mile) up to maximum range. Each cell accepts the peak output of the zero Doppler filter within the clutter cell and reaches a moving average using 16 alternate scans over 32 scans. The clutter map is used to remove the stationary clutter and residues from each of the four other filter outputs. It also sets the RF and IF attenuation in the receiver to keep

the clutter signal, in every range/azimuth cell, within the dynamic range of the receiver and the processor.

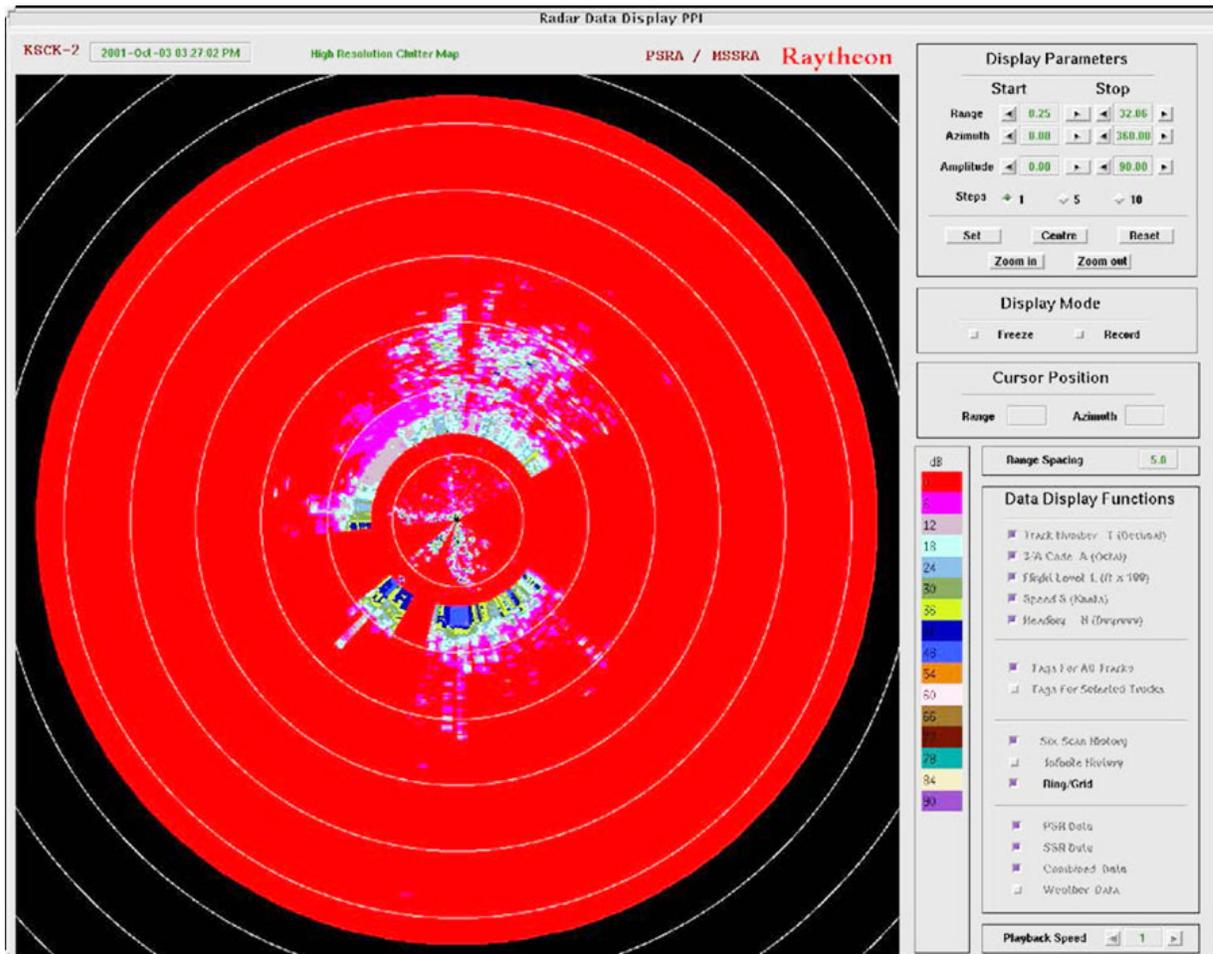


Figure 1-38. Clutter map.

Permanent echoes

The MTD processor detects permanent echoes (isolated, fixed ground clutter returns and/or MTI reflectors) for monitoring PSR performance. Up to 25 permanent echoes are permitted. Range azimuth gating (RAG) windows are adjustable to any point within the PSR instrumented coverage for this purpose. The selected permanent echoes are processed as true targets, but identified individually so downstream processors will not eliminate them. For maintenance, permanent echoes can be inhibited.

Weather processor

The weather processor passes those returns that have the range and Doppler characteristics of weather while attenuating returns from ground clutter, targets, and angels (false targets due to weather anomalies). The I and Q input from the Receiver Weather Channel are processed by the rejection filters. The rejection filters are low Doppler notch filters with different levels of clutter rejection. Rejection filter selection is based upon a preprogrammed filter select derived from the clear day clutter map. In this way, ground clutter returns are removed.

In areas where the filter select indicates there is no clutter, but the adaptive weather clutter map indicates there is; an AP detection algorithm is employed. In these areas, AP is considered to be

present if the output of an average magnitude filter exceeds output of a special AP filter by a predetermined threshold. AP returns are replaced by the weather channel noise floor.

The adaptive weather clutter map is generated, by integrating the output of a low pass filter. A point target, censoring algorithm removes returns not correlated in range such as targets and angels. The remaining returns are averaged over six scans into a set of four weather maps, one for each PRI. The resolution of these PRI diverse weather maps is 1.4 degrees in azimuth by 0.0625 nmi (1/16 of a nautical mile) in range. At the end of six scans, the PRI diverse weather maps are merged into a single weather map. In this way second time around returns are removed. The merged weather map is contoured by comparing it against six National Weather Service (NWS) calibrated level thresholds. The thresholds are based upon weather reflectivity, a beam filling correction, transmit power, receiver gain, receiver STC and the system polarization (circular or linear).

Synchronizer

A programmable synchronizer field programmable gate array (FPGA) on the RIC coordinates the timing events within the ASDP and REX. These include PRF stagger, frequency agility, short and long-pulse triggers, REX switching, zero-range triggers, azimuth data interface, and CPI dead time.

To provide dual channel synchronization, the synchronizer FPGA generates two pairs of RS422 signals to the alternate channel synchronizer FPGA and receives the same two pairs of RS422 signals from the alternate channel Synchronizer FPGA. The first of the two signal pairs is CPI-START, which is a timing strobe generated at the start of each CPI. The second of the two is frame sync, which is a timing strobe, generated at the start of the first CPI of a frame.

When the synchronizer FPGA is generating a system stability test, the CPI start is not generated. The standby channel normally uses the 2.59 MHz timing clock and the in-phase and quadrature (I/Q) data. When the standby channel is performing an internal end-to-end test or stability test, it receives the 2.59 MHz timing clock and I/Q data from the associated REX, and ignores the frame sync and CPI start from the selected channel. The standby channel remains in sync with the selected channel over these CPIs, since the drift between the two local oscillator (LO) clocks is extremely low because of the accuracy of the LO crystals.

Plot processor

The plot processor function, which includes plot extraction and track processing, receives target and weather data from the MTD and outputs target and weather data to the plot and track combiner. The plot processor uses the SBC for plot extraction and track processing.

Plot extraction

From the MTD, the Plot Processor function obtains target detections, which have been filtered to remove returns from stationary targets. In addition, the MTD removes any single detection targets and identifies the first and last detections in a target cluster.

The plot processor allows rejection of clusters by size at various ranges for different reasons, and then calculates the cluster center. If the cluster is an overlap of two or more targets, further processing resolves the cluster into individual targets. (This feature can be inhibited by command from the operator).

Plots are also filtered by a RAG map, which allows for editing of plots that fall in site-programmable range azimuth cells. This feature will normally be used to eliminate false reports from unwanted non-zero velocity targets (i.e., vehicular traffic).

Target information is output by the plot processor as a plot. The plot consists of the range and azimuth of the target as estimated by the plot processor, and a measure of the quality of the plot (the scaled sum of the echo amplitudes of all the detections in the cluster).

Track processing

The plots generated have been validated to represent aircraft targets. The track processor function attempts to correlate plots to existing tracks. An existing track is a record of successful associations of plots over a number of scans (antenna rotations). This plot data is smoothed and used to predict the flight path for the correlation and association of plots on succeeding scans and provides target speed and target heading. Tracks are assigned unique numbers (track file number). If the “slow target filter” is enabled, a target is not reported, if its track fails to meet site-programmable speed criteria. This feature is used to filter out slow-moving vehicular targets.

Plots, which remain after this association attempt, are candidates to start new tracks and are assigned new track file numbers. These new candidate tracks are dropped, if the plots fail to be associated with the next two scans. Candidate plots are reported as primitive targets if the plots fall within site-programmable unconfirmed target zones. Tracks which exist and do not receive new updates (no plots which are associated on the current scan) are ‘coasted’ by using the target calculated speed and direction. The coasted target reports continue for a number of scans (site programmable) until failing a successful plot association with the track, and then the track is dropped.

The track processor function outputs target reports to the track combiner function. Each report consists of the track number, target speed and heading, actual reported target position (range and azimuth of the plot), or, failing receipt of a plot from the plot processor, the forecast position and information on the type of track. Examples include tracked target, test target, coast, cone of silence track, or drop track.

Unconfirmed target reports are also sent as separate reports to the track combiner, if a track has not yet been established. These reports carry similar information to the track update report. The track processor can be adapted to the site environment by adjusting tracking parameters. Examples include initial quality, the correlation count for initiation, the smoothing coefficients, and the maneuver detection criteria.

Plot process weather processing

The plot processor from the MTD weather processor receives weather information. The information received in each of 256 radials (one every 1.4 degree of azimuth) consists of the end range and range extent for each level of weather. The plot processor collects the weather data for all 256 radials and assembles a weather map. Every six scans (or multiple of six scans and up to 90 scans, if selected by the operator), the plot processor transmits the map in a continuous message.

The start of the message contains map serial number, incremented by one every six scans, and then lists (for each radial) the start and end ranges of all-weather levels and ends with the map serial number again. Median Spatial Filtering is applied to smooth the weather contours and reduce the number of data messages.

If the weather map contains more than 2,000 data messages, compaction is performed. The data is discarded and a new map is built on the next scan, omitting lowest-level reports with a range extent that is less than a predetermined threshold. If the map still exceeds 2,000 messages, the threshold is raised. If only the highest level of weather exists and the map still exceeds 2,000 messages, the short high-level reports are also dropped. The requirement is guaranteed to be met within six scans and a map transmitted. The map start message indicates whether compaction has occurred. Once the map is output, the plot processor discards weather data until it is time to build up a new map.

Target processing

The primary radar is able to detect and process at least 700 aircraft targets per a single 360-degree scan. The plot processor processes target information so that, under unusual conditions, the maximum number of tracks the Plot Processor can handle is not exceeded. This is done by deleting tracks at the longer ranges, when the maximum track count has been exceeded. When the number of tracks drops

down, there is a reduction in data and consequently the range is slowly extended until the maximum track count is reached or the maximum range is reached.

The plot processor adaptively thresholds the targets and alarms by amplitude in each 11.25-degree azimuth sector to a maximum of 18 dB above the nominal detection threshold, until the overload is brought under control.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

201. Roles in operational theater

1. What is the purpose of AC&W radar?
2. What is the purpose of the PAR?
3. What does the “T” in TPN-19 designate?

202. Principles and frequency characteristics

1. What is used with proper receiving equipment to detect the presence of a distant object?
2. At what speed do radio waves travel?
3. How long does it take a radar pulse to travel one radar mile?
4. What radar assembly supplies timing signals to coordinate the operation of the complete system?
5. When a transmitter uses a high-power oscillator to produce the output pulse, what switches the oscillator on and off?
6. What radar component permits the use of a single antenna for both transmitting and receiving?

203. Transmitter

1. What are the two basic types of transmitters?
2. In addition to a flat top, what characteristics must a modulator pulse have?
3. What is the frequency range of magnetron oscillators?
4. What three types of storage elements are most often used in modulators?
5. What type of tube best meets the requirements of a modulator switching element?
6. What modulator element controls the rate at which the storage element charges?
7. What two forms of instability are common in magnetrons?
8. What is the typical frequency range about the center frequency of a tunable magnetron?
9. In the power amplifier (shown in figure 1-10), what two signals are mixed to produce the output?
10. What type of klystron is used as the final stage of a power amplifier transmitter?
11. What is the result of pulsing a pulsed RF amplifier when no RF is present?

204. Antennas

1. What are the two general classes of antennas?
2. What determines the width of the antennas main lobe?

3. What is the directivity of a directional antenna?
4. What are the two functions of a horn radiator?
5. What are the functions of the antenna on transmit?
6. What does it mean if an antenna is reciprocal?
7. Why are reflector antennas extremely important and practical devices for use in radar systems?
8. Why is the paraboloid shape useful?
9. What happens when you change the physical shape of the antenna?
10. How can you provide an amount of control over the received beam pattern?
11. What is the purpose of the passive feedhorn?
12. What is an advantage of using MTI?
13. How is range gating adjusted in the 12-feedhorn system?
14. Why is stacked-beam a good technique?
15. How many receivers are used for the pencil beam?
16. How does the gain of the individual pencil beams compare to the fan-beam antenna?

17. What phase-array ability is an important advantage if the required antenna is large?
18. How does the two-dimensional planer array work in rectangular form; in circular aperture form?

205. Receiver

1. What is the greatest limiting factor in a receiver's detectable range?
2. What type of receiver is "almost, always" in radar systems?
3. Which component of the receiver produces the signal that is mixed with the received signal to produce the IF signal?
4. What is the one major disadvantage of the unbalanced crystal mixer?
5. Which receiver component converts the IF pulses to video pulses?
6. Why is AGC not used as frequently as other types of gain control?
7. How does FTC affect receiver gain, if at all?
8. What type of target has a fixed phase relationship from one receiving period to the next?
9. What signal is used to synchronize the coherent oscillator to a fixed phase relationship with the transmitted pulse?
10. What is the phase relationship between the delayed and undelayed video?
11. When a large signal and a small signal are applied to a LIN-LOG amplifier at the same time, what is the effect on the small signal?

12. What happens to the overall gain of a LIN-LOG amplifier as each stage saturates?
13. If a target is on the azimuth axis of the radiated beam, what is the input to the azimuth IF channel?

206. Processor

1. What functions does the ASDP provide for the radar?
2. What does target processing in the ASDP consist of?
3. What is used to suppress large in-band interference returns produced by other radar sources?
4. What is the purpose of pulse compression in the ASDP?
5. What is the purpose of the CFAR function?
6. When does the binary integrator output a detection?
7. What are permanent echoes used for?
8. How does the weather processor remove second time around returns?
9. What is used to coordinate timing events within the ASDP and REX?
10. What information does a plot consist of?

11. What processor function collects the weather data for all 256 radials and assembles a weather map?
12. How many aircraft can the primary radar detect and process in a single 360° scan?

1-2. Radio Frequency Signal Propagation

We have reviewed basic radar system principles and subsystems, but that is not all you must know to understand how radars work. In this section, we will cover radar signal propagation, or how RF travels through the atmosphere. In the previous lessons, we looked at antennas, which send the RF into the atmosphere. Now we will finish the unit with radiation patterns, propagation properties, and anomalies.

207. Radiation patterns

It is important that minor lobes of radar antennas are small compared to the main lobe in order to have an antenna with high directivity, reduce the susceptibility of the antenna to interfering signals, reduce the possibility of detecting a target in a minor lobe, and reduce the probability of interference with other nearby systems.

Therefore, the designers of radar systems should be concerned with the minor lobe structure of antennas in addition to the other requirements, such as main lobe gain and beamwidths. Figure 1-39 shows a main lobe and minor lobes as seen on a spectrum analyzer.

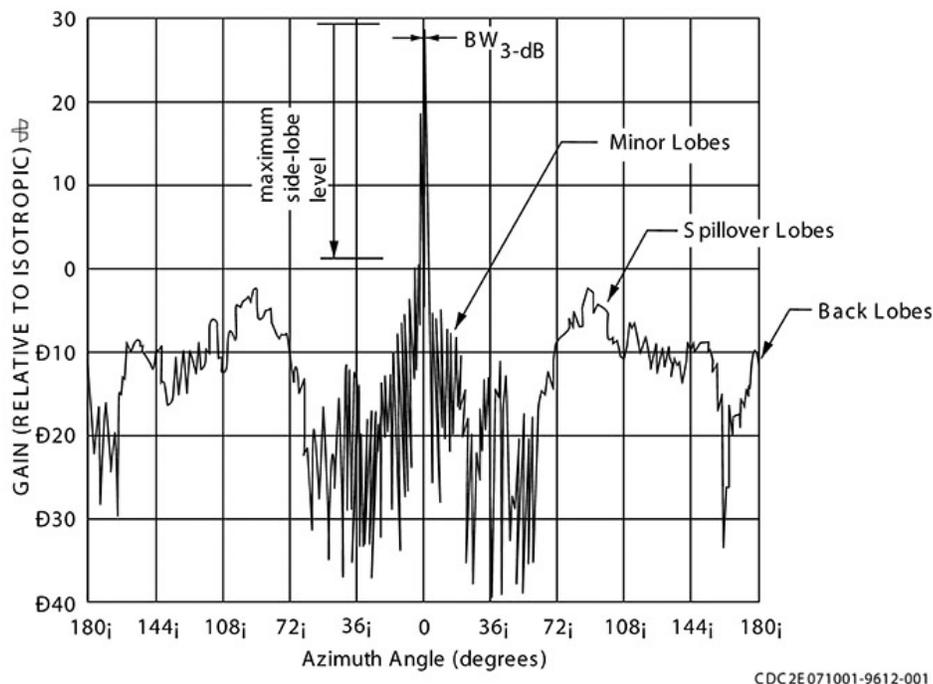


Figure 1-39. Typical antenna pattern on a spectrum analyzer for a search radar.

A fictitious surface called the antenna aperture, located on or near an antenna, is often useful in computing the antenna's performance. Usually the aperture is that part of a plane surface immediately in front of the antenna through which the major part of the radiation passes. The distribution of electromagnetic energy from the antenna over the aperture determines the pattern of the antenna. The

antenna designer can modify the shape of the pattern by altering the distribution of energy over the aperture.

The three primary performance parameters for an antenna are gain, beamwidth, and side-lobe level. This section presents data on these three parameters for both line source and circular symmetry distributions. The line source is used to represent one plane of a rectangular aperture that has a separable aperture distribution.

Antenna reflectors

The radar antenna has two basic functions: to launch and receive electromagnetic energy into the atmosphere or space efficiently, and to direct the energy into an appropriately shaped beam. The shape of the beam of radar energy, its antenna pattern, depends upon the purpose of the radar. Figure 1-40 shows various types of antenna propagation patterns. For search radar we need to measure range and azimuth, but not height. Therefore, we would like the horizontal beam to be as narrow as possible to give good azimuth resolution. A practical beamwidth is 1 to 2 degrees, and the average vertical beam height is about 30 to 35 degrees. By following the optical laws that apply to search lights, we shape this beam using a parabolic reflector. Antennas for the lower frequency radars become huge affairs because the width of the beam must be narrow and the width of the reflector must be several wavelengths wide.

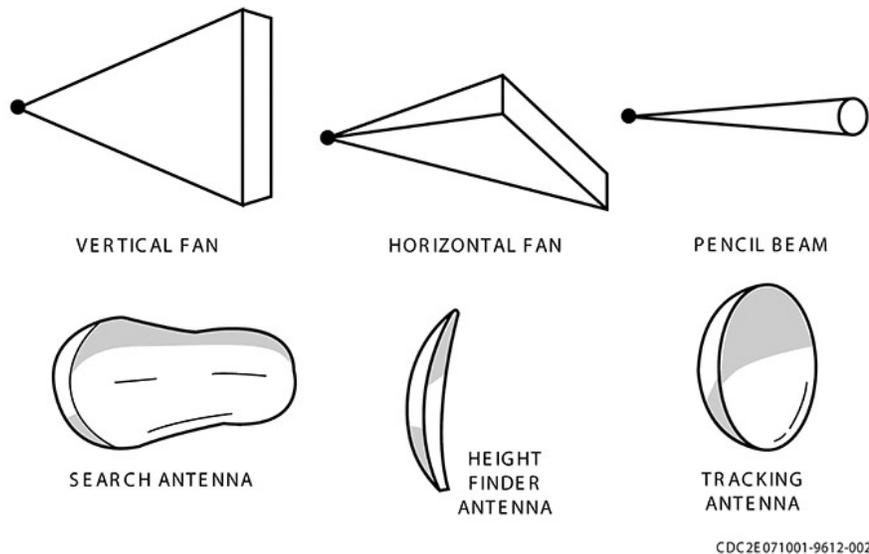


Figure 1-40. Antenna patterns.

There are two other parameters of a radar antenna that are of interest to us—polarization and scan mode. Polarization refers to the orientation of the electromagnetic wave as it travels through space. Every electromagnetic wave consists of electric and magnetic fields that are mutually perpendicular and, by convention; polarization is the direction of the electric field (fig. 1-41). The receiving antenna must have an orientation to match the polarization of the incoming signal. In theory, if the incoming wave has perfect vertical polarization and the receiving antenna has horizontal polarization, no signal will be received. In practice, such perfect isolation is never achieved, but the fact remains that a vertically polarized antenna shows a great propensity for vertically polarized signals and equal disregard for much of the horizontally polarized signals.

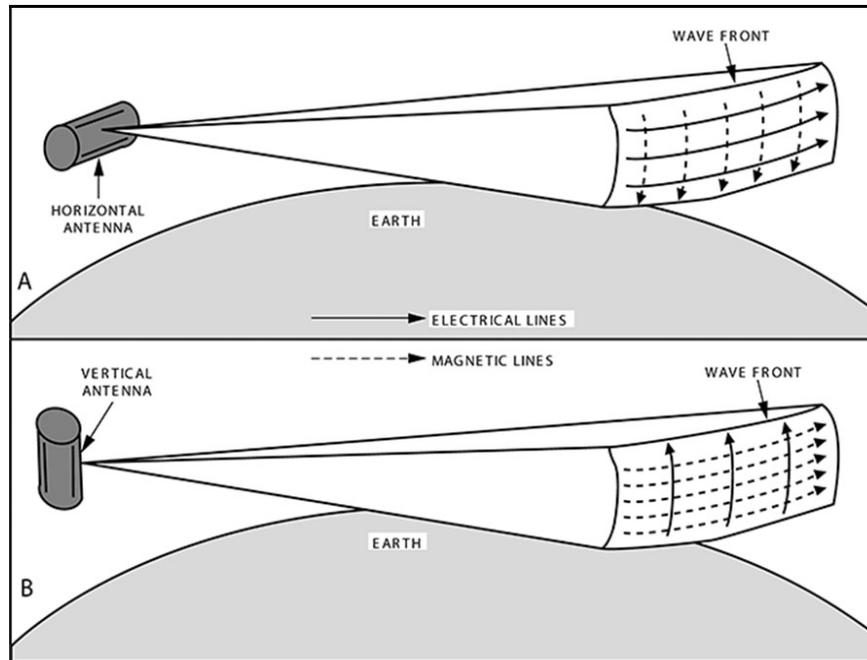


Figure 1-41. Antenna polarization.

Radar antenna scans

The method with which the antenna samples the environment is its scan. The scan type is chosen to enhance the reception of the required data. The scanning method used by the system refers to the motion of the antenna axis (of the beam) as the radar looks for an aircraft.

Conical scan

A conical-scanning radar is a precision tracking radar system that uses continuous rotation of a radar beam that is very thin in azimuth and elevation, called a pencil beam, around the aircraft (fig. 1-42). The radar system then uses the phase of the return signal modulation to maintain track in both azimuth and elevation. For example, if the target is to the left of the scan axis, as shown in figure 1-43, the reflected signals will be of maximum strength as the lobe sweeps through the left part of its cone; the signals will quickly decrease to a minimum as the lobe sweeps through the right part.

Information on the instantaneous position of the beam, relative to the scan axis, and on the strength of the reflected signals is fed to a computer. Such a computer in the radar system is referred to as the angle tracking or angle-servo circuit (also angle-error detector). If the target moves off the scan axis, the computer instantly determines the direction and amount of antenna movement required to continue tracking. The computer output controls servomechanisms that move the antenna. This allows for accurate and automatic target tracking.

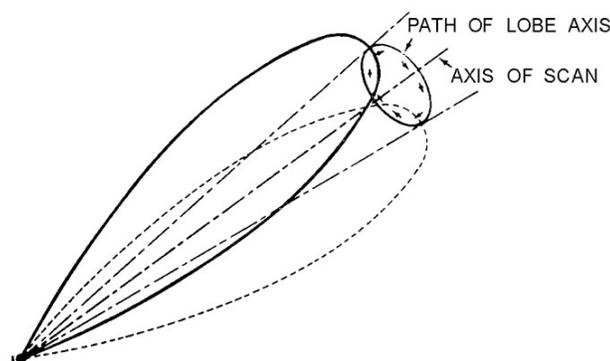


Figure 1-42. Conical scan pattern.

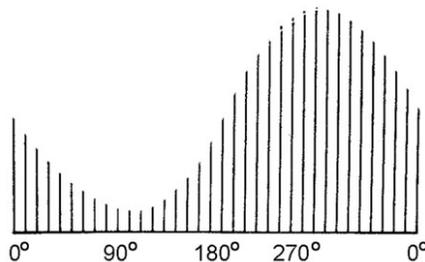
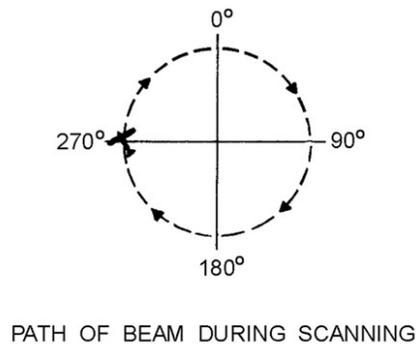


Figure 1-43. Conical scan reflected signal modulation.

Circular scan

The circular scanning radar, shown in figure 1-44, is an antenna system that continuously scans 360° in azimuth. The information desired is the azimuth and range of the aircraft relative to the antenna position; additional systems provide the altitude of the aircraft. The construction of the antenna is such that a fan beam is generated having a large angle in the vertical direction, but a small angle in the horizontal direction. The antenna can thus scan a large volume while still having good azimuth resolution. Circular scan may be identified at the ECM receiver by its regular intervals between illuminations.

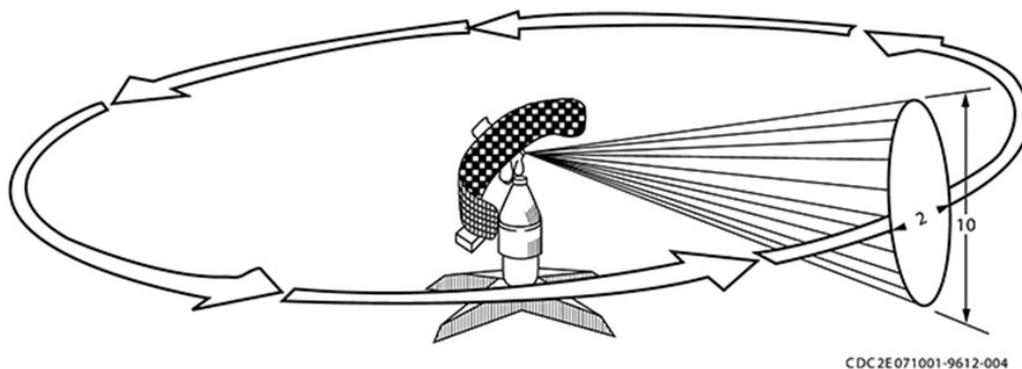


Figure 1-44. Circular scan pattern.

Raster scan

A raster scan is one in which a thin beam is used to cover a rectangular area by horizontally sweeping the area with the angle of elevation being incrementally stepped up or down with each horizontal sweep of the sector. After the sector is covered, the angle of elevation resets to the original value and the process is repeated. Raster scan is used in the acquisition phase by some airborne intercept radars.

Monopulse scan

The monopulse radar gets its name from the fact that each echo pulse from the aircraft being tracked yields a new azimuth and elevation correction signal. It does not rely on pulse amplitude variations, as does conical scan. Instead of rotating a single beam around the aircraft to determine error signals, the monopulse system simultaneously transmits and receives pulse on four different beams.

Helical scan

A helical scan is one in which the antenna rotates on an azimuth sweep, while the elevation angle rises slowly from 0° to 90° . After the vertical sector has been covered, the angle of elevation is reset to the original value and the process repeated.

208. Atmospheric propagation and propagation anomalies

As you have probably noticed, the atmosphere affects light. Rainbows form from the refraction and reflection of light and since RF energy behaves similar to light, it makes sense that the atmosphere also has an influence on RF energy. Because the atmosphere affects RF energy, you must understand the basics of atmospheric propagation and anomalies.

Atmospheric refraction

Electromagnetic (EM) wavefronts, such as radar RF signals, travel through empty space in straight lines at the speed of light, but the refractive index of the atmosphere affects both the travel path and the speed of the electromagnetic wavefront. The path followed by electromagnetic energy in the atmosphere, whether direct or reflected, is slightly curved; and the speed is affected by temperature, atmospheric pressure, and the amount of water vapor present in the atmosphere, which all affect the refractive index. As altitude increases, the combined effects of these influences, under normal atmospheric conditions, cause a small, uniform increase in signal speed. This increase in speed causes the travel path to curve slightly downward, as shown in figure 1-45. The downward curve extends the radar horizon beyond a line tangent to the earth, as illustrated in figure 1-46.

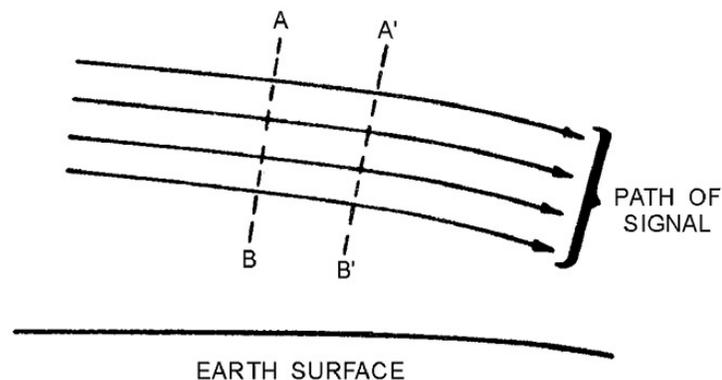


Figure 1-45. Wavefront path.

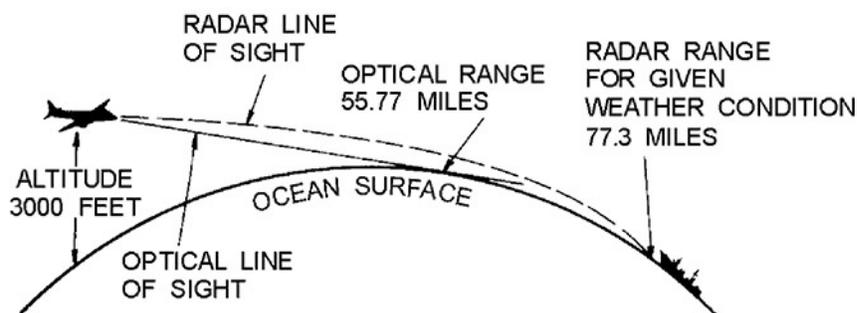


Figure 1-46. Extension of the radar horizon.

The reason for the downward curve can be illustrated using line **AB** in figure 1-45. Line **AB** represents the surface of a wavefront with point A higher in altitude than point B. As wavefront AB moves to the point represented by A 'B', the speed at A and A' is faster than the speed at B and B' since A and A' are at a greater altitude. Therefore, in a given time, the upper part of the wavefront moves farther than the lower part. The wavefront leans slightly forward as it moves. Since the direction of energy propagation is always perpendicular to the surface of a wavefront, the tilted wavefront causes the energy path to curve downward.

Refraction is the bending of electromagnetic waves caused by a change in the density of the medium through which the waves are passing. A visible example of electromagnetic refraction is the apparent displacement of underwater objects caused by the bending of light as it passes from the atmosphere into the water, for example if you stick a pencil into a cup of water the pencil appears to bend at the water's surface. An index of refraction has been established which indicates the degree of refraction, or bending, caused by different substances. Because the density of the atmosphere changes with altitude, the index of refraction changes gradually with height.

Propagation anomalies

The temperature and moisture content of the atmosphere normally decrease uniformly with an increase in altitude. However, under certain conditions the temperature may first increase with height and then begin to decrease. Such a situation is called a temperature inversion. Another important deviation from normal may exist over the water. Since the atmosphere close to the surface over large bodies of water may contain more than a normal amount of moisture, the moisture content may decrease more rapidly at heights just above the sea. This effect is referred to as moisture lapse.

Either temperature inversion or moisture lapse, alone or in combination, can cause a large change in the refraction index of the lowest few-hundred feet of the atmosphere. The result is a greater bending of the radar waves passing through the abnormal condition. The increased bending in such a situation is referred to as ducting and may greatly affect radar performance. The radar horizon may be extended or reduced, depending on the direction the radar waves are bent. Figure 1-47 illustrates how ducting can extend radar coverage.

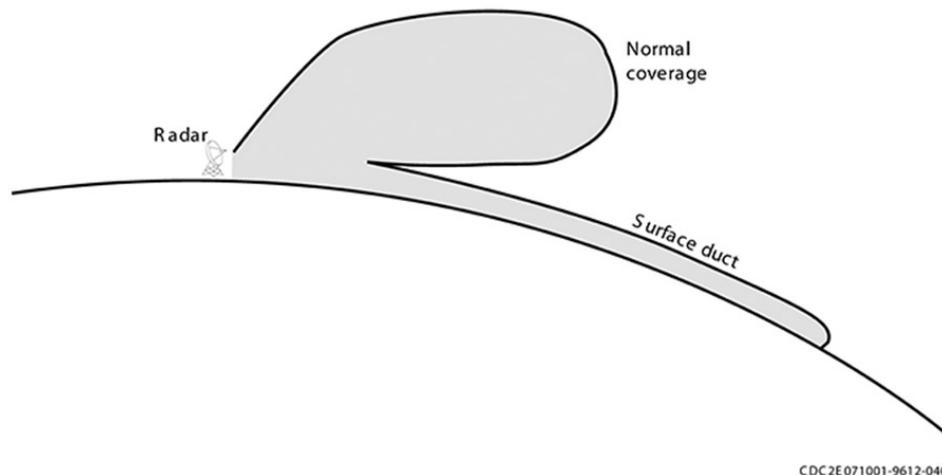


Figure 1-47. Ducting.

Despite the ability of ducting to possibly extend radar coverage, it is very undesirable. It can cause multiple different problems and is very difficult to completely avoid. Figure 1-48 shows how ducting can cause a hole in radar coverage.

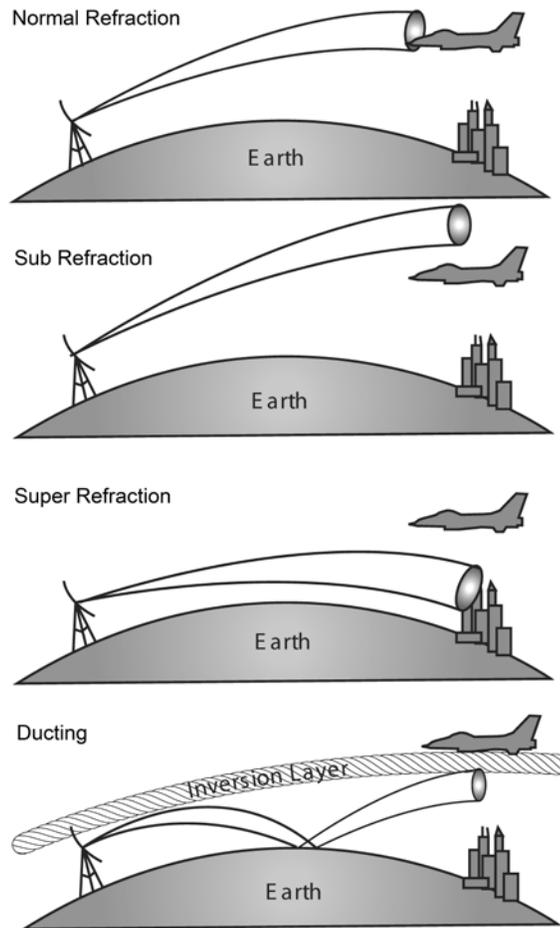


Figure 1-48. Propagation anomalies.

Propagation anomalies are abnormal propagation effects of electromagnetic waves. An example of a propagation anomaly is ducting. Propagation anomalies besides ducting include subrefraction, superrefraction, and multipathing. Although we won't cover all types of propagation anomalies here, we will cover a few common ones. Subrefraction occurs when atmospheric conditions cause EM waves to bend upwards. Subrefraction causes a reduction in radar range. Superrefraction is the opposite, which causes the EM signal to bend down more than normal, and may extend radar range. In cases of extreme superrefraction, ducting may occur and extend range even more. Figure 1-48 illustrates how refraction affects radar performance.

Multipathing

One definition of multipathing is “The propagation of a wave from one point to another by more than one path.” When multipath occurs in radar, it usually consists of a direct path and one or more indirect paths by reflection from the surface of the earth or sea or from large man-made structures. At frequencies below approximately 40 MHz it may also include more than one path through the ionosphere.

The “definition” contains the elements of two types of multipath effects: the simultaneous and the near-simultaneous reception of EM waves that have reached the receiving antenna by both direct and reflected (longer) paths. Depending on the relative phases and amplitudes of the several (two or more) simultaneously received components, the results can be a composite EM field, which can be near zero or as much as twice that received by the direct path alone.

Near-simultaneous reception of “pulse-type” information can result in delayed, but separate, pulses. We saw that reflection from the ionosphere or buildings can produce multipath, but here we’re concerned with reflections from the surface of the earth. This is a particularly important source of radar multipath, although other sources cannot always be ignored.

When a low-altitude target is illuminated by a radar system, or for higher-angle situations involving appreciable antenna sidelobes, energy can enter the tracking antenna by two separate paths: a direct path from the target and an indirect path involving energy reflected from the surface of the earth. The effect of such surface reflections is that the antenna “sees” both the actual target and an image target. These two targets produce signals that combine in the antenna to produce errors. Attempts to reduce multipath effects on radar tracking accuracy include frequency agility, polarization agility, high-resolution antennas, clutter fences, and complex indicated angle-processing techniques.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

207. Radiation patterns

1. Give four reasons why it is important that minor lobes of radar antennas be small compared to the main lobe.
2. How is the fictitious surface used?
3. How is the pattern of the antenna determined?
4. What are the three primary performance parameters for an antenna?
5. Name two basic functions of the radar antenna.
6. What determines the shape of the beam of radar energy and its antenna pattern?
7. In the search radar what do we need to measure?
8. What is a practical beamwidth and vertical height?
9. What is used to shape the radar beam?

10. What refers to the motion of the antenna axis (of the beam) as the radar looks for an aircraft?
11. When using a conical scan, what component of the return signal modulation is used by the radar system to maintain track in both azimuth and elevation?
12. What is identified at the ECM receiver by its regular intervals between illuminations?
13. In what system does a thin beam cover a rectangular area by sweeping it horizontally with the angle of elevation being incrementally stepped up or down with each horizontal sweep of the sector?
14. Which radar gets its name from the fact that each echo pulse from the aircraft being tracked yields a new azimuth and elevation correction signal?
15. In what radar does the antenna rotate on an azimuth sweep, while the elevation angle rises slowly from 0° to 90° ?

208. Atmospheric propagation and propagation anomalies

1. What happens to the speed of electromagnetic energy traveling through air as the altitude increases?
2. What effects can ducting have on radar coverage?
3. Name 4 types of propagation anomalies?
4. What do we call propagation of a wave from one point to another by more than one path?
5. When multipath occurs in radar, of what does it consist?
6. When may a multipath also include more than one path through the ionosphere?

7. What can near-simultaneous reception of “pulse-type” information cause?

8. When a low-altitude target is illuminated by a radar system, or for higher-angle situations involving appreciable antenna sidelobes, by what two paths can energy enter the tracking antenna?

9. What attempts are made to reduce multipath effects on radar tracking accuracy?

Answers to Self-Test Questions

201

1. To control friendly aircraft, detect hostile aircraft, and control interceptors.
2. To assist aircraft in making safe landings during poor weather conditions.
3. Transportable.

202

1. Reflected energy.
2. The speed of light, or 162,000 nautical miles per second.
3. 12.36 μ s.
4. Synchronizer.
5. Modulator high voltage pulse.
6. Duplexer.

203

1. Keyed oscillator and power amplifier chain.
2. Steep leading and trailing edges.
3. 600-30,000 MHz.
4. Capacitor, artificial transmission line, or pulse formed network.
5. Thyatron.
6. The charging impedance.
7. Mode skipping and mode shifting.
8. $\pm 5\%$.
9. Local oscillator and coherent oscillator.
10. Multicavity klystron.
11. Oscillations at an undesired frequency.

204

1. Omnidirectional and directional.
2. The systems purpose and degree of accuracy required.
3. The degree of sharpness of its beam.
4. They serve as an impedance matching device and as a directional radiator.
5. To concentrate the energy in a predetermined beam shape and to point this beam in a predetermined direction.

6. The transmit and receive patterns of the antenna are identical.
7. They offer an economical method of distributing energy over a large aperture area and can produce shaped or pencil beams with high gain.
8. All rays leaving the focal point and striking the reflector are reflected along a path parallel to the focal axis.
9. It gives you a fixed change to the radiated beam pattern but does not give you any way to continuously control or vary the beam pattern.
10. Use two feedhorns, one active (low beam) and one passive (high beam).
11. Used only for receiving.
12. It can reduce the amount of fixed clutter.
13. The range gating will be individually adjustable in each of four azimuth quadrants, relative to the north reference.
14. It uses simultaneous pencil-beam radiation patterns from a single aperture to cover the elevation angles of interest.
15. A separate receiver is provided for each pencil-beam.
16. The individual pencil-beams have a higher gain than a fan shaped beam.
17. Its inherent ability to steer the beam without the necessity of a large mechanical structure.
18. It can generate fan beams; it can generate pencil-beams.

205

1. Noise.
2. Superheterodyne.
3. Local oscillator.
4. Its inability to cancel local oscillator noise.
5. Detector.
6. Because of the widely varying amplitudes of radar return signals.
7. FTC has no effect on receiver gain.
8. Stationary target.
9. COHO locked pulse.
10. Opposite.
11. Amplification of the small signal is reduced.
12. Gain decreases.
13. Zero.

206

1. REX control, digital pulse compression, target processing, and weather processing for the receiver channel in which it resides.
2. Doppler filtering, CFAR detection thresholding, sliding dwell binary integration, plot extraction, and scan-to-scan tracking.
3. Radar interface suppressor.
4. To recover the radar range resolution when long pulse transmissions are used.
5. Remove clutter and weather returns correlated in range.
6. When two or more detections at the same range have occurred in four successive CPI's.
7. Monitoring the performance of the PSR.
8. At the end of six scans the PRI diverse weather maps are merged into a single weather map.
9. Programmable synchronizer FPGA.
10. Range and azimuth of the target as estimated by the plot processor, and a measure of the quality of the plot.
11. Plot processor.
12. 700.

207

1. (1) Have an antenna with high directivity.
(2) Reduce the susceptibility of the antenna to interfering signals.
(3) Reduce the possibility of detecting a target in a minor lobe.
(4) Reduce the probability of interference with other nearby systems.
2. It is often useful in computing the performance of the antenna.
3. The distribution of electromagnetic energy from the antenna over the aperture determines the pattern of the antenna.
4. Gain, beamwidth, and side-lobe level.
5. (1) To efficiently launch and receive electromagnetic energy into the atmosphere or space.
(2) To direct the energy into an appropriately shaped beam.
6. The purpose of the radar.
7. Range and azimuth but not height.
8. A practical beamwidth is 1° to 2° , and the average vertical beam height is about 30° to 35° .
9. A parabolic reflector.
10. The scanning method used by the system.
11. Phase.
12. The circular scan.
13. The raster scan.
14. The monopulse scan.
15. The helical scan.

208

1. Signal speed increases.
2. Extend coverage or create holes.
3. Ducting, subrefraction, superrefraction, and multipathing.
4. A multipath.
5. It usually consists of a direct path and one or more indirect paths by reflection from the surface of the earth or sea or from large man-made structures.
6. At frequencies below about 40 MHz.
7. Delayed, but separate, pulses.
8. A direct path from the target and an indirect path involving energy reflected from the surface of the earth.
9. The use of frequency agility, polarization agility, high-resolution antennas, clutter fences, and complex indicated angle processing techniques.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (201) What type of radar provides critical information to provide ample time to prepare or evacuate in response to natural disturbances?
 - a. Weather.
 - b. Surveillance.
 - c. Precision approach.
 - d. Aircraft control and warning (AC&W).
2. (201) What does the “P” in GPN-30 designate?
 - a. Communications.
 - b. Portable.
 - c. Radio.
 - d. Radar.
3. (202) How many microseconds (μs) does it take radio frequency (RF) to travel one radar mile?
 - a. 3.14.
 - b. 6.18.
 - c. 12.36.
 - d. 24.72.
4. (202) The time from one pulse to the next that the radar sends out is called
 - a. coherent processing interval (CPI).
 - b. pulse repetition frequency (PRF).
 - c. pulse recurrence time (PRT).
 - d. intermediate frequency (IF).
5. (202) Which radar subassembly amplifies the weak, electromagnetic (EM) pulses returned from the reflecting object and reproduces them as video pulses?
 - a. Receiver.
 - b. Duplexer.
 - c. Transmitter.
 - d. Synchronizer.
6. (203) What controls the radar pulse width (PW) by means of a rectangular direct current (DC)?
 - a. Modulator.
 - b. Magnetron.
 - c. Synchronizer.
 - d. Receiver/exciter (REX).
7. (203) In addition to a flat top, what characteristics *must* a modulator pulse have?
 - a. Very steep leading edge and sloped trailing edge.
 - b. Sloped leading edge and sloped trailing edge.
 - c. Sloped leading edge and steep trailing edge.
 - d. Very steep leading edge and trailing edge.

8. (203) What type of modulator is *most* commonly used in modern radar systems?
 - a. Hard tube.
 - b. Line-pulsed.
 - c. Keyed oscillator.
 - d. Power-amplifier.
9. (203) What type of tube *best* meets the requirements of a modulator-switching element?
 - a. Klystron.
 - b. Thyatron.
 - c. Magnetron.
 - d. Traveling-wave tube (TWT).
10. (203) If the magnetic field strength is too high on the magnetron, the magnetron will
 - a. oscillate erratically.
 - b. oscillate too high.
 - c. oscillate too low.
 - d. not oscillate.
11. (204) The power gain of an antenna is the ratio of its radiated power to
 - a. reference dipole.
 - b. reflector power.
 - c. input power.
 - d. feedhorn.
12. (204) Which pattern is *usually* specified and measured for a reciprocal antenna?
 - a. Receive.
 - b. Transmit.
 - c. Low beam.
 - d. High beam.
13. (204) What is the *most* common reflector shape?
 - a. Paraboloid.
 - b. Convex.
 - c. Planar.
 - d. Flat.
14. (204) What do you call the use of contiguous beams stacked in elevation?
 - a. Phased array.
 - b. Stacked beam radars.
 - c. Truncated paraboloid.
 - d. Cylindrical paraboloid.
15. (204) What is an *advantage* of the individual pencil beams when handling rain clutter or chaff?
 - a. Reduces screening.
 - b. Reduces multipath reflections.
 - c. Limits the volume of space observed.
 - d. Increases the volume of space observed.
16. (204) Which array is particularly useful in radar applications?
 - a. Two-dimensional planar.
 - b. Multiple elevation.
 - c. Twelve feedhorn.
 - d. Dual feedhorn.

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17. (204) Which waveguide antenna is *more* suited for one-dimensional scanning than scanning in two coordinates?
- Dual feedhorn.
 - Twelve feedhorn.
 - Truncated paraboloid.
 - Waveguide slot array.
18. (205) What intermediate frequencies are *usually* used in radar receivers?
- 20 megahertz (MHz) or 40 MHz.
 - 25 MHz or 50 MHz.
 - 30 MHz or 60 MHz.
 - 45 MHz or 90 MHz.
19. (205) What receiver circuit/stage actually produces the intermediate frequency (IF)?
- Mixer.
 - Detector.
 - Coherent oscillator (COHO).
 - Intermediate frequency amplifier.
20. (205) Which stage of the intermediate frequency (IF) section is the *most* critical?
- Amplifier stage.
 - Input (1st stage).
 - Transmit stage.
 - Detector stage.
21. (205) Immediately after the transmitter fires, sensitivity time control (STC) reduces the receiver gain to what level?
- Zero.
 - 30 percent.
 - 50 percent.
 - 70 percent.
22. (205) What signal is used to synchronize the coherent oscillator (COHO) to a fixed phase relationship with the transmitted pulse?
- Frame sync.
 - Trigger pulse.
 - Direct current (DC) modulator pulse.
 - Coherent oscillator lock pulse.
23. (205) What is the phase relationship between the delayed and non-delayed video?
- In-phase.
 - Opposite polarity.
 - 45° out of phase.
 - 90° out of phase.
24. (205) What happens to the overall gain of a linear logarithmic (LIN-LOG) amplifier as each stage saturates?
- No change.
 - Gain increases.
 - Gain decreases.
 - Gain is shut off completely.

25. (205) How many separate channels does a monopulse receiver have?
- One.
 - Two.
 - Three.
 - Four.
26. (206) What is used to interface target and weather channel signals to the signal processor?
- Azimuth beam/sensitivity time control (STC) interface.
 - Radar interface suppressor (RIS).
 - Binary integrator.
 - Video amplifier.
27. (206) What unit's *primary* function is to accept the output of the receiver/exciter (REX), and decide, for every range and azimuth cell in the radar coverage area, whether a moving target is present or not?
- Radar interface suppressor (RIS).
 - Binary integrator.
 - Target processor.
 - Video amplifier.
28. (206) How many permanent echoes are permitted by the advanced signal data processor (ASDP)?
- 10.
 - 25.
 - 50.
 - 75.
29. (206) What processor function attempts to correlate plots to existing tracks?
- Plot extractor.
 - Track processor.
 - Target processor.
 - Weather processor.
30. (207) What type of reflector is used to shape the radar beam?
- Planar.
 - Convex.
 - Parabolic.
 - Multipath.
31. (207) What refers to the orientation of the electromagnetic (EM) wave as it travels through space?
- Refraction.
 - Reflection.
 - Polarization.
 - Multipathing.
32. (207) What refers to the motion of the antenna axis (of the beam) as the radar looks for an aircraft?
- Tracking.
 - Propagation.
 - Refractive index.
 - Scanning method.

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-
33. (207) What precision radar system uses continuous rotation of a pencil beam (narrow angle in both dimensions) around the aircraft and uses the phase of the return signal modulation to maintain track in both azimuth and elevation?
- Raster scan.
 - Helical scan.
 - Conical scan.
 - Circular scan.
34. (207) When using a conical scan, what component of the return signal modulation is used by the radar system to maintain track in both azimuth and elevation?
- Phase.
 - Polarity.
 - Amplitude.
 - Polarization.
35. (207) What scanning method is identified at the electronic countermeasure (ECM) receiver by its regular intervals between illuminations?
- Raster.
 - Helical.
 - Conical.
 - Circular.
36. (207) Which radar gets its name from the fact that each echo pulse from the aircraft being tracked yields a new azimuth and elevation correction angle?
- Raster scan.
 - Helical scan.
 - Conical scan.
 - Monopulse scan.
37. (208) What happens to the speed of electromagnetic (EM) energy traveling through air as the altitude increases?
- Signal speed remains the same.
 - Signal speed decreases.
 - Signal speed increases.
 - Signal speed is erratic.
38. (208) The bending of electromagnetic (EM) waves caused by a change in the density of the medium through which the waves are passing is referred to as
- multipathing.
 - reflection.
 - refraction.
 - ducting.
39. (208) What is it called when temperature first increases with height and then begins to decrease?
- Subrefraction.
 - Superrefraction.
 - Temperature inversion.
 - Atmospheric refraction.

40. (208) What do you call propagation of a wave from one point to another by more than one path?
- a. Ducting.
 - b. Multipathing.
 - c. Subrefraction.
 - d. Superrefraction.

Unit 2. Introduction to Radar Support Systems

2-1. Indicator Basics	2-1
209. Types of indicators	2-1
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RADAR SYSTEMS rely on much more than the primary radar equipment. There are several important support systems, without which radar operations could not effectively fulfill their mission. We will look at a couple of these vital support systems and cover indicators and identification friend or foe/selective identification features (IFF/SIF) as they apply to radar systems in general. Lastly, we will explain the RF waveguide system and support functions that assist in equipment placement and monitoring.

2-1. Indicator Basics

Radars would be essentially useless without indicators to show the operators what the radar is detecting. As a Radar, Airfield and Weather Systems (RAWS) technician, you will need to make sure the indicators are operating correctly at all times for your system. You can isolate problems quickly only if you understand the system's overall operation. In this section, we will cover general indicator basics and basic indicator components that apply to most radar systems.

209. Types of indicators

The indicator, as the name implies, is the radar unit that displays corresponding radar information on a CRT. When we speak of the indicator, the radar operator thinks of the display tube, while maintenance personnel think of the power supplies, amplifier, sweep circuits, and control potentiometers. Radar indicators are normally referred to by their type, either an electrostatic or an electromagnetic CRT. When the requirements call for lightweight, compact equipment as used in aircraft, you use the electrostatic type CRT. Ground radar equipment mostly uses the electromagnetic type. The radar is designed so that the operator can determine from the indicator the number of targets, their range, speed, azimuth, and elevation. You can also determine whether an aircraft is friend or foe, and to some extent, their relative size.

In either type of indicator, the "picture" is "painted" or scanned by an electron beam focused on the face of the CRT. Since the beam scans the tube face, we describe the indicator by the type of scan it uses. There are many different types of indicator scans, but we will only cover those that apply to the radar indicators used within the RAWS arena. They are the A-scan, B-scan, plan-position indicator (PPI) scan, and the Raster scan.

A-scan

An A-scan indicator (fig. 2-1) is the most basic of indicators. An analog oscilloscope is an excellent example. It is a deflection-modulated presentation, which means the electron beam remains a constant intensity traveling across the face of the CRT and information is presented as a vertical deflection. The straight-line horizontal deflection is developed using sawtooth waves applied to the deflection

plates. At the time of the start trigger, the sawtooth wave starts its ramp, causing the electron stream to be deflected at a constant speed across the face of the indicator. When the stream reaches the right side of the indicator, it is blanked out, jumps quickly back to the left side, and repeats the process when the next start trigger occurs. Information is presented as a vertical deflection from the horizontal baseline. An input signal causes a vertical deflection of the stream, roughly proportional to the strength of the signal. The horizontal distance between the start trigger and the input signal represents time. The principal function of this type of scan is to determine the timing of the input signal.

Figure 2-1 displays a TX pulse that is triggered onto the start trigger. It shows an input signal from a target around mid-range of the set radar scan range. For example, if the setting for the radar range is 5 miles, the target would be roughly 2.5 miles away.

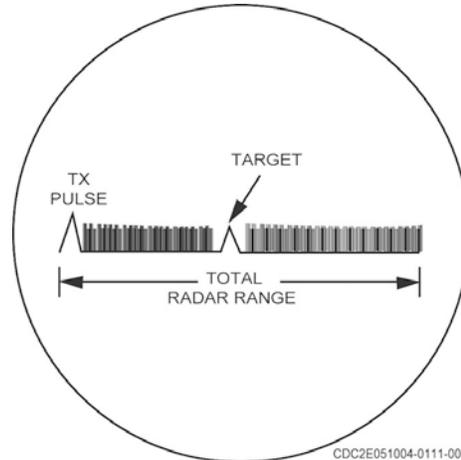


Figure 2-1. A-scan presentation.

B-scan

The PAR indicator is an example of a B-scan indicator. This type of indicator uses an intensity-modulated electron beam that presents the target as bright spots (fig. 2-2). When a target is received, the target video is impressed on the control grid of the CRT, causing a bright spot to appear on the screen. The PAR uses this type of sweep for both azimuth and elevation presentations. The indicator uses a split screen configuration that presents azimuth and range on the lower portion of the indicator, while elevation and range are presented on the upper portion. In the azimuth presentation, the time base moves bottom-to-top of the screen in synchronization with the azimuth antenna scan. In the elevation presentation, the time base moves bottom-to-top of the screen in synchronization with the elevation antenna scan. You read range from left-to-right across the screen.

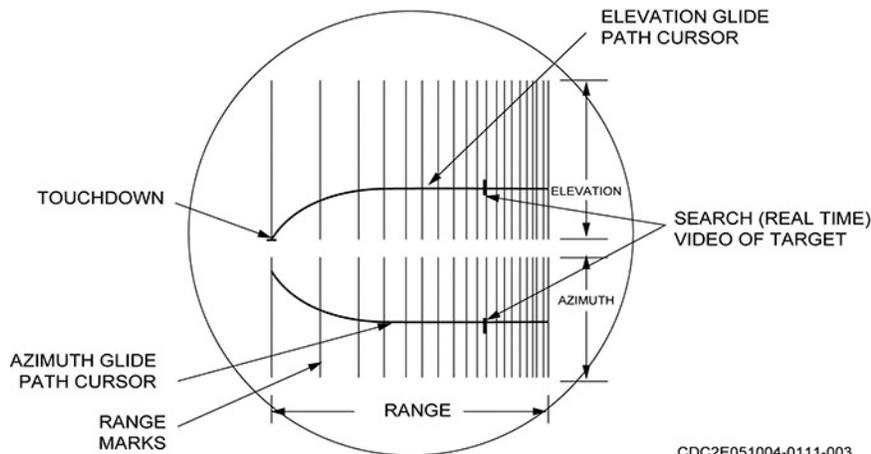


Figure 2-2. B-scan presentation.

Plan-position indicator scan

The PPI scan is the standard radar scope that most people think of, shown in figure 2-3. It plots target range and azimuth information in polar coordinates. The antenna is generally rotated uniformly about the vertical axis so that searching is done in a horizontal plane. The beam is usually narrow in azimuth and broad in elevation, and large numbers of pulses are transmitted for each rotation of the antenna. As each pulse is transmitted, the unintensified spot starts from the center of the CRT and moves toward the edge along a radial line. Upon reaching the edge of the CRT, the spot quickly jumps back to the center, and starts another trace or sweep as soon as the next pulse is transmitted. As the antenna rotates, the sweep rotates around the center of the indicator screen. The angle of the radial line indicates the azimuth of the antenna beam. The distance out from the center of the indicator indicates the range. When a target is received and processed, its video is applied to the CRT. This increases the intensity of the sweep at that point so that a bright spot remains on the screen after the sweep has passed. As several signals are received from one target, the points accumulate into a small dash that indicates the target's range and azimuth. Since ground echoes are also received, it is possible with this scan to "paint" a map of the area within range of the radar. This includes areas of heavy rain or clouds. Radar sets with this type of scan are primarily used in surveillance radars.

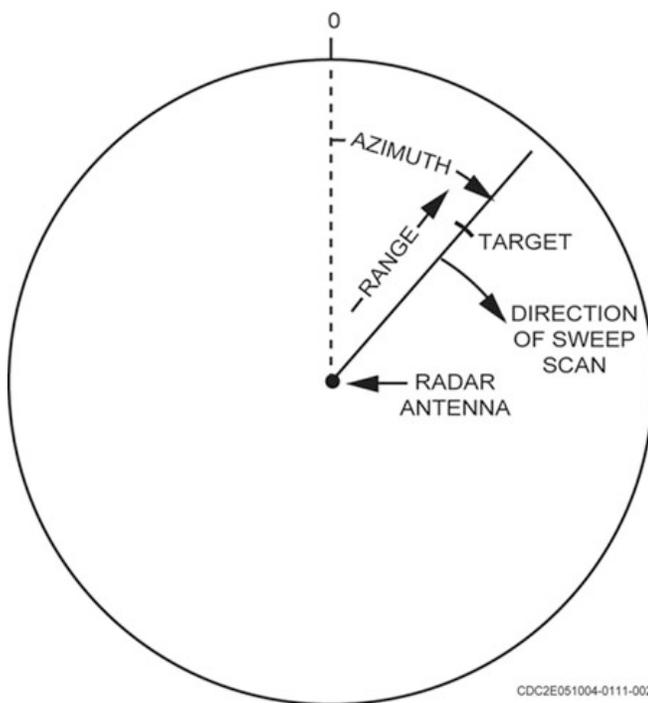


Figure 2-3. PPI presentation.

Raster scan

A Raster scan indicator is the same as a television and probably one of the most complicated. It uses a scanning electron beam to display information on the CRT. The electron beam scans a phosphor-coated screen on the CRT in a pattern that goes from left to right and in incremental vertical steps from top to bottom. The vertical scan or field only contains half of the total picture. After each field, the electron beam starts their scanning pattern again; only this time, they scan the area between the lines scanned in the preceding field. Two complete fields or vertical scan periods produce one complete picture called a frame (fig. 2-4).

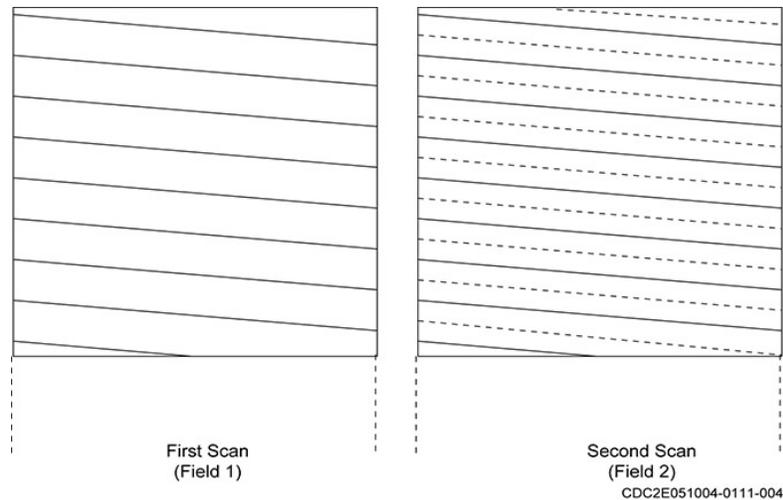


Figure 2-4. Raster scan presentation pattern.

210. Basic indicator components

Now that we know the different types of indicators that are used today, we can look at the basic components that they share. Figure 2-5 shows a basic indicator block diagram that we will use to show the individual components. All indicators, regardless of type, require power supplies, data processing circuits, video circuits, deflection circuits, a CRT, and front panel controls. We will discuss these items and their functions.

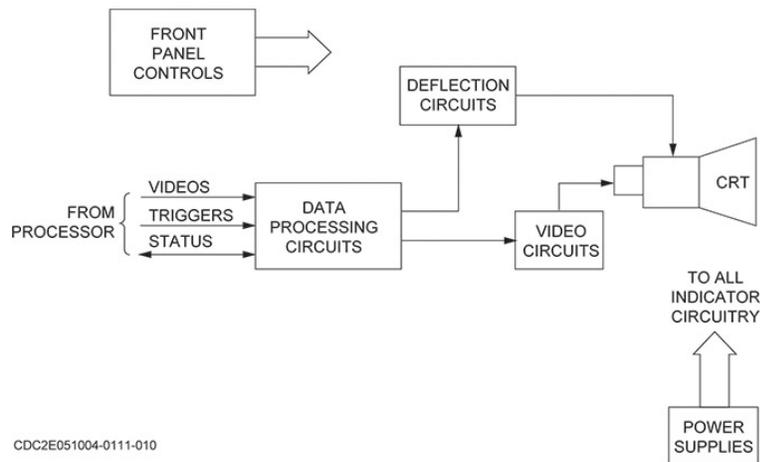


Figure 2-5. Basic indicator block diagram.

Power supplies

Power supplies provide the operating voltages for all of the circuits and components within the indicator. Normally, this is done with a low voltage power supply and a separate high voltage power supply. The low voltage power supply furnishes the multitude of voltages that are required by most of the indicator components except for the CRT. The high voltage power supply furnishes the operating voltages for the CRT.

Data processing circuits

The data processing circuits do three very important functions within the indicator. They are the control operations and data calculations function, interface function, and the data distribution function. This area examines them a little closer.

Look at the control operations as the brains of the indicator. The signals produced determine the overall operation of what the indicator will do. In addition to the control operations, instructions are provided for data calculating, formatting, and displaying information on the CRT.

The second function of the data processing circuits is it provides an interface with the radar set. The data supplied from the radar is collected and used to generate target symbols, messages, and graphics display information. This interface provides a continuous transfer of target and graphics data between the indicator and the radar.

The third function of the data processing circuits is data distribution. It ensures that the required information is provided to the different circuits within the indicator so they can do their assigned tasks.

Video circuits

The main purpose of the video circuits is to control the intensity of the CRT electron beam. To do this, the video circuits receive video from several sources. During radar sweeps, the video circuits use the selected analog and digital signals from the radar set. Range and azimuth marks are added to the CRT by pulses that intensify the radar video signal. During other operations, the video circuits receive video signals from the data processing circuits.

A secondary purpose of the video circuits is to protect the CRT during certain malfunctions by disabling the CRT high-voltage power supply. The video circuits also provide blanking signals for display processing and power supply malfunctions.

Deflection circuits

The deflection circuits convert digital display data from the data processing circuits into analog drive signals that are then applied to the CRT deflection coils, commonly called yoke. These analog signals position the electron beam to the correct position on the CRT screen. The data processing circuits specify beam position using X and Y coordinates, with the origin at the center of the CRT screen. The deflection circuits automatically draw vectors, sweeps, characters, and symbols as a series of strokes consisting of several short line segments. When the radar sweeps, the deflection circuits are synchronized by the radar range and azimuth timing signals.

Cathode-ray tube

The CRT is made up of a large glass outer shell, shaped as shown in figure 2-6. The long, cylindrical glass part between the base and the tapered section is called the neck. The front of the CRT is called the faceplate, and a phosphor material is deposited on the internal surface of the faceplate to form the viewing screen. The color of the display is directly related to the type of phosphor coating applied.

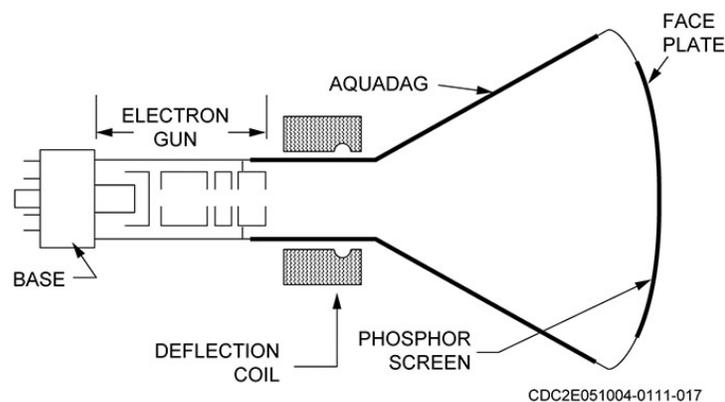


Figure 2-6. CRT construction.

At the base of the CRT is the electron gun. The electron gun is a group of electrodes that shape and accelerate the electron beam. The electron gun assembly must shape the electron stream into a fine beam for accurate display presentations.

CRTs are classified as either electrostatic or electromagnetic; depending on the method used to deflect the electron beam. The CRTs used in ground radar indicators is of the electromagnetic deflection type. This type uses magnetic fields to focus and direct the electron beam. The magnetic fields are established by passing current through coils of wire around the neck of the CRT. These coils of wire are called deflection coils, as shown in figure 2-6.

The tapered portion of the CRT is lined with a conductive graphite coating and is called the aquadag. Since it is conductive, it shields the electron beam from unwanted electric fields. The aquadag also keeps light from striking the back of the phosphor screen and gathers the secondary electrons emitted from the screen. The aquadag may also provide additional acceleration to the electron beam by applying a high positive voltage to it to give a brighter screen image.

Once the electron beam is formed by the gun assembly, the electrons must travel some distance before reaching the screen. Since even a small number of collisions between the moving electrons and air molecules would hinder CRT operation, the tube is sealed and air is removed (highly evacuated). The high vacuum and large surface area of the tube make the tube especially vulnerable to dangerous implosions. In many cases, sudden jarring or slight nicks or scratches in the glass are sufficient to cause implosion. This is the primary hazard for CRTs, so be very careful handling them. Do not try to install or remove these tubes without wearing the appropriate safety equipment. When you service equipment containing CRTs, be careful the tube is not bumped or scratched by tools.

Front panel controls

Front panel controls are different for each type of indicator depending on its purpose. Generally, the front panel controls are used to allow the operator to select input signals and messages, enter operating parameters, and adjust indicator format. These controls determine what and how the radar information is on the indicator. In addition, some indicators have built-in test equipment (BITE) diagnostics initiated by front panel controls to isolate indicator function faults. A thorough understanding of these controls is essential to understanding the capabilities and limitations of the indicator itself and then explaining their function to the operator that uses them.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

209. Types of indicators

1. When would you use an electrostatic instead of an electromagnetic CRT?
2. How is information presented on an A-scan indicator?
3. How is time represented on an A-scan indicator?
4. How is the video presented on a B-scan indicator?

5. What type of radar uses the B-scan indicator?
6. What target information does a PPI scan present?
7. What type of pattern does a Raster scan indicator use to scan the CRT?

210. Basic indicator components

1. What components do all indicators have regardless of type?
2. What furnishes the operating voltages for the CRT?
3. List the three functions performed by the data processing circuits.
4. How do the video circuits protect the CRT during certain malfunctions?
5. How do the data processing circuits specify beam position?
6. List the two types of CRTs.
7. What part of a CRT shields the electron beam from unwanted electric fields?
8. What is the primary hazard involved with high-vacuum CRTs?
9. What do indicator front panel controls allow the operator to do?

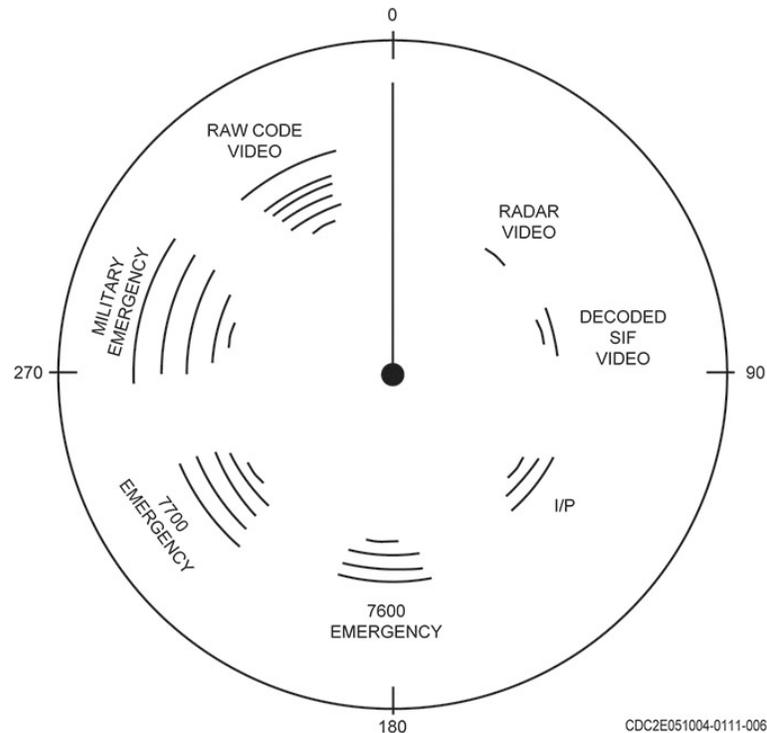


Figure 2-8. Displayed SIF video.

This system of selective identification is effective and offers many advantages over the old World War II IFF system. The following is a list of advantages:

- Modes can be interlaced.
- Special responses can be provided.
- Interrogations and responses are pulse coded.
- All coding and decoding is done automatically.
- There are several modes of operation to provide various data.

Identification friend or foe/selective identification feature coding

The modern selective identification feature (SIF) system uses four modes during normal operation, modes 1, 2, 3 and C. The coded signal transmitted by the interrogator consists of two 0.8- μ s pulses spaced 3, 5, 8, or 21 μ s apart, respectively, depending on the mode of operation.

(**NOTE:** all references of pulse spacing are referenced from the leading edge to the leading edge unless otherwise noted). Figure 2-9 shows the P1 and P3 pulses for all four SIF modes.

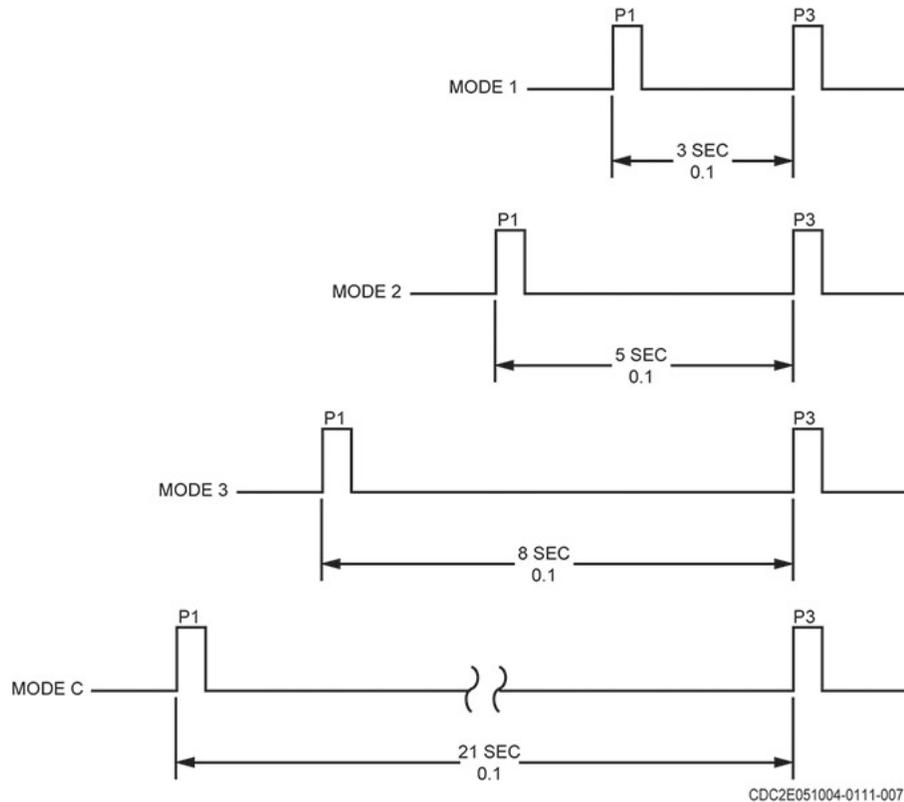


Figure 2-9. Interrogation pulse spacing.

If IFF is used with the SIF system, a mode 4 encrypted interrogation always starts with a control group of pulses called a preamble. The preamble contains four pulses and a blank space. Each pulse is $0.5 \mu\text{s}$ wide, and the pulses are spaced $2 \mu\text{s}$ apart. The rest of the mode 4 interrogation is a classified encrypted sequence of pulses that cannot be divulged in this course. The coding of IFF/SIF interrogations can be done in a coder unit built into the interrogator or a mode 4 computer. Regardless of which coder is used, the interrogator transmits the SIF pulse pairs or the mode 4 code train to the aircraft at a frequency of 1030 MHz. If the aircraft has a transponder on board, it answers the interrogation by transmitting a reply pulse train signal back to the ground station at a frequency of 1090 MHz.

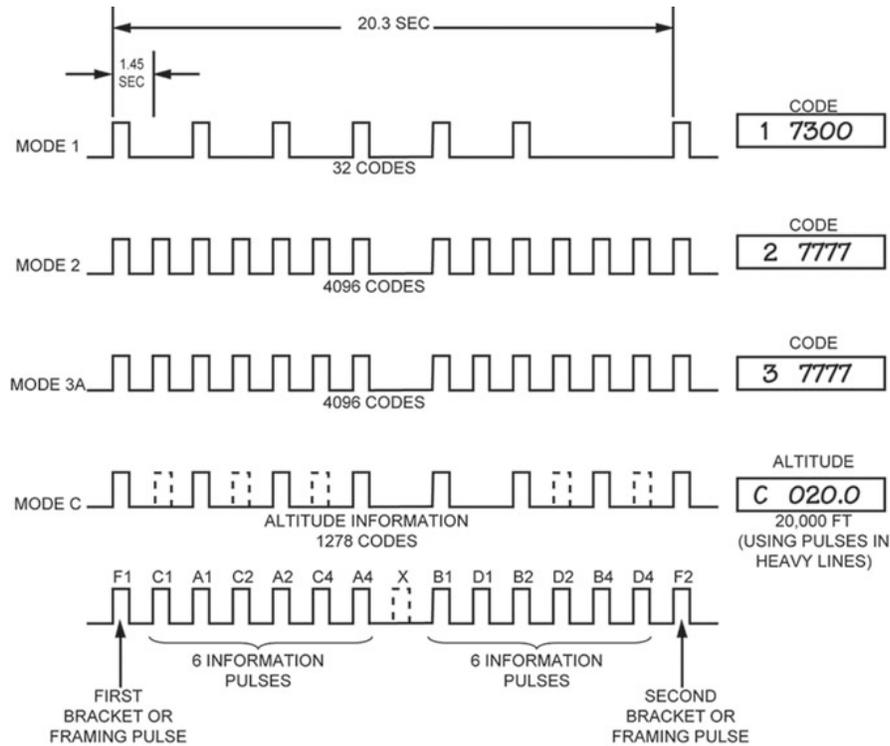
Interrogator side-lobe suppression

As you have learned in your previous studies, radars do receive and present targets that are in the sidelobes of the main radar antenna. Unless sidelobe blanking is used, these targets show as valid targets. The IFF/SIF systems used with today's radars also have this problem. The system's antenna also has sidelobes, and unless something is done, close range targets are received and presented as false IFF/SIF targets.

To eliminate sidelobe reception, a $0.8\text{-}\mu\text{s}$ P2 pulse is generated and transmitted $2 \mu\text{s}$ after P1 in the SIF system or during the blank space in the mode 4 control group of pulses in IFF systems. This P2 pulse is transmitted in an omnidirectional pattern around the ground radar site and in a pattern large enough to cover the side and back lobes of the main IFF/SIF antenna. The aircraft transponder compares the P1 and P2 it receives. If the P2 pulse is received at an equal or greater power level than the P1 pulse, the transponder assumes it is being interrogated in either the sidelobe or back lobe. In this case, the transponder does not generate a response. Only aircraft in front of the antenna receives the P1 and P3 pulses at a greater power than the P2 pulse. These are the only aircraft to respond to the interrogation. This entire action is called interrogation side-lobe suppression (ISLS).

212. Response coding

As we have seen, a pair of SIF interrogation pulses or a mode 4 IFF code train interrogates every aircraft within our radar's range. If the aircraft has a transponder on board, it automatically transmits a reply to our interrogation. This reply is usually a code train of information pulses that must be decoded to give the operator valid information about each aircraft. The normal SIF reply codes for all four SIF modes are shown in figure 2-10.



CDC2E051004-0111-008

Figure 2-10. SIF reply codes.

Mode 1

As figure 2-10 shows, mode 1 has fewer pulses than the others do. It uses the A1, A2, A4 and B1, B2 pulses only to determine the code. This is because it was an earlier SIF code and required further spacing between the pulses to decode; this limits its total possible codes to 32. Its binary count determines the code. The mode 1 code is determined by adding the binary count of the pulses present. For example, in figure 2-10, pulse A1, A2, and A4 are present which equals a binary count of 7; this is the first digit of the code. Also, pulses B1 and B2 are present which equals a binary count of 3; this is the second digit of the code. Since there are no further possible digits in a mode 1 code, the final 2 digits are zero. This results in a mode 1 code of 7300.

Mode 2 and 3/A

Unlike mode 1, mode 2 and 3/A use all of the A, B, C, and D pulses. To determine the code, simply add up the numbers of the pulses present. If all of the pulses are present, as shown for mode 2, simply add up the numbers to get the code. The "A" pulses correspond to the first digit of the code; the "B" pulses to the second digit, and so forth. Therefore, A1 plus A2 plus A4 equals 7 for the first digit of the reply. B1 plus B2 plus B4 equals 7 for the second digit. The same goes for the remaining "C" and "D" pulses that correspond to the third and fourth digit respectively. As you can see, the largest single digit for any reply is a 7. This is true for SIF modes 1, 2, and 3/A. Mode C is somewhat different.

Mode C

Mode C, or altitude information, is not decoded directly from pulses, as are modes 1, 2, and 3/A; mode C does not use the D1 pulse. When an aircraft is interrogated in mode C, the reply is a Gray Code train of pulses that represents the aircraft's altitude in 100-foot increments. Using this Gray Code, instead of binary as used in modes 1, 2, and 3/A, allows single-digit readings up to 9. This feature is necessary to get altitude readings from aircraft flying at 29.2 thousand feet or 18.9 thousand feet, for example.

The decoded reply code trains, shown in figure 2-10, appear in the boxes to the right, as they would on the active readouts of a decoder. Normally, aircraft reply code trains do not contain all the pulses as shown. To test SIF decoders properly, you need to know the various combinations of pulses needed to get specific codes.

Framing pulses

The first and last pulses must always be present for a SIF reply to be valid. These pulses are called brackets or framing pulses and are spaced 20.3 μs apart with a width of 0.45 μs . Information pulses, inside the brackets, are also 0.45 μs wide.

X pulse

There is a possibility of another pulse added to the reply code. Among the labeled pulses at the bottom of figure 2-10, there is an X pulse in the center of the code train. This X pulse can be present in any of the four SIF reply trains. Its presence in a code train means that the aircraft that sent the reply is a pilotless aircraft, such as a missile or a drone.

Special responses and identification friend or foe replies

As you look back at figure 2-8, you see that many types of SIF responses can be presented on a radar indicator. Anything other than decoded SIF or beacon/code video is classed as a *special response*. This is not normally presented on the scope, except in special circumstances such as:

- Identification of position (I/P).
- Hijacking emergency (7500).
- Communications failure emergency (7600).
- Civil emergency (7700).
- Military emergency (4X).
- IFF response (mode 4).

Special responses are an important, sometimes critical, factor between the radar operator and the aircraft. Now look at the significance of each special response.

Identification of position

The I/P response is manually generated by the aircraft pilot. When two or more aircraft are responding with the same code and are flying close together, the radar operator can “lose” the particular aircraft that he or she is controlling. If this happens, the operator simply calls the aircraft on the radio and requests an I/P. The pilot manually presses a button to generate the I/P response.

When the aircraft pilot presses the I/P button, another pulse is added 4.35 μs behind the normal SIF code train. If your decoder is “looking” for this pulse, it is processed and presented on the indicator as an I/P decode. The I/P response is presented on the indicator as a second arc, about 2 miles in range behind the decoded SIF arc. The I/P decode, as a special response has no priority. In fact, any decoders that have not been switched to I/P manually will not decode the I/P response. The next special responses are 7600 and 7700, which can only be decoded if interrogating mode 3/A. They are civilian emergencies and are two of the three possible emergency replies—the third one being a military emergency.

7500 emergency reply

A 7500 emergency reply signifies a hijacking on board an aircraft. With hijackers onboard the aircraft, this is the only way the pilot can let the ground station know without alerting the terrorist. Air traffic control decoders constantly monitor mode 3/A responses for a 7500 reply. When the decoder receives this emergency reply, three things happen: (1) an emergency light is activated on the decoder, (2) an audible alarm sounds, (3) and the control is notified by a special symbol. The AN/TPS-75 radar SIF equipment does not monitor the 7500 reply.

7600 emergency reply

A 7600 emergency reply signifies a communications failure on board the aircraft. With no radios operable, this is the only way the pilot can let the ground station know there is a problem. Our decoders constantly monitor mode 3/A responses for a 7600 reply. When the decoder receives this emergency reply, three things happen: (1) an emergency light is activated on the decoder, (2) an audible alarm sounds, (3) and three arcs one mile apart are presented behind the radar target on the indicator. The 7600 reply is the lowest priority emergency because nothing is wrong with the aircraft's flight capability.

7700 emergency reply

A 7700 emergency reply signifies a civil emergency and is also monitored by mode 3/A. Civilian aircraft transmit this signal when there is an in-flight emergency such as hydraulic or electrical problems, engine failure, or landing gear faults. A 7700 emergency reply has the second priority. That is, if a 7600 reply and a 7700 reply are received at the same time, the 7700 reply takes precedence. It also actuates a light and an audible alarm. In figure 2-8, you can see the video presented on the indicator as four arcs, 1 mile apart, behind the radar target.

Military emergency reply

A military emergency is the highest priority emergency reply. It is used only by military aircraft, and is presented on the indicator as four arcs, 2 miles apart, behind the radar target. It can be received in any SIF mode, including mode C. The military emergency consists of four complete code train replies, spaced 4.35 μ s apart.

The decoder has three separate lights, one for each type of emergency. A communications failure reply causes a yellow light (labeled 76) to flash on and off. A civil emergency causes a green light (labeled 77) to flash on and off. A military emergency causes a blue light to flash on and off.

Mode 4 identification friend or foe reply

A mode 4 IFF reply looks just like a decoded SIF reply. The mode 4 reply is presented on the indicator as one arc behind the radar target. The actual mode 4 reply received by the ground station consists of three 0.5- μ s pulses, spaced 1.8 μ s apart. These pulses are compressed to a single pulse, if the spacing is correct.

This single pulse is then sent to the mode 4 computer to verify it is a valid mode 4 reply. Only a US military aircraft can present a single-arc IFF reply on the scope.

Any unfriendly aircraft that tries to reply to our mode 4 interrogation is presented on the scope as a group of randomly spaced dots around the radar target. This lets the operator know that the aircraft is hostile. The design of the mode 4 IFF system is to let us know the difference between friendly and unfriendly aircraft.

213. AN/UPM-155 test set overview

The AN/UPM-155 radar test set is the US Department of Defense (DOD) standard for IFF test equipment. It is used by the Army, Air Force, and Navy to test a wide range of IFF/SIF equipment. It is a general-purpose test set, capable of testing all MK X and MK XII compatible IFF equipment, including transponders, interrogators and other associated system components. The AN/UPM-155

test set is the replacement for the antiquated AN/UPM-137 and AN/TPM-25 test sets. It replaces the need for external cabling by incorporating a computer-controlled interface that is menu driven. This welcomed change has cut down on the amount of time required to test interrogators and decoders.

The AN/UPM-155, as shown in figure 2-11, is made up of seven specific functional areas; they consist of control and interface, IFF simulator, measurement system, interface, front panel, oscilloscope and power distribution. The test set overall functional block diagram is shown in figure 2-12. The Analog Control Multiplexer (ACM) and unit under test (UUT) are not part of the test set, but are shown for reference only.

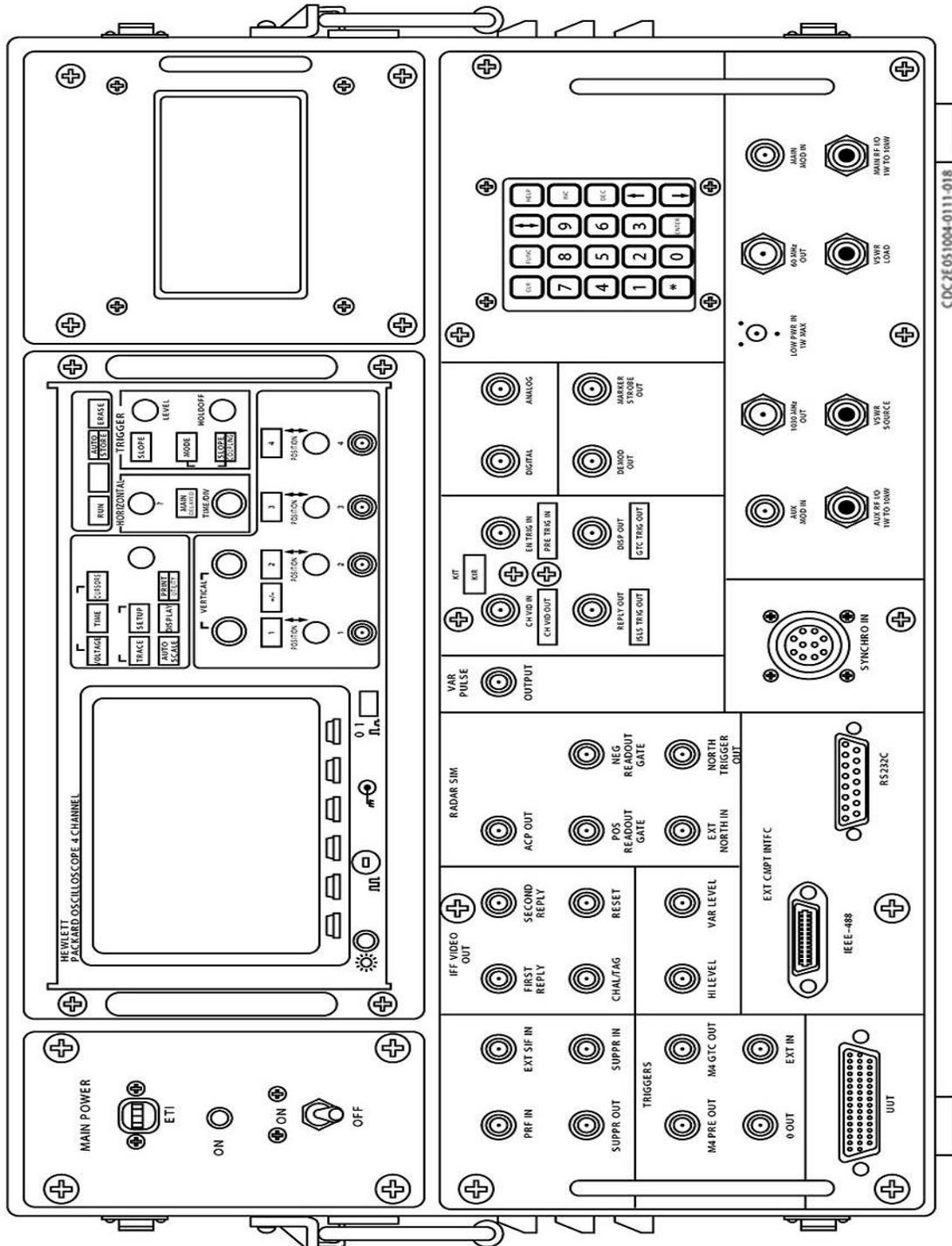


Figure 2-11. AN/UPM-155 radar test set front panel.

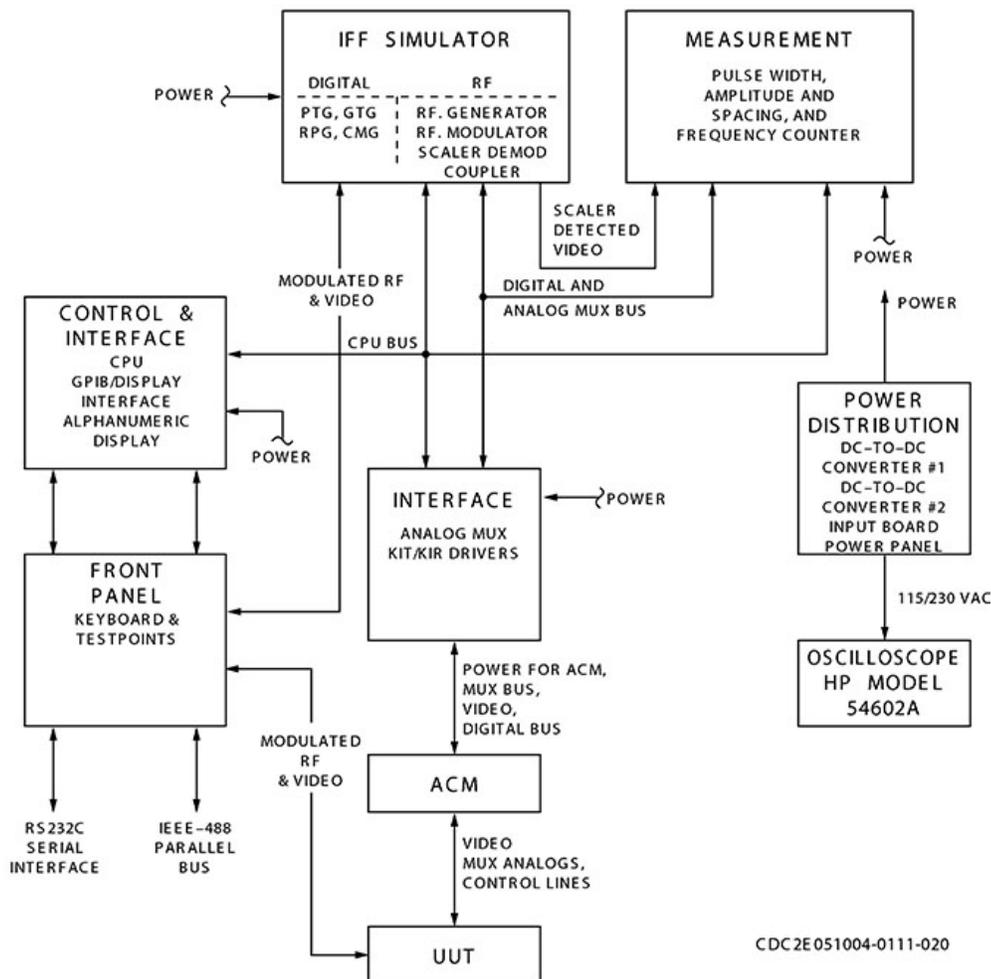


Figure 2-12. AN/UPM-155 overall block diagram.

The test set tests IFF equipment manually and automatically. During automatic testing, a series of tests, by the ACM, are preferred on the UUT. When an out of tolerance condition occurs, the failed test step will be displayed. A list of possible failed UUT modules may also be displayed.

Manual test modes, operated locally with a keyboard and an alphanumeric display, allow the operator to select test setups or make measurements and display the results on the test set display.

In the local mode, the test set is menu-driven on the front panel. Menus and operator prompting are provided for manual and automatic testing of IFF equipment. All menu selections are associated with a number that corresponds to a key on the keyboard. The test setup for a particular interrogator is dependent on the UUT.

Remote operation of the test set is accomplished using the recommended standard (RS)-232C or Institute of Electrical and Electronics Engineers (IEEE)-488 interface. All local measurements and setups can be made through these interfaces.

Communication between the control and interface, the IFF simulator, measurement and the interface functions are through a central processing unit (CPU) bus. The CPU bi-directional data bus is controlled by the CPU in the control and interface function and contains a Z80 microprocessor. Digital and analog signals are routed through the test set in a digital and analog multiplex bus controlled by the CPU. Modulated RF and video signals between the UUT and the IFF simulator are routed through the front panel. Power is distributed from the power supply to all functions.

Control and interface

This function provides overall control of the other functions. It interfaces with the front panel and, as stated above, contains the CPU.

Identification friend or foe simulator

The digital section provides timing and system clocks; performs reply and challenge-inhibit functions; forms the reply pulse train in response to an interrogation; and simulates interrogations when testing transponders.

The RF section generates ultra-high frequency (UHF) stimulus/reply signals to the UUT and also receives and processes signals from the UUT for the measurement function. The RF section calibrates RF signals; routes RF signals to appropriate measurement circuits; and routes internally generated signals to the appropriate front panel output connectors.

Measurement

The measurement function primary responsibility is measuring pulse width, amplitude, spacing, frequency, and voltage standing wave ratio (VSWR) of UUT signals. The CPU controlled internal circuitry performs these functions and provides their results to be displayed for operator viewing.

Interface

The interface function is the primary link between the test set and the UUT when the ACM is used for automatic testing. It provides signal conditioning required for testing transponders and interrogators. The analog multiplexer routes video signals to the measurement module for measurement and conditions, and routes front panel inputs to appropriate modules.

Front panel

The front panel contains the keyboard, the display, UUT connector, IEEE-488, and the RS-232C connector. The keyboard is used to make selections and input variables on various menus. The UUT connector interfaces the UUT to the test set by an ACM. The IEEE-488 and RS-232C connectors provide parallel and serial remote operation of the test set.

Oscilloscope

The test set incorporates a Hewlett-Packard Model 54602A digital oscilloscope that is mounted directly within the enclosure. The oscilloscope is used to view and measure various signals under test.

Power distribution

The power distribution function is responsible for providing all required voltages to the individual functions within the test set. It accomplishes this by using the voltage applied to the test set from the power cable connected in the rear. There are two different power cables depending on the voltage being supplied to the test set, either 115 or 230 AC as selected by the rear selection switch as shown in figure 2-13 and sent to the MAIN POWER on/off switch located on the test set front panel.

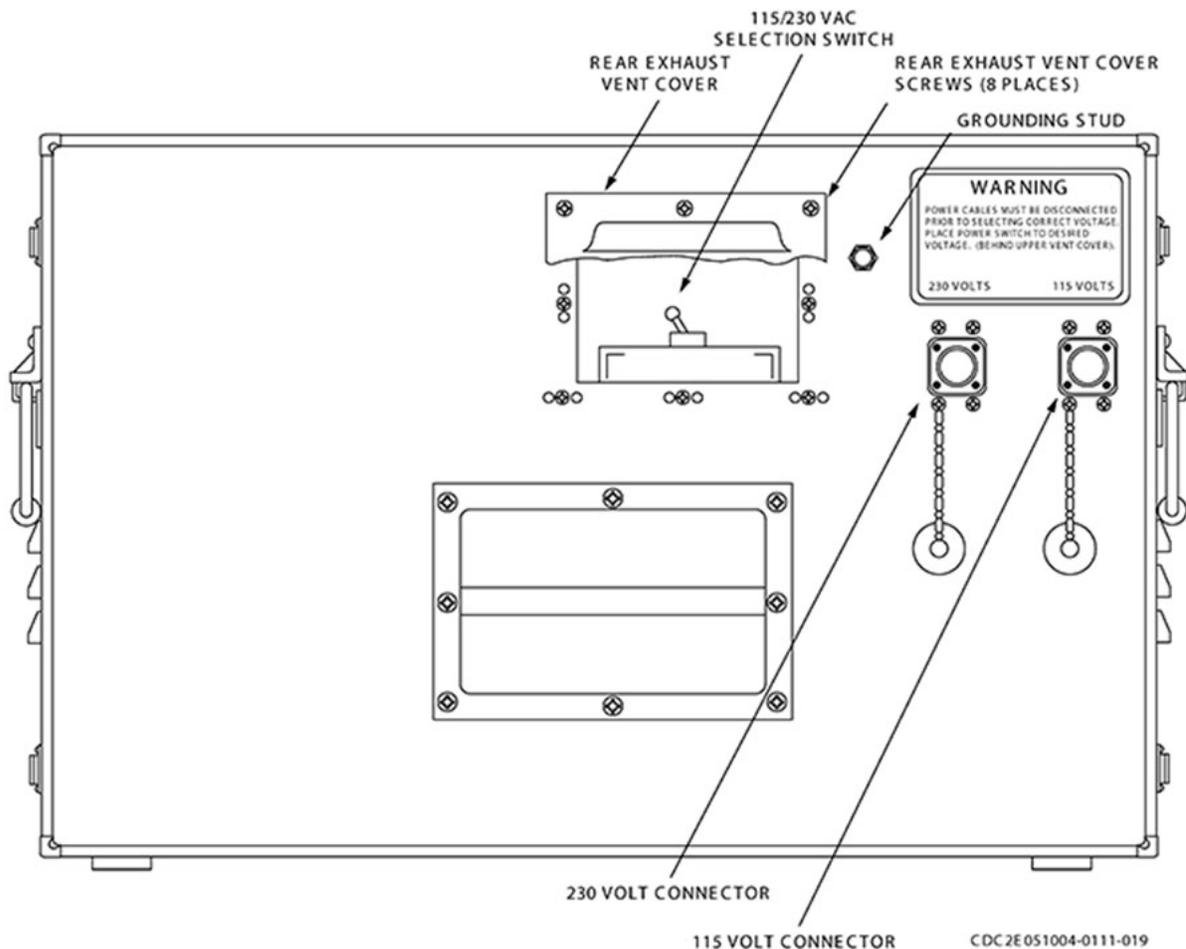


Figure 2-13. AN/UPM-155 rear panel voltage selection.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

211. Coding and interrogator side-lobe suppression

1. What are the SIF modes used to interrogate an aircraft?
2. What is the spacing between P1 and P3 pulses for the four SIF modes?
3. Explain the contents of the mode 4 preamble.
4. What is the transmitted frequency of interrogation pulses?
5. What is the purpose of transmitting a P2 pulse?

212. Response coding

1. What is the limit of total possible codes in mode 1?
2. What is the largest single digit for any SIF modes 1, 2, and 3/A reply?
3. What type of code and what are the increments of the altitude information received in mode C?
4. What terms are used for the first and last pulse present in a SIF?
5. What is the bracket pulse spacing on a normal SIF code train?
6. What signifies that the SIF reply has been transmitted by a missile or drone?
7. What is the purpose of a reply pulse that is 4.35 μ s after the last bracket pulse of a SIF code train?
8. What is the only IFF/SIF mode that can decode civilian emergencies?
9. How is a communications failure emergency received by the ground station?
10. Which modes will decode military emergencies?
11. What type of aircraft can present a single-arc IFF reply on the scope?

213. AN/UPM-155 test set overview

1. What are the seven functions within the AN/UPM-155 test set?
2. Column A contains statements describing the functional areas within the AN/UPM-155. Match each statement with its function name in column B. Place the alphabet designator for the function from column B in the space provided in column A. Each option will be used only once.

<i>Column A</i>	<i>Column B</i>
____ (1) Used for automatic testing.	a. Control and interface.
____ (2) Used to view signals under test.	b. IFF simulator.
____ (3) Provides overall control.	c. Measurement.
____ (4) Measure VSWR.	d. Interface.
____ (5) Simulates interrogations.	e. Front panel.
____ (6) Provides all required voltages.	f. Oscilloscope.
____ (7) Contains keyboard and display.	g. Power distribution.

2-3. Waveguide and System Support Functions

A waveguide is the equivalent of a coaxial cable with the central conductor and supporting insulation spacing removed so that all that remains is a hollow pipe. Because of its looks, it is commonly referred to as “RF plumbing.” In reality, RF plumbing is not only waveguide, it also includes all special purpose RF devices placed into the system to route a signal to the antenna and back to the receiver. Remote radar operations and system performance monitoring are also very important in day-to-day maintenance. This section will describe waveguide characteristics and other RF devices that help propagate a radar signal. Lastly, this lesson will cover remote system characteristics and test equipment that will assist you in gathering radar status information.

214. Radio frequency waveguide

A waveguide becomes necessary as higher microwave frequencies are used in order to minimize energy loss and maximize power output. Other methods could be used, but a waveguide is more feasible and efficient for the path of RF energy in radar signals. Waveguide is normally rectangular or cylindrical in shape and fabricated out of material having good electrical conductivity.

Waveguide construction

Waveguide components come in all shape and sizes in order to carry the transmitted and received signals through the antenna assembly. Figure 2-14 illustrates the different types of waveguide that are available. Notice, rectangular waveguide sections can be straight, have various degrees of bend, and be flexible. This will allow the radar installation the flexibility necessary to interconnect the components. Waveguide choke joints couple the components to prevent RF leakage between waveguide sections (fig. 2-15).

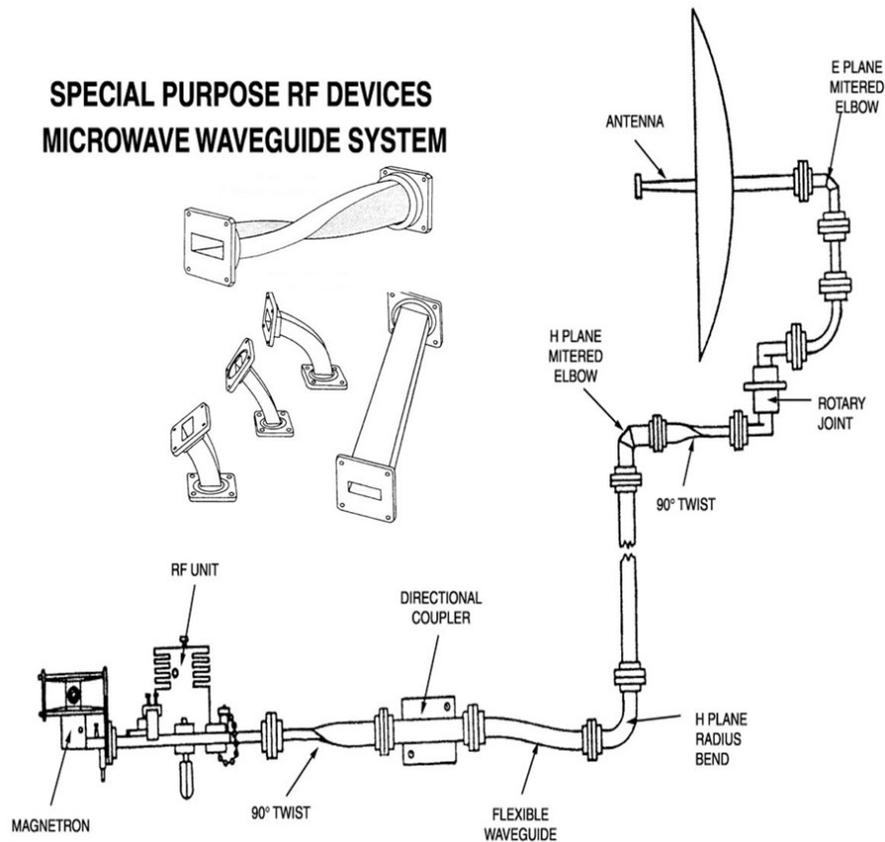


Figure 2-14. Types of waveguide and RF devices.

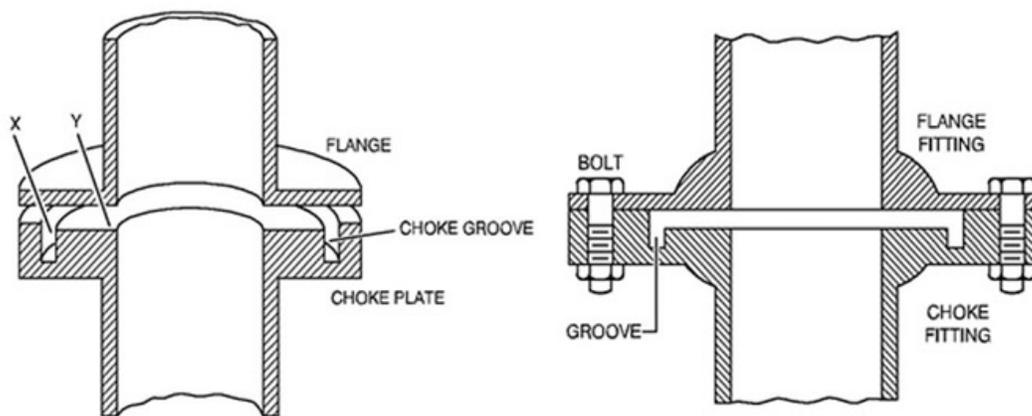


Figure 2-15. Waveguide choke joint.

Waveguides are pressurized for protection against dirt, moisture, and mold growth. These factors can seriously deteriorate the operation of waveguide equipment by reducing its power-handling capacity. Such conditions could cause arcing, reducing effective and efficient radar operations.

To prevent this arcing condition most radars use air compressors to supply dehydrated air for pressurizing the waveguide system. Dry air in waveguide components prevents arc-over during normal operation. Applying dry air at a pressure greater than that of the atmosphere will prevent moist air from entering waveguide.

Compressors

Waveguide compressors are divided into two subsystems: airflow and electrical. The airflow system compresses and dries air for delivery to the waveguide. The electrical subsystem controls operation of the airflow subsystem and indicates normal operating conditions or malfunctions. The waveguide compressor system is used primarily in mobile equipment where the waveguide must be disassembled and reassembled. In a fixed radar environment, the waveguide may be pressurized with air or inert gases.

215. Other radio frequency devices

Many parts may make up a waveguide system. Rotary and choke joints, duplexers, RF switches, diplexers, RF filters, directional couplers, and polarizers will be covered in this lesson in order for you to understand the full concept of how a waveguide system operates.

Rotary joints

A rotary joint (fig. 2-16) is a specialized waveguide device that allows one waveguide section to remain stationary while the other section rotates on its axis. It is commonly used where a stationary transmitter is coupled to a rotating antenna. RF power from the waveguide components in the RF assembly is brought in at the bottom of the joint through a rectangular waveguide. The center section of the joint is a circular waveguide.



Figure 2-16. Rotary joints.

Power is taken from the rectangular waveguide and coupled into the circular waveguide section. Filters at the top and bottom of the circular waveguide section suppress unwanted RF signals generated because of the transition from rectangular to circular waveguide.

Choke joints

A rotating choke joint separates the rotating and stationary parts of the cylinder. The portion of the cylinder above the rotating choke joint rotates about its axis. The polarization of the field remains the same in both the rotating and stationary portions of the cylinder. The choke joint prevents RF leakage at the junction. At the top of the rotating cylinder, energy is taken out of the circular guide in the same fashion as it is fed at the bottom.

Duplexer

Usually, the same antenna is used for both transmitting and receiving. When one antenna is used, a switching device called a duplexer is required to connect the antenna to the transmitter during transmission and to the receiver during the interval between transmit pulses. In radar systems, it allows the waveguide system to be connected to both transmitter and receiver, while allowing them to share a common antenna.

Figure 2-17 illustrates the sub-components that constitute a duplexer. It consists of a 4 port circulator, a transmit-receive (TR) tube and a dummy load. Circulators accept RF transmit power from the transmitter and directs it through the waveguide to the antenna assembly. The circulator performs a second function by directing incoming target pulses to the receiver path.

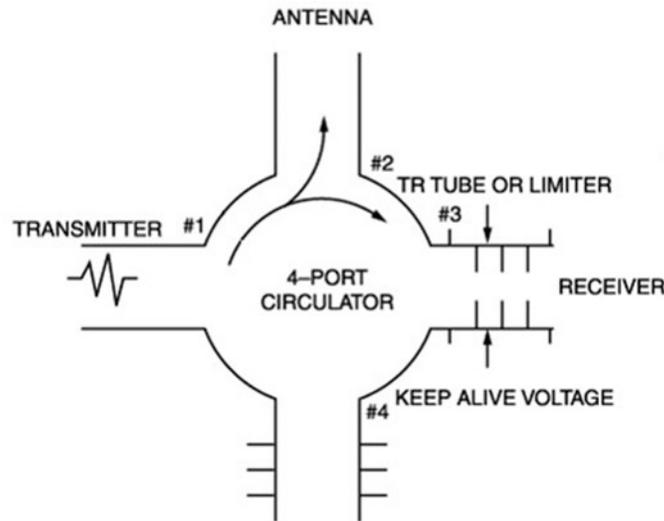


Figure 2-17. Duplexer.

Circulator

Circulators contain a ferrite material that only allows RF to travel in one direction (fig. 2-18). A permanent magnetic field permeates the ferrite material of each circulator, causing electromagnetic energy (RF) to bend within the circulator. Simply stated, the majority of the RF energy entering one port of a circulator will exit the next highest numbered port of the circulator.

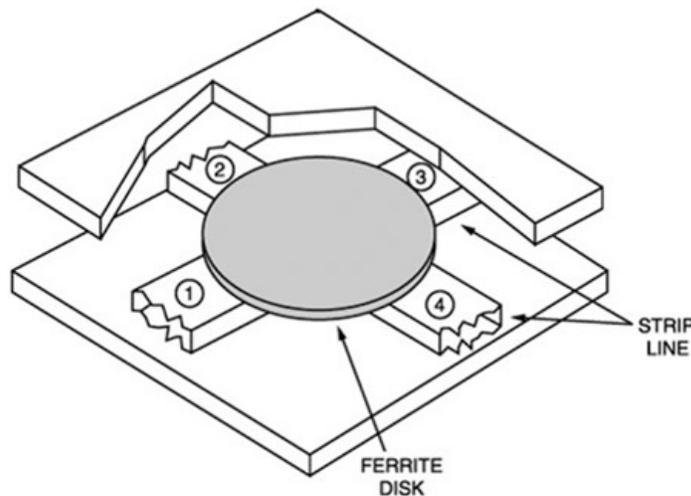


Figure 2-18. Circulator.

Transmit energy, entering port 1 (fig. 2-17), is forced to the right where it escapes through port 2, to the antenna. A portion of the transmitted pulse may bypass port 2 proceeding in a clockwise direction bypassing port 3 (due to the TR tube) and enter port 4 where it is dissipated in the dummy load. Moments later target echoes entering port 2 from the feedhorn are forced to the right and allowed to enter port 3 to the receiver.

Transmit-receive tube

The TR Tube, considered the duplexer's switch, must close the RF system to the receiver during transmission. To do this, the TR tube varies the impedance in the RF conduction paths. It protects the receiver from the high-power transmitter pulse.

The TR tube is filled with a radioactive gas that is kept close to ionization by a "Keep Alive" voltage that allows the high-powered transmitter pulse to complete the ionization. This places a short across the receiver path, (port 3) as seen in figure 2-17. This action keeps most of the transmitter pulse out of the receiver thus, protecting the receiver components during transmit.

The very weak low powered radar echoes enter port 2 from the antenna; they proceed to port 3 and can enter the deionized (opened) TR tube. The echo returns are not powerful enough to ionize the gas and short the tube. Therefore, these returns can enter the receiver and be processed.

Radio frequency switch

An RF switch may be thought of as a 2 to 1 multiplexer, but it is a little more complicated. One noticeable difference between a multiplexer and RF switch is the switch is a waveguide component.

When a radar set uses dual transmitting channels, a waveguide switch provides the required switching action between the antenna, the dummy load, and channel 1 and 2 waveguide components for routing of the RF signals.

Figure 2-19 shows a simplified drawing of a controlled rotating element waveguide switch. A channel change control circuit controls the drive motor that is mounted inside the switch housing. The motor shaft is connected to a worm gear. The worm gear is coupled to a disk by a flexible coupling. The flexible coupling provides spring tension to assure that the waveguide switch is held against its mechanical stops. A mechanical stop is mounted on the base of the switch at either extremity of travel.

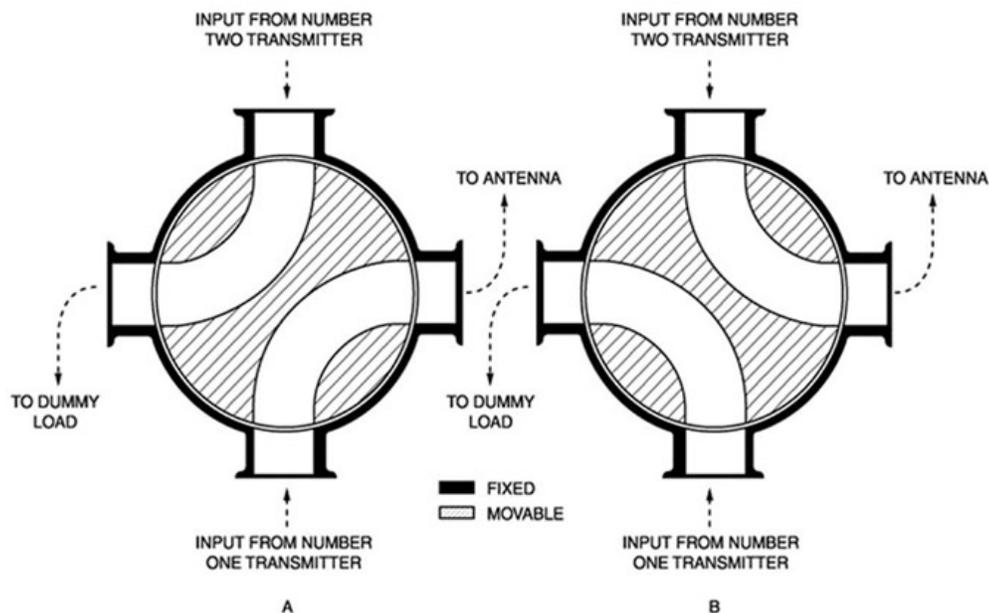


Figure 2-19. Controlled rotating element waveguide switch.

This mechanical stop provides accurate positioning for the rotating assembly. The shaft of the rotating structure is attached to a lever that operates the two sets of limit switches. This lever de-energizes the drive motor when the mechanical alignment reaches its limit, enabling the travel-limiting micro-switch. Two additional micro-switches are mounted adjacent to the travel-limiting switches.

The switches actuate the channel change check circuitry. This control circuit determines whether the waveguide switch has completed its operation on a change of channels. To prevent leakage of RF through the small gap between the rotating and stationary waveguide sections, choke flanges are used.

Diplexer

A diplexer is used in the waveguide to allow two channels (transmit or receive) to be connected to the same antenna (see fig. 2-20). The high-powered transmit line consists of two filters, a connecting tee, waveguide pressure windows, and protective cover.

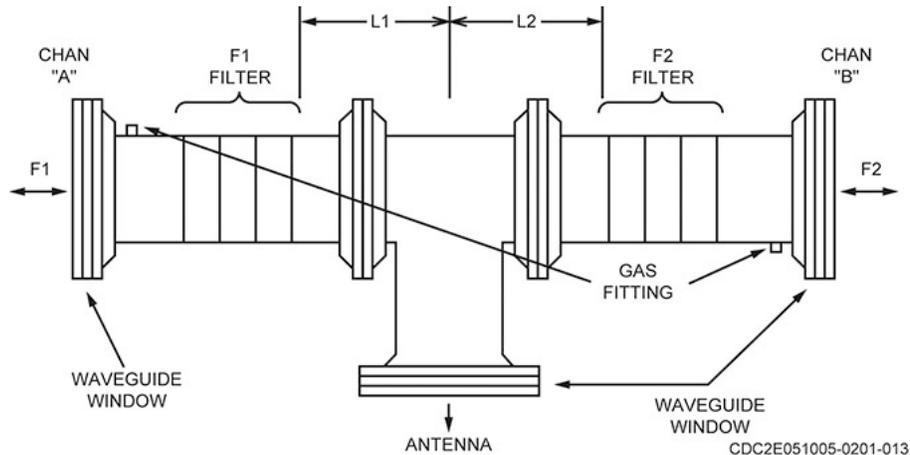


Figure 2-20. Diplexer.

To withstand a peak power of 500 kilowatts (kW), the high-power diplexer must be filled with sulfur hexafluoride. The unit is pressurized to 6 - 8 pounds per square inch (psi) under normal conditions; however, it will provide satisfactory operation at atmospheric pressure if the unit is filled with sulfur hexafluoride.

The receive (low-power) diplexer is identical, except it does not have the pressure windows, gas fittings, and the filter elements are designed to operate in a normal air atmosphere rather than a sulfur hexafluoride atmosphere. The basic diplexer consists of two RF filters, each fixed-tuned to the operating frequency of its respective channel and waveguide.

F1 frequency enters the channel A port and passes through the F1 RF filter. At the tee junction, the F2 RF filter blocks the F1 frequency. Therefore, all of channel A's power is conducted to the antenna through the antenna port. During receive the same condition exists. The frequency F1 returns are coupled to channel A and F2 returns are conducted to channel B. This is the key to having two different channel frequencies with their own tuned RF filters attached to one antenna.

Radio frequency filters

RF filters may be part of the coaxial transmission line on the input to the power amplifier, or part of the waveguide as the RF travels to the antenna. Very simply, RF filters filter out harmonic or unwanted frequencies.

Remember that the process of heterodyning (mixing) produces four frequencies, the two original frequencies, the sum, and the difference frequencies. Naturally, we only want to pass one of the frequencies. Usually, after such a process an RF filter is used. It will be tuned to the desired frequency of the circuit and filter spurious frequencies and harmonics of the RF pulse.

In addition, transients are generated when the electron beam is gated on and off. Therefore, its output is fed through a directional coupler to an RF filter that passes only those frequencies which are within the desired radar spectrum. The filter is entirely passive and requires no external AC power. From the filter, the RF energy is transferred to the antenna by rigid and flexible waveguide. The directional coupler, filter, and all waveguide elements are pressurized.

Directional coupler

The purpose of the directional coupler (fig. 2-21) is to enable maintenance personnel to monitor signals from the waveguide system, or inject test signals into the waveguide system.

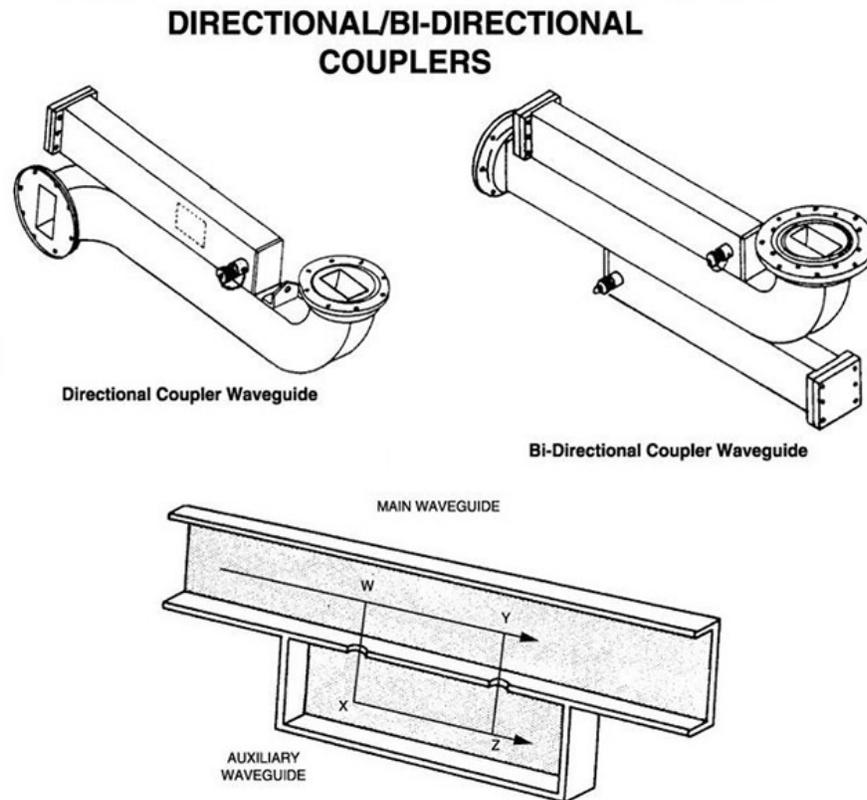


Figure 2-21. Directional couplers.

There are two basic types of directional couplers, bi-directional (two directions) and directional (one direction). In a bi-directional coupler, you can sample transmitted or received energy, whereas in a directional coupler sampling only one direction is possible.

Most radar sets actually use two directional couplers attached to the main waveguide and reversed with respect to each other (bi-directional coupler). One is above, and the other is usually below the main guide. At one coupler, you can monitor the incident energy while the other is reflected energy. An example of this would be to take a sample of the transmitter signal (incident) to check the power level of the transmitter. You could also inject a signal toward the receiver to check its sensitivity or how well it was picking up echo returns.

Directional couplers are normally used for testing purposes only. It should be noted that you will experience some loss of signal strength upon sampling or injecting a signal into the directional coupler. This attenuation is indicated on each directional coupler and therefore should be taken into account when making calculations.

Polarizer

Radar is susceptible to interference from rain and snow. Such precipitation can completely mask or clutter the radar indicator making aircraft detection impossible. A remedy for this problem is circular polarized radiation. This is accomplished with the use of a polarizer (fig. 2-22) that has a feedhorn attached. When used, the display of precipitation is reduced to nearly zero, permitting the aircraft target to be seen where it was previously invisible. It also reduces weather clutter seen on the

indicator. Most radar assemblies are designed so normal horizontal polarization can be used during clear weather, but switched to circular polarization when the need arises.

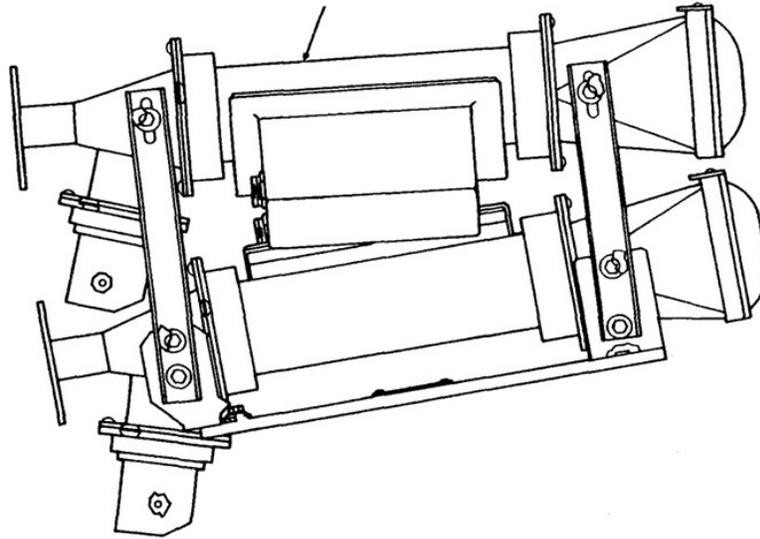


Figure 2-22. Polarizer.

Linear and circular modes are possible in the same antenna. Rotating specialized sections of the waveguide with a drive motor converts from one mode to the other. Return signals are horizontally polarized and are routed back through the waveguide in their original plane.

However, how does it really work? Spherical reflectors (rain) respond equally well to vertically and horizontally polarized energy. In fact, spheres respond the same to energy in any plane. Consequently, the return from a raindrop will be of constant amplitude, even when the polarization is effectively rotating (circular). The return from an irregular object, such as an aircraft, will show wide variations as the polarization is changed.

Each surface of the aircraft will respond differently to the horizontal and vertical components of the rotating energy. This difference between the constant return from a raindrop and irregular return of an aircraft allows the radar to differentiate between them, canceling one and amplifying the other to be displayed on an indicator. This process ultimately reduces the effects of bad weather on an indicator.

216. Radar system support functions

Often, it isn't possible or practical to locate the transmitting radar equipment near the operator's location. Therefore, this information must be transferred from the radar set to the control center with the highest degree of accuracy possible. Control signals must also be sent from the operations area to the radar equipment. It is also important to monitor the system for problems or test the equipment for reliability. This section will explain remoting and performance monitoring for radar equipment.

Remoting

Remoting is used to gather the necessary data and transfer it to where it is needed. This system can be configured to use several types of transmission media. The two most often used in radar are cable/land lines, and radio microwave links (RML) as shown in figure 2-23. A block diagram of various remote and control connections are displayed in figure 2-24.

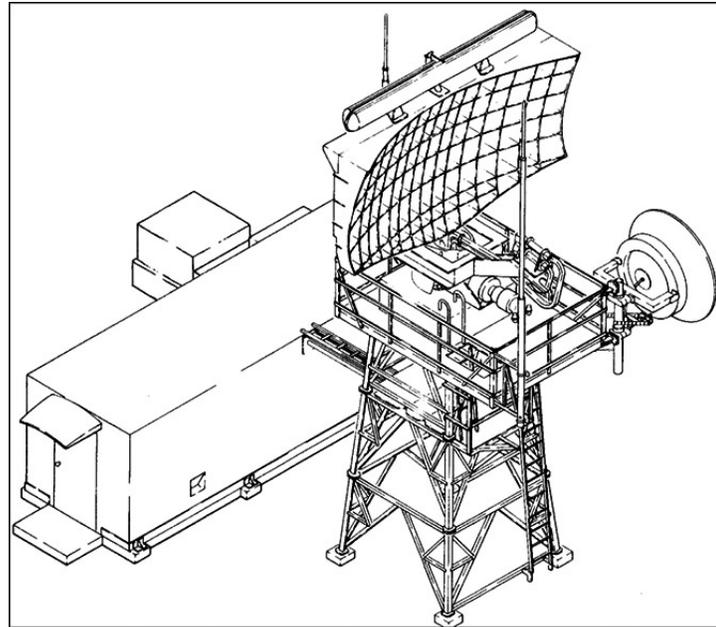


Figure 2-23. Radio microwave link.

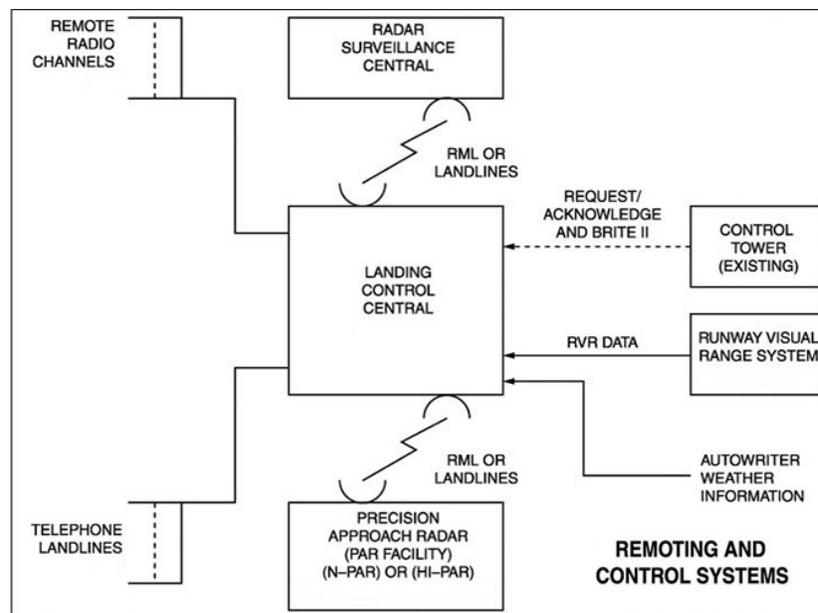


Figure 2-24. Remoting and control connections.

Coaxial cable remoting systems, while usually requiring less maintenance, have high signal loss through coaxial cable. For this reason, remote distances are limited to about 12,000 feet. Another disadvantage of cable is if run through wide valleys, rivers, or over roadways, it may be damaged. Where these conditions exist, radio microwave remoting is preferable. Microwave systems have a much longer range but are not without their specialized problems. Weather conditions, such as temperature inversion layers or other atmospheric conditions, may render the system unusable. Listening to a radio during a thunderstorm will give you a general idea of the problems atmospheric conditions may cause. Also, vehicles driven between the antennas may cause a temporary outage of the remoting system, if it completely blocks the RF energy (line of sight only). For this reason, you must be careful when planning a microwave remoting shot. The root of any remoting system is the process of combining all the information into a form that can be transferred with the least amount of equipment.

Performance monitoring

Performance monitors and BITE are used by the maintenance technician to help determine the operational usability and to troubleshoot the system. There are several types of built-in systems that present information on the operation of the radar. An example is displayed in figure 2-25.

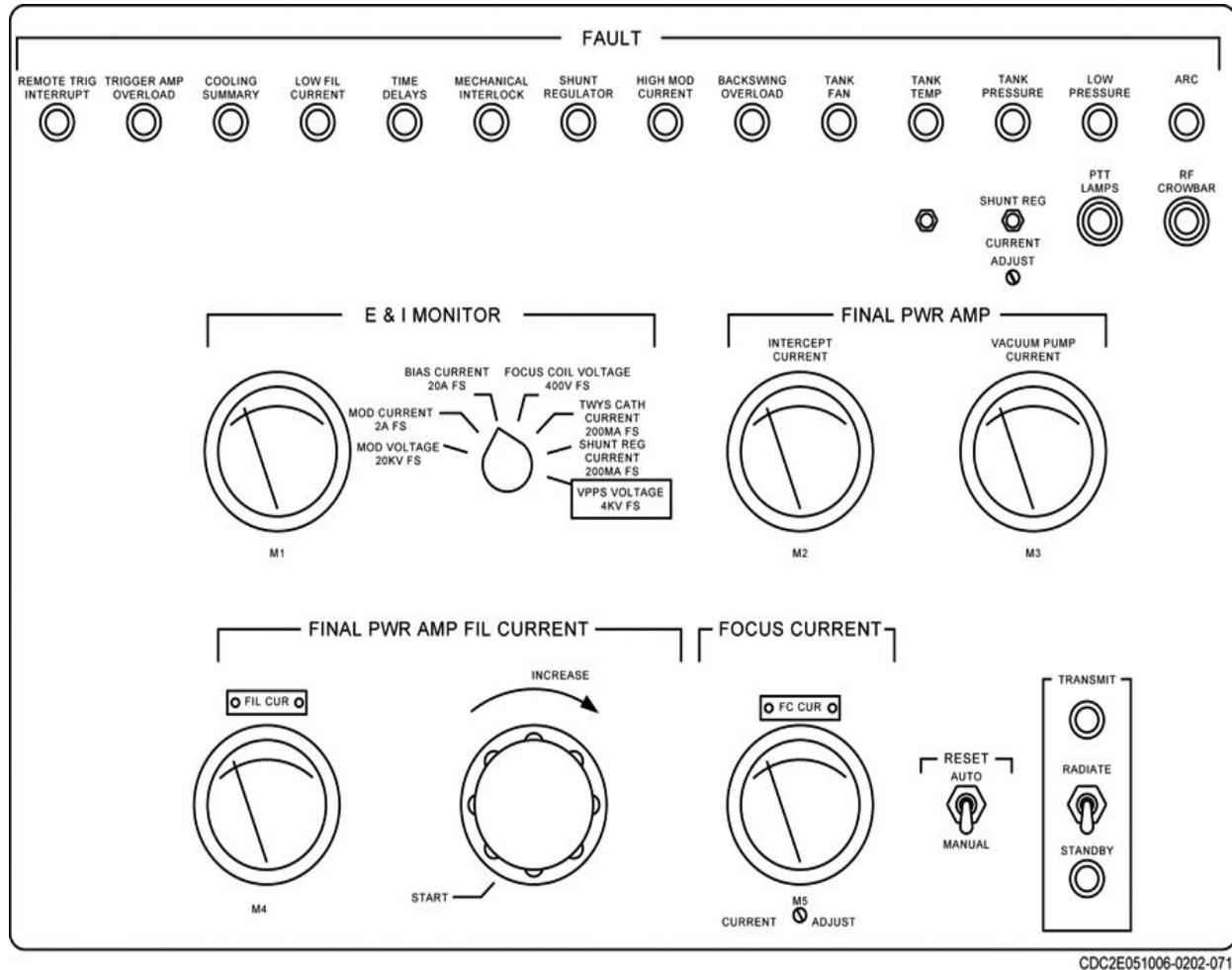


Figure 2-25. Built-in-test equipment.

These systems may be as simple as a fault light or as complex as a built-in spectrum analyzer. The signals measured can vary from input voltage to receiver sensitivity. These devices are intended to give a relative indication of system operation without having the maintainer set up several pieces of test equipment. While older radar systems had only a few pieces of BITE, modern systems have nearly every aspect of critical operation monitored by some sort of indicating device.

Performance monitoring can be in one of two realms. The first is to monitor signals produced by the radar system for normal operation (real-time), while the second uses signals injected and measured during non-operating times (dead-time). This dead-time is after the end of the receiver listening time but before the transmitter fires for the next PRT. These signals, of known characteristics, are then checked to ensure they have been processed correctly and displayed as either a meter indication or a signal on some type of display (fault panel, digital display, etc.). Performance monitors and BITE can be either on-line (working while the radar system is operating) or off-line (the radar set must be taken out of service).

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

214. Radio frequency waveguide

1. What is used to couple the components between waveguide sections to prevent RF leakage?
2. What process is used on waveguides to prevent arcing?
3. How are waveguides pressurized in fixed environments?

215. Other radio frequency devices

1. Explain how a rotary joint works.
2. What component allows the waveguide system to be connected to both transmitter and receiver, while allowing them to share a common antenna?
3. After the majority of the RF energy enters one port of a circulator, where will it exit?
4. What is the purpose of the TR tube?
5. When a radar set uses dual transmitting channels, what is needed to properly route the RF signals between the waveguide, antenna, and dummy load?
6. Explain the differences between a low-power and high-power diplexer.
7. The RF filters will filter out all frequencies *except* what frequency?
8. State the purpose of the directional coupler.
9. What important factor must you consider when making directional coupler measurements?

10. What component reduces precipitation and clutter to nearly zero?

11. Explain the differences in radar returns from raindrops and aircraft.

216. Radar system support functions

1. Name the two most commonly used mediums to remote radar equipment.
2. What is the distance restriction when remotng radar systems with coaxial cable?
3. What two things can assist a technician in determining the operational usability and troubleshooting of a radar system?

Answers to Self-Test Questions

209

1. When the requirements call for lightweight, compact equipment as used in aircraft.
2. As a vertical deflection from the horizontal baseline.
3. By the horizontal distance between the start trigger and the input signal.
4. An intensity-modulated electron beam presents the target as bright spots.
5. The PAR for both azimuth and elevation presentations.
6. It plots target range and azimuth information in polar coordinates.
7. The electron beam scans a phosphor-coated screen on the CRT in a pattern that goes from left to right and in incremental vertical steps from top to bottom.

210

1. Power supplies, data processing circuits, video circuits, deflection circuits, a CRT, and front panel controls.
2. The high voltage power supply.
3. (1) Control operations and data calculations.
(2) Interface.
(3) Data distribution.
4. By disabling the CRT high-voltage power supply.
5. By using X and Y coordinates with the origin at the center of the CRT screen.
6. Electrostatic and electromagnetic.
7. The aquadag.
8. The high vacuum and large surface area of the tube make the tube especially vulnerable to dangerous implosions.
9. To select input signals and messages, enter operating parameters, and adjust indicator format.

211

1. Mode 1, mode 2, mode 3/A, and mode C.
2. Mode 1 is 3 μ s, mode 2 is 5 μ s, mode 3/A is 8 μ s, and mode C is 21 μ s.
3. The mode 4 preamble contains four pulses and a blank space. Each pulse is 0.5 μ s wide, and the pulses are spaced 2 μ s apart.
4. 1030 MHz.
5. To eliminate sidelobe reception.

212

1. 32.
2. 7.
3. Mode C utilizes the Gray Code and has 100 feet increments.
4. Bracket or framing pulses.
5. 20.3 μ s apart.
6. The presence of an X pulse in the reply code train.
7. It signifies an I/P response has been generated by the aircraft pilot at the request of the operator.
8. Mode 3/A.
9. A 7600 emergency reply signifies a communications failure.
10. It can be received in any SIF mode, including mode C.
11. Only a US military aircraft.

213

1. Control and interface, IFF simulator, measurement system, interface, front panel, oscilloscope and power distribution.
2. (1) d.
(2) f.
(3) a.
(4) c.
(5) b.
(6) g.
(7) e.

214

1. Choke joints.
2. Air compressors supply dehydrated air for pressurizing the waveguide system.
3. Pressurized with air or inert gases.

215

1. It allows one waveguide section to remain stationary while the other section rotates on its axis.
2. Duplexer.
3. It will exit the next highest numbered port of the circulator.
4. It closes the RF system to the receiver during transmission.
5. RF switch.
6. The low-power diplexer does not have pressure windows, gas fittings, and the filter elements are designed to operate in a normal air atmosphere rather than a sulfur hexafluoride atmosphere.
7. The desired frequency of the circuit.
8. It enables maintenance personnel to monitor signals from the waveguide system, or inject test signals into the waveguide system.
9. The loss of signal strength upon sampling or injecting a signal into the directional coupler. This attenuation is indicated on each directional coupler.

10. Polarizer.
11. The return from a raindrop will be of constant amplitude, even when the polarization is effectively rotating (circular). The return from an irregular object, such as an aircraft, will show wide variations as the polarization is changed.

216

1. Cable/land lines, and RMLs.
2. 12,000 feet.
3. Performance monitors and BITE.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to AFCDA.

41. (209) What radar unit displays corresponding radar information on a cathode ray tube (CRT)?
 - a. Indicator.
 - b. Waveguide.
 - c. Analog Control Multiplexer (ACM).
 - d. Identification friend or foe/selective identification features (IFF/SIF).
42. (209) What type of cathode ray tube (CRT) is *mostly* used in ground radar equipment?
 - a. C-scan.
 - b. Raster beam.
 - c. Electrostatic.
 - d. Electromagnetic (EM).
43. (209) The *most* basic type of scanning indicator is the
 - a. A.
 - b. B.
 - c. C.
 - d. plan-position indicator (PPI).
44. (209) The scanning indicator that plots target range and azimuth information in polar coordinates is the
 - a. A.
 - b. B.
 - c. C.
 - d. plan-position indicator (PPI).
45. (209) What type of scanning indicator do surveillance radars *primarily* use?
 - a. B.
 - b. C.
 - c. Plan-position indicator (PPI).
 - d. Vertical scan electron beam display.
46. (209) What type of scanning indicator completes two vertical scan periods to produce one complete picture called a frame?
 - a. A.
 - b. Raster.
 - c. Plan-position indicator (PPI).
 - d. Vertical scan electron beam display.
47. (210) Which indicator power supply furnishes the cathode ray tube (CRT) operating voltages?
 - a. Deflection circuit.
 - b. Panel control.
 - c. High voltage.
 - d. Low voltage.

48. (210) Along with determining the overall operation of the indicator, the data processing circuits
- provide data distribution and interface with the radar.
 - protect the cathode ray tube (CRT) during certain malfunctions.
 - control the intensity of the cathode ray tube electron beam.
 - convert digital display data from the data processing circuits into analog drive signals.
49. (210) What indicator circuit converts digital display data from the data processing circuits into analog drive signals?
- Video.
 - Deflection.
 - Data processing.
 - Front panel control.
50. (210) What part of the cathode ray tube (CRT) is tapered and lined with a conductive graphite coating?
- Aquadag.
 - Faceplate.
 - Electron gun.
 - Deflection coils.
51. (210) The high vacuum and large surface area of the cathode ray tube (CRT) make it especially vulnerable to
- a large number of electron collisions.
 - interference.
 - implosions.
 - leakage.
52. (211) Which is *not* an advantage of identification friend or foe/selective identification feature (IFF/SIF) equipment?
- All coding and decoding is done automatically.
 - Interrogations and responses are pulse coded.
 - Only one mode is used for simplicity.
 - Special responses can be provided.
53. (211) An aircraft transponder answers an interrogation by transmitting a reply pulse train signal back to the ground station at a frequency of
- 1000 megahertz (MHz).
 - 1030 MHz.
 - 1060 MHz.
 - 1090 MHz.
54. (211) To eliminate interrogator side-lobe suppression (ISLS), the ground radar site transmits the P2 signal in what type of radiating pattern?
- Bi-directional.
 - Omnidirectional.
 - Directional, towards the lobes.
 - Directional, away from the lobes.
55. (212) What selective identification feature (SIF) mode has a limit of 32 codes?
- 1.
 - 2.
 - 3/A.
 - C.

-
-
56. (212) What generates an identification of position (I/P) response?
- Military radar facility.
 - Civilian facility.
 - Aircraft pilot.
 - AN/UPM-55.
57. (212) A 7600 emergency reply signifies an aircraft
- hijacking.
 - civilian emergency.
 - military emergency.
 - communications failure.
58. (212) What is the only type of aircraft that can present a single-arc identification friend or foe (IFF) reply on a scope?
- Civilian.
 - Military.
 - Unfriendly.
 - Commercial balloons and blimps.
59. (213) What function of the AN/UPM-155 test set provides overall control of the other functions?
- Interface.
 - Measurement.
 - Control and interface.
 - Control and measurement.
60. (213) What function of the AN/UPM-155 test set provides signal conditioning required for testing transponders and interrogators?
- Interface.
 - Measurement.
 - Control and interface.
 - Control and measurement.
61. (214) What are used to couple waveguide components and sections to prevent radio frequency (RF) leakage?
- Choke joints.
 - Compressors.
 - Radio frequency filters.
 - Radio frequency thermocouples.
62. (214) What do *most* radars use in their waveguide system to prevent arcing?
- Choke joints.
 - Air compressors.
 - Radio frequency (RF) filters.
 - Radio frequency thermocouples.
63. (214) What waveguide compressor subsystem controls operation of airflow and indicates normal or malfunction conditions?
- Filter.
 - Display.
 - Air flow.
 - Electrical.

64. (215) What duplexer sub-component accepts radio frequency (RF) transmit power from the transmitter and directs it through the waveguide to the antenna assembly?
- Radio frequency switch.
 - Transmit-receive (TR) tube.
 - Linear polarizer.
 - Circulator.
65. (215) What waveguide component has a mechanical stop mounted on its base to limit movement to each extremity of travel?
- Radio frequency (RF) switch.
 - Transmit-receive (TR) tube.
 - Linear polarizer.
 - Circulator.
66. (215) What antenna device reduces precipitation display to nearly zero on an indicator?
- Radio frequency (RF) switch.
 - Directional coupler.
 - Polarizer.
 - Diplexer.
67. (216) The two *most* often used radar remoting configurations are
- cable/land lines and radio microwave links.
 - cable/land lines and satellite links.
 - cable/land lines and omnidirectional antennas.
 - remote microwave links (RML) and omnidirectional antennas.
68. (216) Due to high signal loss, about how many feet are coaxial cable remoting systems limited to?
- 10,000.
 - 11,000.
 - 12,000.
 - 13,000.

Glossary of Abbreviations and Acronyms

μs	microsecond
AC	alternating current
AC&W	Air Control and Warning
ACM	Analog Control Multiplexer
AFC	automatic frequency control
AGC	automatic gain control
AP	anomalous propagation
ASDP	advanced signal/data processor
BITE	built-in test equipment
CCA	circuit card assembly
CFAR	constant false alarm rate
COHO	coherent oscillator
CPI	coherent processing interval
CPU	central processing unit
CRT	cathode ray tube
CW	continuous wave
DASR	digital air surveillance radar
DATCALs	deployable air traffic control and landing systems
dB	decibel
DC	direct current
DOD	Department of Defense
DSP	digital signal processor
E	electric
ECCM	electronic counter-countermeasures
ECM	electronic countermeasures
e_i	voltage
EM	electromagnetic
e_o	negative voltage
FIR	finite impulse response
FM	frequency modulated
FPGA	field programmable gate array
FTC	fast-time-constant
GCA	ground control approach
H	magnetic

I/P	identification of position
I/Q	in-phase and quadrature
IAGC	instantaneous automatic gain control
IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate frequency
IFF	identification friend or foe
IFF/SIF	identification friend or foe/selective identification features
ISLS	interrogation side-lobe suppression
kW	kilowatt
LIN-LOG	linear logarithmic
LO	local oscillator
MHz	megahertz
MTD	moving target detection
MTI	moving target indicator
mW	milliwatt
nm	nautical mile
nmi	1/16 nautical miles
NWS	National Weather Service
PAR	precision approach radar
PPI	plan-position indicator
pps	pulses per second
PRF	pulse repetition frequency
PRI	pulse recurrence interval
PRT	pulse recurrence time
psi	pounds per square inch
PSR	primary surveillance radar
PW	pulse width
radar	radio detection and ranging
RAG	range azimuth gating
RAWS	Radar, Airfield and Weather Systems
REX	receiver/exciter
RF	radio frequency
RIC	radar interface card
RIS	radar interface suppressor
RML	remote microwave link
RS	recommended standard

SBC	single board computer
SIF	selective identification features
STC	sensitivity time control
TR	transmit-receive
TWT	traveling-wave tube
UHF	ultra-high frequency
UUT	unit under test
VSWR	voltage standing wave ratio

Student Notes

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