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April 2013

Navy Electricity and Electronics Training Series

Module 18-Radar Principles

NAVEDTRA 14190A

S/N 0504LP1133062

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PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the *Manual of Navy Enlisted Manpower Personnel Classifications and Occupational Standards*, NAVPERS 18068.

THE QUESTIONS: The questions that appear in this course are designed to help you understand the material in the text.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

2013 Edition

Published by
Center for Surface Combat Systems (CSCS)

NAVSUP Logistics Tracking Number
0504-LP-113-3062

Sailor's Creed

“I am a United States Sailor.

I will support and defend the
Constitution of the United States of
America and I will obey the orders of those
appointed over me.

I represent the fighting spirit of the Navy
and those who have gone before me to
defend freedom and democracy around the
world.

I proudly serve my country's Navy combat
team with honor, courage and commitment.

I am committed to excellence and the fair
treatment of all.”

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NAVY ELECTRICITY AND ELECTRONICS TRAINING SERIES

The Navy Electricity and Electronics Training Series (NEETS) was developed for use by personnel in many electrical and electronic-related Navy ratings. Written by, and with the advice of, senior technicians in these ratings, this series provides beginners with fundamental electrical and electronic concepts through self-study. The presentation of this series is not oriented to any specific rating structure, but is divided into modules containing related information organized into traditional paths of instruction.

The series is designed to give small amounts of information that can be easily digested before advancing further into the more complex material. For a student just becoming acquainted with electricity or electronics, it is highly recommended that the modules be studied in their suggested sequence.

Considerable emphasis has been placed on illustrations to provide a maximum amount of information. In some instances, knowledge of basic algebra may be required.

Course descriptions and ordering information may be found at <https://www.netc.navy.mil> then click on the Programs tab, then select the Nonresident Training Courses from the list.

Throughout the text of this course and while using technical manuals associated with the equipment you will be working on, you will find the below notations at the end of some paragraphs. The notations are used to emphasize that safety hazards exist and care must be taken or observed.

WARNING

AN OPERATING PROCEDURE, PRACTICE, OR CONDITION, ETC., WHICH MAY RESULT IN INJURY OR DEATH IF NOT CAREFULLY OBSERVED OR FOLLOWED.

CAUTION

AN OPERATING PROCEDURE, PRACTICE, OR CONDITION, ETC., WHICH MAY RESULT IN DAMAGE TO EQUIPMENT IF NOT CAREFULLY OBSERVED OR FOLLOWED.

NOTE

An operating procedure, practice, or condition, etc., which is essential to emphasize.

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1 RADAR FUNDAMENTALS

LEARNING OBJECTIVES

After you finish this chapter, you should be able to do the following:

1. Define range, bearing, and altitude as they relate to a radar system.
2. Discuss how pulse width, peak power, and beam width affect radar performance.
3. Describe the factors that contribute to or detract from radar accuracy.
4. Using a block diagram, describe the basic function, principles of operation, and interrelationships of the basic units of a radar system.
5. Explain the various ways in which radar systems are classified, including the standard Army/Navy classification system.
6. Explain the basic operation of cw, pulse, and Doppler radar systems.

1.1 INTRODUCTION TO RADAR FUNDAMENTALS

The term RADAR is common in today's everyday language. You probably use it yourself when referring to a method of recording the speed of a moving object. The term *Radar* is an acronym made up of the words radio detection and ranging. The term is used to refer to electronic equipment that detect the presence, direction, height, and distance of objects by using reflected electromagnetic energy. Electromagnetic energy of the frequency used for radar is unaffected by darkness and also penetrates weather to some degree, depending on frequency. It permits radar systems to determine the positions of ships, planes, and land masses that are invisible to the naked eye because of distance, darkness, or weather.

The development of radar into the highly complex systems in use today represents the accumulated developments of many people and nations. The general principles of radar have been known for a long time, but many electronics discoveries were necessary before a useful radar system could be developed. World War II provided a strong incentive to develop practical radar, and early versions were in use soon after the war began. Radar technology has improved in the years since the war. We now have radar systems that are smaller, more efficient, and better than those early versions.

Modern radar systems are used for early detection of surface or air objects and provide extremely accurate information on distance, direction, height, and speed of the objects. Radar is also used to guide missiles to targets and direct the firing of gun systems. Other types of radar provide long-distance surveillance and navigation information.

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1.2 BASIC RADAR CONCEPTS

The electronics principle on which radar operates is very similar to the principle of sound-wave reflection. If you shout in the direction of a sound-reflecting object (like a rocky canyon or cave), you will hear an echo. If you know the speed of sound in air, you can then estimate the distance and general direction of the object. The time required for a return echo can be roughly converted to distance if the speed of sound is known. Radar uses electromagnetic energy pulses in much the same way, as shown in figure 1-1. The radio-frequency (rf) energy is transmitted to and reflects from the reflecting object. A small portion of the energy is reflected and returns to the radar set. This returned energy is called an ECHO, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting object.

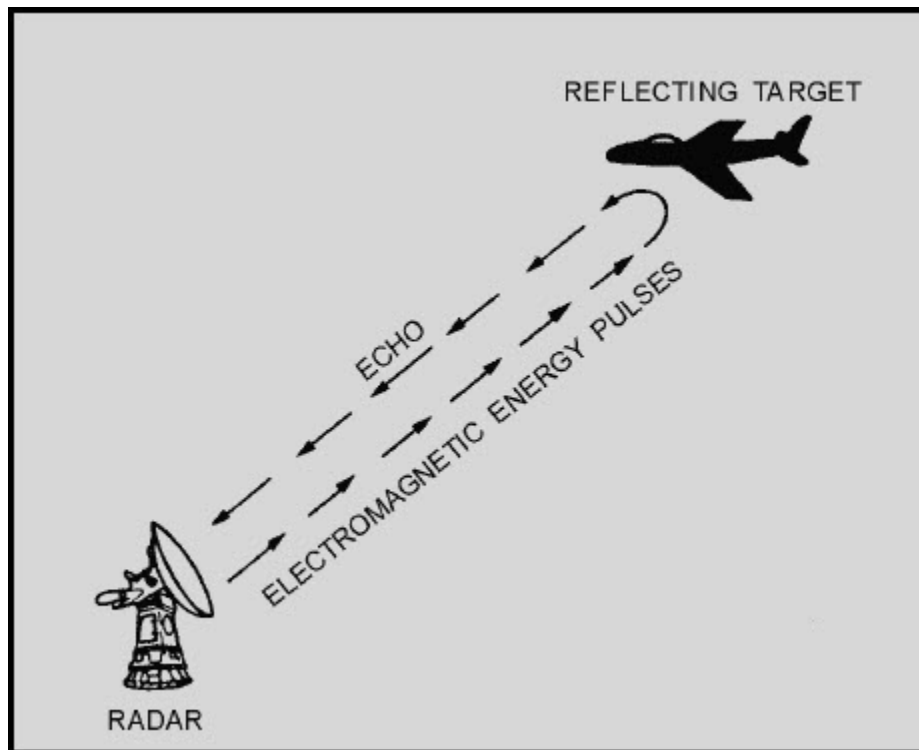


Figure 1-1 Radar echo

NOTE: The terms TARGET, RETURN, ECHO, CONTACT, OBJECT, and REFLECTING OBJECT are used interchangeably throughout this module to indicate a surface or airborne object that has been detected by a radar system.

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Radar systems also have some characteristics in common with telescopes. Both provide only a limited field of view and require reference coordinate systems to define the positions of detected objects. If you describe the location of an object as you see it through a telescope, you will most likely refer to prominent features of the landscape. Radar requires a more precise reference system. Radar surface angular measurements are normally made in a clockwise direction from TRUE NORTH, as shown in figure 1-2, or from the heading line of a ship or aircraft. The surface of the earth is represented by an imaginary flat plane, tangent (or parallel) to the earth's surface at that location. This plane is referred to as the HORIZONTAL PLANE. All angles in the up direction are measured in a second imaginary plane that is perpendicular to the horizontal plane.

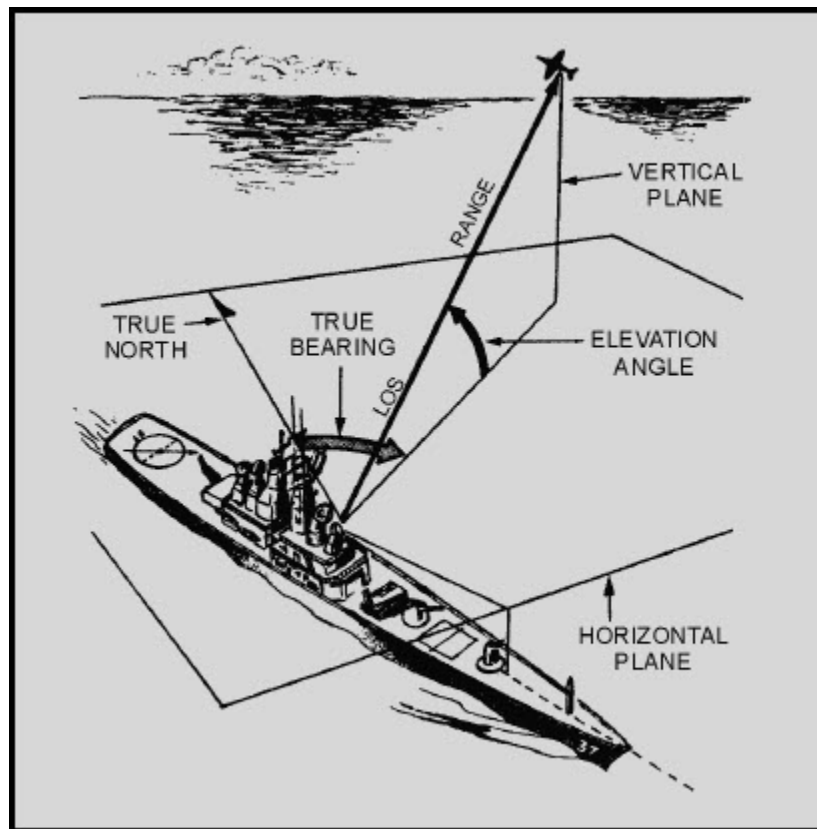


Figure 1-2 Radar reference coordinates

This second plane is called the VERTICAL PLANE. The radar location is the center of this coordinate system. The line from the radar set directly to the object is referred to as the LINE OF SIGHT (LOS). The length of this line is called RANGE. The angle between the horizontal plane and the LOS is the ELEVATION ANGLE. The angle measured clockwise from true north in the horizontal plane is called the TRUE BEARING or AZIMUTH angle. These three coordinates of range, bearing, and elevation describe the location of an object with respect to the antenna.

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Q1. Radar surface-angular measurements are referenced to true north and measured in what plane?

Q2. The distance from a radar set to a target measured along the line of sight is identified by what term?

1.2.1 Range

Radar measurement of range, or distance, is made possible because of the properties of radiated electromagnetic energy. This energy normally travels through space in a straight line, at a constant speed, and will vary only slightly because of atmospheric and weather conditions. The effects atmosphere and weather have on this energy will be discussed later in this chapter; however, for this discussion on determining range, these effects will be temporarily ignored.

Electromagnetic energy travels through air at approximately the speed of light, which is 186,000 STATUTE MILES per second. The Navy uses NAUTICAL MILES to calculate distances; 186,000 statute miles is approximately 162,000 nautical miles. While the distance of the statute mile is approximately 5,280 feet, the distance for a nautical mile is approximately 6,080 feet.

Radar timing is usually expressed in microseconds. To relate radar timing to distances traveled by radar energy, you should know that radiated energy from a radar set travels at approximately 984 feet per microsecond. With the knowledge that a nautical mile is approximately 6,080 feet, we can figure the approximate time required for radar energy to travel one nautical mile using the following calculation:

$$\begin{aligned} &\text{time for energy to travel one nautical mile} \\ &= \frac{6,080 \text{ feet}}{984 \text{ feet per microsecond}} \\ &= 6.18 \text{ microseconds (approx.)} \end{aligned}$$

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The same answer can be obtained using yards instead of feet. In the following calculation, the 6,080 foot approximation of a nautical mile is converted to 2,027 yards and energy speed is changed from 984 feet to 328 yards per microsecond:

$$\begin{aligned} \text{time for energy} \\ \text{to travel one} &= \frac{2,027 \text{ yards}}{328 \text{ yards per microsecond}} \\ \text{nautical mile} \\ &= 6.18 \text{ microseconds} \\ &\quad (\text{approx.}) \end{aligned}$$

A pulse-type radar set transmits a short burst of electromagnetic energy. Target range is determined by measuring elapsed time while the pulse travels to and returns from the target. Because two-way travel is involved, a total time of 12.36 (6.18 x 2) microseconds per nautical mile will elapse between the start of the pulse from the antenna and its return to the antenna from a target. This 12.36 microsecond time interval is sometimes referred to as a RADAR MILE, RADAR NAUTICAL MILE, or NAUTICAL RADAR MILE. The range in nautical miles to an object can be found by measuring the elapsed time during a *round trip* of a radar pulse and dividing this quantity by 12.36. In equation form, this is:

$$\text{range} = \frac{\text{elapsed time}}{12.36 \text{ microseconds per nautical mile}}$$

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For example, if the elapsed time for an echo is 62 microseconds, then the distance is 5 miles, as shown in the following calculation:

$$\begin{aligned} \text{range} &= \frac{\text{elapsed time}}{12.36 \text{ microseconds per nautical mile}} \\ &= \frac{62 \text{ microseconds}}{12.36 \text{ microseconds per nautical mile}} \\ &= 5 \text{ nautical miles (approx.)} \end{aligned}$$

NOTE: Unless otherwise stated all distances will be expressed as nautical miles throughout this module.

1.2.1.1 Minimum Range

Recall from NEETS, Module 11, *Microwave Principles*, that the DUPLEXER alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver. As you probably already realize, timing of this switching action is critical to the operation of the radar system. What you may not realize is that the minimum range ability of the radar system is also affected by this timing. The two most important times in this action are PULSE WIDTH and RECOVERY TIME.

This timing action must be such that during the transmitted pulse (pulse width), only the transmitter can be connected to the antenna. Immediately after the pulse is transmitted, the antenna must be reconnected to the receiver.

The leading edge of the transmitted pulse causes the duplexer to align the antenna to the transmitter. This action is essentially instantaneous. At the end of the transmitted pulse, the trailing edge of the pulse causes the duplexer to line up the antenna with the receiver; however, this action is not instantaneous. A small amount of time elapses at this point that is referred to as recovery time.

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Therefore, the total time in which the receiver is unable to receive the reflected pulse is equal to the pulse width plus the recovery time. Note that any reflected pulses from close targets returning before the receiver is connected to the antenna will be undetected. The minimum range, in yards, at which a target can be detected is determined using the following formula (pulse width and recovery time are expressed in microseconds or fractions of microseconds):

$$\text{minimum range} = \frac{\text{pulse width} + \text{recovery time}}{2} \times 328 \text{ yards}$$

or

$$\text{minimum range} = (\text{pulse width} + \text{recovery time}) \times 164 \text{ yds}$$

For example, minimum range for a radar system with a pulse width of 25 microseconds and a recovery time of 0.1 microseconds is figured as follows:

$$\begin{aligned} \text{minimum range} &= (25 + 0.1) \times 164 \text{ yards} \\ &= 25.1 \times 164 \text{ yards} \\ &= 4,116 \text{ yards (approximate)} \end{aligned}$$

Most modern radar systems are designed with such small recovery times that this figure can often be ignored when figuring minimum range.

1.2.1.2 Maximum Range

The maximum range of a pulse radar system depends upon CARRIER FREQUENCY, PEAK POWER of the transmitted pulse, PULSE-REPETITION FREQUENCY (prf) or PULSE REPETITION RATE (prr), and RECEIVER SENSITIVITY with prf as the primary limiting factor. The peak power of the pulse determines what maximum range the pulse can travel to a target and still return a usable echo. A usable echo is the smallest signal detectable by a receiver system that can be processed and presented on an indicator.

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The frequency of the rf energy in the pulse radiated by a radar is referred to as 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 radio frequency energy above 3,000 megahertz is rapidly attenuated by the atmosphere. This decreases the usable range of radio-frequency energy. Therefore, as the carrier frequency is increased, the transmitted power must also be increased to cover the same range. Long-range coverage is more easily achieved at lower frequencies because atmospheric conditions have less effect on low-frequency energy.

Radar systems radiate each pulse at the carrier frequency during transmit time, wait for returning echoes during listening or rest time, and then radiate a second pulse, as shown in figure 1-3. The number of pulses radiated in one second is called the pulse-repetition frequency (prf), or the pulse-repetition rate (pr). The time between the beginning of one pulse and the start of the next pulse is called **PULSEREPETITION TIME** (prt) and is equal to the reciprocal of prf as follows:

$$\text{prt} = \frac{1}{\text{prf}}$$

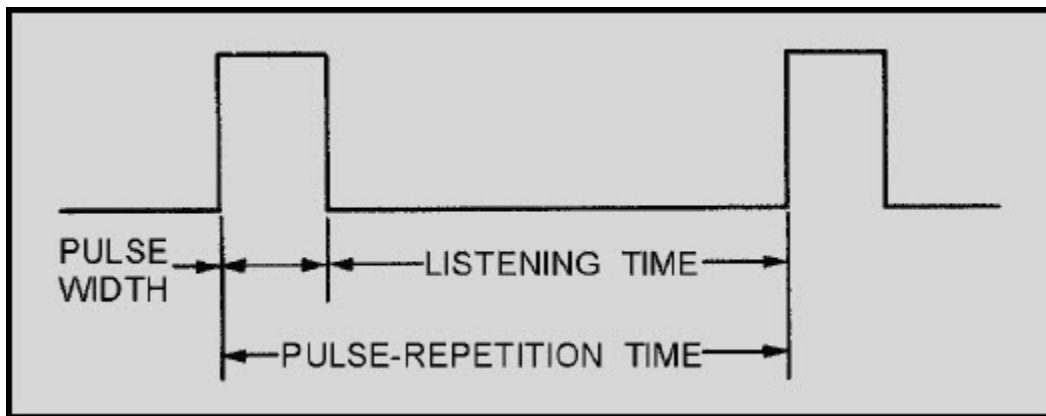


Figure 1-3 Radar pulse relationships

AMBIGUOUS RETURNS.—The radar timing system must be reset to zero each time a pulse is radiated. This is to ensure that the range detected is measured from time zero each time. The prt of the radar becomes important in maximum range determination because target return times that exceed the prt of the radar system appear at incorrect locations (ranges) on the radar screen. Returns that appear at these incorrect ranges are referred to as **AMBIGUOUS RETURNS** or **SECOND-SWEEP ECHOES**.

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Figure 1-4 illustrates a radar system with a 1 millisecond prt. The pulses are shown at the top, and examples of two transmitted pulses hitting targets and returning are shown at the bottom. In the case of target A, the pulse travels round trip in 0.5 millisecond, which equates to a target range of 82,000 yards. Since 0.5 millisecond is less than 1 millisecond, displaying a correct range is no problem. However, target B is 196,800 yards distant from the radar system. In this case, total pulse travel time is 1.2 milliseconds and exceeds the prt limitation of 1 millisecond for this radar. While the first transmitted pulse is traveling to and returning from target B, a second pulse is transmitted and the radar system is reset to 0 again. The first pulse from target B continues its journey back to the radar system, but arrives during the timing period for the second pulse. This results in an inaccurate reading. In this case, the first return pulse from target B arrives 0.2 millisecond into the second timing period. This results in a range of 32,800 yards instead of the actual 196,800 yards. You should see from this example that pulse returns in excess of the prt of the radar system result in ambiguous ranges while pulse returns within the prt limits result in normal (unambiguous) ranges. The maximum unambiguous range for a given radar system can be determined by the following formula:

$$R_{\text{max unambiguous}} = \frac{162,000 \text{ miles/second}}{2} \times \text{prt}$$

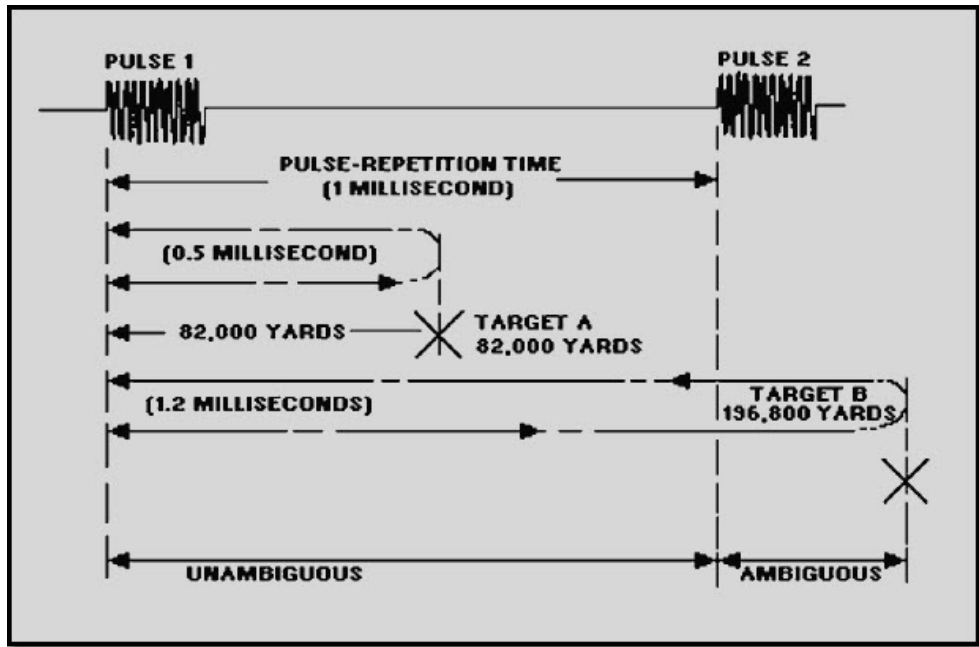


Figure 1-4 Maximum unambiguous range

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Q3. What is the speed of electromagnetic energy traveling through air?

Q4. How much time is required for electromagnetic energy to travel 1 nautical mile and return to the source?

Q5. In addition to recovery time, what determines the minimum range of a radar set?

PULSE-REPETITION FREQUENCY AND POWER CALCULATIONS.—The energy content of a continuous-wave radar transmission may be easily figured because the transmitter operates continuously. However, pulsed radar transmitters are switched on and off to provide range timing information with each pulse. The resulting waveform for a transmitter was shown in figure 1-3. The amount of energy in this waveform is important because maximum range is directly related to transmitter output power. The more energy the radar system transmits, the greater the target detection range will be. The energy content of the pulse is equal to the **PEAK (maximum) POWER LEVEL** of the pulse multiplied by the pulse width. However, meters used to measure power in a radar system do so over a period of time that is longer than the pulse width. For this reason, pulse-repetition time is included in the power calculations for transmitters. Power measured over such a period of time is referred to as **AVERAGE POWER**. Figure 1-5 illustrates the way this average power would be shown as the *total* energy content of the pulse. The shaded area represents the total energy content of the pulse; the crosshatched area represents average power and is equal to peak power spread out over the prt. (Keep in mind, as you look at figure 1-5, that *no energy is actually present between pulses* in a pulsed radar system. The figure is drawn just to show you how average power is calculated.) Pulse-repetition time is used to help figure average power because it defines the total time from the beginning of one pulse to the beginning of the next pulse. Average power is figured as follows:

Where: P_{avg} = average power
 P_{pk} = peak power
pw = pulse width
prt = pulse-repetition time

$$P_{avg} = P_{pk} \times \frac{pw}{prt}$$

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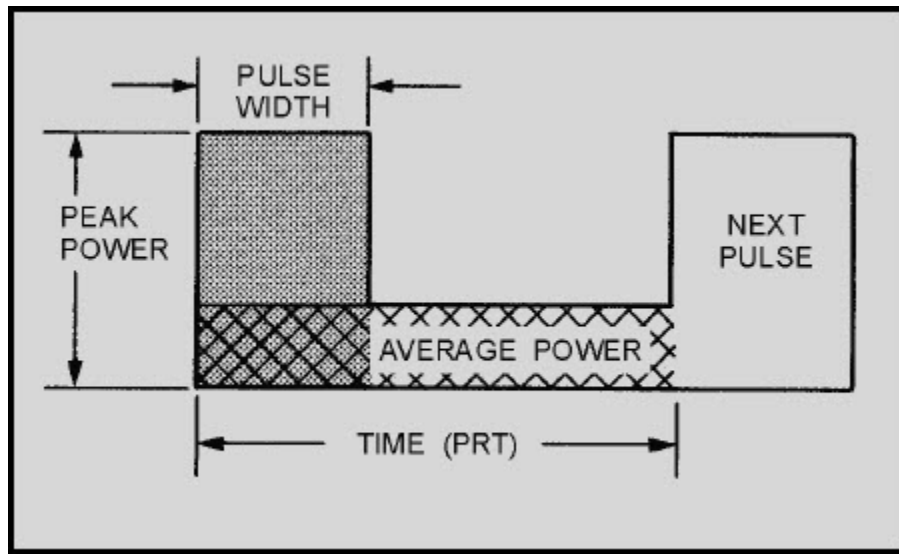


Figure 1-5 Pulse energy content

Because $1/\text{prt}$ is equal to prf , the formula may be written as follows:

$$P_{\text{avg}} = P_{\text{pk}} \times \text{pw} \times \text{prf}$$

The product of pulse width (pw) and pulse-repetition frequency (prf) in the above formula is called the **DUTY CYCLE** of a radar system. The duty cycle is a ratio of the *time on* to the *time off* of the transmitter, as shown in figure 1-6. The duty cycle is used to calculate both the peak power and average power of a radar system. The formula for duty cycle is shown below:

$$\text{duty cycle} = \text{pw} \times \text{prf}$$

NOTE: Pulse repetition frequency (prf) and pulse repetition rate (pr) are interchangeable terms.

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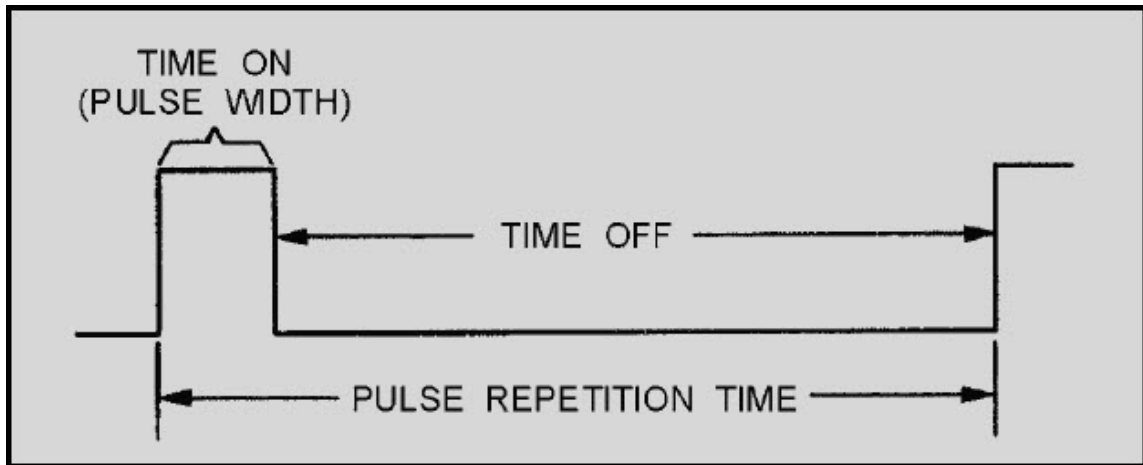


Figure 1-6 Duty cycle

Since the duty cycle of a radar is usually known, the most common formula for average power is expressed as:

$$P_{avg} = P_{pk} \times \text{duty cycle}$$

Transposing the above formula gives us a common formula for peak power:

$$P_{pk} = \frac{P_{avg}}{\text{duty cycle}}$$

Peak power must be calculated more often than average power. This is because, as previously mentioned, most measurement instruments measure average power directly. An example is shown below:

$$\begin{aligned} P_{avg} &= 20,000 \text{ watts} \\ pw &= 20 \text{ microseconds } (20 \times 10^{-6}) \\ prf &= 1,000 \text{ or } 10^3 \text{ pulses per second} \end{aligned}$$

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Before figuring P_p , you must figure duty cycle as follows:

$$\begin{aligned} \text{duty cycle} &= \text{pw} \times \text{prf} \\ &= 20 \times 10^{-6} \times 10^3 \times 20 \times 10^{-3} \\ &= .02 \end{aligned}$$

Now that you have duty cycle, P_p may be calculated as follows:

$$\begin{aligned} P_{pk} &= \frac{P_{avg}}{\text{duty cycle}} \\ &= \frac{20,000}{.02} \\ &= 1,000,000 \text{ or } 10^6 \text{ watts} \end{aligned}$$

ANTENNA HEIGHT AND SPEED.—Another factor affecting radar range is antenna height. The high-frequency energy transmitted by a radar system travels in a straight line and does not normally bend to conform to the curvature of the earth. Because of this, the height of both the antenna and the target are factors in detection range. The distance to the horizon (in nautical miles) for a radar system varies with the height of the antenna according to the following formula:

$$\text{radar horizon distance} = 1.25 \sqrt{\text{antenna height in feet}} \\ \text{(in nautical miles)}$$

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For example, assume antenna height to be 64 feet in the following calculations:

$$\text{range} = \frac{\text{elapsed time}}{12.36 \text{ microseconds per nautical mile}}$$

A target at a range greater than the radar horizon will not be detected unless it is high enough to be above the horizon. An example of the antenna- and target-height relationship is shown in figure 1-7.

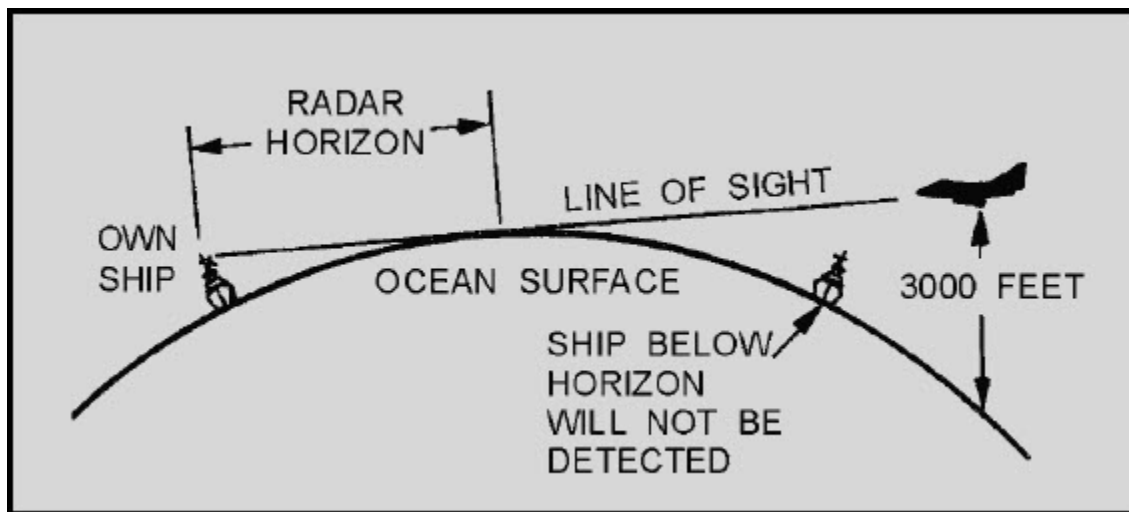


Figure 1-7 Radar horizon

The antenna-rotation rate also affects maximum detection range. The slower an antenna rotates, the greater the detection range of a radar system. When the antenna is rotated at 10 revolutions per minute (rpm), the beam of energy strikes each target for just one-half the time it would if the rotation were 5 rpm.

The number of strikes per antenna revolution is referred to as HITS PER SCAN. During each revolution enough pulses must be transmitted to return a usable echo.

NOTE: The more pulses transmitted to a given area (at slower antenna speeds), the greater the number of hits per scan.

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As an example, if the antenna rotates at 20 rpm, it completes a revolution in 3 seconds. During this time, a transmitter with a prf of 200 pulses per second (pps) transmits 600 pulses. Since 360 degrees of azimuth must be covered, the following formula shows the number of pulses for each degree of azimuth:

$$\frac{600 \text{ pulses per revolution}}{360 \text{ degrees per revolution}} = 1.67 \text{ pulses per degree}$$

Such a low number of pulses for any given target area greatly increases the likelihood that some targets will be missed entirely; therefore, prf and antenna speed must be matched for maximum efficiency.

Q6. Atmospheric interference with the travel of electromagnetic energy increases with what rf energy characteristic?

Q7. How is prt related to prf?

Q8. What type of radar transmitter power is measured over a period of time?

Q9. What term is used to describe the product of pulse width and pulse-repetition frequency?

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1.2.2 Bearing

The TRUE BEARING (referenced to true north) of a radar target is the angle between true north and a line pointed directly at the target. This angle is measured in the horizontal plane and in a clockwise direction from true north. The bearing angle to the radar target may also be measured in a clockwise direction from the centerline of your own ship or aircraft and is referred to as the RELATIVE BEARING. Both true and relative bearing angles are illustrated in figure 1-8.

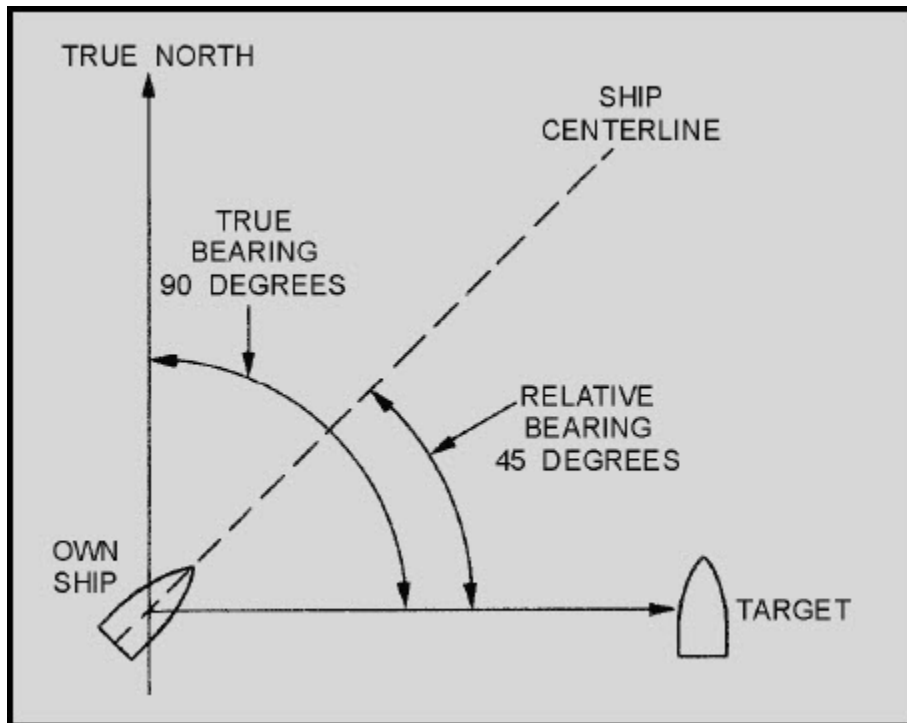


Figure 1-8 True and relative bearings

The antennas of most radar systems are designed to radiate energy in a one-directional lobe or beam that can be moved in bearing simply by moving the antenna. As you can see in figure 1-9, the shape of the beam is such that the echo signal strength varies in amplitude as the antenna beam moves across the target. At antenna position **A**, the echo is minimal; at position **B**, where the beam axis is pointing directly at the target, the echo strength is maximum. Thus, the bearing angle of the target can be obtained by moving the antenna to the position at which the echo is strongest. In actual practice, search radar antennas move continuously; the point of maximum echo return is determined by the detection circuitry as the beam passes the target or visually by the operator. Weapons-control and guidance radar systems are positioned to the point of maximum signal return and maintained at that position either manually or by automatic tracking circuits.

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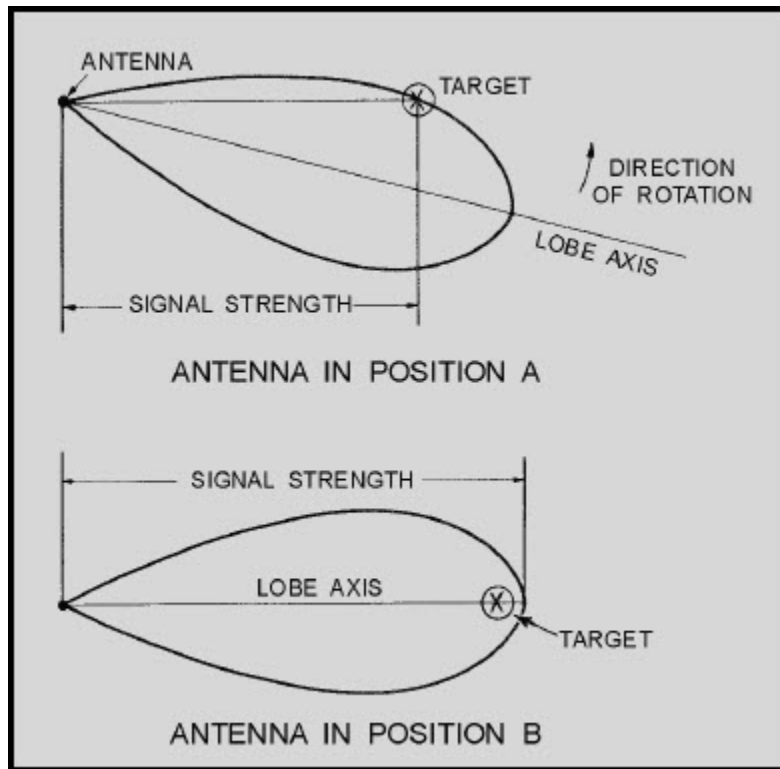


Figure 1-9 Determination of bearing

1.2.3 Altitude

Many radar systems are designed to determine only the range and bearing of an object. Such radar systems are called TWO-DIMENSIONAL (2D) radars. In most cases these systems are further described as SEARCH RADAR SYSTEMS and function as early-warning devices that search a fixed volume of space. The range and bearing coordinates provide enough information to place the target in a general area with respect to the radar site and to determine distance, direction of travel, and relative speed. However, when action must be taken against an airborne target, altitude must be known as well. A search radar system that detects altitude as well as range and bearing is called a THREE-DIMENSIONAL (3D) radar.

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Altitude- or height-finding search radars use a beam that is very narrow in the vertical plane. The beam is scanned in elevation, either mechanically or electronically, to pinpoint targets. Height-finding radar systems that also determine bearing must have a beam that is very narrow in both the vertical and horizontal planes. An electronic elevation-scanning pattern for a search radar set is illustrated in figure 1-10. Lines originating at the antenna indicate the number of beam positions required for complete elevation coverage. In practice the beams overlap slightly to prevent any gaps in the coverage. Each beam position corresponds to a slight change in either the frequency or phase of the radiated energy. A change in either phase or frequency of the energy causes it to leave the antenna at a different angle. Thus, the frequency or phase can be predetermined to create an orderly scanning pattern that covers the entire vertical plane. Electronic scanning permits automatic compensation for an unstable radar platform (site), such as a ship at sea. Error signals are produced by the roll and pitch of the ship and are used to correct the radar beam to ensure complete elevation coverage.

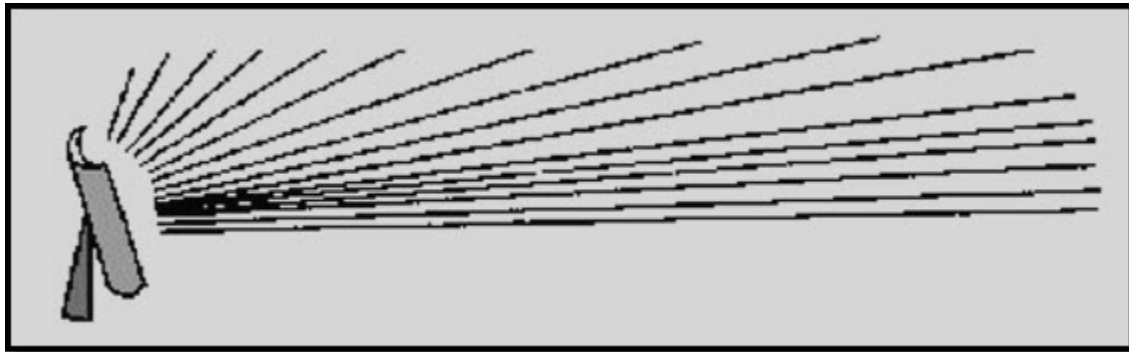


Figure 1-10 Electronic elevation scan

Mechanical elevation scanning is achieved by mechanically moving the antenna or radiation source. Weapons-control and tracking radar systems commonly use mechanical elevation scanning techniques. Most electronically scanned radar systems are used as air search radars. Some older air-search radar systems use a mechanical elevation scanning device; however, these are being replaced by electronically scanned radar systems.

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Q10. What type of target bearing is referenced to your ship?

Q11. What type of radar detects range, bearing, and height?

Q12. What characteristic(s) of radiated energy is (are) altered to achieve electronic scanning?

1.2.4 Target Resolution

The TARGET RESOLUTION of a radar is its ability to distinguish between targets that are very close together in either range or bearing. Weapons-control radar, which requires great precision, should be able to distinguish between targets that are only yards apart. Search radar is usually less precise and only distinguishes between targets that are hundreds of yards or even miles apart. Resolution is usually divided into two categories; RANGE RESOLUTION and BEARING RESOLUTION.

1.2.4.1 Range Resolution

Range resolution is the ability of a radar system to distinguish between two or more targets on the same bearing but at different ranges. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator. Pulse width is the primary factor in range resolution. A well-designed radar system, with all other factors at maximum efficiency, should be able to distinguish targets separated by one-half the pulse width time. Therefore, the theoretical range resolution of a radar system can be calculated from the following formula:

$$\text{range resolution} = \frac{\text{pw (microseconds)}}{2} \times 328 \text{ yards per microsecond}$$

(in yards)

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The above formula is often written as:

$$\text{range resolution} = \text{pw} \times 164 \text{ yards per microsecond}$$

For example, if a radar system has a pulse width of 5 microseconds, the range resolution is calculated as follows:

$$\begin{aligned} \text{range resolution} &= \text{pw} \times 164 \text{ yards per microsecond} \\ &= 5 \times 164 \text{ yards per microsecond} \\ &= 820 \text{ yards} \end{aligned}$$

In the above example, targets on the same bearing would have to be separated by more than 820 yards to show up as two targets on your indicator.

1.2.4.2 Bearing Resolution

Bearing, or azimuth, resolution is the ability of a radar system to separate objects at the same range but at different bearings. The degree of bearing resolution depends on radar beam width and the range of the targets. Range is a factor in bearing resolution because the radar beam spreads out as range increases. A RADAR BEAM is defined in width in terms of HALF-POWER POINTS. All the points off the centerline of the beam that are at one-half the power level at the center are plotted to define beam width. When the half-power points are connected to the antenna by a curve, such as that shown in figure 1-11, the resulting angular width of the curve is called the ANTENNA BEAM WIDTH. The physical size and shape of the antenna determines beam width. Beam width can vary from about 1 degree up to 60 degrees. In figure 1-11, only the target within the half-power points will reflect a useful echo. Two targets at the same range must be separated by at least one beam width to be distinguished as two objects.

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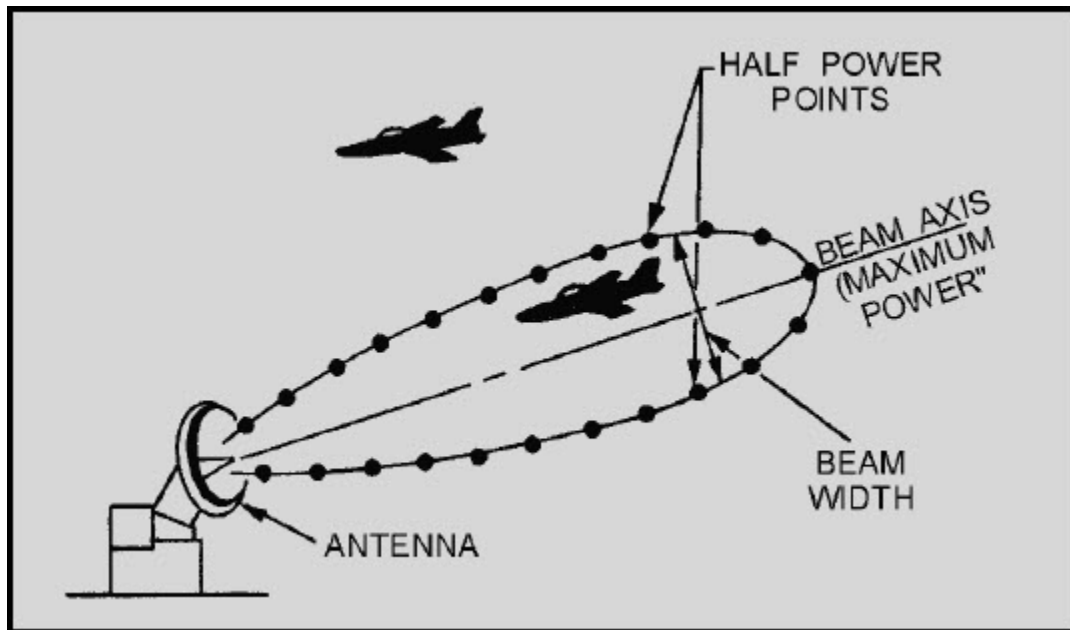


Figure 1-11 Beam half-power points

1.2.5 Radar Accuracy

Radar accuracy is a measure of the ability of a radar system to determine the correct range, bearing, and, in some cases, height of an object. The degree of accuracy is primarily determined by the resolution of the radar system. Some additional factors affecting accuracy are pulse shape and atmospheric conditions.

1.2.5.1 Pulse Shape

In the case of a pulse radar, the shape and width of the rf pulse influences minimum range, range accuracy, and maximum range. The ideal pulse shape is a square wave having vertical leading and trailing edges. However, equipments do not usually produce the ideal waveforms.

The factors influencing minimum range are discussed first. Since the receiver cannot receive target reflections while the transmitter is operating, you should be able to see that a narrow pulse is necessary for short ranges. A sloping trailing edge extends the width of the transmitter pulse, although it may add very little to the total power generated. Therefore, along with a narrow pulse, the trailing edge should be as near vertical as possible.

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A sloping leading edge also affects minimum range as well as range accuracy since it provides no definite point from which to measure elapsed time on the indicator time base. Using a starting point at the lower edge of the pulse's leading edge would increase minimum range. Using a starting point high up on the slope would reduce the accuracy of range measurements at short ranges which are so vital for accurate solution of the fire-control problem.

Maximum range is influenced by pulse width and pulse repetition frequency (prf). Since a target can reflect only a very small part of the transmitted power, the greater the transmitted power, the greater the strength of the echo that could be received. Thus, a transmitted pulse should quickly rise to its maximum amplitude, remain at this amplitude for the duration of the desired pulse width, and decay instantaneously to zero. Figure 1-12 illustrates the effects of pulse shapes.

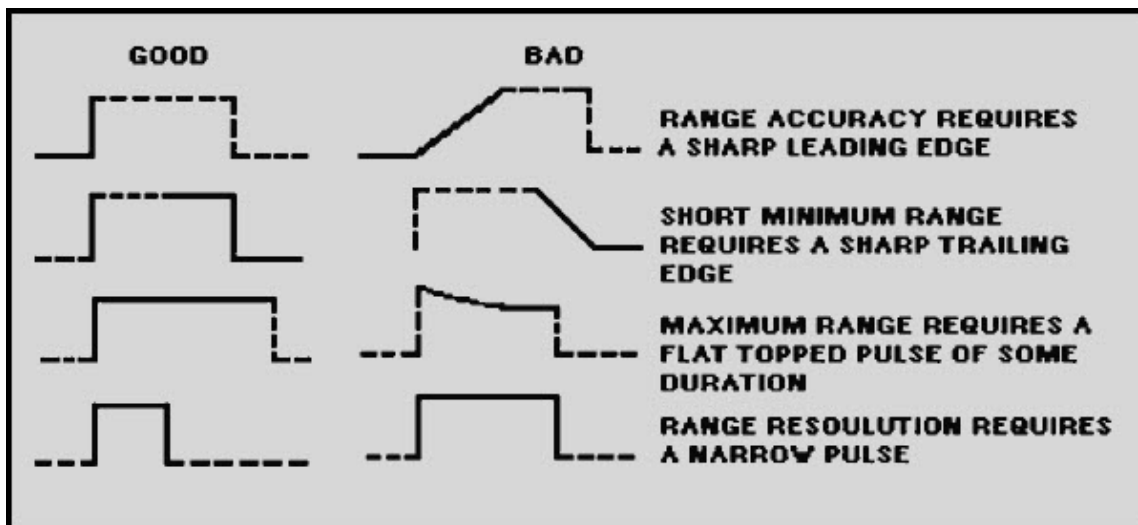


Figure 1-12 Pulse shapes and effects

1.2.5.2 Atmospheric Conditions

Electromagnetic wavefronts 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, usually 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 1-13. The downward curve extends the radar horizon beyond a line tangent to the earth, as illustrated in figure 1-14.

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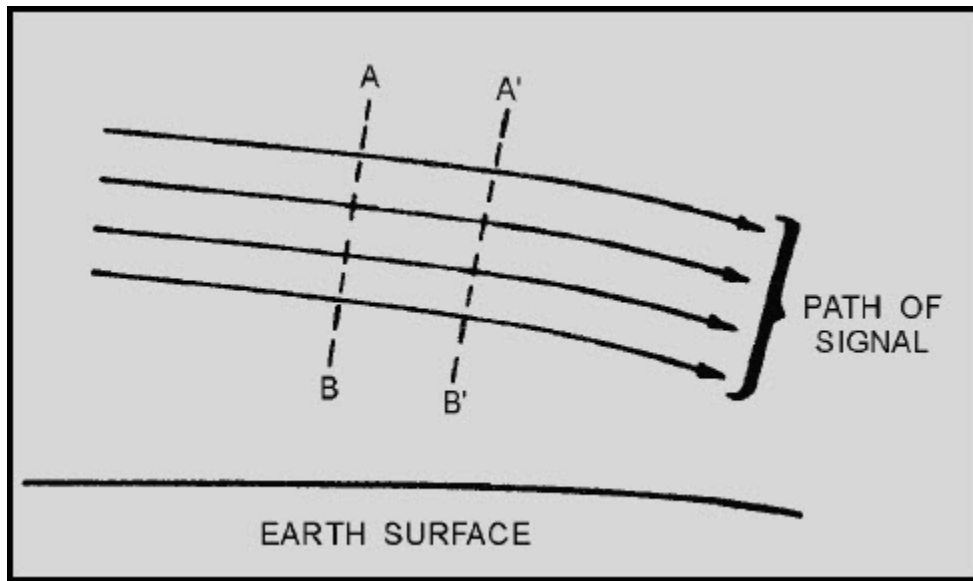


Figure 1-13 Wavefront path

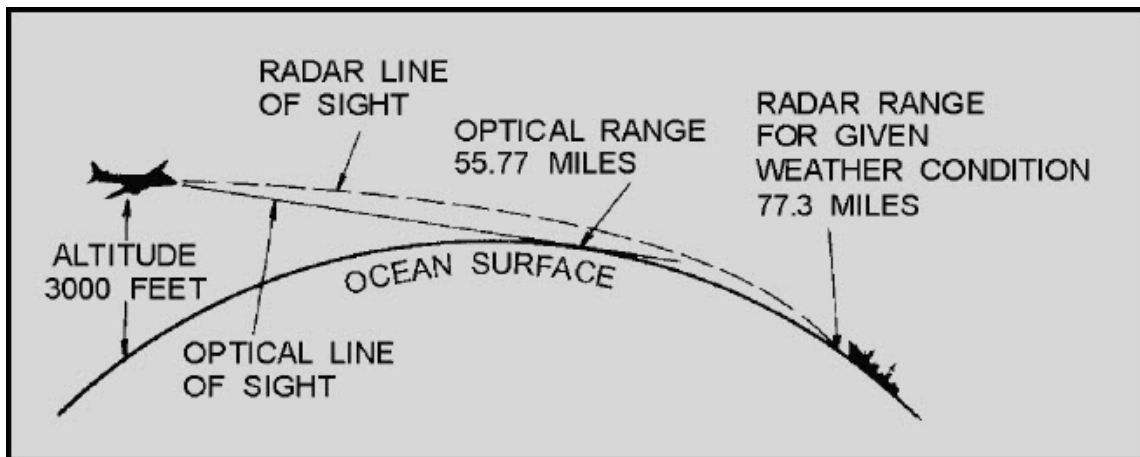


Figure 1-14 Extension of the radar horizon

The reason for the downward curve can be illustrated using line **AB** in figure 1-13. 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.

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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. 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.

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. An even more important deviation from normal may exist over the ocean. 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. The effect of ducting on radar waves is illustrated in figure 1-15.

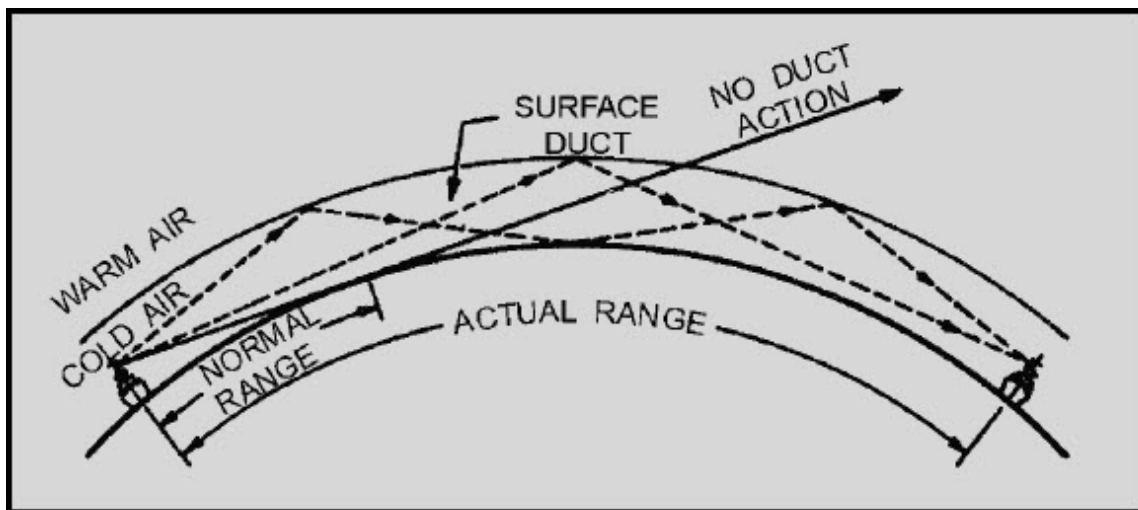


Figure 1-15 Ducting effect on the radar wave

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Another effect of the atmosphere on radar performance is caused by particles suspended in the air. 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 it is affected by weather conditions such as rain or clouds. In some parts of the world, dust suspended in the air can greatly decrease the normal range of high-frequency radar.

Q13. What term is used to describe the ability of a radar system to distinguish between targets that are close together?

Q14. The degree of bearing resolution for a given radar system depends on what two factors?

Q15. What happens to the speed of electromagnetic energy traveling through air as the altitude increases?

Q16. What term is used to describe a situation in which atmospheric temperature first increases with altitude and then begins to decrease?

1.3 RADAR PRINCIPLES OF OPERATION

Radar systems, like other complex electronics systems, are composed of several major subsystems and many individual circuits. This section will introduce you to the major subsystems common to most radar sets. A brief functional description of subsystem principles of operation will be provided. A much more detailed explanation of radar subsystems will be given in chapters 2 and 3. Since most radar systems in use today are some variation of the pulse radar system, the units discussed in this section will be those used in pulse radar. All other types of radar use some variation of these units, and these variations will be explained as necessary.

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1.3.1 RADAR COMPONENTS

Pulse radar systems can be functionally divided into the six essential components shown in figure 1-16. These components are briefly described in the following paragraphs and will be explained in detail after that:

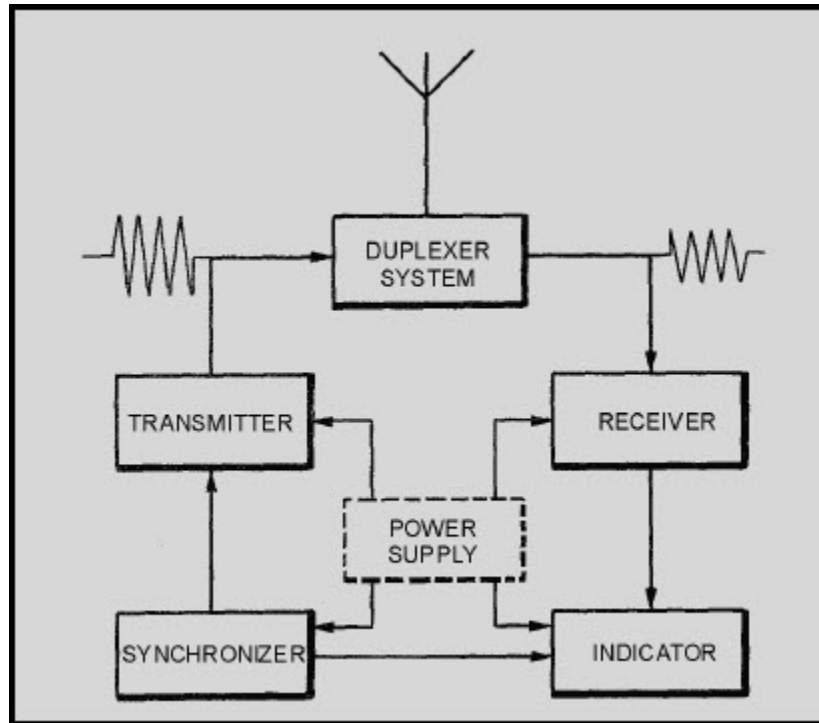


Figure 1-16 Functional block diagram of a basic radar system

- The SYNCHRONIZER (also referred to as the TIMER or KEYSER) supplies the synchronizing signals that time the transmitted pulses, the indicator, and other associated circuits.
- The TRANSMITTER generates electromagnetic energy in the form of short, powerful pulses.
- The DUPLEXER allows the same antenna to be used for transmitting and receiving.
- The ANTENNA SYSTEM routes the electromagnetic energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and routes those echoes to the receiver.
- The RECEIVER amplifies the weak, electromagnetic pulses returned from the reflecting object and reproduces them as video pulses that are sent to the indicator.

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- The INDICATOR produces a visual indication of the echo pulses in a manner that, at a minimum, furnishes range and bearing information.

While the physical configurations of radar systems differ, any radar system can be represented by the functional block diagram in figure 1-16. 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, a brief description of the operation of each of the major components is given.

1.3.1.1 Synchronizer (Timer)

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

1.3.1.2 Transmitter

The transmitter generates powerful pulses of electromagnetic energy at precise intervals. The required power is obtained by using a high-power microwave oscillator, such as a magnetron, or a microwave amplifier, such as a klystron, that is supplied by a low-power rf source. (The construction and operation of microwave components can be reviewed in NEETS, Module 11, *Microwave Principles*.) 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 unit 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. Safety precautions must always be strictly observed when working in or around a radar transmitter.

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1.3.1.3 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 previously mentioned, 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.

1.3.1.4 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 a minimum of 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.

1.3.1.5 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 SUPER HETERODYNE 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.

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1.3.1.6 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 sweep frequency of the radar indicator is determined by the pulse-repetition frequency of the radar system. Sweep duration is determined by the setting of 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.

Q17. What radar subsystem supplies timing signals to coordinate the operation of the complete system?

Q18. When a transmitter uses a high-power oscillator to produce the output pulse, what switches the oscillator on and off?

Q19. What radar component permits the use of a single antenna for both transmitting and receiving?

1.3.2 Scanning

Radar systems are often identified by the type of SCANNING the system uses. Scanning is the systematic movement of a radar beam in a definite pattern while searching for or tracking a target. The type and method of scanning used depends on the purpose and type of radar and on the antenna size and design. In some cases, the type of scan will change with the particular system mode of operation. For example, in a particular radar system, the search mode scan may be quite different from that of the track mode scan.

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1.3.2.1 Stationary-Lobe Scanning

A SINGLE STATIONARY-LOBE SCANNING SYSTEM is the simplest type of scanning. This method produces a single beam that is stationary in relation to the antenna. The antenna is then mechanically rotated continuously to obtain complete 360-degree azimuth coverage. A stationary lobe, however, cannot satisfactorily track a moving object because it does not provide enough information about the object's movement to operate automatic tracking circuits, such as those in fire-control tracking radar. A two-dimensional search radar, however, does use a single-lobe that is scanned in a 360-degree pattern because automatic tracking circuits are not normally used in 2D radars.

Single-lobe scanning is unsuitable for use as a tracking radar for several reasons. For example, let's assume that a target is somewhere on the lobe axis and the receiver is detecting signals reflected from the target. If these reflected signals begin to decrease in strength, the target likely has flown off the lobe axis. In this case, the beam must be moved to continue tracking. The beam might be moved by an operator tracking the target with an optical sight, but such tracking is slow, inaccurate, and limited by conditions of visibility. An automatic tracking system would require that the beam SCAN, or search, the target area in such a case.

Again, assume that a missile is riding (following) the axis of a single beam. The strength of the signals it receives (by means of a radar receiver in the missile) will gradually decrease as its distance from the transmitter increases. If the signal strength decreases suddenly, the missile will know, from built-in detection circuitry, that it is no longer on the axis of the lobe. But it will *not* know which way to turn to get back on the axis. A simple beam does not contain enough information for missile guidance.

1.3.2.2 Methods of Beam Scanning

The two basic methods of beam scanning are MECHANICAL and ELECTRONIC. In mechanical scanning, the beam can be moved in various ways: (1) The entire antenna can be moved in the desired pattern; (2) the energy feed source can be moved relative to a fixed reflector; or (3) the reflector can be moved relative to a fixed source. In electronic scanning, the beam is effectively moved by such means as (1) switching between a set of feeder sources, (2) varying the phasing between elements in a multielement array, or (3) comparing the amplitude and phase differences between signals received by a multielement array. A combination of mechanical and electronic scanning is also used in some antenna systems.

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MECHANICAL SCANNING.—The most common type of mechanical scanning is the rotation of the antenna through 360 degrees to obtain azimuth coverage. Most search radar sets use this method. A common form of scanning for target tracking or missile beam-rider systems is CONICAL (cone-like) SCANNING. This is generally accomplished mechanically by NUTATING the rf feed point.

Nutation is difficult to describe in words but easy to demonstrate. Hold a pencil in two hands. While holding the eraser end as still as possible, swing the point in a circular motion. This motion of the pencil is referred to as nutation; the pencil point corresponds to the open, or transmitting, end of the waveguide antenna. The important fact to remember is that polarization of the beam is not changed during the scanning cycle. This means that the axis of the moving feeder does not change either horizontal or vertical orientation while the feeder is moving. You might compare the feeder movement to that of a ferris wheel; that is, the vertical orientation of each seat remains the same regardless of the position of the wheel.

Recall that a waveguide is a metal pipe, usually rectangular in cross section, used to conduct the rf energy from the transmitter to the antenna. The open end of the waveguide faces the concave side of the reflector and the rf energy it emits is bounced from the reflector surface.

A conical scan can be generated by nutation of the waveguide. In this process the axis of the waveguide itself is moved through a small conical pattern. In an actual installation of a nutating waveguide, the three-dimensional movement is fast and of small amplitude. To an observer, the waveguide appears merely to be vibrating slightly.

By movement of either the waveguide or the antenna, you can generate a conical scan pattern, as shown in figure 1-17. The axis of the radar lobe is made to sweep out a cone in space; the apex of this cone is, of course, at the radar transmitter antenna or reflector. At any given distance from the antenna, the path of the lobe axis is a circle. Within the useful range of the beam, the inner edge of the lobe always overlaps the axis of scan.

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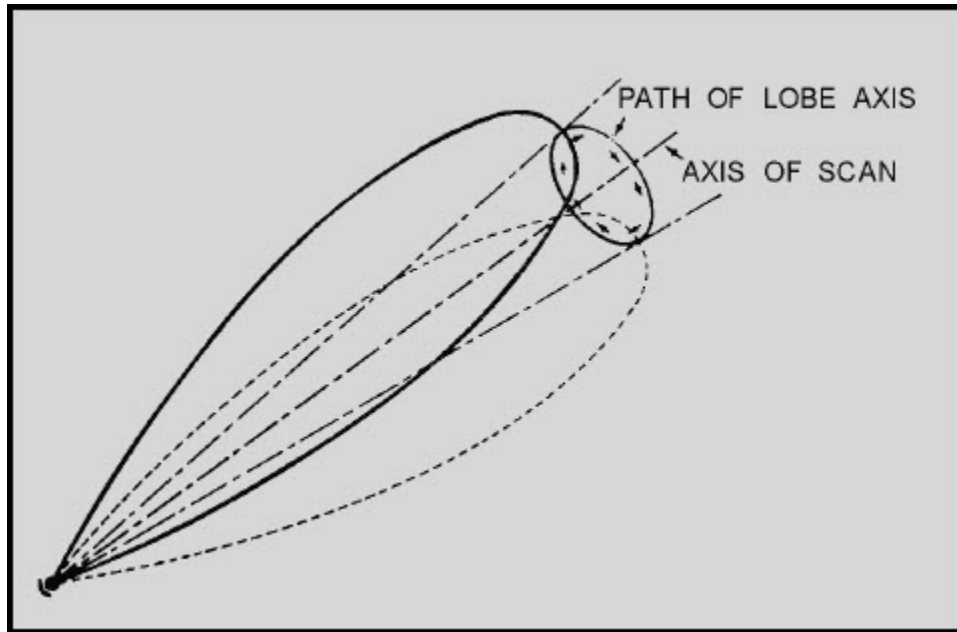


Figure 1-17 Conical scanning.

Now assume that we use a conically scanned beam for target tracking. If the target is on the scan axis, the strength of the reflected signals remains constant (or changes gradually as the range changes). But if the target is slightly off the axis, the amplitude of the reflected signals will change at the scan rate. For example, if the target is to the left of the scan axis, as shown in figure 1-18, 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 is used to control servomechanisms that move the antenna. In this way, the target is tracked accurately and automatically.

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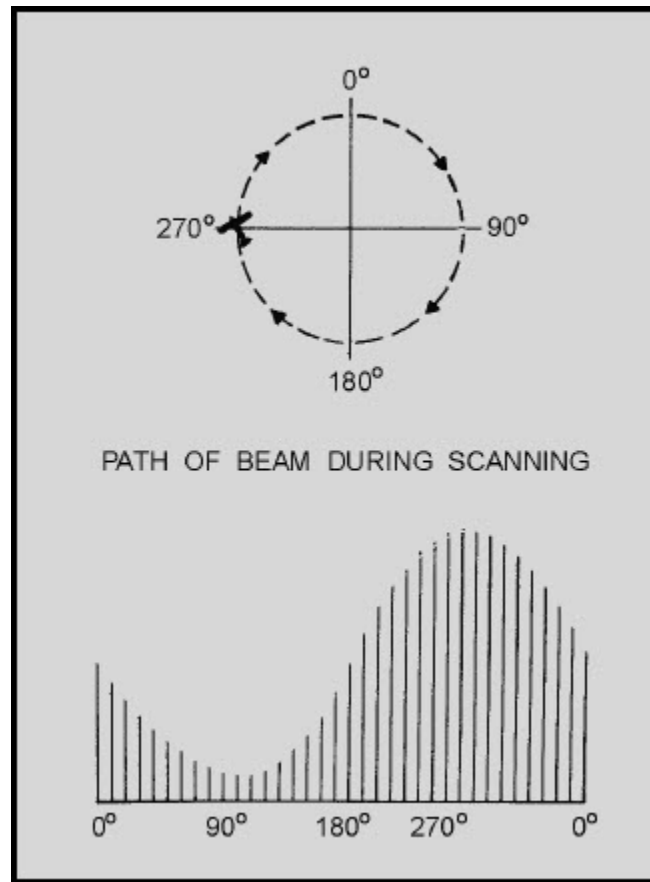


Figure 1-18 Reflected signal strength

Q20. What is the simplest type of scanning?

Q21. How does the operator of a single-lobe scanning system determine when the target moves off the lobe axis?

Q22. What are the two basic methods of scanning?

Q23. Rotation of an rf-feed source to produce a conical scan pattern is identified by what term?

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ELECTRONIC SCANNING.—Electronic scanning can accomplish lobe motion more rapidly than, and without the inherent maintenance disadvantages of, the mechanical systems. Because electronic scanning cannot generally cover as large an area of space, it is sometimes combined with mechanical scanning in particular applications.

With **MONOPULSE (SIMULTANEOUS) LOBING**, all range, bearing, and elevation-angle information of a target is obtained from a single pulse. Monopulse scanning is used in fire-control tracking radars.

For target tracking, the radar discussed here produces a narrow circular beam of pulsed-rf energy at a high pulse-repetition rate. Each pulse is divided into four signals which are equal both in amplitude and phase. These four signals are radiated at the same time from each of four feedhorns that are grouped in a cluster. The resulting radiated energy is focused into a beam by a microwave lens. Energy reflected from targets is refocused by the lens back into the feedhorns. The total amount of the energy received by each horn varies, depending on the position of the target relative to the beam axis. This is illustrated in figure 1-19 for four targets at different positions with respect to the beam axis. Note that a phase inversion takes place at the microwave lens similar to the image inversion that takes place in an optical system.

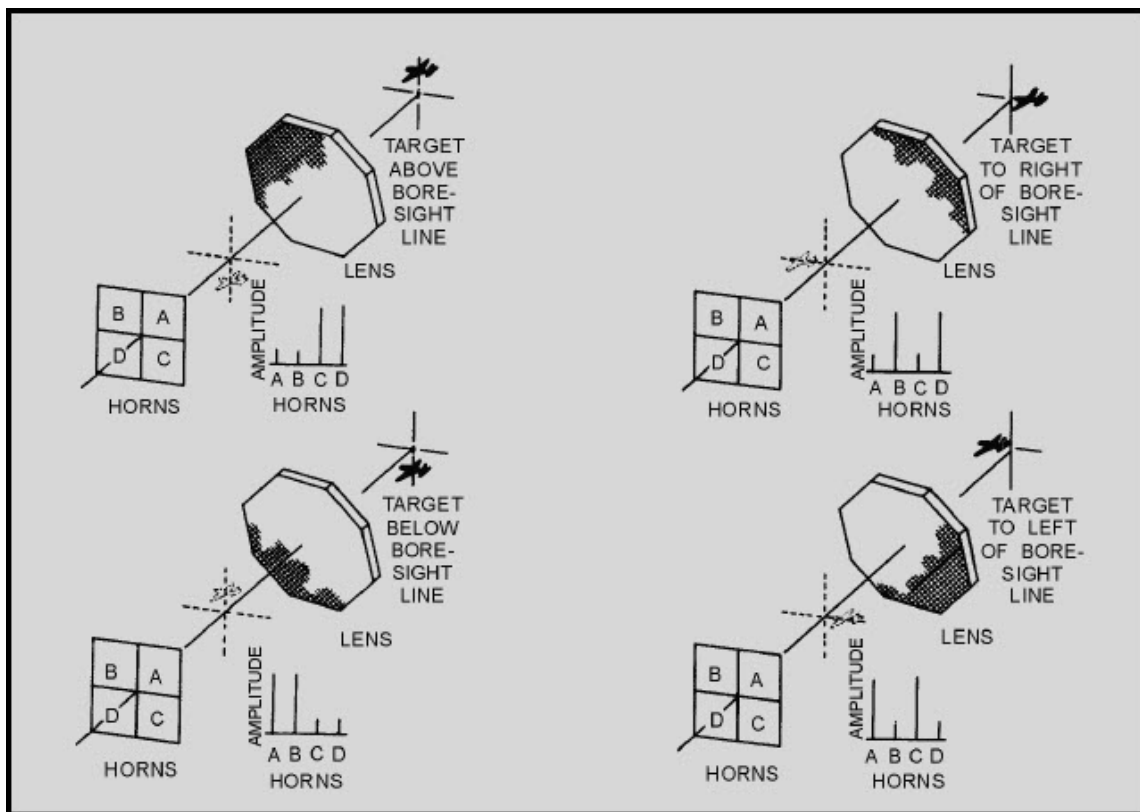


Figure 1-19 Monopulse scanning

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The amplitude of returned signals received by each horn is continuously compared with those received in the other horns. Error signals are generated which indicate the relative position of the target with respect to the axis of the beam. Angle servo circuits receive these error signals and correct the position of the radar beam to keep the beam axis on target.

The TRAVERSE (BEARING) SIGNAL is made up of signals from horn **A** added to **C** and from horn **B** added to **D**. By waveguide design, the sum of **B** and **D** is made 180 degrees out of phase with the sum of **A** and **C**. These two are combined and the traverse signal is the difference of $(\mathbf{A} + \mathbf{C}) - (\mathbf{B} + \mathbf{D})$. Since the horns are positioned as shown in figure 1-19, the relative amplitudes of the horn signals give an indication of the magnitude of the traverse error. The elevation signal consists of the signals from horns **C** and **D** added 180 degrees out of phase with horns **A** and **B** $[(\mathbf{A} + \mathbf{B}) - (\mathbf{C} + \mathbf{D})]$. The sum, or range, signal is composed of signals from all four feedhorns added together in phase. It provides a reference from which target direction from the center of the beam axis is measured. The range signal is also used as a phase reference for the traverse and elevation-error signals.

The traverse and elevation error signals are compared in the radar receiver with the range or reference signal. The output of the receiver may be either positive or negative pulses; the amplitudes of the pulses are proportional to the angle between the beam axis and a line drawn to the target. The polarities of the output pulses indicate whether the target is above or below, to the right or to the left of the beam axis. Of course, if the target is directly on the line of sight, the output of the receiver is zero and no angle-tracking error is produced.

An important advantage of a monopulse-tracking radar over radar using conical scan is that the instantaneous angular measurements are not subject to errors caused by target SCINTILLATION. Scintillation can occur as the target maneuvers or moves and the radar pulses bounce off different areas of the target. This causes random reflectivity and may lead to tracking errors. Monopulse tracking radar is not subject to this type of error because each pulse provides an angular measurement without regard to the rest of the pulse train; no such cross-section fluctuations can affect the measurement. An additional advantage of monopulse tracking is that no mechanical action is required.

ELECTRONIC SCANNING used in search radar systems was explained in general terms earlier in this chapter during the discussion of elevation coverage. This type of electronic scanning is often called FREQUENCY SCANNING. An in-depth explanation of frequency scanning theory can be found in the fire control technician rate training manuals.

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1.4 RADAR TRANSMISSION METHODS

Radar systems are normally divided into operational categories based on energy transmission methods. Up to this point, we have mentioned only the pulse method of transmission to illustrate basic radar concepts. Although the pulse method is the most common method of transmitting radar energy, two other methods are sometimes used in special applications. These are the continuous-wave (cw) method and the frequency modulation (fm) method. All three basic transmission methods are often further subdivided to designate specific variations or combinations.

1.4.1 Continuous-Wave Method

When radio-frequency energy transmitted from a fixed point continuously strikes an object that is either moving toward or away from the source of the energy, the *frequency* of the reflected energy is changed. This shift in frequency is known as the **DOPPLER EFFECT**. The difference in frequency between the transmitted and reflected energy indicates both the presence and the speed of a moving target.

1.4.1.1 Doppler Effect

A common example of the Doppler effect in action is the changing pitch of the whistle of an approaching train. The whistle appears to change pitch from a high tone, as the train approaches, to a lower tone as it moves away from the observer. As the train approaches, an apparent increase in frequency (an increase in pitch) is heard; as the train moves away, an apparent decrease in frequency (a decrease in pitch) is heard. This pitch variation is known as the Doppler effect.

Let's examine the reason for this apparent change in pitch. Assume that the transmitter emits an audio signal at a frequency of 60 hertz and that the transmitter is traveling at a velocity of 360 feet per second (fps). At the end of 1 second, the transmitter will have moved from point P to point P1 as shown in view A of figure 1-20. The total distance from point P to the observer is 1,080 feet. The velocity of sound is 1,080 feet per second; thus, a sound emitted at point P will reach the observer in 1 second. To find the wavelength of this transmitted signal, you divide the velocity of the signal (1,080 fps) by the frequency (60 hertz). The result is 18 feet, as shown below:

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$$\begin{aligned} \text{wavelength} &= \frac{\text{velocity}}{\text{frequency}} \\ &= \frac{1,080 \text{ fps}}{60 \text{ Hz}} \\ &= 18 \text{ feet} \end{aligned}$$

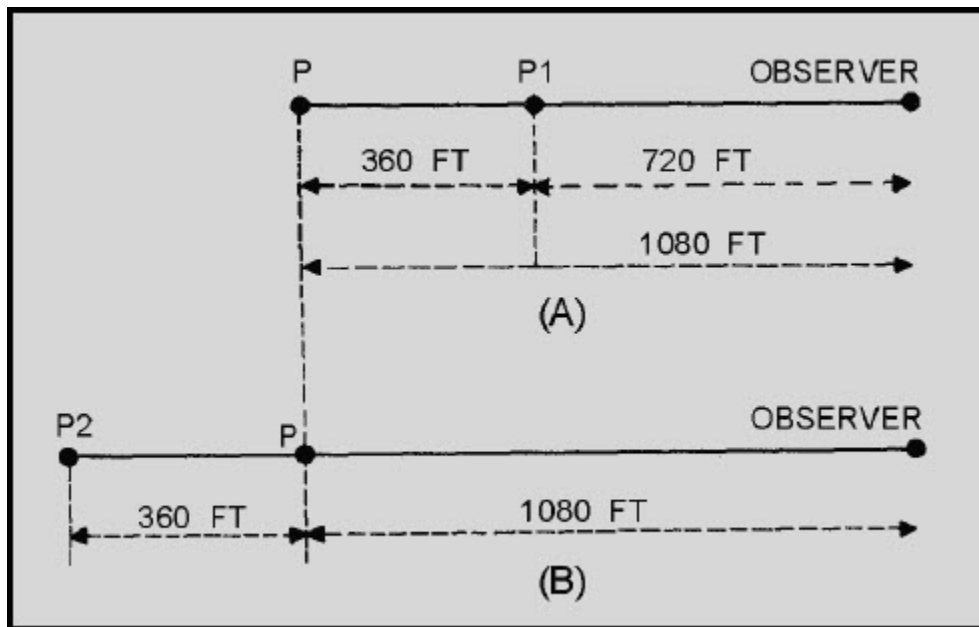


Figure 1-20 Transmitter moving relative to an observer

In 1 second the transmitter moves 360 feet and transmits 60 hertz. At the end of 1 second, the first cycle of the transmitted signal reaches the observer, just as the sixtieth cycle is leaving the transmitter at point P1. Under these conditions the 60 hertz emitted is located between the observer and point P1. Notice that this distance is only 720 feet (1,080 minus 360). The 60 hertz is spread over the distance from point P1 to the observer and has a wavelength of just 12 feet (720 divided by 60). To find the new frequency, use the following formula:

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$$\begin{aligned} \text{frequency} &= \frac{\text{velocity}}{(\text{wavelength})} \\ &= \frac{1,080}{12} \\ &= 90 \text{ hertz} \end{aligned}$$

The original frequency, 60 hertz, has changed to an apparent frequency of 90 hertz. This new frequency only applies to the observer. Notice that the Doppler frequency variation is directly proportional to the velocity of the approaching transmitter. The faster the transmitter moves toward the observer, the greater the number of waves that will be crowded into the space between the transmitter and the observer.

Suppose the transmitter were stationary and the observer moving. When approaching the transmitter, the observer would encounter waves per unit of time. As a result, the observer would hear a higher pitch than the transmitter would actually emit.

If the transmitter were traveling away from the observer, as shown in view B of figure 1-20, the first cycle would leave the transmitter at point P and the sixtieth at point P2. The first cycle would reach the observer when the transmitter reached P2. You would then have 60 cycles stretched out over 1,080 plus 360 feet, a total of 1,440 feet. The wavelength of these 60 hertz is 1,440/60, or 24 feet. The apparent frequency is 1,080 divided by 24, or 45 hertz.

1.4.1.2 Uses of CW Doppler System

The continuous-wave, or Doppler, system is used in several ways. In one radar application, the radar set differentiates between the transmitted and reflected wave to determine the speed of the moving object.

The Doppler method is the best means of detecting fast-moving objects that do not require range resolution. As a moving object approaches the transmitter, it encounters and reflects more waves per unit of time. The amount of frequency shift produced is very small in relation to the carrier frequency. This is because the velocity of propagation of the signal is very high compared to the speed of the target. However, because the carrier frequencies used in radar are high, larger frequency shifts (in the audio frequency range) are produced. The *amount* of shift is proportional to the *speed* of the reflecting object. One-quarter cycle shift at 10,000 megahertz will provide speed measurements accurate to a fraction of a percent.

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If an object is moving, its velocity, relative to the radar, can be detected by comparing the transmitter frequency with the echo frequency (which differs because of the Doppler shift). The DIFFERENCE or BEAT FREQUENCY, sometimes called the DOPPLER FREQUENCY (f_d), is related to object velocity.

The separation of the background and the radar contact is based on the Doppler frequency that is caused by the reflection of the signal from a moving object. Disadvantages of the Doppler system are that it does not determine the range of the object, nor is it able to differentiate between objects when they lie in the same direction and are traveling at the same speed. Moreover, it does not "see" stationary or slow moving objects, which a pulse radar system can detect.

To track an object with cw Doppler, you must determine the radar range. Since the Doppler frequency is not directly related to range, another method is needed to determine object range. By using two separate transmitters that operate at two different frequencies (f_1 and f_2), you can determine range by measuring the relative phase difference between the two Doppler frequencies. In such a system, a mixer is used to combine the two transmitted frequencies and to separate the two received frequencies. This permits the use of one transmitting and receiving antenna.

Instead of using two transmitter frequencies, you can find the range by sweeping the transmitter frequency uniformly in time to cover the frequency range from f_1 to f_2 . The beat, or difference, frequency between the transmitted and received signals is then a function of range. In this type of radar, the velocity as well as range is measured.

Q24. The Doppler effect causes a change in what aspect of rf energy that strikes a moving object?

Q25. The Doppler variation is directly proportional to what radar contact characteristic?

Q26. The Doppler method of object detection is best for what type objects?

Q27. The beat frequency in a swept-frequency transmitter provides what contact information?

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1.4.2 Frequency-Modulation Method

In the frequency-modulation method, the transmitter radiates radio-frequency waves. The frequency of these rf waves is continually increasing and decreasing from a fixed reference frequency. At any instant, the frequency of the returned signal differs from the frequency of the radiated signal. The amount of the difference frequency is determined by the time it took the signal to travel the distance from the transmitter to the object.

An example of a frequency-modulated signal, plotted against time, is shown in figure 1-21. As shown, the 420-megahertz frequency increases linearly to 460 megahertz and then quickly drops to 420 megahertz again. When the frequency drops to 420 megahertz the frequency cycle starts over again.

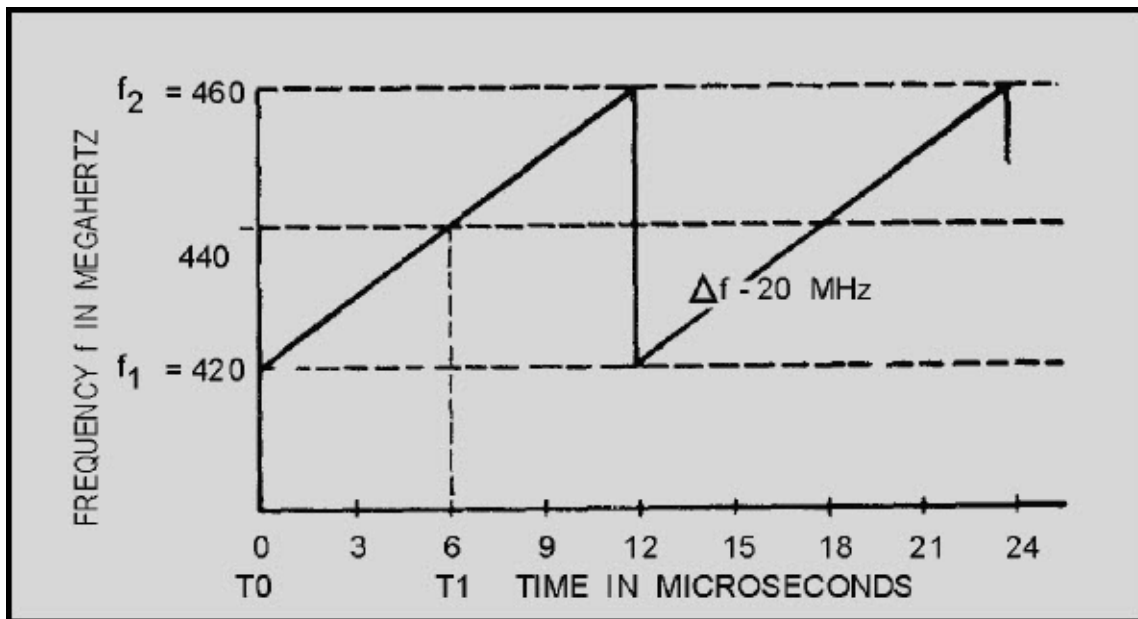


Figure 1-21 Frequency-modulation chart

The frequency regularly changes 40 megahertz with respect to time; therefore, its value at any time during its cycle can be used as the basis for computing the time elapsed after the start of the frequency cycle. For example, at T0 the transmitter sends a 420-megahertz signal toward an object. It strikes the object and returns to the receiver at T1, when the transmitter is sending out a new frequency of 440 megahertz. At T1, the 420-megahertz returned signal and the 440-megahertz transmitter signal are fed to the receiver simultaneously. When the two signals are mixed in the receiver, a beat frequency results. The beat frequency varies directly with the distance to the object, increasing as the distance increases. Using this information, you can calibrate a device that measures frequency to indicate range.

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This system works well when the detected object is stationary. It is used in aircraft altimeters which give a continuous reading of the height above the earth of the aircraft. The system is not satisfactory for locating moving objects. This is because moving targets produce a frequency shift in the returned signal because of the Doppler effect; this affects the accuracy of the range measurement.

1.4.3 Pulse-Modulation Method

The pulse-modulation method of energy transmission was analyzed to some extent earlier in this chapter. As the previous discussions indicated, radio-frequency energy can also be transmitted in very short bursts, called pulses. These pulses are of extremely short time duration, usually on the order of 0.1 microsecond to approximately 50 microseconds. In this method, the transmitter is turned on for a very short time and the pulse of radio-frequency energy is transmitted, as shown in view A of figure 1-22. The transmitter is then turned off, and the pulse travels outward from the transmitter at the velocity of light (view B). When the pulse strikes an object (view C), it is reflected and begins to travel back toward the radar system, still moving at the same velocity (view D). The pulse is then received by the radar system (view E). The time interval between transmission and reception is computed and converted into a visual indication of range in miles or yards. The radar cycle then starts over again by transmitting another pulse (view F). This method does not depend on the relative frequency of the returned signal or on the motion of the target; therefore, it has an important advantage over cw and fm methods.

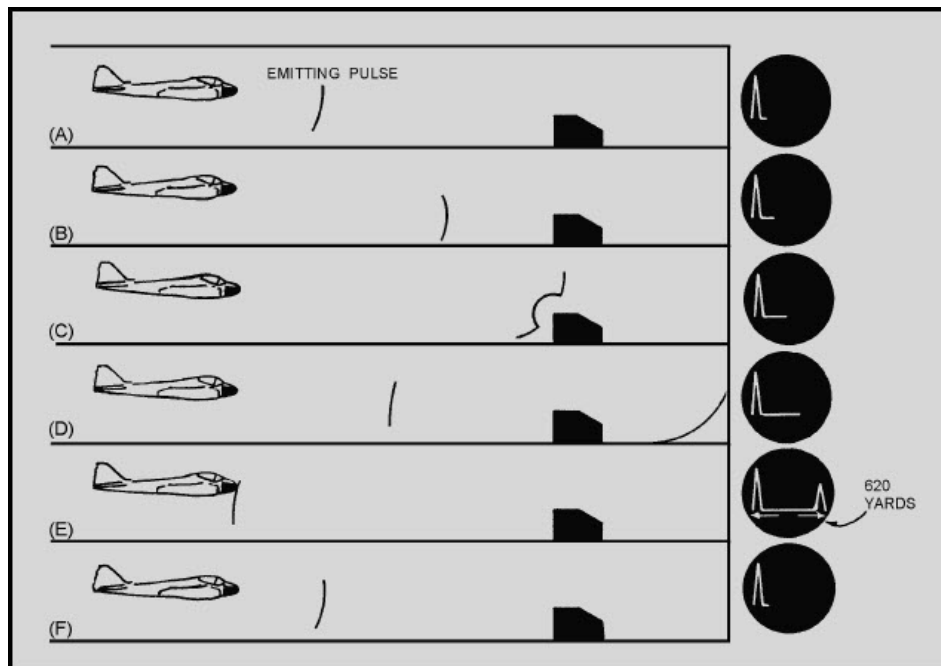


Figure 1-22 Pulse detection

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1.4.4 Pulse-Doppler Method

Pulse radar systems may be modified to use the Doppler effect to detect a moving object.

A requirement for any Doppler radar is COHERENCE; that is, some definite phase relationship must exist between the transmitted frequency and the reference frequency, which is used to detect the Doppler shift of the receiver signal. Moving objects are detected by the phase difference between the target signal and background noise components. Phase detection of this type relies on coherence between the transmitter frequency and the receiver reference frequency.

In coherent detection, a stable cw reference oscillator signal, which is locked in phase with the transmitter during each transmitted pulse, is mixed with the echo signal to produce a beat or difference signal. Since the reference oscillator and the transmitter are locked in phase, the echoes are effectively compared with the transmitter in frequency and phase.

The phase relationships of the echoes from fixed objects to the transmitter is constant and the amplitude of the beat signal remains constant. A beat signal of varying amplitude indicates a moving object. This is because the phase difference between the reference oscillator signal and the echo signal changes as the range to the reflecting object changes. The constant amplitude beat signal is filtered out in the receiver. The beat signal of varying amplitude is sent to the radar indicator scope for display.

Q28. What factor determines the difference between the transmitted frequency and the received frequency in an fm transmitter?

Q29. What type of objects are most easily detected by an fm system?

Q30. What transmission method does NOT depend on relative frequency or target motion?

Q31. What transmission method uses a stable cw reference oscillator, which is locked in phase with the transmitter frequency?

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1.5 RADAR CLASSIFICATION AND USE

Radar systems, like cars, come in a variety of sizes and have different performance specifications. Some radar systems are used for air-traffic control at airports and others are used for long-range surveillance and early-warning systems. A radar system is the heart of a missile guidance system. Small portable radar systems that can be maintained and operated by one person are available as well as systems that occupy several large rooms.

1.5.1 Military Classification of Radar Systems

The large number of radar systems used by the military has forced the development of a joint services classification system for accurate identification. The Federal Aviation Agency (FAA) also makes extensive use of radar systems for commercial aircraft in-flight and landing control, but does not use the military classification system.

Radar systems are usually classified according to specific function and installation vehicle. Some common examples are listed below:

FUNCTION	INSTALLATION VEHICLE
Search	Ground or land based
Track	Airborne
Height-finder	Shipboard

The joint-service standardized classification system further divides these broad categories for more precise identification. Table 1-1 is a listing of equipment identification indicators. Use of the table to identify a particular radar system is illustrated in figure 1-23. Note that for simplicity, only a portion of the table has been used in the illustration.

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TABLE OF EQUIPMENT INDICATORS			Miscellaneous Identification
Installation (1st letter)	Type of Equipment (2d letter)	Purpose (3rd letter)	
A—Piloted aircraft	A—invisible light, heat radiation	B—Bombing	X, Y, Z—Changes in voltage, phase, or frequency T—Training (V)—Variable grouping
B—Underwater mobile, submarine	C—Carrier	C—Communications (receiving and transmitting)	
D—Pilotless carrier	D—Radic	D—Direction finder reconnaissance and/or surveillance	
F—Fixed ground	G—Telegraph or Teletype	E—Ejection and/or release	
G—General ground use	I—Interphone and public address	G—Fire control, or search-light directing	
K—Amphibious	J—Electromechanical or Inertial wire covered	H—Recording and/or reproducing (graphic meteorological and sound)	
M—Ground, mobile	K—Telemetry	K—Computing	
P—Portable	L—Countermeasures	M—Maintenance and/or test assemblies (including tools)	
S—Water	M—Meteorological	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing)	
T—Ground, transportable	N—Sound in air	Q—Special, or combination of purposes	
U—General utility	P—Radar	R—Receiving, passive detecting	
V—Ground, vehicular	Q—Sonar and underwater sound	S—Detecting and/or range and bearing, search	
W—Water surface and under water combination	R—Radio	T—Transmitting	
Z—Piloted and pilotless airborne vehicle combination	S—Special types, magnetic, etc., or combinations of types	W—Automatic flight or remote control	
	T—Telephone (wire)	X—Identification and recognition	
	V—Visual and visible light	Y—Surveillance (search detect, and multiple target tracking) and control (both fire control and air control)	
	W—Armament (peculiar to armament, not otherwise covered)		
	X—Facsimile or television	X—Facsimile or television	
	Y—Data processing		

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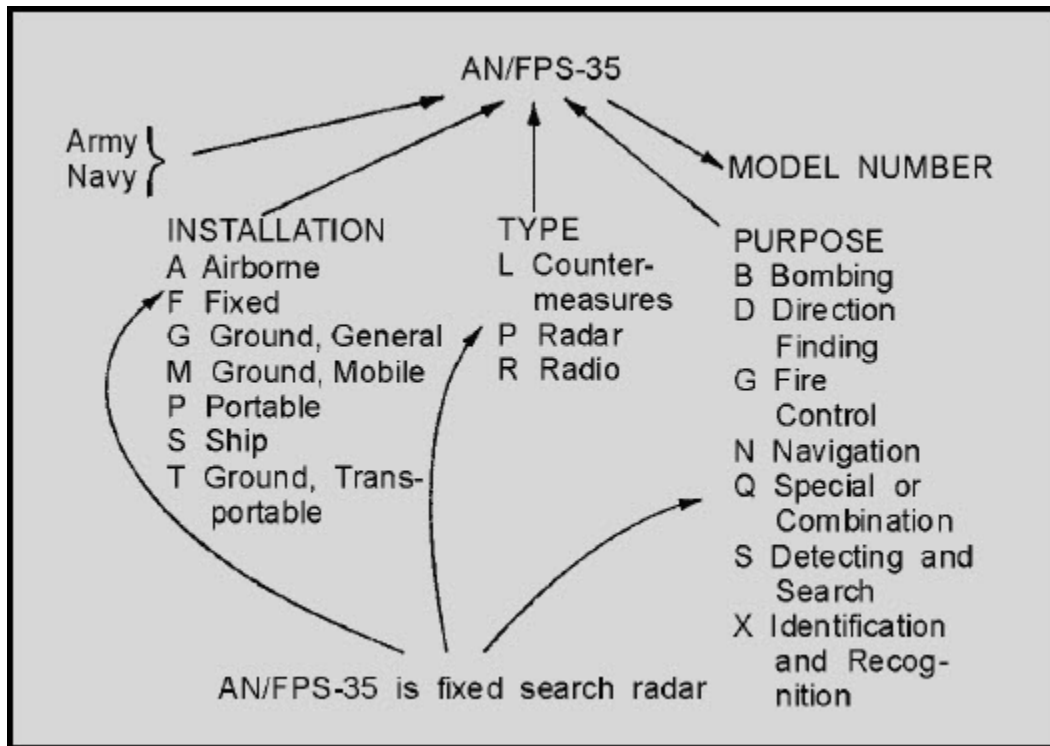


Figure 1-23 Joint service classification system

1.5.2 Radar Functions

No single radar system has yet been designed that can perform all of the many radar functions required by the military. Some of the newer systems combine several functions that formerly required individual radar systems, but no single system can fulfill all the requirements of modern warfare. As a result, modern warships, aircraft, and shore stations usually have several radar systems, each performing a different function.

One radar system, called SEARCH RADAR, is designed to continuously scan a volume of space to provide initial detection of all targets. Search radar is almost always used to detect and determine the position of new targets for later use by TRACK RADAR. Track radar provides continuous range, bearing, and elevation data on one or more targets. Most of the radar systems used by the military are in one of these two categories, though the individual radar systems vary in design and capability.

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Some radar systems are designed for specific functions that do not precisely fit into either of the above categories. The radar speed gun is an example of radar designed specifically to measure the speed of a target. The military uses much more complex radar systems that are adapted to detect only fast moving targets such as aircraft. Since aircraft usually move much faster than weather or surface targets, velocity-sensitive radar can eliminate unwanted clutter from the radar indicator. Radar systems that detect and process only moving targets are called MOVING-TARGET INDICATORS (mti) and are usually combined with conventional search radar.

Another form of radar widely used in military and civilian aircraft is the RADAR ALTIMETER. Just as some surface-based radars can determine the height of a target, airborne radar can determine the distance from an aircraft to the ground. Many aircraft use radar to determine height above the ground. Radar altimeters usually use frequency-modulated signals of the type discussed earlier in the chapter.

1.6 RADAR TYPES

The preceding paragraphs indicated that radar systems are divided into types based on the designed use. This section presents the general characteristics of several commonly used radar systems. Typical characteristics are discussed rather than the specific characteristics of any particular radar system.

1.6.1 Search Radar

Search radar, as previously mentioned, continuously scans a volume of space and provides initial detection of all targets within that space. Search radar systems are further divided into specific types, according to the type of object they are designed to detect. For example, surface-search, air-search, and height-finding radars are all types of search radar.

1.6.1.1 Surface-Search Radar

A surface-search radar system has two primary functions: (1) the detection and determination of accurate ranges and bearings of surface objects and low-flying aircraft and (2) the maintenance of a 360-degree search pattern for all objects within line-of-sight distance from the radar antenna.

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The maximum range ability of surface-search radar is primarily limited by the radar horizon; therefore, higher frequencies are used to permit maximum reflection from small, reflecting areas, such as ship masthead structures and the periscopes of submarines. Narrow pulse widths are used to permit a high degree of range resolution at short ranges and to achieve greater range accuracy. High pulse-repetition rates are used to permit a maximum definition of detected objects. Medium peak power can be used to permit the detection of small objects at line-of-sight distances. Wide vertical-beam widths permit compensation for the pitch and roll of own ship and detection of low flying aircraft. Narrow horizontal beam widths permit accurate bearing determination and good bearing resolution. For example, a common shipboard surface-search radar has the following design specifications:

- Transmitter frequency 5,450-5,825 MHz
- Pulse width .25 or 1.3 microseconds
- Pulse-repetition rate between 625 and 650 pulses per second
- Peak power between 190 and 285 kW
- Vertical beam width between 12 and 16 degrees
- Horizontal beam width 1.5 degrees

Surface-search radar is used to detect the presence of surface craft and low flying aircraft and to determine their presence. Shipboard surface-search radar provides this type of information as an input to the weapons system to assist in the engagement of hostile targets by fire-control radar. Shipboard surface search radar is also used extensively as a navigational aid in coastal waters and in poor weather conditions. A typical surface-search radar antenna is shown in figure 1-24.

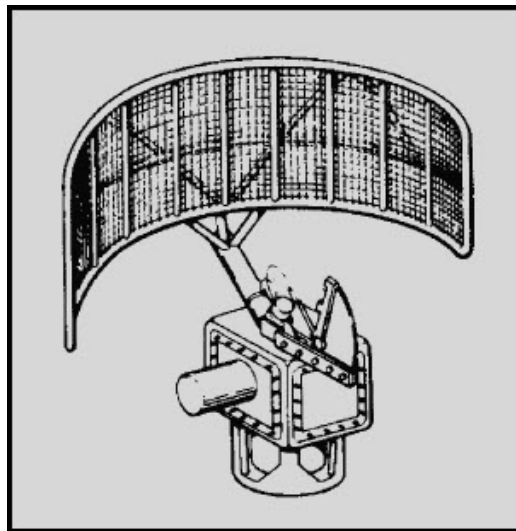


Figure 1-24 Surface-search radar

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Q32. What type of radar provides continuous range, bearing, and elevation data on an object?

Q33. Radar altimeters use what type of transmission signal?

Q34. A surface-search radar normally scans how many degrees of azimuth?

Q35. What limits the maximum range of a surface-search radar?

Q36. What is the shape of the beam of a surface-search radar?

1.6.1.2 Air-Search Radar

Air-search radar systems initially detect and determine the position, course, and speed of air targets in a relatively large area. The maximum range of air-search radar can exceed 300 miles, and the bearing coverage is a complete 360-degree circle. Air-search radar systems are usually divided into two categories, based on the amount of position information supplied. As mentioned earlier in this chapter, radar sets that provide only range and bearing information are referred to as two-dimensional, or 2D, radars. Radar sets that supply range, bearing, and height are called three-dimensional, or 3D, radars. (3D radar will be covered in the next section.) The coverage pattern of a typical 2D radar system is illustrated in figure 1-25. A typical 2D air-search radar antenna is shown in figure 1-26.

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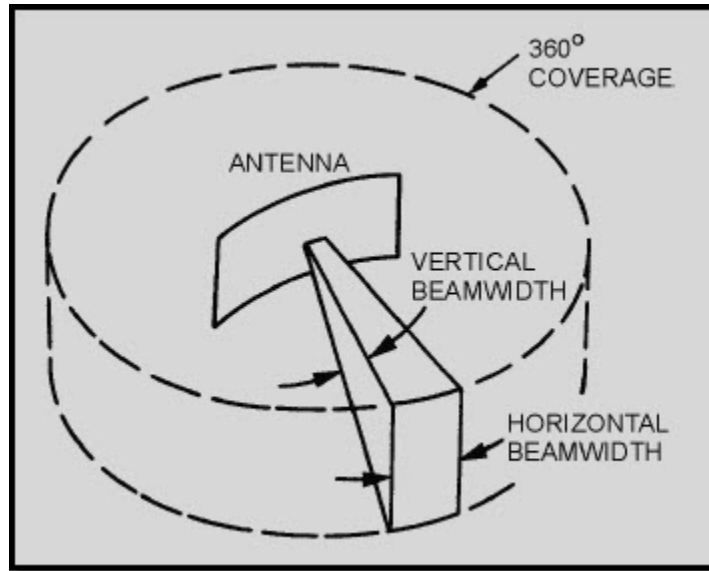


Figure 1-25 2D radar coverage pattern

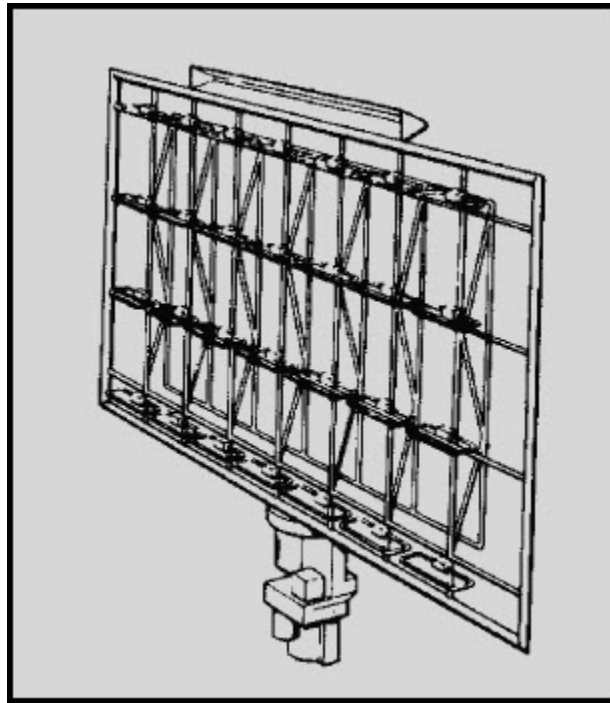


Figure 1-26 2D air-search radar

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Relatively low transmitter frequencies are used in 2D search radars to permit long-range transmissions with minimum attenuation. Wide pulse widths and high peak power are used to aid in detecting small objects at great distances. Low pulse-repetition rates are selected to permit greater maximum range. A wide vertical-beam width is used to ensure detection of objects from the surface to relatively high altitudes and to compensate for pitch and roll of own ship. The output characteristics of specific air-search radars are classified; therefore, they will not be discussed.

Air-search radar systems are used as early-warning devices because they can detect approaching enemy aircraft or missiles at great distances. In hostile situations, early detection of the enemy is vital to a successful defense against attack. Antiaircraft defenses in the form of shipboard guns, missiles, or fighter planes must be brought to a high degree of readiness in time to repel an attack. Range and bearing information, provided by air-search radars, used to initially position a fire-control tracking radar on a target. Another function of the air-search radar system is guiding combat air patrol (CAP) aircraft to a position suitable to intercept an enemy aircraft. In the case of aircraft control, the guidance information is obtained by the radar operator and passed to the aircraft by either voice radio or a computer link to the aircraft.

1.6.1.3 Height-Finding Search Radar

The primary function of a height-finding radar (sometimes referred to as a three-coordinate or 3D radar) is that of computing accurate ranges, bearings, and altitudes of aircraft targets detected by air search radars. Height-finding radar is also used by the ship's air controllers to direct CAP aircraft during interception of air targets. Modern 3D radar is often used as the primary air-search radar (figure 1-27). This is because of its high accuracy and because the maximum ranges are only slightly less than those available from 2D radar.

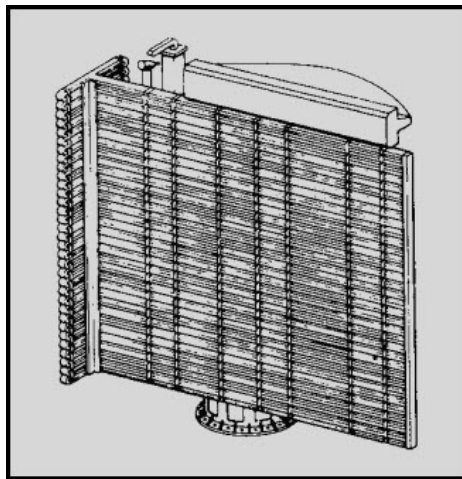


Figure 1-27 3D air-search radar

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The range capability of 3D search radar is limited to some extent by an operating frequency that is higher than that of 2D radar. This disadvantage is partially offset by higher output power and a beamwidth that is narrower in both the vertical and horizontal planes.

The 3D radar system transmits several narrow beams to obtain altitude coverage and, for this reason, compensation for roll and pitch must be provided for shipboard installations to ensure accurate height information.

Applications of height-finding radars include the following:

- Obtaining range, bearing, and altitude data on enemy aircraft and missiles to assist in the control of CAP aircraft
- Detecting low-flying aircraft
- Determining range to distant land masses
- Tracking aircraft over land
- Detecting certain weather phenomena
- Tracking weather balloons
- Providing precise range, bearing, and height information for fast, accurate initial positioning of fire-control tracking radars

Q37. Air-search radar is divided into what two basic categories?

Q38. What position data are supplied by 2D search radar?

Q39. Why do 2D air-search radars use relatively low carrier frequencies and low pulse-repetition rates?

Q40. Why is the range capability of 3D radar usually less than the range of 2D radar?

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1.6.2 Tracking Radar

Radar that provides continuous positional data on a target is called tracking radar. Most tracking radar systems used by the military are also fire-control radar; the two names are often used interchangeably.

Fire-control tracking radar systems usually produce a very narrow, circular beam.

Fire-control radar must be directed to the general location of the desired target because of the narrow-beam pattern. This is called the DESIGNATION phase of equipment operation. Once in the general vicinity of the target, the radar system switches to the ACQUISITION phase of operation. During acquisition, the radar system searches a small volume of space in a prearranged pattern until the target is located. When the target is located, the radar system enters the TRACK phase of operation. Using one of several possible scanning techniques, the radar system automatically follows all target motions. The radar system is said to be *locked on* to the target during the track phase. The three sequential phases of operation are often referred to as MODES and are common to the target-processing sequence of most fire control radars.

Typical fire-control radar characteristics include a very high prf, a very narrow pulse width, and a very narrow beam width. These characteristics, while providing extreme accuracy, limit the range and make initial target detection difficult. A typical fire-control radar antenna is shown in figure 1-28. In this example the antenna used to produce a narrow beam is covered by a protective radome.

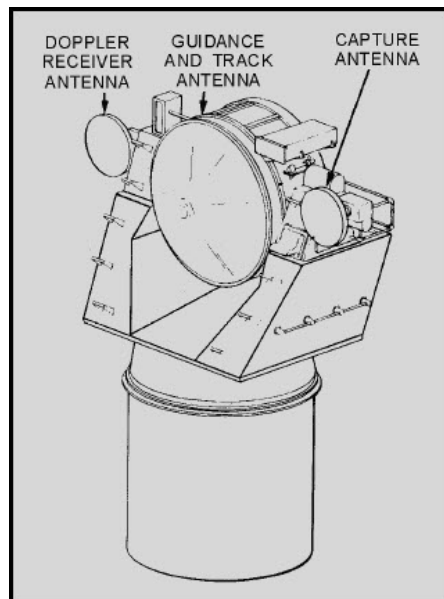


Figure 1-28 Fire-control radar

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1.6.3 Missile-Guidance Radar

A radar system that provides information used to guide a missile to a hostile target is called GUIDANCE RADAR. Missiles use radar to intercept targets in three basic ways: (1) Beam-rider missiles follow a beam of radar energy that is kept continuously pointed at the desired target; (2) homing missiles detect and home in on radar energy reflected from the target; the reflected energy is provided by a radar transmitter either in the missile or at the launch point and is detected by a receiver in the missile; (3) passive homing missiles home in on energy that is radiated by the target. Because target position must be known at all times, a guidance radar is generally part of, or associated with, a fire-control tracking radar. In some instances, three radar beams are required to provide complete guidance for a missile. The beam riding missile, for example, must be launched into the beam and then must ride the beam to the target. Initially, a wide beam is radiated by a capture radar to gain (capture) control of the missile. After the missile enters the capture beam, a narrow beam is radiated by a guidance radar to guide the missile to the target. During both capture and guidance operations, a tracking radar continues to track the target. Figure 1-29 illustrates the relationships of the three different radar beams.

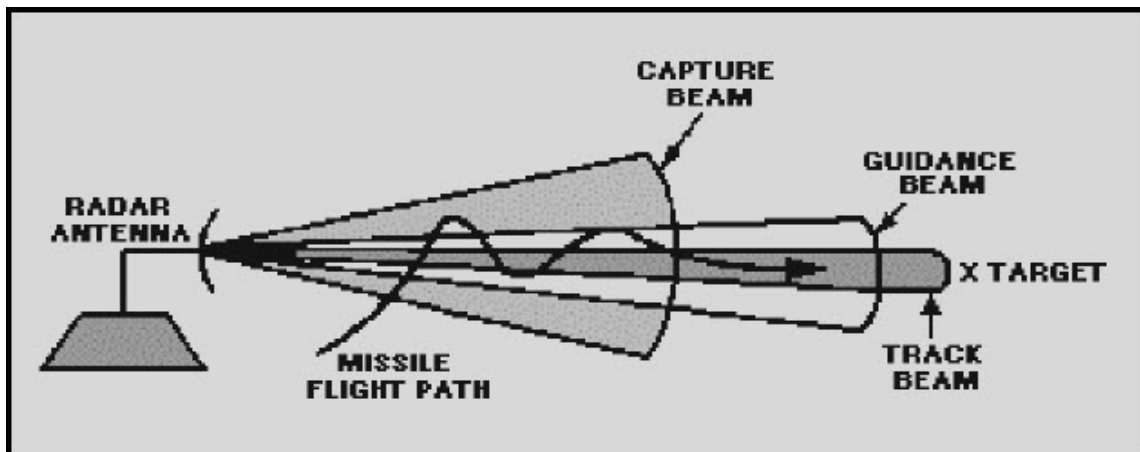


Figure 1-29 Beam relationship of capture, guidance, and track beams

Q41. Fire-control tracking radar most often radiates what type of beam?

Q42. Tracking radar searches a small volume of space during which phase of operation?

Q43. What width is the pulse radiated by fire-control tracking radar?

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Q44. Which beam of missile-guidance radar is very wide?

1.6.4 Carrier-Controlled Approach (CCA) and Ground-Controlled Approach (GCA Radar)

CARRIER-CONTROLLED APPROACH and GROUND-CONTROLLED APPROACH radar systems are essentially shipboard and land-based versions of the same type of radar. Shipboard CCA radar systems are usually much more sophisticated systems than GCA systems. This is because of the movements of the ship and the more complicated landing problems. Both systems, however, guide aircraft to safe landing under conditions approaching zero visibility. By means of radar, aircraft are detected and observed during the final approach and landing sequence. Guidance information is supplied to the pilot in the form of verbal radio instructions, or to the automatic pilot (autopilot) in the form of pulsed control signals.

1.6.5 Airborne Radar

Airborne radar is designed especially to meet the strict space and weight limitations that are necessary for all airborne equipment. Even so, airborne radar sets develop the same peak power as shipboard and shore-based sets.

As with shipboard radar, airborne radar sets come in many models and types to serve many different purposes. Some of the sets are mounted in blisters (or domes) that form part of the fuselage; others are mounted in the nose of the aircraft.

In fighter aircraft, the primary mission of a radar is to aid in the search, interception, and destruction of enemy aircraft. This requires that the radar system have a tracking feature. Airborne radar also has many other purposes. The following are some of the general classifications of airborne radar: search, intercept and missile control, bombing, navigation, and airborne early warning.

1.7 SUMMARY

The following paragraphs summarize the important points of this chapter.

RADAR is an electronic system that uses reflected electromagnetic energy to detect the presence and position of objects invisible to the eye.

TARGET POSITION is defined in reference to true north, the horizontal plane, and the vertical plane.

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TRUE BEARING is the angle between true north and the line of sight to the target, measured in a clockwise direction in the horizontal plane.

ELEVATION ANGLE is the angle between the horizontal plane and the line of sight, measured in the vertical plane.

RANGE is the distance from the radar site to the target measured along the line of sight.

RANGE to any target can be calculated by measuring the time required for a pulse to travel to a target and return to the radar receiver and by dividing the elapsed time by 12.36 microseconds.

The **MAXIMUM RANGE** of a pulse radar system depends on the **CARRIER FREQUENCY**, **PEAK POWER**, **PULSE-REPETITION FREQUENCY**, and **RECEIVER SENSITIVITY**.

PULSE-REPETITION TIME is the time between the beginning of one pulse and the beginning of the next pulse and is the reciprocal of prf.

AMBIGUOUS RETURNS are echoes from targets that exceed the prt of the radar system and result in false range readings.

The **PEAK POWER** of a radar system is the total energy contained in a pulse. Peak power is obtained by multiplying the maximum power level of a pulse by the pulse width.

Since most instruments are designed to measure **AVERAGE POWER** over a period of time, prt must be included in transmitter power measurements.

The product of pw and prf is called the **DUTY CYCLE** of a radar system and is the ratio of transmitter time on to time off.

Antenna height and **ROTATION SPEED** affect radar range. Since high-frequency energy does not normally bend to follow the curvature of the earth, most radar systems cannot detect targets below the **RADAR HORIZON**.

The slower an antenna rotates, the larger the **HITS PER SCAN** value. The likelihood that a target will produce a usable echo is also increased.

The bearing to a target may be referenced to true north or to your own ship. Bearing referenced to true north is **TRUE BEARING** and bearing referenced to your ship is **RELATIVE BEARING**, as shown in the illustration. The bearing angle is obtained by moving the antenna to the point of maximum signal return.

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Radar systems that detect only range and bearing are called TWO-DIMENSIONAL (2D) radars. Radars that detect height as well as range and bearing are called THREE-DIMENSIONAL (3D) RADARS.

The target RESOLUTION of a radar system is its ability to distinguish between targets that are very close together.

RANGE RESOLUTION is the ability to distinguish between two or more targets on the same bearing and is primarily dependent on the pulse width of the radar system.

BEARING RESOLUTION is the ability of a radar to separate targets at the same range but different bearings. The degree of bearing resolution is dependent on beam width and range. The accuracy of radar is largely dependent on resolution.

ATMOSPHERIC CONDITIONS affect the speed and direction of travel of electromagnetic wavefronts traveling through the air. Under normal conditions, the wavefronts increase uniformly in speed as altitude increases which causes the travel path to curve downward. The downward curve extends the radar horizon as shown in the illustration. The density of the atmosphere, the presence of water vapor, and temperature changes also directly affect the travel of electromagnetic wavefronts.

The major components in a typical PULSE RADAR SYSTEM are shown in the illustration. The SYNCHRONIZER supplies the timing signals to coordinate the operation of the entire system. The TRANSMITTER generates electromagnetic energy in short, powerful pulses. The DUPLEXER allows the same antenna to be used to both transmit and receive. The RECEIVER detects and amplifies the return signals. The INDICATOR produces a visual indication of the range and bearing of the echo.

SCANNING is the systematic movement of a radar beam while searching for or tracking a target.

STATIONARY-LOBE SCANNING is the simplest type of scanning and is usually used in 2D search radar. Monopulse scanning, used in fire-control radars, employs four signal quantities to accurately track moving targets. The two basic methods of scanning are MECHANICAL and ELECTRONIC.

Radar systems are often divided into operational categories based on energy transmission methods—continuous wave (cw), frequency modulation (fm), and pulse modulation (pm).

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The **CONTINUOUS WAVE (cw)** method transmits a constant frequency and detects moving targets by detecting the change in frequency caused by electromagnetic energy reflecting from a moving target. This change in frequency is called the **DOPPLER SHIFT** or **DOPPLER EFFECT**.

In the **FREQUENCY MODULATION (fm)** method, a signal that constantly changes in frequency around a fixed reference is used to detect stationary objects.

The **PULSE-MODULATION (pm) METHOD** uses short pulses of energy and relatively long listening times to accurately determine target range. Since this method does not depend on signal frequency or target motion, it has an advantage over cw and fm methods. It is the most common type of radar.

Radar systems are also classified by function. **SEARCH RADAR** continuously scans a volume of space and provides initial detection of all targets. **TRACK RADAR** provides continuous range, bearing, and elevation data on one or more specific targets. Most radar systems are variations of these two types.

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ANSWERS TO QUESTIONS Q1. AND Q44.

- A1. *Horizontal plane.*
- A2. *Range.*
- A3. *Approximately the speed of light (162,000 nautical miles per second).*
- A4. *12.36 microseconds.*
- A5. *Pulse width.*
- A6. *Frequency.*
- A7.

$$\frac{1}{prt} = \text{prf}$$

- A8. *Average power.*
- A9. *Duty cycle.*
- A10. *Relative bearing.*
- A11. *Three-dimensional.*
- A12. *Frequency or phase.*
- A13. *Target resolution.*
- A14. *Beam width and range.*
- A15. *Speed increases.*
- A16. *Temperature inversion.*
- A17. *Synchronizer.*
- A18. *High-voltage pulse from the modulator.*

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- A19. *Duplexer.*
- A20. *Single lobe.*
- A21. *The reflected signals decrease in strength.*
- A22. *Mechanical and electronic.*
- A23. *Nutation.*
- A24. *Frequency.*
- A25. *Velocity.*
- A26. *Fast-moving targets.*
- A27. *Range.*
- A28. *Travel time.*
- A29. *Stationary.*
- A30. *Pulse modulation.*
- A31. *Pulse-Doppler.*
- A32. *Track radar.*
- A33. *Frequency modulated (fm).*
- A34. *360 degrees.*
- A35. *Radar horizon.*
- A36. *Wide vertically, narrow horizontally.*
- A37. *2D and 3D.*
- A38. *Range and bearing.*
- A39. *Increased maximum range.*
- A40. *Higher operating frequency.*

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A41. A narrow circular beam.

A42. Acquisition.

A43. Very narrow.

A44. Capture beam.

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2 RADAR SUBSYSTEMS

LEARNING OBJECTIVES

After you finish this chapter, you should be able to do the following:

1. Describe, in general terms, the function of a radar synchronizer.
2. State the basic requirements and types of master synchronizers.
3. Describe the purpose, requirements, and operation of a radar modulator.
4. Describe the basic operating sequence of a keyed-oscillator transmitter.
5. Describe the basic operating sequence of a power-amplifier transmitter.
6. State the purpose of a duplexer.
7. State the operational principles of tr and atr tubes.
8. Describe the basic operating sequence of series and parallel connected duplexers.
9. List the basic design requirements of an effective radar receiver.
10. List the major sections of a typical radar receiver.
11. Using a block diagram, describe the operational characteristics of a typical radar receiver.

2.1 INTRODUCTION TO RADAR SUBSYSTEMS

Any radar system has several major subsystems that perform standard functions. A typical radar system consists of a SYNCHRONIZER (also called the TIMER or TRIGGER GENERATOR), a TRANSMITTER, a DUPLEXER, a RECEIVER, and an INDICATOR. These major subsystems were briefly described in chapter 1. This chapter will describe the operation of the synchronizer, transmitter, duplexer, and receiver of a typical pulse radar system and briefly analyze the circuits used. Chapter 3 will describe typical indicator and antenna subsystems. Because radar systems vary widely in specific design, only a general description of representative circuits is presented in this chapter.

2.1.1 Synchronizers

The synchronizer is often referred to as the "heart" of the radar system because it controls and provides timing for the operation of the entire system. Other names for the synchronizer are the TIMER and the KEYER. We will use the term synchronizer in our discussion. In some complex systems the synchronizer is part of a system computer that performs many functions other than system timing.

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2.1.2 Synchronizer Function

The specific function of the synchronizer is to produce TRIGGER PULSES that start the transmitter, indicator sweep circuits, and ranging circuits.

Timing or control is the function of the majority of circuits in radar. Circuits in a radar set accomplish control and timing functions by producing a variety of voltage waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks. Although all of these circuits can be broadly classified as timing circuits, the specific function of any individual circuit could also be wave shaping or wave generation. The operation of many of these circuits and associated terms were described in detail in NEETS, Module 9, *Wave-Generation and Wave-Shaping Circuits*.

Q1. What is the purpose of the synchronizer in a radar system?

Q2. What is the purpose of the majority of circuits in a radar system?

2.1.3 Synchronizer Operation

Radar systems may be classified as either SELF-SYNCHRONIZED or EXTERNALLY SYNCHRONIZED systems. In a self-synchronized system, the timing trigger pulses are generated in the transmitter. In an externally synchronized system, the timing trigger pulses are generated by a MASTER OSCILLATOR, which is usually external to the transmitter.

The master oscillator in an externally synchronized system may be a BLOCKING OSCILLATOR, a SINE-WAVE OSCILLATOR, or an ASTABLE (FREE-RUNNING) MULTI-VIBRATOR. When a blocking oscillator is used as a master oscillator, the timing trigger pulses are usually obtained directly from the oscillator. When a sine-wave oscillator or an astable multivibrator is used as a master oscillator, pulse-shaping circuits are required to form the necessary timing trigger pulses. In an externally synchronized radar system, the pulse repetition rate (prf) of the timing trigger pulses from the master oscillator determines the prf of the transmitter.

In a self-synchronized radar system, the prf of the timing trigger pulses is determined by the prf of the modulator or transmitter.

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Associated with every radar system is an indicator, such as a cathode-ray tube, and associated circuitry. The indicator can present range, bearing, and elevation data in visual form so that a detected object may be located. Trigger pulses from the synchronizer are frequently used to produce gate (or enabling) pulses. When applied to the indicator, gate pulses perform the following functions:

1. Initiate and time the duration of the indicator sweep voltage
2. Intensify the cathode-ray tube electron beam during the sweep period so that the echo pulses may be displayed
3. Gate a range marker generator so that range marker signals may be superimposed on the indicator presentation

Figure 2-1 shows the time relationships of the various waveforms in a typical radar set. The timing trigger pulses are applied to both the transmitter and the indicator. When a trigger pulse is applied to the transmitter, a short burst of transmitter pulses (rf energy) is generated.

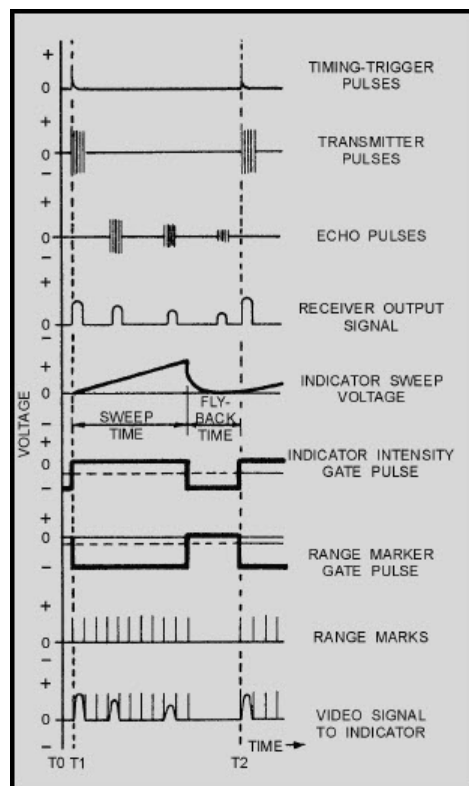


Figure 2-1 Time relationship of waveforms

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This energy is conducted along a transmission line to the radar antenna. It is radiated by the antenna into space. When this transmitter energy strikes one or more reflecting objects in its path, some of the transmitted energy is reflected back to the antenna as echo pulses. Echo pulses from three reflecting targets at different ranges are illustrated in figure 2-1. These echoes are converted to the corresponding receiver output signals as shown in the figure. The larger initial and final pulses in the receiver output signal are caused by the energy that leaks through the duplexer when a pulse is being transmitted.

The indicator sweep voltage shown in figure 2-1 is initiated at the same time the transmitter is triggered. In other applications, it may be more desirable to delay the timing trigger pulse that is to be fed to the indicator sweep circuit. Delaying the trigger pulse will initiate the indicator sweep *after* a pulse is transmitted.

Note in figure 2-1 that the positive portion of the indicator intensity gate pulse (applied to the cathode-ray tube control grid) occurs only during the indicator sweep time. As a result, the visible cathode-ray tube trace occurs only during sweep time and is eliminated during the flyback (retrace) time. The negative portion of the range-marker gate pulse also occurs during the indicator sweep time. This negative gate pulse is applied to a range-marker generator, which produces a series of range marks.

The range marks are equally spaced and are produced only for the duration of the range-marker gate pulse. When the range marks are combined (mixed) with the receiver output signal, the resulting video signal applied to the indicator may appear as shown at the bottom of figure 2-1.

Q3. A self-synchronized radar system obtains timing trigger pulses from what source?

Q4. What type of multivibrator can be used as a radar master oscillator?

Q5. In an externally synchronized radar, what determines the prr of the transmitter?

Q6. In figure 2-1, what causes the initial and final pulses on the receiver output signal?

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2.1.4 Basic Synchronizer Circuits

The basic synchronizer circuit should meet the following three basic requirements:

1. It must be *free running* (astable). Because the synchronizer is the heart of the radar, it must establish the zero time reference and the prf (prf).
2. It should be *stable in frequency*. For accurate ranging, the prf and its reciprocal, pulse-repetition time (prt), must not change between pulses.
3. The *frequency must be variable* to enable the radar to operate at different ranges.

Three basic synchronizer circuits can meet the above mentioned requirements. They are the SINEWAVE OSCILLATOR, the SINGLE-SWING BLOCKING OSCILLATOR, and the MASTERTRIGGER (ASTABLE) MULTIVIBRATOR.

Figure 2-2 shows the block diagrams and waveforms of these three synchronizers as they are used in externally synchronized radar systems. In each case, equally spaced timing trigger pulses are produced. The prf of each series of timing trigger pulses is determined by the operating frequency of the associated master oscillator.

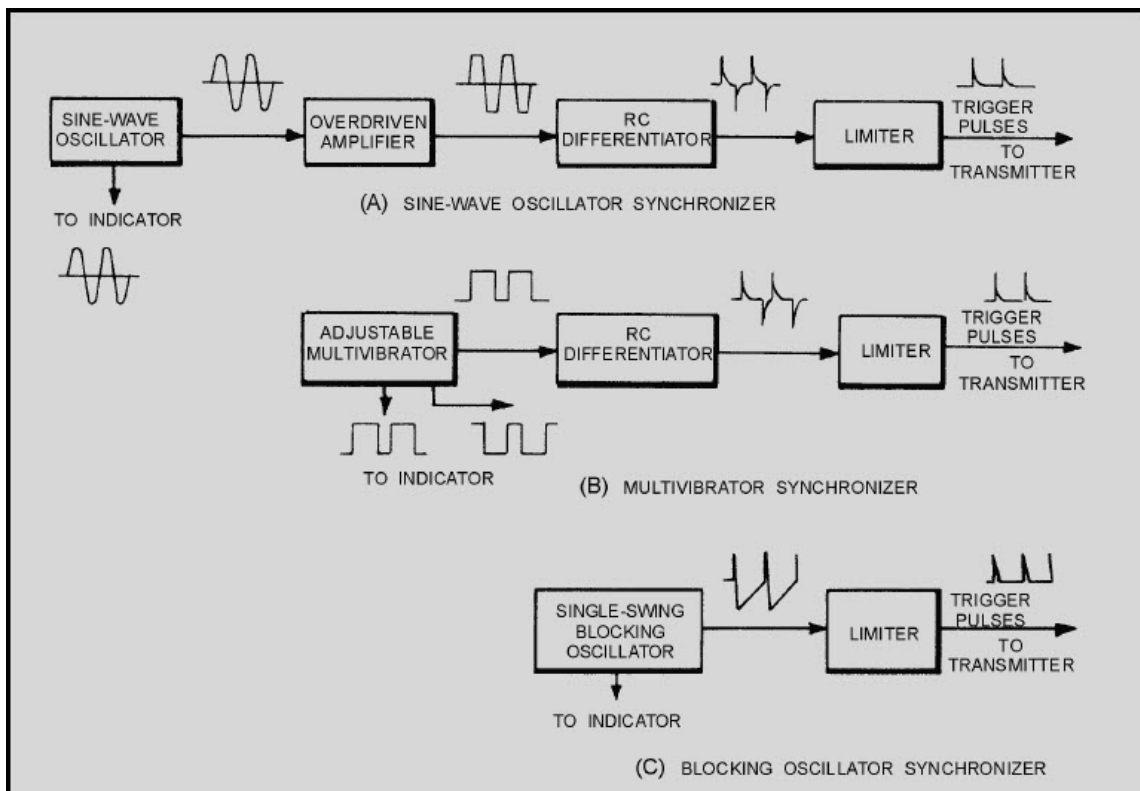


Figure 2-2 Timers used in externally synchronized radar systems

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2.1.4.1 Sine-Wave Oscillator Synchronizer

In the sine-wave oscillator synchronizer (figure 2-2, view A), a sine-wave oscillator is used for the basic timing device (master oscillator). The oscillator output is applied to both an overdriven amplifier and the radar indicator. The sine waves applied to the overdriven amplifier are shaped into square waves. These square waves are then converted into positive and negative timing trigger pulses by means of a short-time-constant RC differentiator.

By means of a limiter, either the positive or negative trigger pulses from the RC differentiator are removed. This leaves trigger pulses of only one polarity. For example, the limiter in view A of figure 2-2 is a negative-lobe limiter; that is, the limiter removes the negative trigger pulses and passes only positive trigger pulses to the radar transmitter.

A disadvantage of a sine-wave oscillator synchronizer is the large number of pulse-shaping circuits required to produce the necessary timing trigger pulses.

2.1.4.2 Master Trigger (Astable) Multivibrator Synchronizer

In a master trigger (astable) multivibrator synchronizer (view B, figure 2-2), the master oscillator generally is an astable multivibrator. The multivibrator is either ASYMMETRICAL or SYMMETRICAL. If the multivibrator is asymmetrical, it generates rectangular waves. If the multivibrator is symmetrical, it generates square waves. In either case, the timing trigger pulses are equally spaced after a limiter removes undesired positive or negative lobes.

There are two transistors in an astable multivibrator. The two output voltages are equal in amplitude, but are 180 degrees out of phase. The output of the astable multivibrator consists of positive and negative rectangular waves. Positive rectangular waves are applied to an RC differentiator and converted into positive and negative trigger pulses. As in the sine-wave synchronizer, the negative trigger pulses are removed by means of a negative-lobe limiter, and the positive pulses are applied to the transmitter.

Both positive and negative rectangular waves from the astable multivibrator are applied to the indicator. One set of waves is used to intensify the cathode-ray tube electron beam for the duration of the sweep. The other set of waves is used to gate (turn on) the range marker generator.

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2.1.4.3 Single-Swing Blocking Oscillator Synchronizer

In the single-swing, blocking-oscillator synchronizer, shown in view C of figure 2-2, a free-running, single-swing blocking oscillator is generally used as the master oscillator. The advantage of the single swing blocking oscillator is that it generates sharp trigger pulses without additional shaping circuitry. Timing trigger pulses of only one polarity are obtained by means of a limiter.

Gating pulses for the indicator circuits are produced by applying the output of the blocking oscillator to a one-shot multivibrator or another variable time delay circuit (not shown). Crystal-controlled oscillators may be used when very stable frequency operation is required.

Q7. What basic circuits meet the requirements of an externally synchronized master oscillator?

Q8. Name a disadvantage of sine-wave oscillator synchronizers.

Q9. Which of the basic timing circuits produces sharp trigger pulses directly?

2.2 TRANSMITTERS

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. The oscillator tube is keyed by a high-power dc pulse of energy generated by a separate unit called the MODULATOR (discussed in the following section). 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 is 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.

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2.2.1 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 2-3 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.

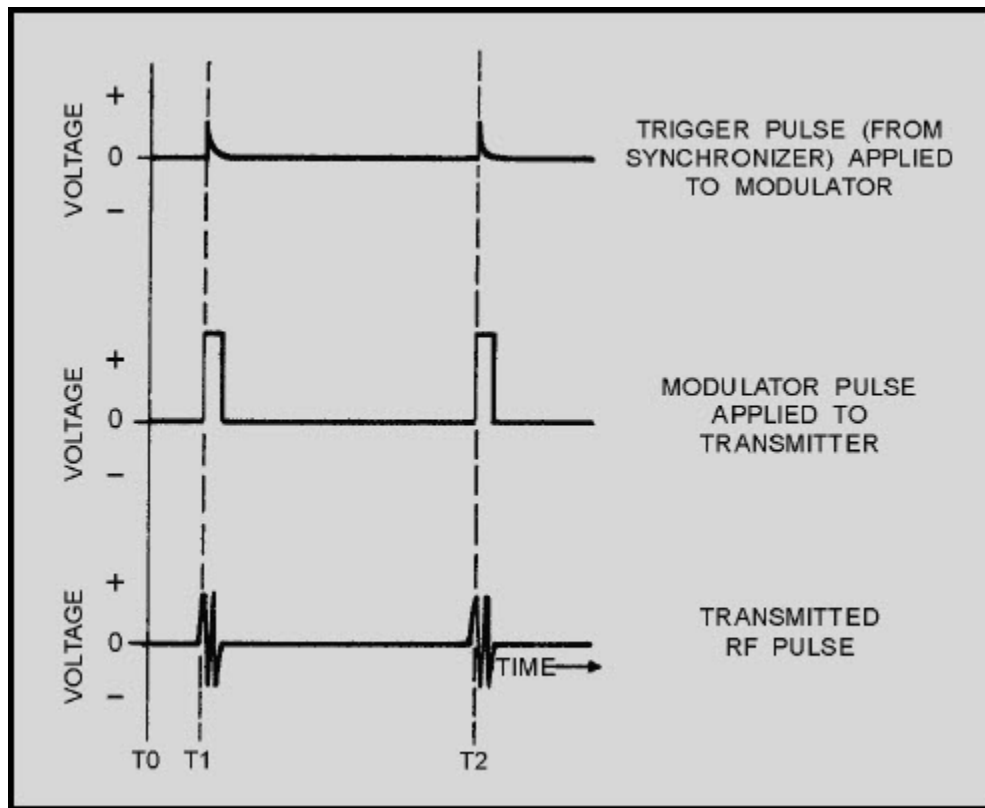


Figure 2-3 Transmitter waveforms

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, 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.

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MAGNETRON OSCILLATORS are capable of generating rf pulses with very high peak power at frequencies ranging from 600 to 30,000 megahertz. However, if its cathode voltage changes, the magnetron oscillator shifts in frequency. To avoid such a frequency change, you must ensure that 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:

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

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.

A transmitted rf pulse with a steep trailing edge is essential for the detection of objects at short ranges. If the magnetron output voltage drops gradually from its maximum value to zero, it contributes very little to the usable energy of the transmitted rf pulse. Furthermore, part of the magnetron output voltage enters the receiver and obscures nearby object echoes.

2.2.1.1 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. The hard tube modulator has been replaced by the line-pulsed modulator in most cases. 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.

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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 principally used modulator in modern radar, it is the only type that will be discussed.

Figure 2-4 shows the basic sections of a radar modulator. They are as follows:

- 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).

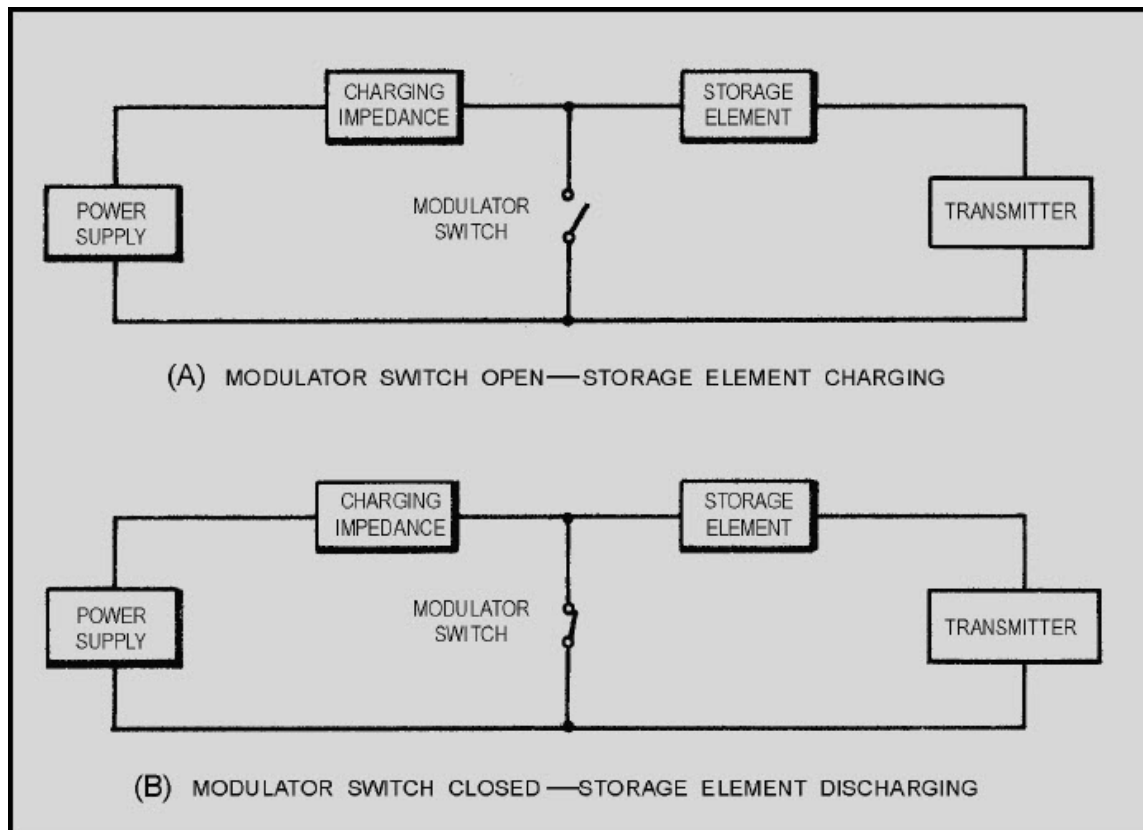


Figure 2-4 Basic line-pulsing modulator block diagram

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View A of figure 2-4 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.

2.2.1.2 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 2-5, 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) and (2) to discharge and form a rectangular dc pulse (modulator pulse) of the required duration when the modulator switch is closed.

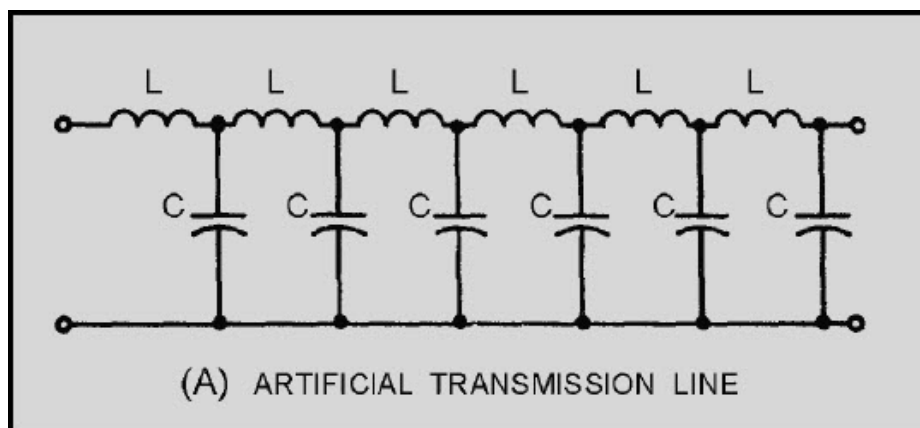


Figure 2-5A Modulator storage elements

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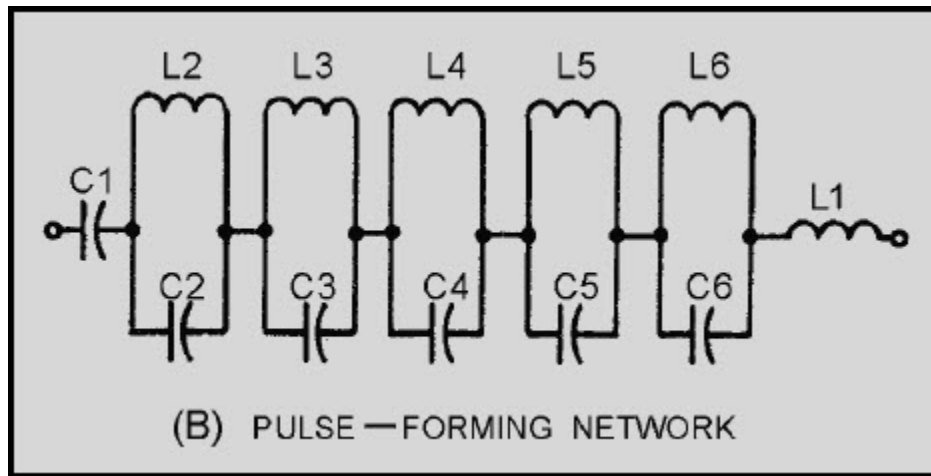


Figure 2-5B.—Modulator storage elements

The duration of the modulator pulse depends on the values of inductance and capacitance in each LC section of the artificial transmission line in view A and the number of LC sections used. Other arrangements of capacitors and inductors (such as the pulse-forming network shown in view B) are very similar in operation to artificial transmission lines.

ARTIFICIAL TRANSMISSION LINES and PULSE-FORMING NETWORKS (pfn) are used more often than the capacitor-type storage elements.

ARTIFICIAL TRANSMISSION LINE.—Figure 2-6 shows a radar modulator that uses an artificial transmission line as its storage element. A modulator switch controls the pulse-repetition rate. When the modulator switch is open (between transmitted rf pulses), the transmission line charges.

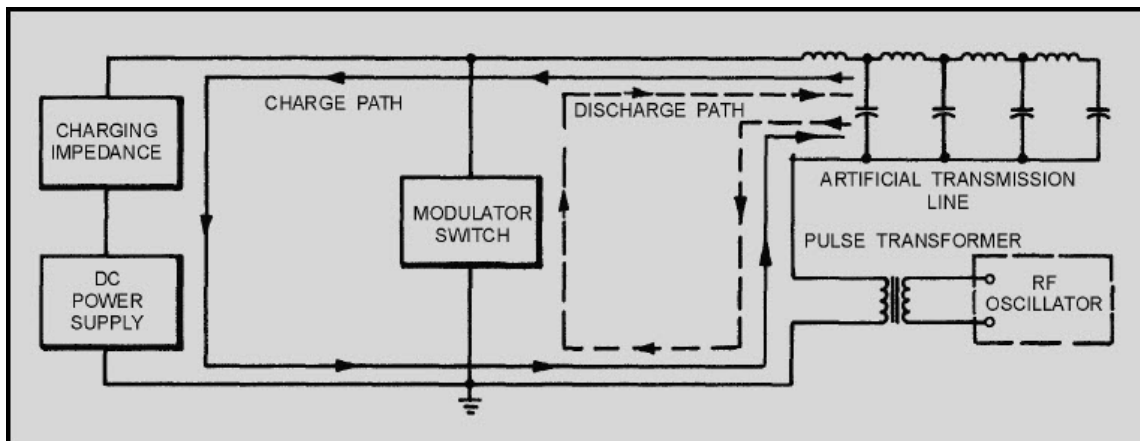


Figure 2-6 Modulator with an artificial transmission line for the storage element

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The charge path includes the primary of the pulse transformer, the dc power supply, and the charging impedance. When the modulator switch is closed, the transmission line discharges through the series circuit. This circuit consists of the modulator switch and the primary of the pulse transformer.

The artificial transmission line is effectively an open circuit at its output end. Therefore, when the voltage wave reaches the output end of the line, it is reflected. As the reflected wave propagates from the output end back toward the input end of the line, it completely discharges each section of the line. When the reflected wave reaches the input end of the line, the line is completely discharged, and the modulator pulse ceases abruptly. If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, the voltage pulse that appears across the transformer primary equals one-half the voltage to which the line was initially charged.

The width of the pulse generated by an artificial transmission line depends on the time required for a voltage wave to travel from the input end to the output end of the line and back. Therefore, we can say the pulse width depends on the velocity of propagation along the line (determined by the inductances and capacitances of each section of the line) and the number of line sections (the length of the line).

PULSE-FORMING NETWORKS.—A pulse-forming network is similar to an artificial transmission line in that it stores energy between pulses and produces a nearly rectangular pulse. The pulse-forming network in view B of figure 2-5 consists of inductors and capacitors so arranged that they approximate the behavior of an artificial transmission line.

Each capacitor in the artificial transmission line, shown in view A, must carry the high voltage required for the modulator pulse. Because each capacitor must be insulated for this high voltage, an artificial transmission line consisting of many sections would be bulky and cumbersome.

The pulse-forming network, shown in view B of figure 2-5, can carry high voltage but does not require bulky insulation on all of its capacitors. Only series capacitor C1 must have high-voltage insulation. Because the other capacitors are in parallel with the corresponding inductors, the modulator pulse voltage divides nearly equally among them. Thus, except for C1, the elements of the pulse-forming network are relatively small.

Pulse-forming networks are often insulated by immersing each circuit element in oil. The network is usually enclosed in a metal box on which the pulse width, characteristic impedance, and safe operating voltage of the network are marked. If one element in such a network fails, the entire network must be replaced.

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Q10. What are the two basic types of transmitters?

Q11. What controls transmitter pulse width?

Q12. In addition to a flat top, what characteristics must a modulator pulse have?

Q13. What type of modulator is most commonly used in modern radar systems?

Q14. What three types of storage elements most often are used in modulators?

Q15. What characteristic is determined by the time required for a voltage wave to travel from the input end of an artificial transmission line to the output end and back again?

2.2.1.3 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 microsecond
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

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These switching and conducting requirements are met best by the THYRATRON tube. The thyatron 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 thyatron 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 thyatron tube is highly ionized. While the storage element discharges, the plate-to-cathode resistance of the thyatron is practically zero. When the storage element is completely discharged, current ceases to flow through the thyatron and the gases become deionized; the negative grid bias regains control, and the thyatron 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 2-7, 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.

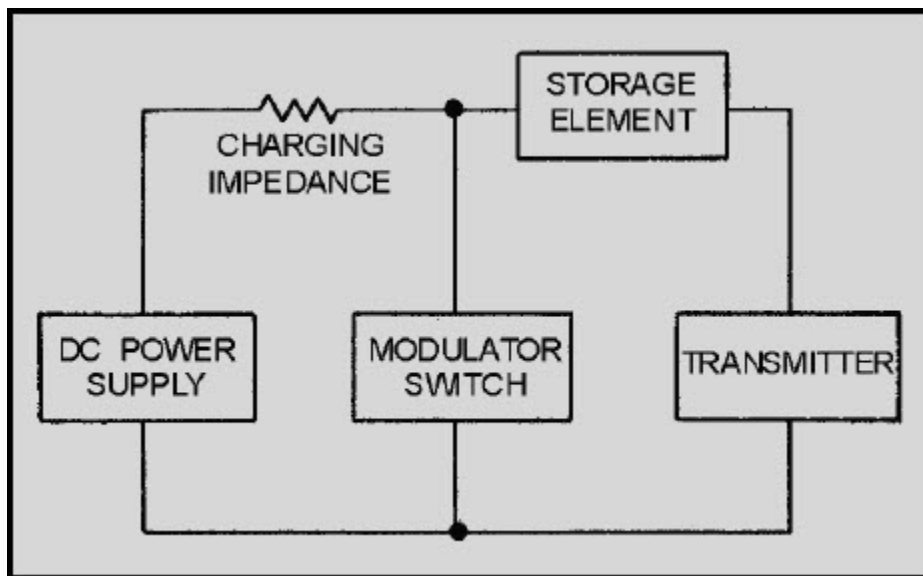


Figure 2-7 Modulator charging impedance

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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 (ac or dc)
2. The type of storage element
3. The amount of modulator pulse voltage required
4. The pulse-repetition rate
5. The frequency of the available ac supply voltage

Q16. What type of tube best meets the requirements of a modulator switching element?

Q17. What modulator element controls the rate at which the storage element charges?

2.2.2 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 2-8 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 2-9.

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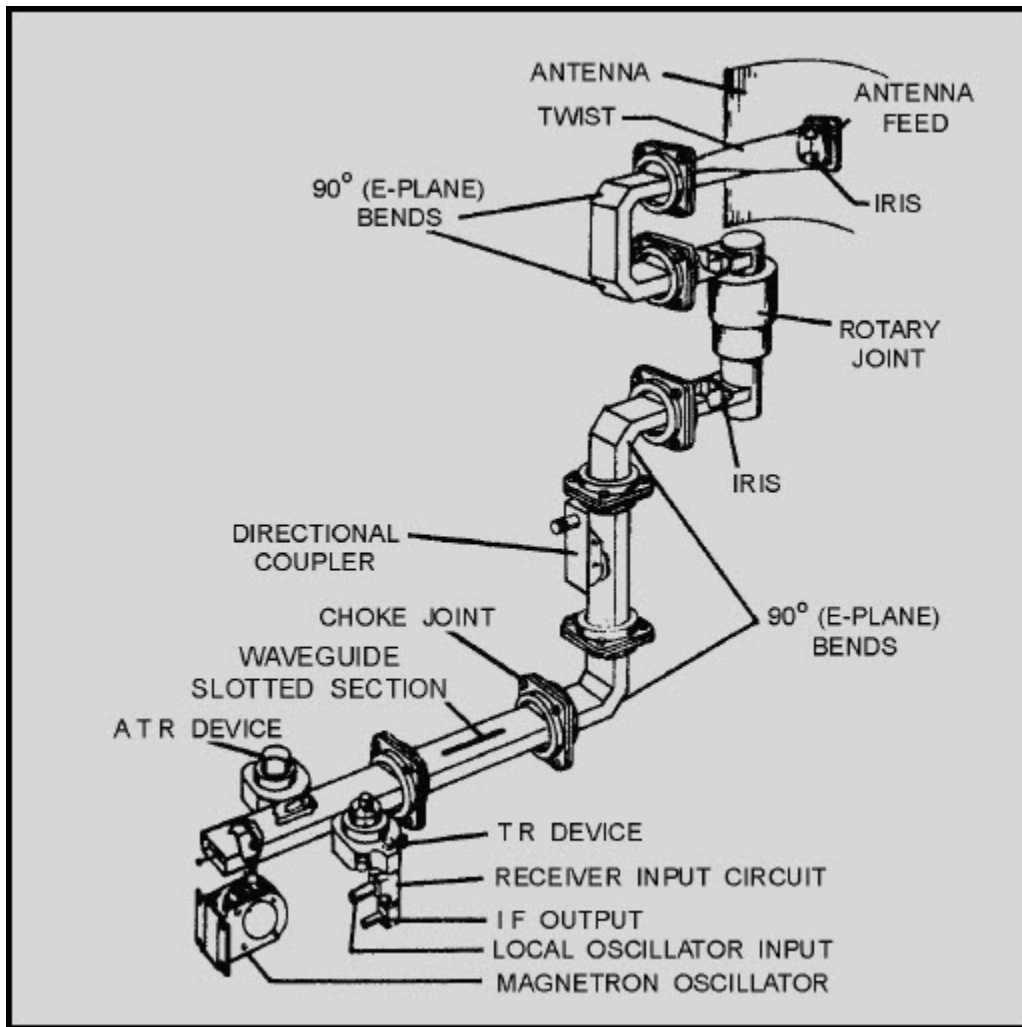


Figure 2-8 Keyed oscillator transmitter physical layout

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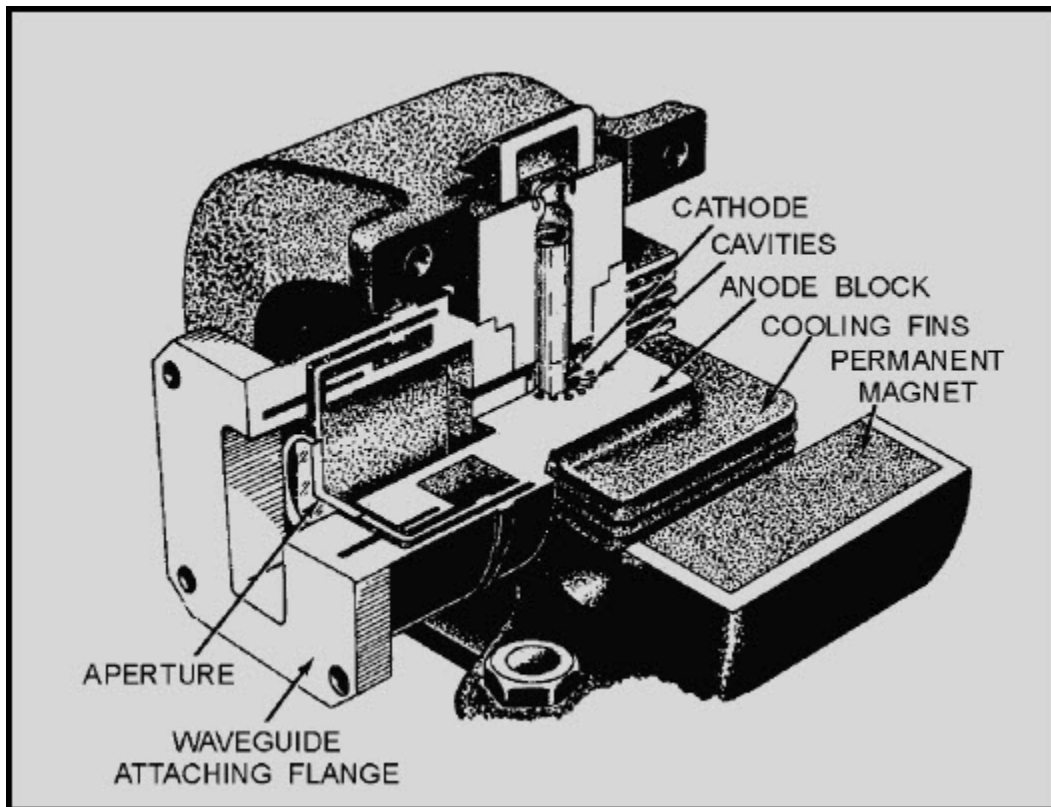


Figure 2-9 Typical magnetron

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 megahertz. (If you wish to review magnetron operation in more detail, refer to NEETS, Module 11, *Microwave Principles*.)

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

- Stability
- Pulse characteristics
- The magnet
- Output coupling

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2.2.2.1 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 does not occur if the modulator pulse is of the proper shape, unless the cathode of the magnetron is in very poor condition.

2.2.2.2 Pulse Characteristics

PULSE CHARACTERISTICS are the make up 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.

2.2.2.3 Magnet

The purpose of the MAGNET is to produce a fairly 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 for proper operation. 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.

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2.2.2.4 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 2-9. 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, and 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 about 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.

WARNING

All radar transmitters contain lethal voltages. Extreme care and strict observance of all posted safety precautions are essential when working on a radar transmitter.

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Q18. What is the frequency range of magnetron oscillators?

Q19. What two forms of instability are common in magnetrons?

Q20. What is the effect on magnetron operation if the magnetic field strength is too high?

Q21. What is the typical frequency range about the center frequency of a tunable magnetron?

2.2.3 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 stability problems. It generates, shapes, and amplifies pulses of rf energy for transmission.

Figure 2-10 is a block diagram of a typical power-amplifier transmitter system. In this transmitter system a multicavity klystron tube amplifies lower-powered rf pulses that have been generated and shaped in other stages. **CROSSED-FIELD AMPLIFIERS (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.

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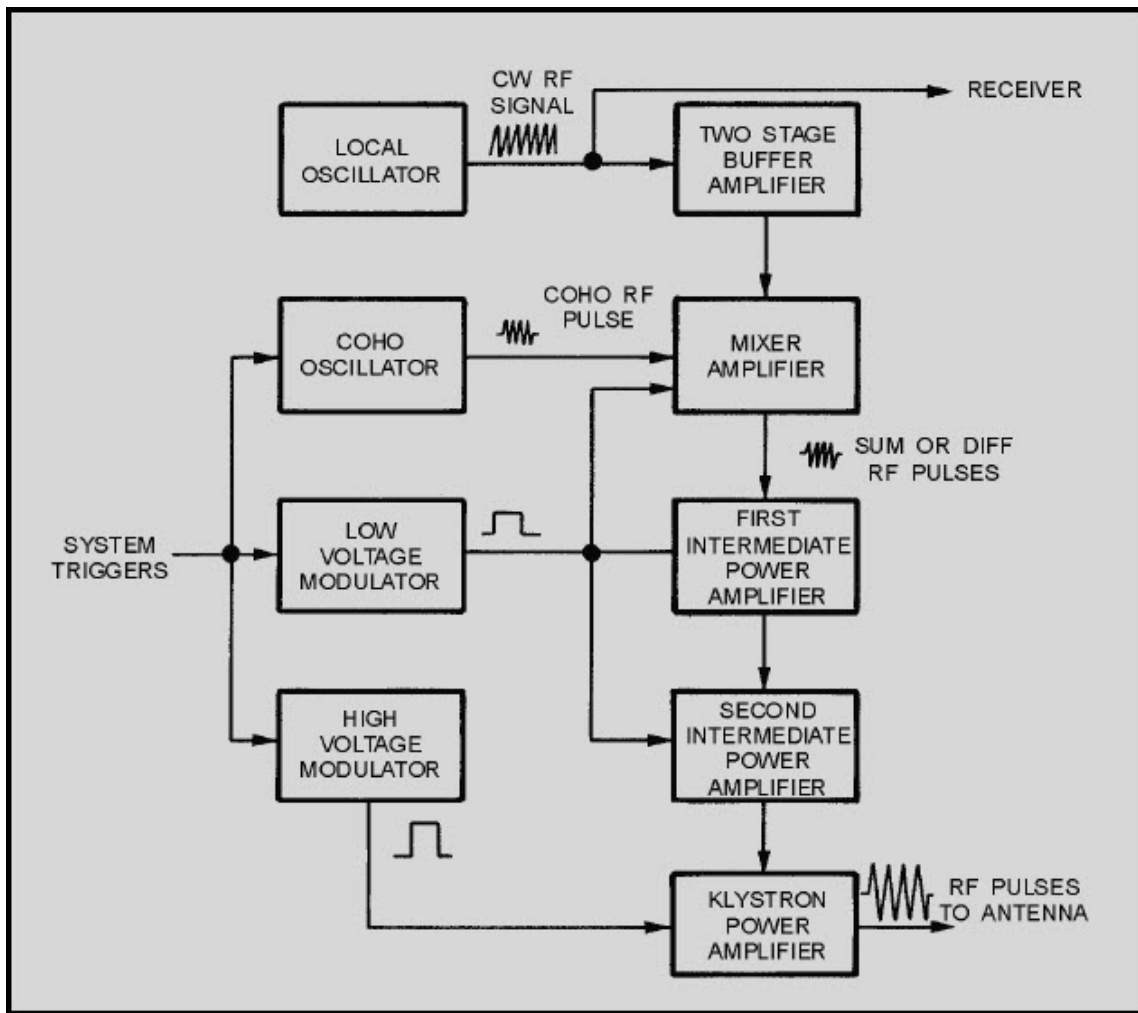


Figure 2-10 Power amplifier transmitter block diagram

In figure 2-10, 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 section 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.

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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 2-10 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 also isolate the local oscillator.

The COHERENT OSCILLATOR (COHO) is triggered by the system trigger and produces as its output an rf pulse. 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 stage is a multicavity power 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.

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Q22. What is the primary advantage of power-amplifier transmitters over keyed-oscillator transmitters?

Q23. In the power amplifier shown in figure 2-10, what two signals are mixed to produce the output signal?

Q24. What type of klystron is used as the final stage of a power-amplifier transmitter?

Figure 2-11 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.

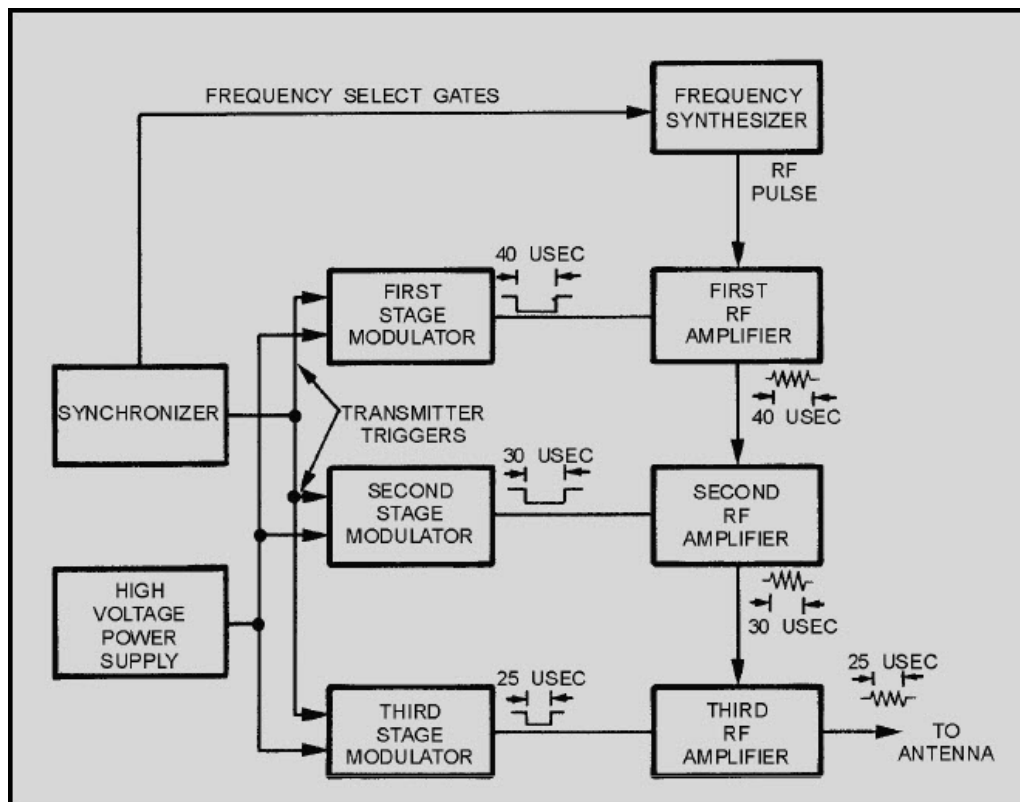


Figure 2-11 Power amplifier transmitter using crossed-field amplifiers

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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 manual 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 2-11, the same procedure is repeated in the third and final stage.

The amplifiers in this type of power-amplifier transmitter must be broad-band 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 cross-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.

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Q25. What transmitter component allows the radiation of a large number of discrete frequencies over a wide band?

Q26. What is the result of pulsing a pulsed rf amplifier when no rf is present?

2.3 DUPLEXERS

Whenever a single antenna is used for both transmitting and receiving, as in a radar system, problems arise. Switching the antenna between the transmit and receive modes presents one problem; ensuring that maximum use is made of the available energy is another. The simplest solution is to use a switch to transfer the antenna connection from the receiver to the transmitter during the transmitted pulse and back to the receiver during the return (echo) pulse. No practical mechanical switches are available that can open and close in a few microseconds. Therefore, ELECTRONIC SWITCHES must be used. Switching systems of this type are called DUPLEXERS.

2.3.1 Basic Duplexer Operation

In selecting a switch for this task, you must remember that protection of the receiver input circuit is as important as are output power considerations. At frequencies where amplifiers may be used, amplifier tubes can be chosen to withstand large input powers without damage. However, the input circuit of the receiver is easily damaged by large applied signals and must be carefully protected. An effective radar duplexing system must meet the following four requirements:

1. During the period of transmission, the switch must connect the antenna to the transmitter and disconnect it from the receiver.
2. The receiver must be thoroughly isolated from the transmitter during the transmission of the high power pulse to avoid damage to sensitive receiver components.
3. After transmission, the switch must rapidly disconnect the transmitter and connect the receiver to the antenna. For targets close to the radar to be seen, the action of the switch must be extremely rapid.
4. The switch should absorb an absolute minimum of power both during transmission and reception.

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Therefore, a radar duplexer is the microwave equivalent of a fast, low-loss, single-pole, double throw switch. The devices developed for this purpose are similar to spark gaps in which high-current microwave discharges furnish low-impedance paths. A duplexer usually contains two switching tubes (spark gaps) connected in a microwave circuit with three terminal transmission lines, one each for the transmitter, receiver, and antenna. As shown in views A and B of figure 2-12, these circuits may be connected in parallel or in series. Both systems will be discussed in detail in this section. One tube is called the TRANSMIT-RECEIVER TUBE, or TR TUBE; the other is called the ANTITRANSMITRECEIVE TUBE, or ATR TUBE. The tr tube has the primary function of disconnecting the receiver, and the atr tube of disconnecting the transmitter.

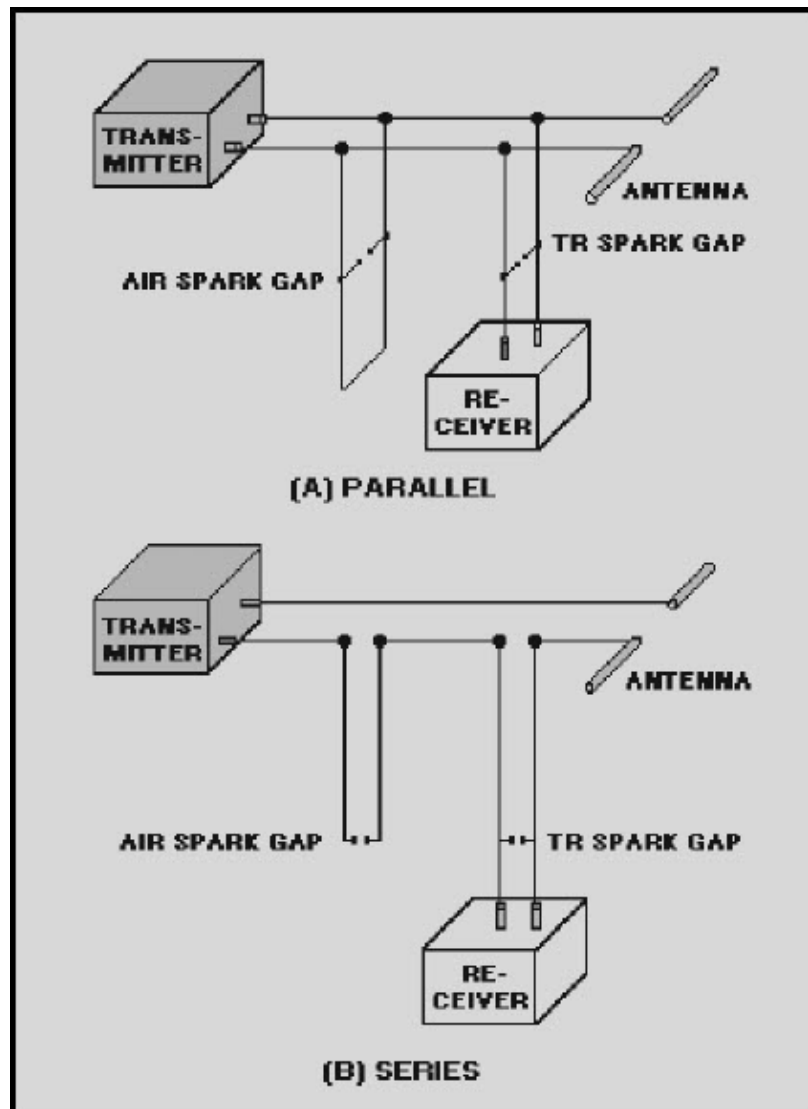


Figure 2-12 Duplexer systems

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The overall action of the tr and atr circuits depends upon the impedance characteristics of the quarter-wavelength section of transmission line. A quarter-wavelength, or an odd multiple of the quarter wavelength, transmission line presents opposite impedance values at the ends; one end of the line appears as a short and the other end appears as an open.

2.3.1.1 TR Tube

The type of spark gap used as a tr tube may vary. It may be one that is simply formed by two electrodes placed across the transmission line; or it may be one enclosed in an evacuated glass envelope with special features to improve operation. The requirements of the spark gap are (1) high impedance prior to the arc and (2) very low impedance during arc time. At the end of the transmitted pulse the arc should be extinguished as rapidly as possible. Extinguishing the arc stops any loss caused by the arc and permits signals from nearby targets to reach the receiver.

The simple gap formed in air has a resistance during conduction of from 30 to 50 ohms. This is usually too high for use with any but an open-wire transmission line. The time required for the air surrounding the gap to completely deionize after the pulse voltage has been removed is about 10 microseconds. During this time the gap acts as an increasing resistance across the transmission line to which it is connected. However, in a tr system using an air gap, the echo signals reaching the receiver beyond the gap will be permitted to increase to half their proper magnitude 3 microseconds after the pulse voltage has been removed. This interval is known as RECOVERY TIME.

Tr tubes are usually conventional spark gaps enclosed in partially evacuated, sealed glass envelopes, as shown in figure 2-13. The arc is formed as electrons are conducted through the ionized gas or vapor. You may lower the magnitude of voltage necessary to break down a gap by reducing the pressure of the gas that surrounds the electrodes. Optimum pressure achieves the most efficient tr operation. You can reduce the recovery time, or DEIONIZATION TIME, of the gap by introducing water vapor into the tr tube. A tr tube containing water vapor at a pressure of 1 millimeter of mercury will recover in 0.5 microseconds. It is important for a tr tube to have a short recovery time to reduce the range at which targets near the radar can be detected. If, for example, echo signals reflected from nearby objects return to the radar before the tr tube has recovered, those signals will be unable to enter the receiver.

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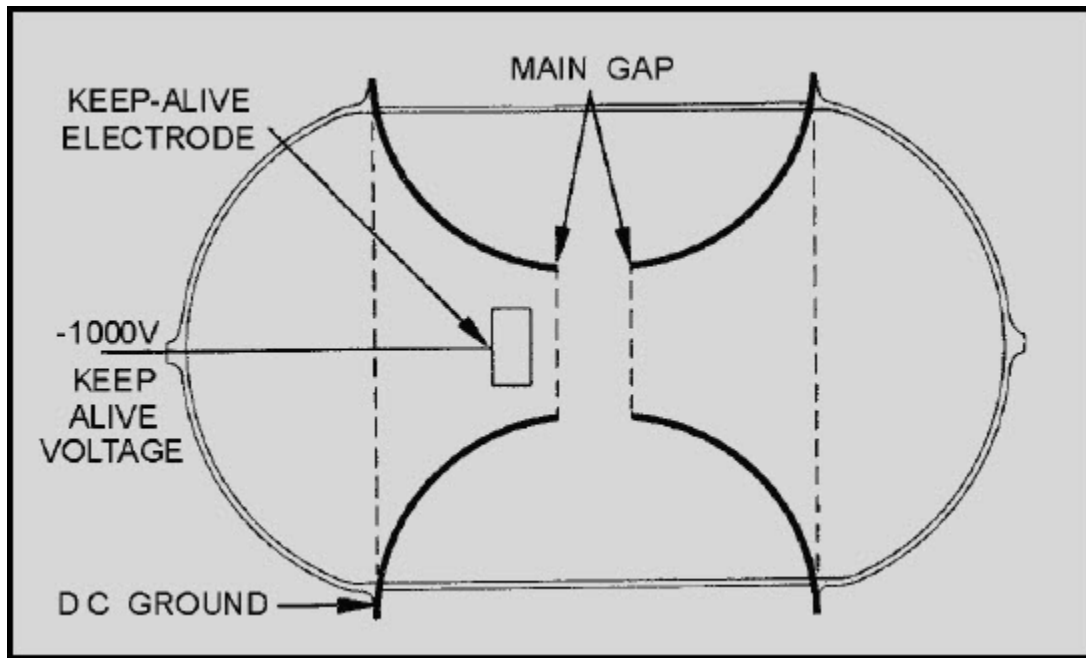


Figure 2-13 Tr tube with keep-alive electrode

Tr tubes used at microwave frequencies are built to fit into, and become a part of, a resonant cavity. You may increase the speed with which the gap breaks down after the transmitter fires by placing a voltage across the gap electrodes. This potential is known as **KEEP-ALIVE VOLTAGE** and ranges from 100 volts to 1,000 volts. A glow discharge is maintained between the electrodes. (The term **GLOW DISCHARGE** refers to the discharge of electricity through a gas-filled electron tube. This is distinguished by a cathode glow and voltage drop much higher than the gas-ionization voltage in the cathode vicinity.) This action provides for rapid ionization when the transmitter pulse arrives.

Failure of the tr tube is primarily caused by two factors. The first and most common cause of failure is the gradual buildup of metal particles that have been dislodged from the electrodes. Such metal bits become spattered on the inside of the glass envelope. These particles act as small, conducting areas and tend to lower the **Q** of the resonant cavity and dissipate power. If the tube continues in use for too long a period in this condition, the particles will form a detuning wall within the cavity and eventually prevent the tube from functioning. A second cause of failure is the absorption of gas within the enclosure by the metal electrodes. This results in a gradual reduction of pressure within the tube to a point where gap breakdown becomes very difficult. The final result is that extremely strong signals (from the transmitter) are coupled to the receiver. Because both types of failures develop gradually, the tr tube periodically must be checked carefully to determine performance level.

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Q27. What type of switches are used as duplexers?

Q28. What tube in a duplexer has the primary function of disconnecting the receiver?

Q29. How may the tr tube ionization speed be increased?

2.3.1.2 ATR Tube

The atr tube is usually a simpler device than a tr tube. An atr tube might use a pure inert gas, such as argon, because recovery time generally is not a vital factor. Furthermore, a priming agent, such as keep alive voltage, is not needed. The absence of either a chemically active gas or a keep-alive voltage results in atr tubes having longer useful lives than tr tubes.

WARNING

Tr and atr tubes may contain radioactive material. Handle with care to avoid breakage and possible contamination.

There are two basic tr-atr duplexer configurations. They are the parallel-connected and the series connected duplexer systems. The following paragraphs describe the operation of both systems.

2.3.1.3 Parallel Connected Duplexer Operation

First, let's consider a PARALLEL-CONNECTED DUPLEXER system, as shown in figure 2-14. The tr spark gap shown in figure 2-14 is located in the receiver coupling line one-quarter wavelength from the T-junction. A half-wavelength, closed-end section of transmission line, called a STUB, is shunted across the main transmission line. An atr spark gap is located in this line one-quarter wavelength from the main transmission line and one-quarter wavelength from the closed end of the stub. As shown in the figure, antenna impedance, line impedance, and transmitter output impedance, when transmitting, are all equal. The action of the circuit during transmission is shown in figure 2-15.

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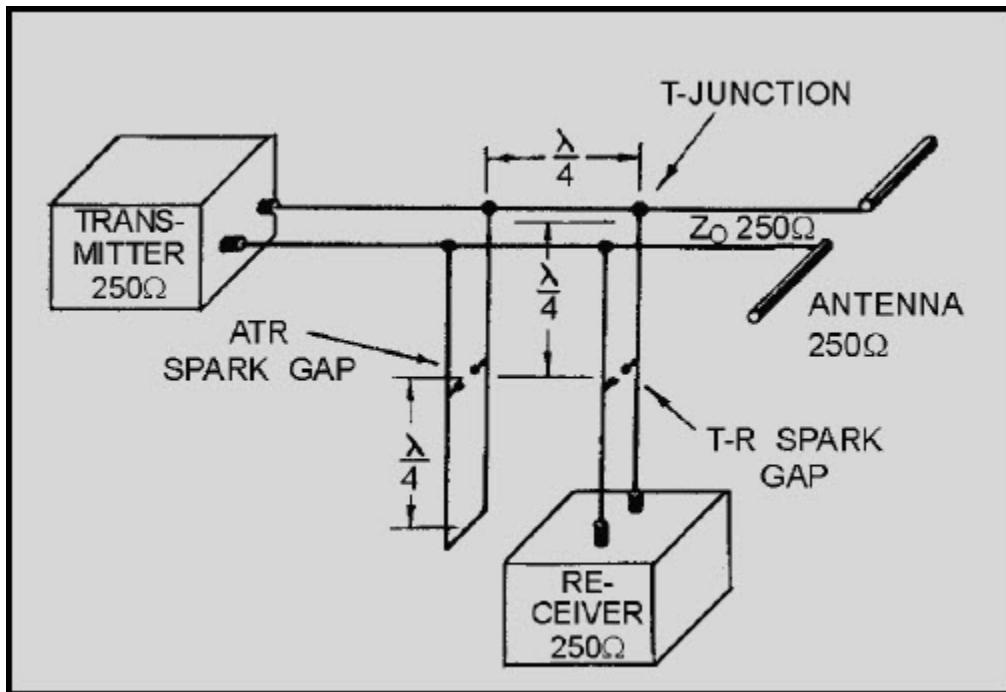


Figure 2-14 Parallel-connected duplexer showing distance and impedance

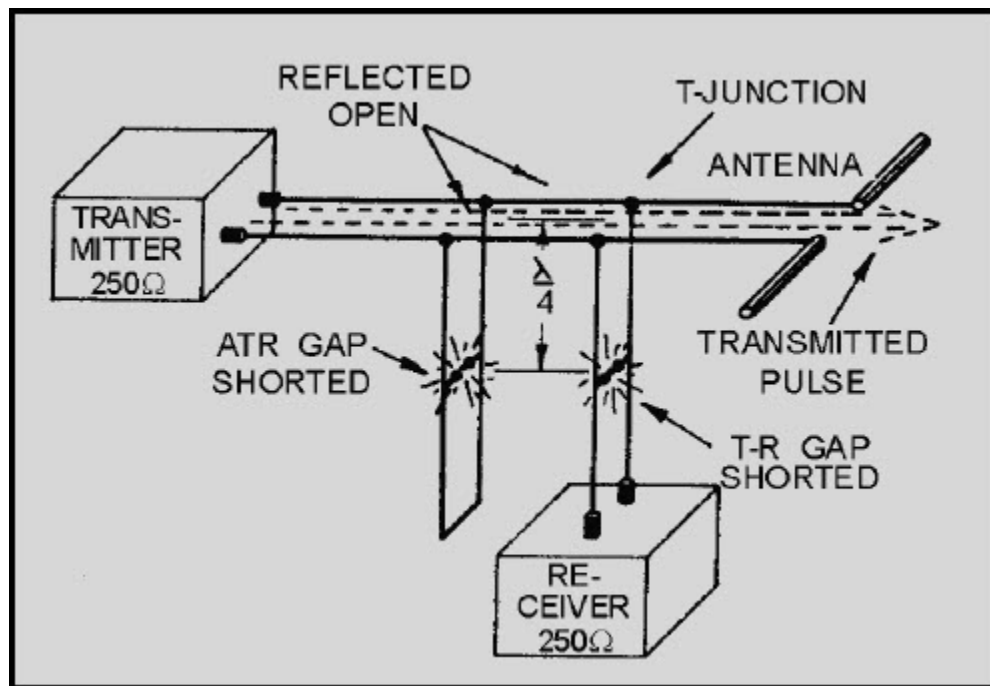


Figure 2-15 Parallel-connected duplexer during transmission

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During the transmitting pulse, an arc appears across both spark gaps and causes the tr and atr circuits to act as shorted (closed-end) quarter-wave stubs. The circuits then reflect an open circuit to the tr and atr circuit connections to the main transmission line. None of the transmitted energy can pass through these reflected opens into the atr stub or into the receiver. Therefore, all of the transmitted energy is directed to the antenna.

During reception, as shown in figure 2-16, the amplitude of the received echo is not sufficient to cause an arc across either spark gap. Under this condition, the atr circuit now acts as a half-wave transmission line terminated in a short-circuit. This is reflected as an open circuit at the receiver T-junction, three-quarter wavelengths away. The received echo sees an open circuit in the direction of the transmitter. However, the receiver input impedance is matched to the transmission line impedance so that the entire received signal will go to the receiver with a minimum amount of loss.

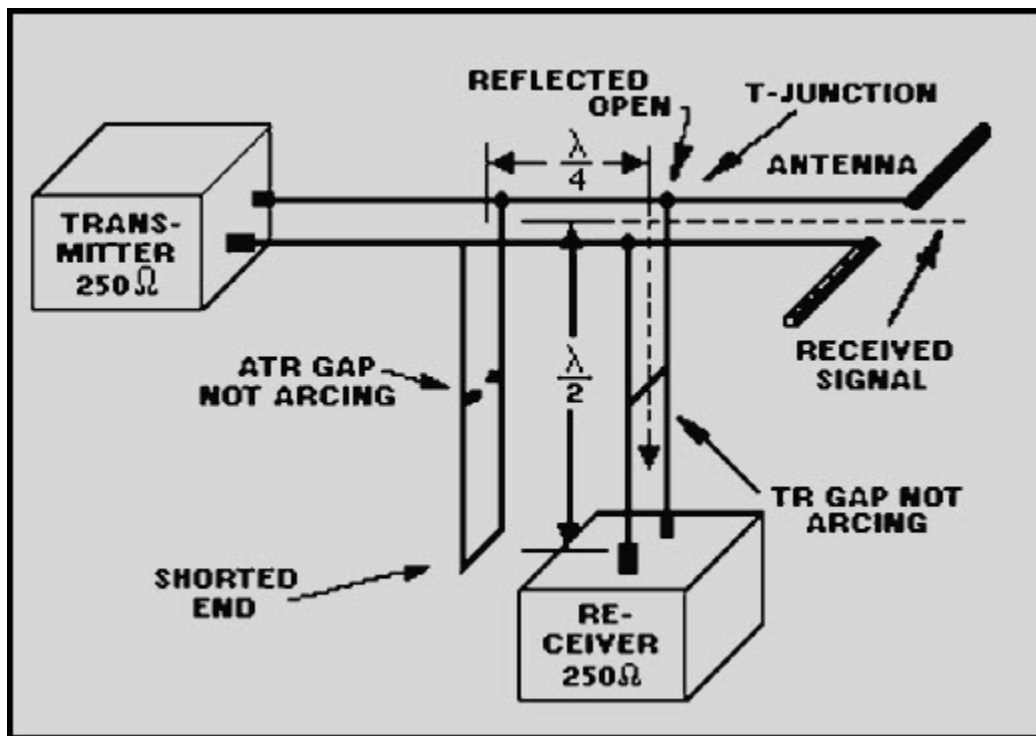


Figure 2-16 Parallel-connected duplexer during reception

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2.3.1.4 Series-Connected Duplexer Operation

In the SERIES-CONNECTED DUPLEXER SYSTEM, shown in figure 2-17, the tr spark gap is located one-half wavelength from the receiver T-junction. The atr spark gap is located one-half wavelength from the transmission line and three-quarters wavelength from the receiver T-junction. During transmission, the tr and atr gaps fire in the series-connected duplexer system, as shown in figure 2-18. This causes a short-circuit to be reflected at the series connection to the main transmission line one half wavelength away. The transmitted pulse "sees" a low impedance path in the direction of the antenna and does not go into the atr stub or the receiver.

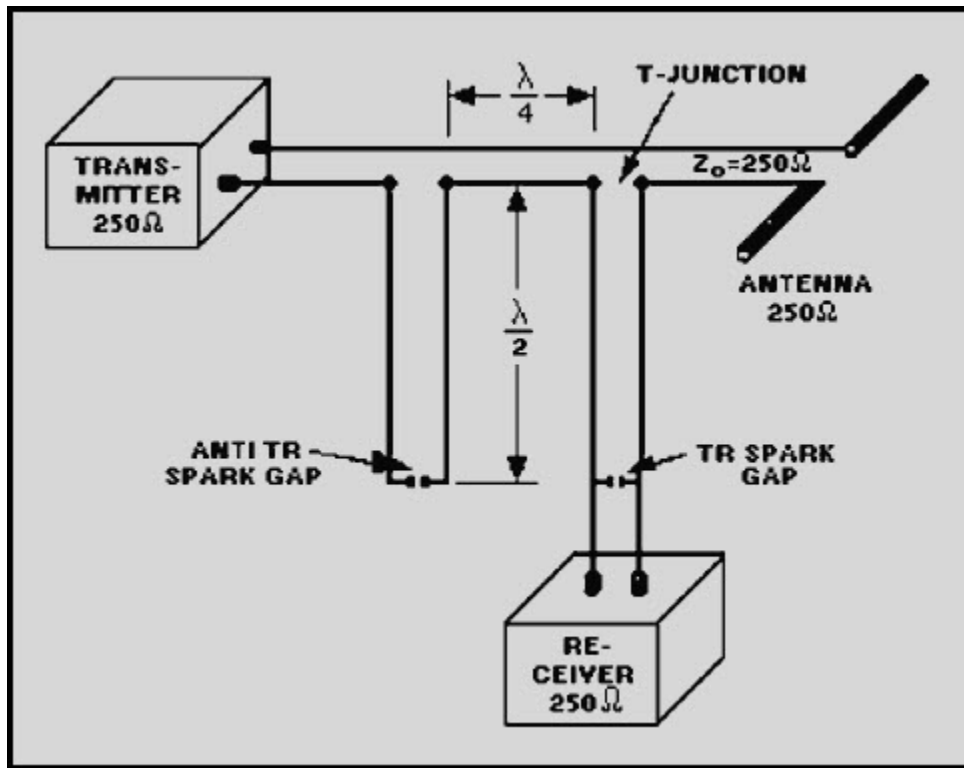


Figure 2-17 Series-connected duplexer showing distance and impedance

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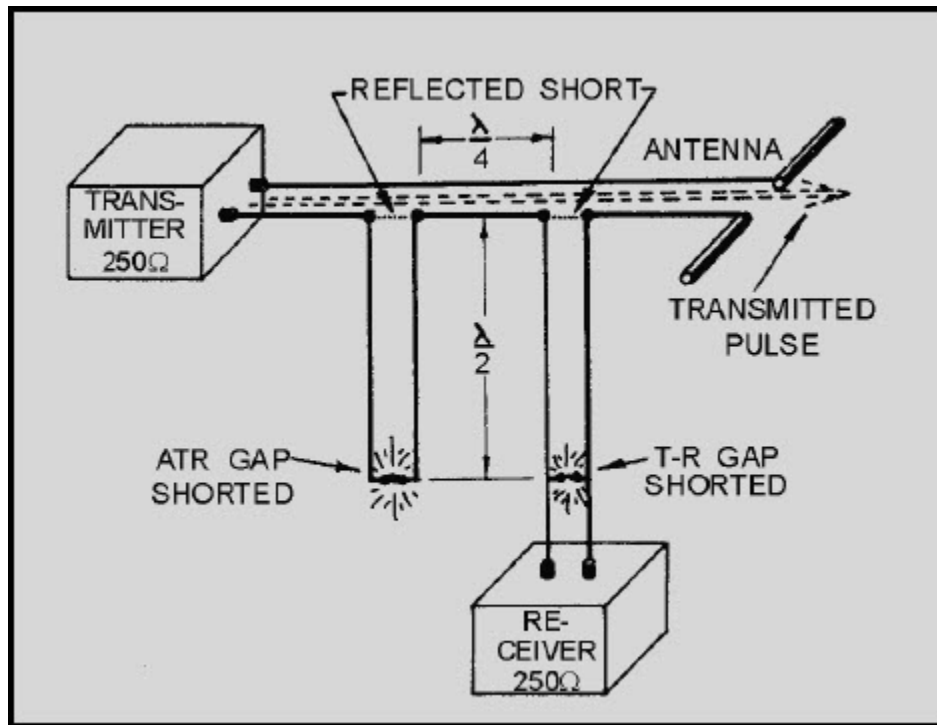


Figure 2-18 Series-connected duplexer during transmission

During reception, neither spark gap is fired, as shown in figure 2-19. The atr acts as a half-wave stub terminated in an open. This open is reflected as a short-circuit at the T-junction three-quarters of a wavelength away. Consequently, the received signal sees a low impedance path to the receiver, and none of the received signal is lost in the transmitting circuit.

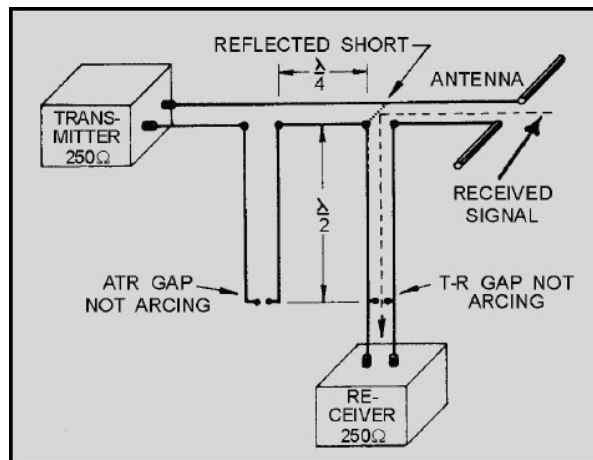


Figure 2-19 Series-connected duplexer during reception

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2.3.2 Duplexer Types

Duplexers are constructed in many forms, such as RESONANT-CAVITY COAXIAL SYSTEMS, WAVEGUIDE SYSTEMS, and HYBRID RINGS. Since waveguide and hybrid-ring duplexers are most common in radar systems, those will be discussed in this section.

2.3.2.1 Waveguide Duplexer

WAVEGUIDE DUPLEXERS usually consist of tr tubes and atr tubes housed in a resonant cavity and attached to a waveguide system in some manner. Resonant-cavity tr tubes may be applied to waveguides, either directly or indirectly, to obtain switching action. The indirect method uses a coaxial line system, and then couples the coaxial line into the waveguide that feeds the antenna. If large losses are incurred by the use of a coaxial line, the resonant cavity can be coupled directly to the waveguide. Figure 2-20 shows a direct method of cavity tr switching in a waveguide system. The waveguide terminates in the antenna at one end and in a shorting plate at the other. The magnetron uses a voltage probe to excite the waveguide. The transmitted pulse travels up the guide and moves into the tr box through a slot. The cavity builds up a strong electric field across the gap, breaks it down, and detunes the cavity. This action effectively seals the opening and passes the pulse energy to the antenna.

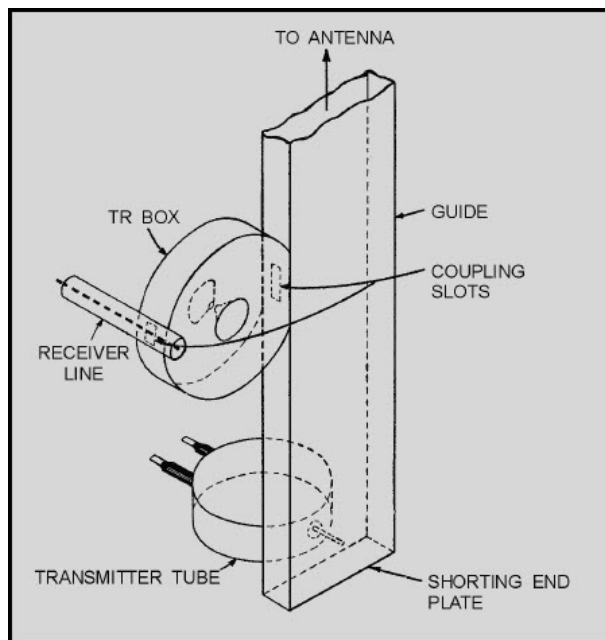


Figure 2-20 Waveguide duplexer with cavity tr tube

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The signals received during the resting time travel down the guide to the magnetron and the shorting end plate where they are reflected. The slot coupling the waveguide to the cavity is located at a point where the standing-wave magnetic field produced by reflections in the waveguide is maximum. The maximum magnetic field, therefore, energizes the cavity. The echo signals are not strong enough to cause an arc, and the cavity field is undisturbed by the gap. Therefore, the cavity field couples rf energy into the receiver coaxial line and provides maximum energy transfer.

The cavity tr switch can also be applied to branch lines of the waveguide, as shown in figure 2-21. The magnetron is coupled to the guide by a voltage probe to produce proper excitation.

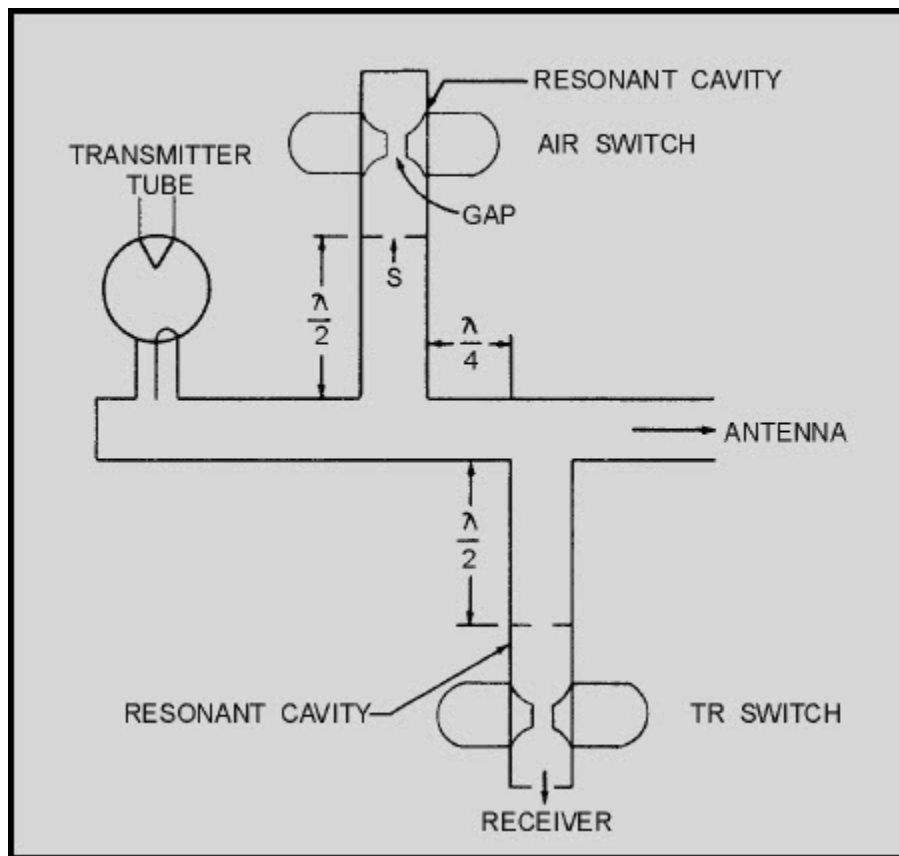


Figure 2-21 Branched waveguide duplexer

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Maximum use of the received signals is ensured by an atr tube. The transmitted pulse travels from the magnetron to the atr branch where part of the energy is diverted into the gap. A slot (S) is placed across the waveguide one-half wavelength from the main guide, and passes the rf energy through it and into the cavity. The cavity builds up the electric field that breaks down the gap, detunes the cavity, and, as a result, effectively closes the slot. One-half wavelength away, this action effectively closes the entrance to the atr branch and limits the amount of energy entering the atr branch to a small value.

Most of the energy is, therefore, directed down the guide to the antenna. Upon reaching the receiver branch, the same effect is produced by the tr tube in the receiver line. Because the energy entering both openings is effectively limited by the gaps, maximum energy is transferred between the magnetron and the antenna.

During the resting time, the atr spark gap is not broken down by the received signals. The received signal sets up standing waves within the cavity that cause it to resonate. At resonance, the low impedance of the atr cavity is reflected as a high impedance at the entrance to the transmitter waveguide (three quarter wavelength away). This ensures that the maximum received signal will enter the receiver branch.

2.3.2.2 Hybrid Ring Duplexer

The HYBRID RING is used as a duplexer in high-power radar systems. It is very effective in isolating the receiver during transmission. A simplified version of the hybrid-ring duplexer is shown in views A and B of figure 2-22. The operation of the duplexer, in terms of the E field distribution during transmission and reception, is illustrated in views C and D. The H lines, though present, have been omitted to simplify the explanation.

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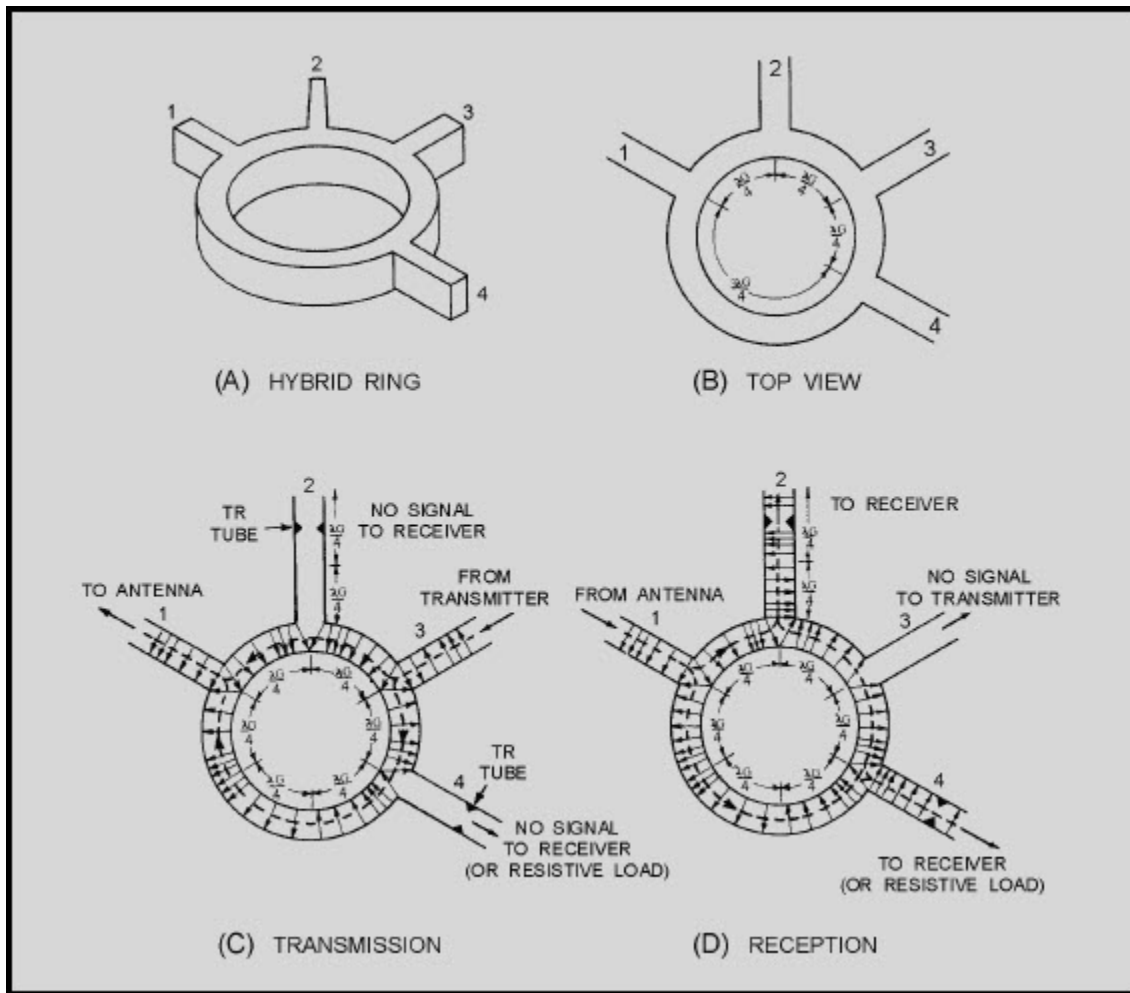


Figure 2-22 Hybrid-ring duplexer

During transmission the E field from the transmitter enters arm 3 and divides into two fields 180 degrees out of phase. One field moves clockwise around the ring and the other moves counterclockwise. The two fields must be 180 degrees out of phase at the entrance of an arm to propagate any energy down the arm. The field moving clockwise from arm 3 ionizes the tr tube in arm 4, and the energy is blocked from the receiver. The tr tube reflects a high impedance equivalent to an open circuit. This high impedance prevents any energy from entering the receiver - even though the two fields are out of phase at the entrance to arm 4. The field moving counterclockwise from arm 3 ionizes the tr tube in arm 2, which reflects a short circuit back to the ring junction. No energy is sent to the receiver, however, because the fields arriving at arm 2 are in phase. The clockwise and counterclockwise fields arrive at arm 1 out of phase by 180 degrees. They are then propagated through the arm to the antenna.

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During reception, the relatively weak field from the antenna enters arm 1 and divides at the junction into two out-of-phase components. Neither field is sufficient to fire the tr tubes in arms 2 and 4; since the fields arrive at these arms out of phase, energy is propagated to the receiver. The energy arriving at arm 3 is in phase and will not be coupled to the transmitter. Since the operation of the arms of a hybrid ring is the same as the operation of E-type waveguide T-junctions, you may find it helpful to review NEETS, Module 11, *Microwave Principles*.

Q30. The actions of the tr and atr circuits depend on the impedance characteristics of what length of transmission line?

Q31. During which of the transmit or receive cycles are both the tr and atr tubes of a parallel connected duplexer ionized (arcing)?

Q32. In a series-connected duplexer, what tube (tr or atr), if any, fires during the receive cycle?

Q33. To propagate energy down an arm of a hybrid ring duplexer, the two fields at the junction of the arm and the ring must have what phase relationship?

2.4 RECEIVERS

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.

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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 cathode-ray tube under the following conditions: (1) when 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, and (3) the pulses last for only a few microseconds.

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

2.4.1 Radar Receiver Requirements

The following characteristics determine the design requirements of an effective radar receiver:

- Noise
- Gain
- Tuning
- Distortion
- Blocking

2.4.1.1 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.

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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.

2.4.1.2 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.

2.4.1.3 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 frequency control (afc) for this purpose.

2.4.1.4 Distortion

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

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2.4.1.5 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 microsecond, or it may take several hundred microseconds, 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.

2.4.2 Receiver Block Diagram

The SUPERHETERODYNE receiver is almost always used in microwave radar systems. A typical superheterodyne radar receiver is shown in figure 2-23. 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.

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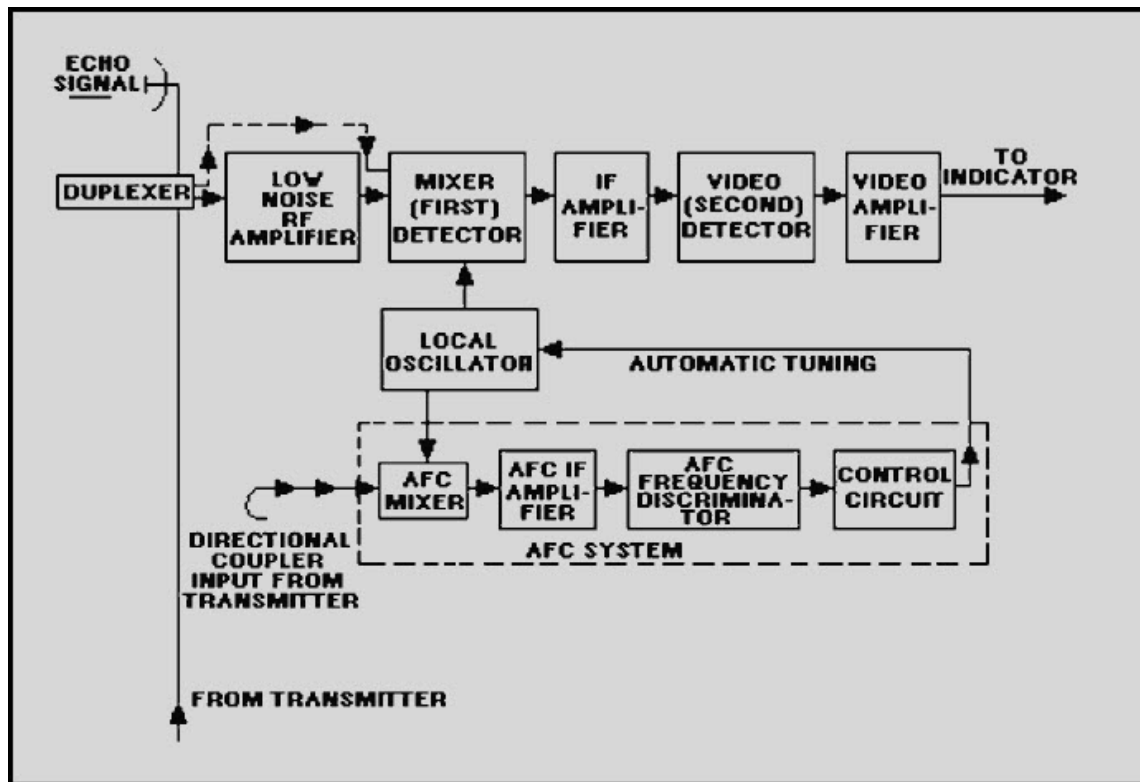


Figure 2-23 Typical superheterodyne radar receiver

The MIXER stage is often called the FIRST DETECTOR. The function of this stage is to convert the received rf energy to a lower, intermediate frequency (IF) that is easier to amplify and manipulate electronically. The intermediate frequency is usually 30 or 60 megahertz. 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.

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As in all superheterodyne receivers, controlling the frequency of the local oscillator keeps the receiver tuned. Since this tuning is critical, some form of automatic frequency control (afc) is essential to avoid constant manual tuning. Automatic frequency control 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.

2.4.3 Receiver Components

This section 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.

2.4.3.1 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. These amplifiers are discussed in detail in NEETS, Module 11, *Microwave Principles*. Some older systems may still use a traveling-wave tube (twt) as a low-noise first stage amplifier. However, the solid-state amplifiers produce lower noise levels and more gain.

2.4.3.2 Local Oscillator

Most radar receivers use a 30 or 60 megahertz intermediate frequency. The IF is produced by mixing a local oscillator signal with the incoming signal. 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 megahertz, a frequency change of 0.1 percent will produce a frequency shift of 3 megahertz. This is equal to the bandwidth of most receivers and would greatly decrease receiver gain.

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The power output requirement for most local oscillators is small (20 to 50 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 megahertz in the 4,000-megahertz region. The local oscillator must compensate for any changes in the transmitted frequency and maintain a constant 30 or 60 megahertz 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 automatic frequency control (afc) circuit to control the output of the local oscillator. A block diagram of a typical afc circuit is included in figure 2-23. 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 megahertz. If the output of the mixer is correct, the discriminator will have no output. If the mixer output is above 30 megahertz, the output of the discriminator will be positive dc pulses; if the mixer output is below 30 megahertz, 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 megahertz. 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 megahertz below the transmitter frequency.

Q34. What is the greatest limiting factor in a receiver's detectable range?

Q35. What type of receiver is most often used in radar systems?

Q36. What IF frequencies are normally used in radar receivers?

Q37. Which component of the receiver produces the signal that is mixed with the received signal to produce the IF signal?

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2.4.3.3 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 2-24. 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.

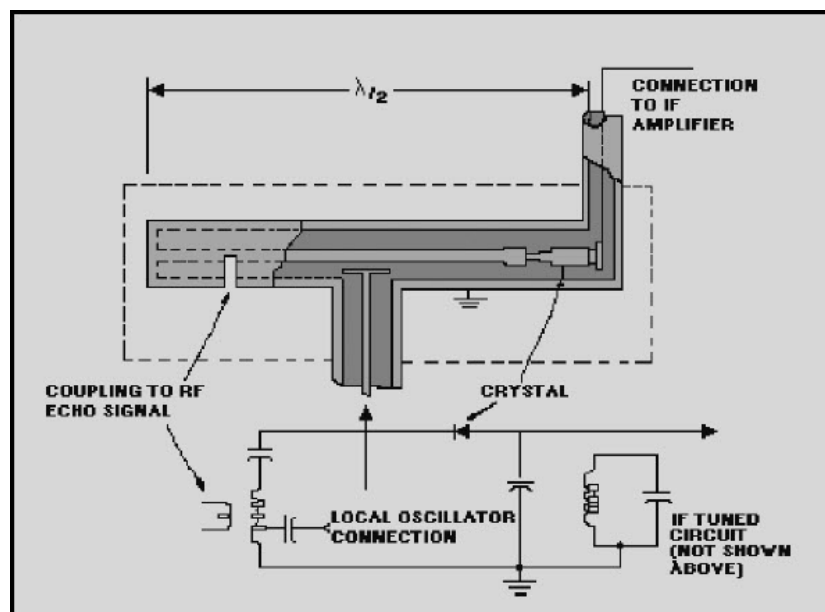


Figure 2-24 Single-ended crystal mixer

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One type of mixer which cancels local oscillator noise is the BALANCED, OR HYBRID, MIXER (sometimes called the MAGIC T). Figure 2-25 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 2-26. 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.

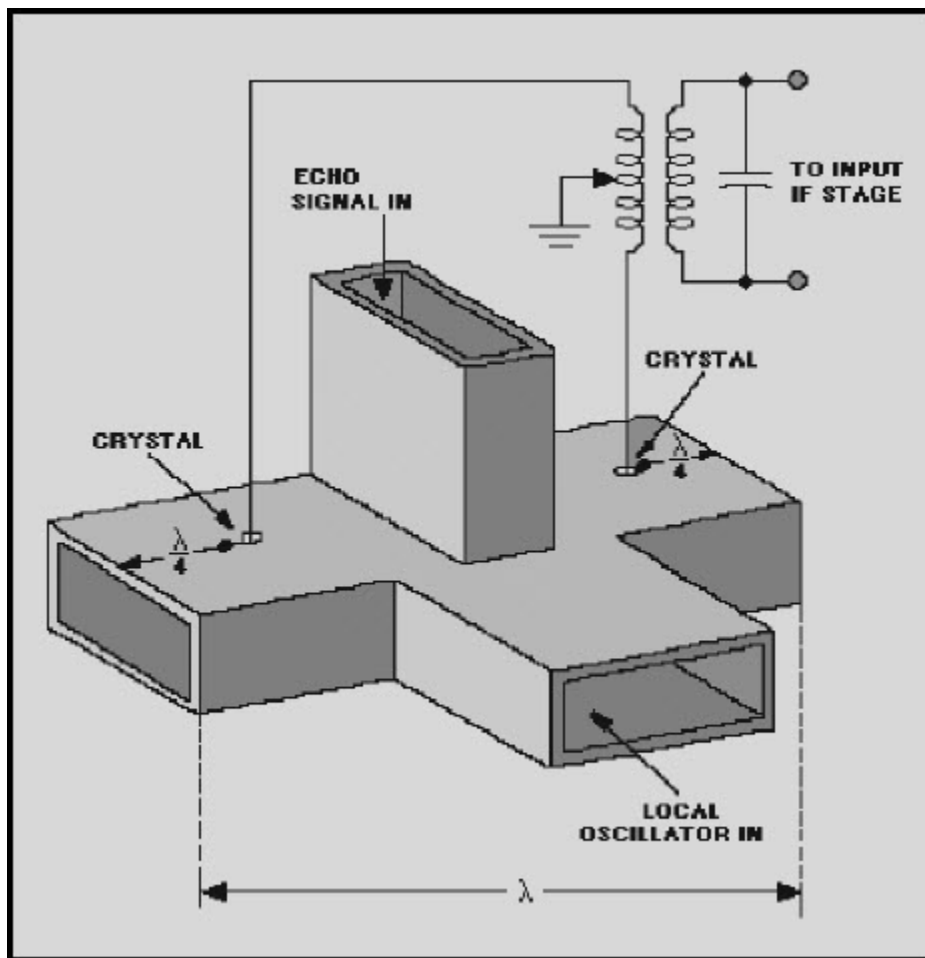


Figure 2-25 Balanced (hybrid) crystal mixer

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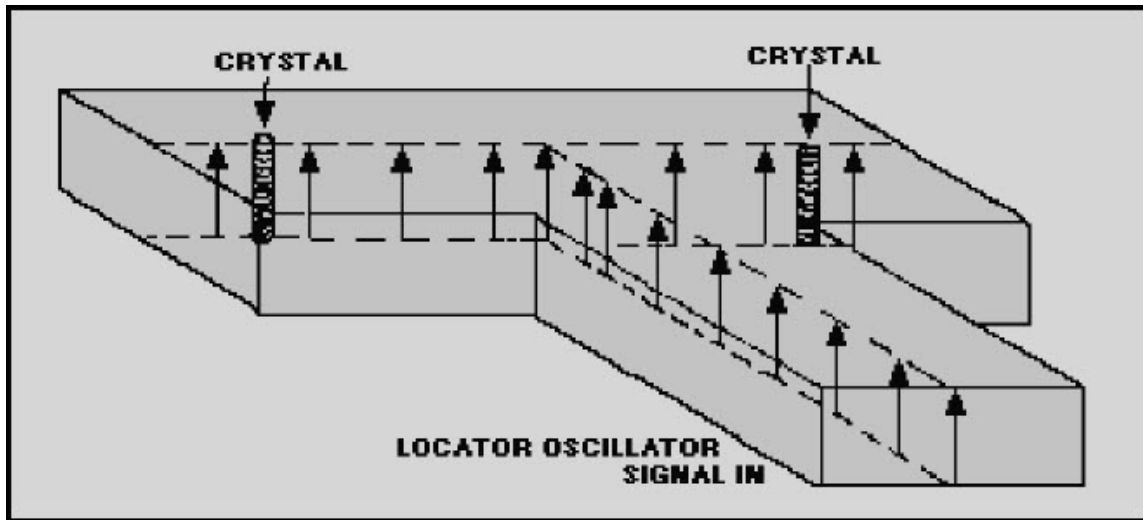


Figure 2-26A Balanced mixer fields. WAVEGUIDE AND LOCAL OSCILLATOR ARM

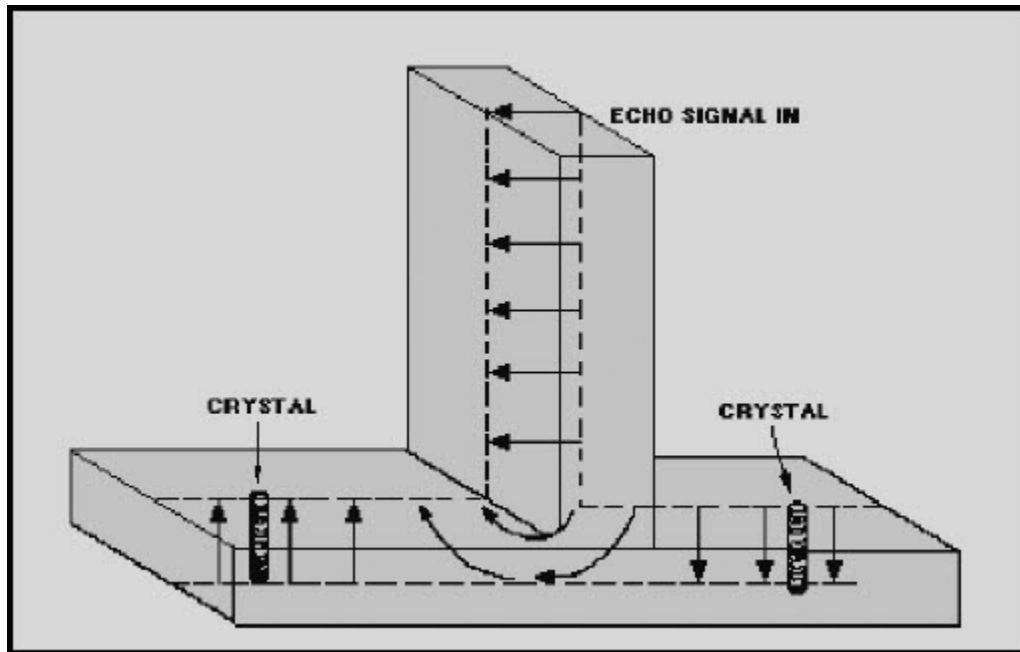


Figure 2-26B.—Balanced mixer fields. WAVEGUIDE AND ECHO SIGNAL ARM

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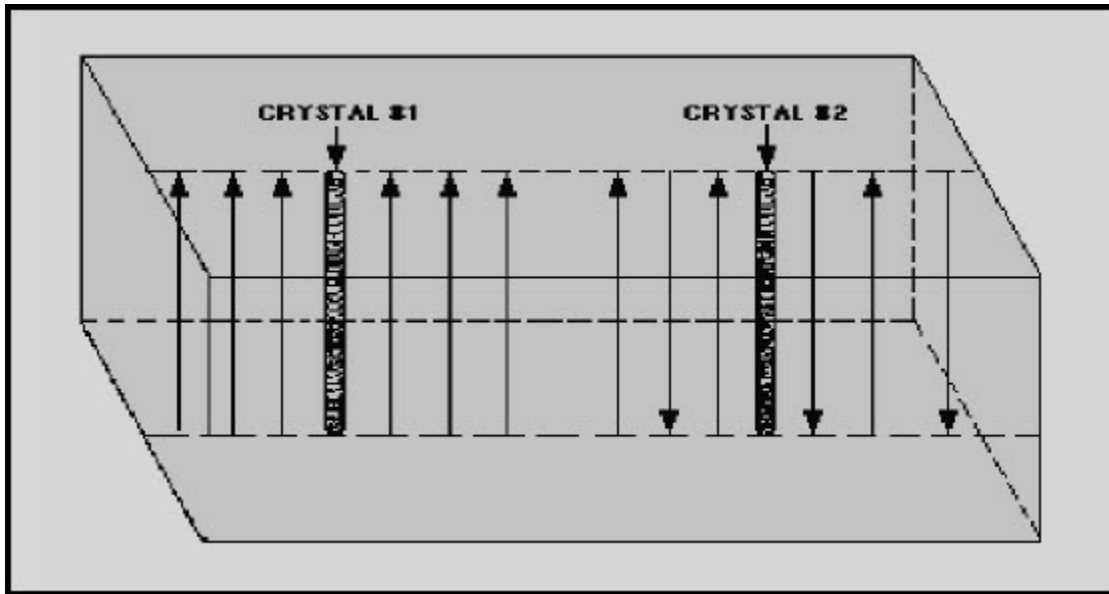


Figure 2-26C.—Balanced mixer fields. WAVEGUIDE

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 (figure 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.

2.4.3.4 IF 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 both 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 2-27 is a block diagram of an IF amplifier that meets these requirements.

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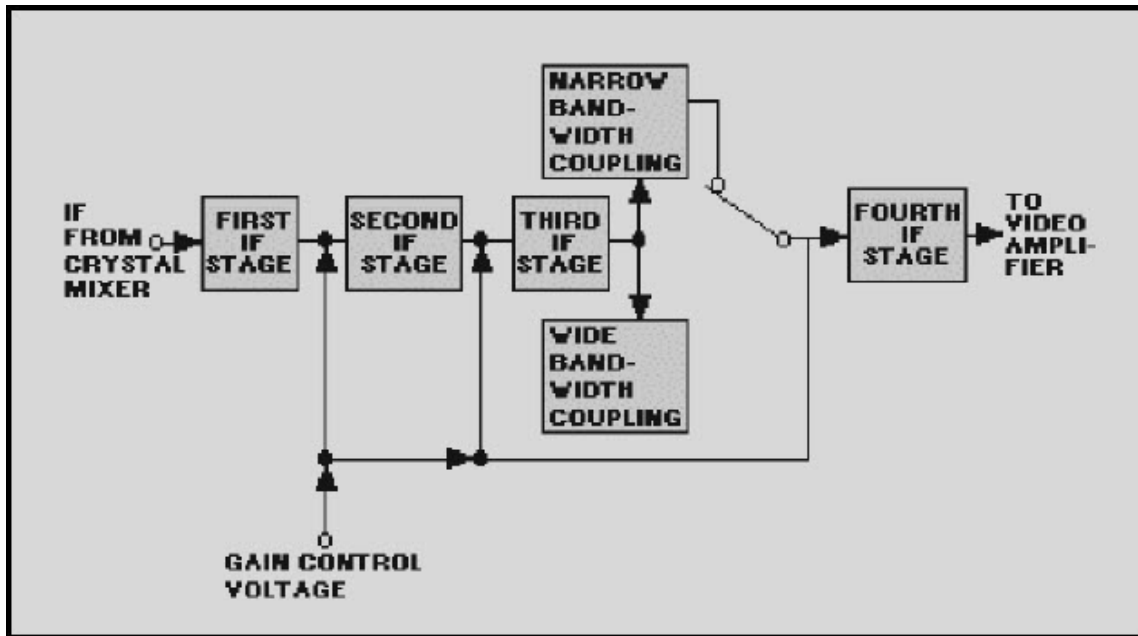


Figure 2-27 IF amplifier block diagram

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.

2.4.3.5 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.

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A diode detector circuit is shown in view A of figure 2-28. 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.

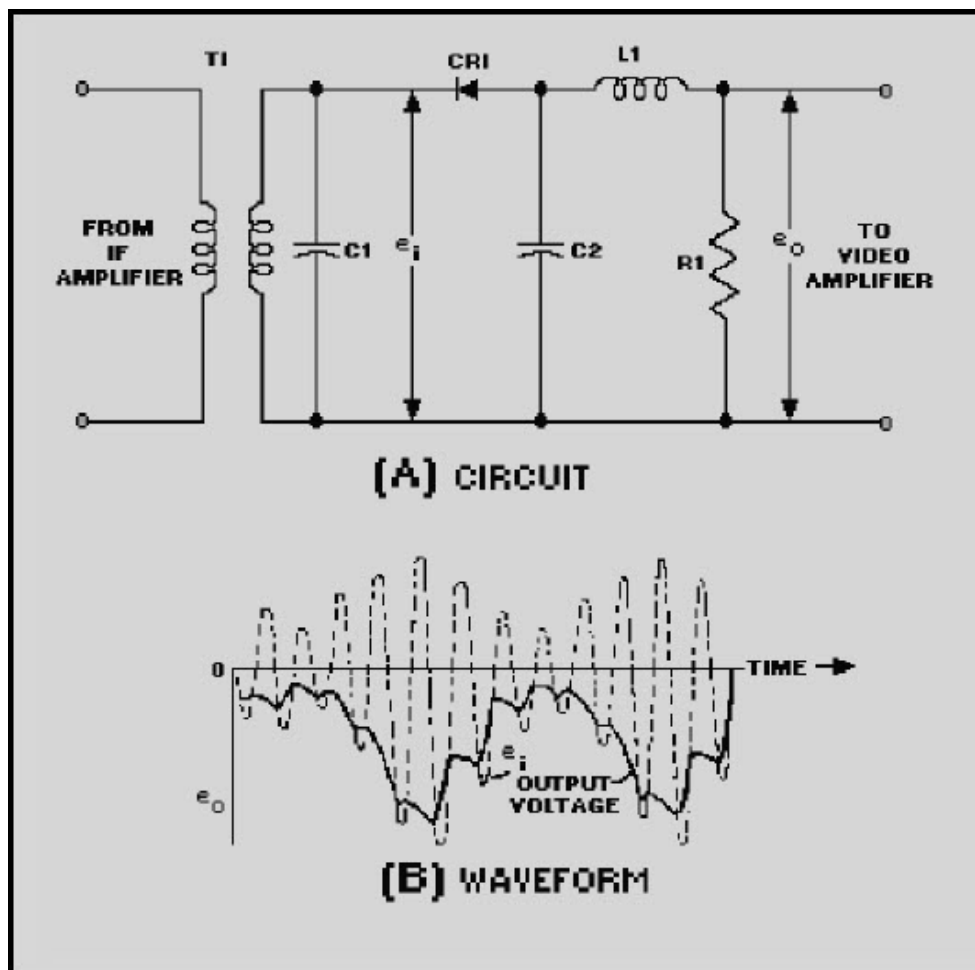


Figure 2-28 Diode detector

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2.4.3.6 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. The types of frequency compensation networks that may be used in a video amplifier stage are discussed in detail in NEETS, Module 8, *Amplifiers*.

Q38. What receiver circuit actually produces the IF frequency?

Q39. The IF amplifiers are connected in what amplifier configuration?

Q40. Which receiver component converts the IF pulses to video pulses?

2.4.4 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 megahertz. 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 counter measures (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 ENHANCEMENT FEATURES, ANTIJAMMING CIRCUITS, or ELECTRONIC COUNTERCOUNTERMEASURES (ECCM) CIRCUITS. This section will discuss, in general terms, some of the more common video enhancement features associated with radar receivers.

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2.4.4.1 Automatic Gain Control (AGC)

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. When only one IF stage is controlled, the range of iagc is limited to approximately 20 dB. When more than one IF stage is controlled, iagc range can be increased to approximately 40 dB.

2.4.4.2 Sensitivity Time Control (STC)

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 stc circuits.

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Sensitivity time-control circuits apply a bias voltage that varies with time to the IF amplifiers to control receiver gain. Figure 2-29 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.

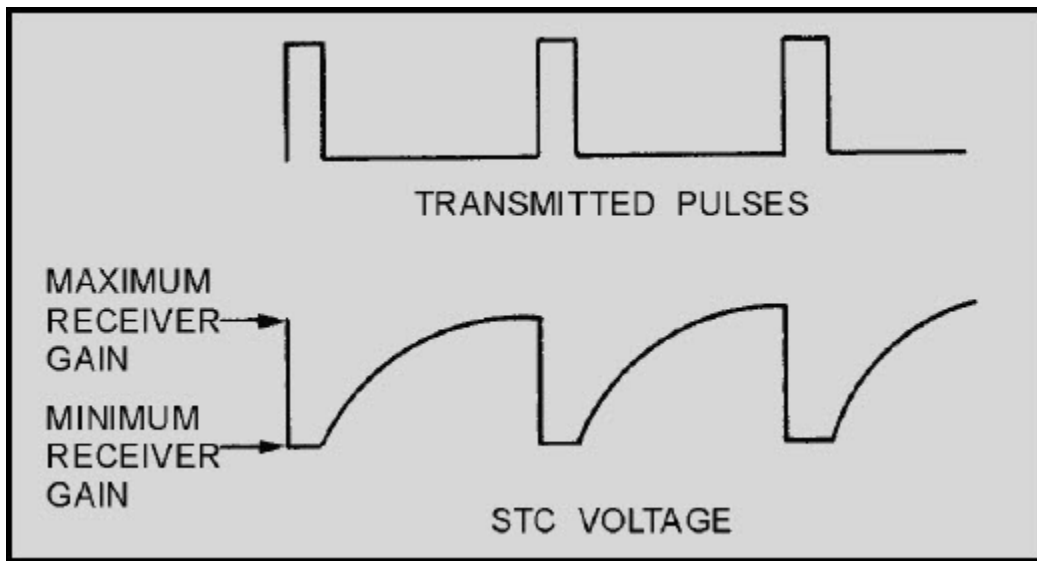


Figure 2-29 Stc voltage waveform

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.

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2.4.4.3 Antijamming 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.

Q41. Which of the two types of automatic gain control, agc or iagc, is most effective in radar use for the Navy?

Q42. Immediately after the transmitter fires, stc reduces the receiver gain to what level?

Q43. How does ftc affect receiver gain, if at all?

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2.4.5 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 moving target indicator (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.

2.4.5.1 Moving Target Indicator (mti) System

The MOVING TARGET INDICATOR (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 land masses), 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 of time 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 2-30, 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.

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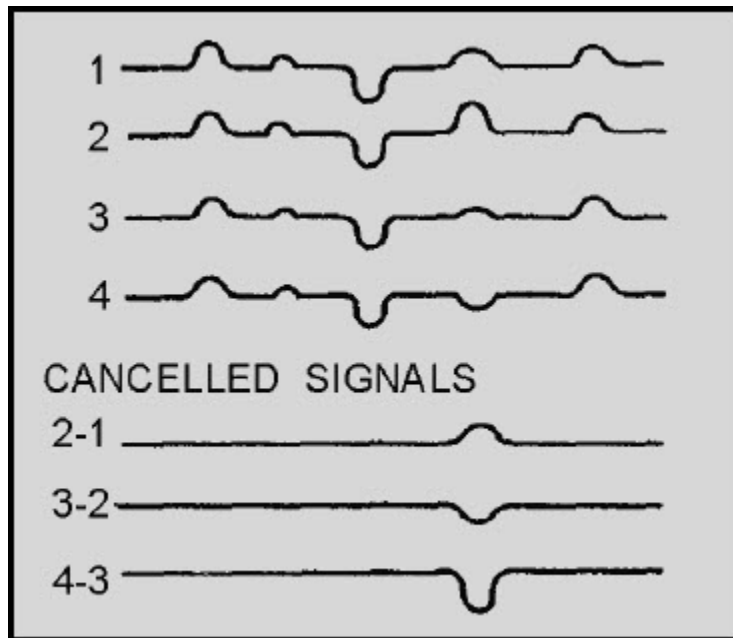


Figure 2-30A Fixed target cancellation

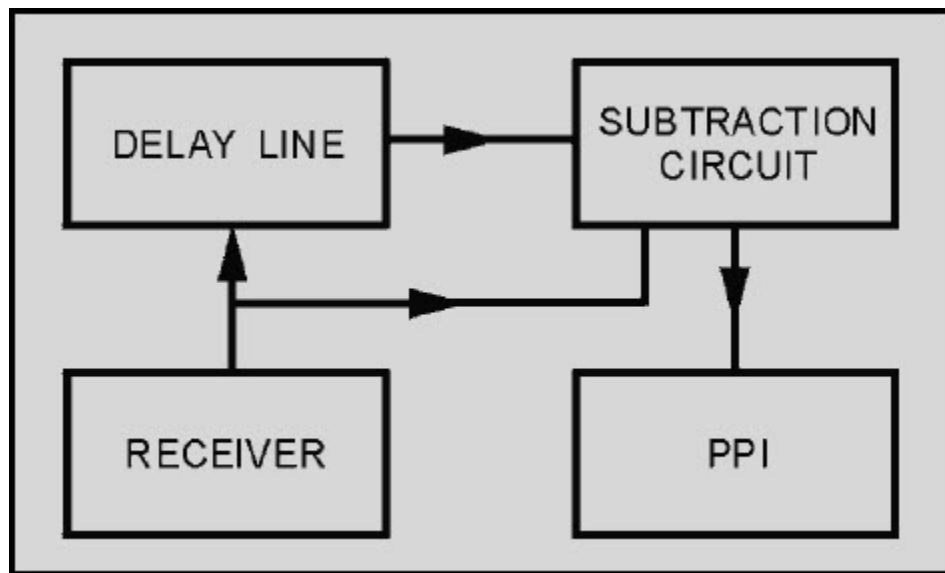


Figure 2-30B.—Fixed target cancellation.

In figure 2-31, 30-megahertz signals from the signal mixer are applied to the 30-megahertz amplifier. The signals are then amplified, limited, and fed to the phase detector. Another 30-megahertz signal, obtained from the coherent oscillator (coho) mixer, is applied as a lock pulse to the coho. The coho lock pulse is originated by the transmitted pulse. It is used to synchronize the coho to a fixed phase relationship with the transmitted frequency at each transmitted pulse. The 30-megahertz, cw reference signal output of the coho is applied, together with the 30-megahertz echo signal, to the phase detector.

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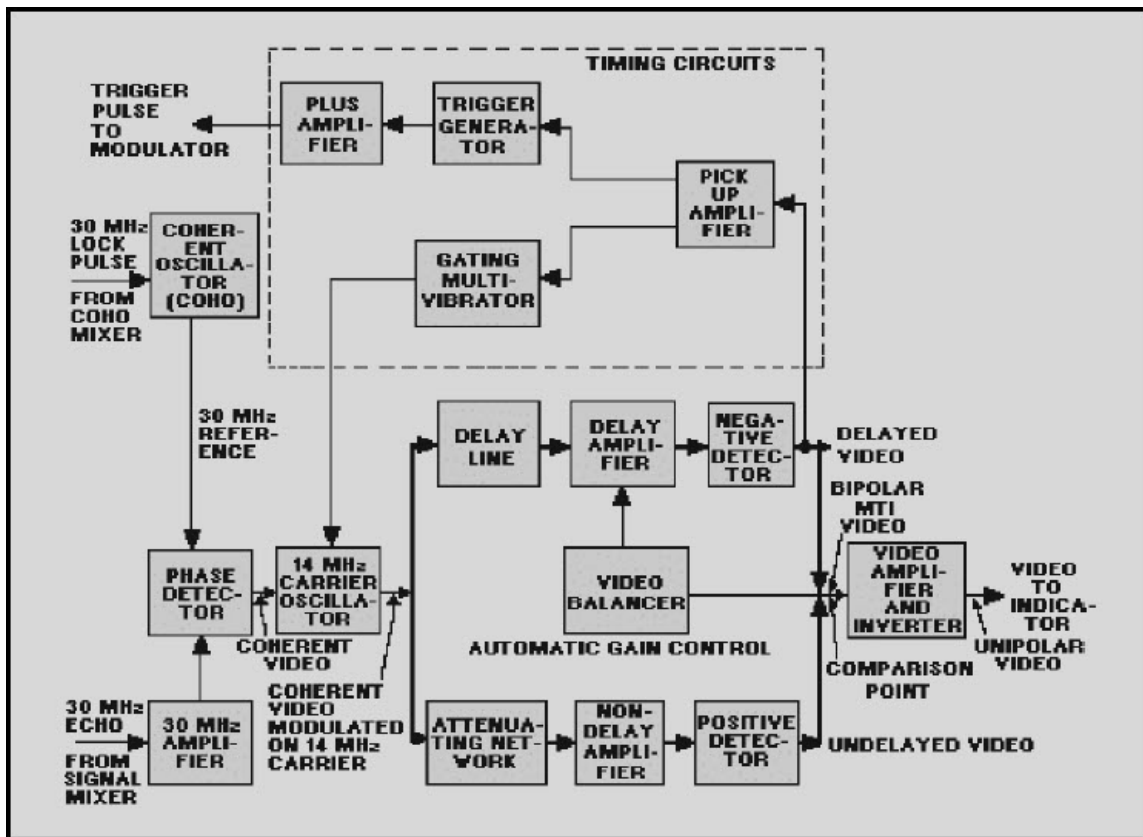


Figure 2-31 Mti block diagram

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-megahertz cw carrier oscillator.

The 14-megahertz 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-megahertz 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 megahertz.

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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 nondelayed 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 2-31, 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 2-31, 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 gating multivibrator is also triggered by the negative spike from the differentiated square wave. This stage applies a 2,000-microsecond negative gate to the 14-megahertz oscillator. The oscillator operates for 2,400 microseconds and is then cut off. Because the delay line time is 2,500 microseconds, the 14-megahertz 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- microsecond wave train. The 100 microseconds 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.

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Q44. What type of target has a fixed phase relationship from one receiving period to the next?

Q45. What signal is used to synchronize the coherent oscillator to a fixed phase relationship with the transmitted pulse?

Q46. What is the phase relationship between the delayed and undelayed video?

2.4.5.2 Logarithmic Receiver

The LOGARITHMIC RECEIVER uses a linear logarithmic amplifier, commonly called a LIN-LOG AMPLIFIER, instead of a normal IF amplifier. The lin-log amplifier is a nonsaturating 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 2-32. 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.

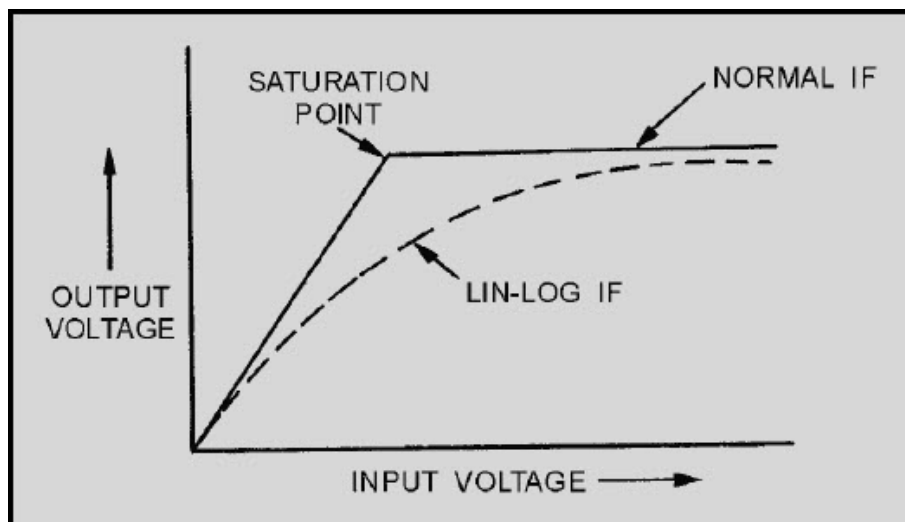


Figure 2-32 Lin-Log amplifier versus normal IF amplifier

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A typical circuit for obtaining a lin-log response is shown in figure 2-33. 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.

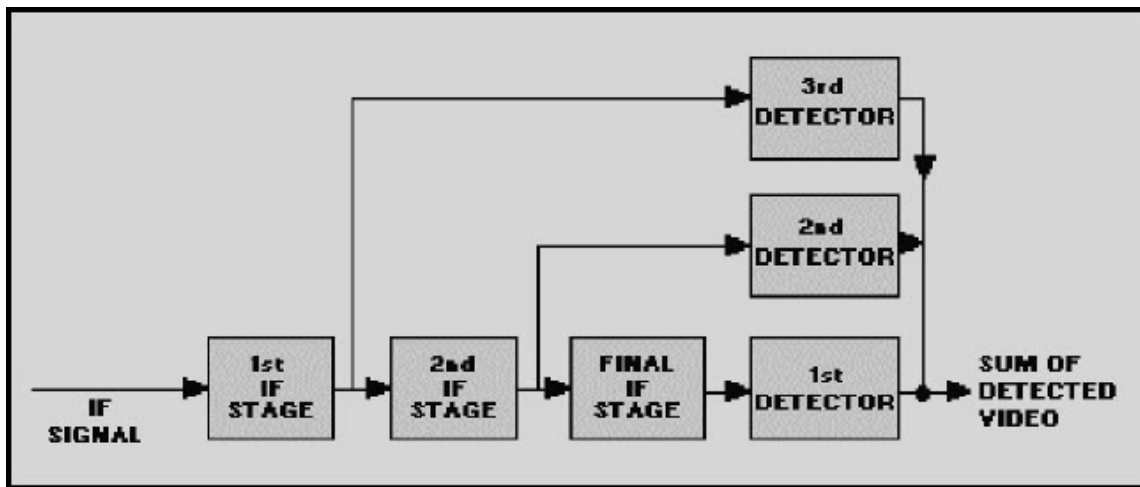


Figure 2-33 Lin-Log receiver block diagram

Figure 2-34, shows the response curves of the three IF stages in the lin-log amplifier shown in figure 2-33. The responses of the individual stages produce a segmented overall response curve for the receiver.

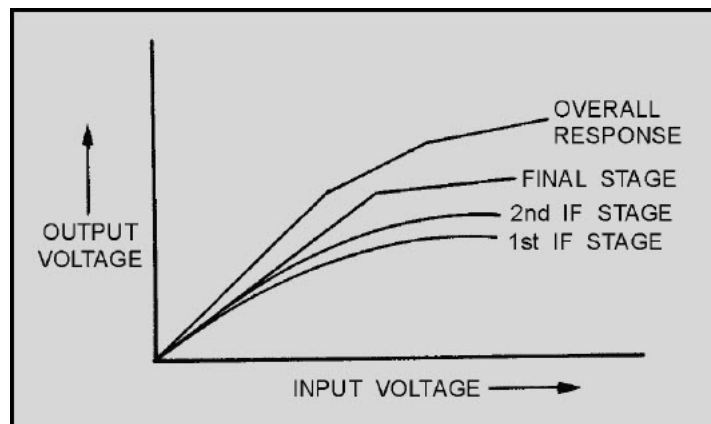


Figure 2-34 Lin-Log amplifier stage response curves

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2.4.5.3 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, bearing, and elevation from a single pulse. The receiver for a monopulse radar must have three separate channels to process range, bearing, and elevation information. The block diagram of a simplified monopulse receiver is shown in figure 2-35.

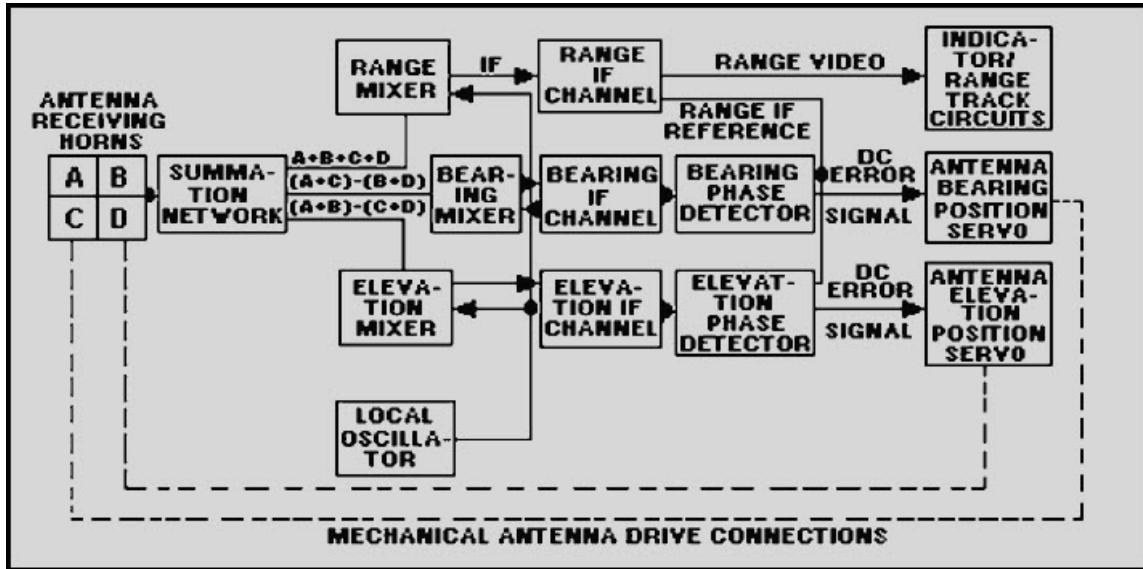


Figure 2-35 Monopulse receiver block diagram

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. Bearing information is obtained by subtracting the energy from horns B and D from the energy from horns A and C:

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

and mixing the difference with the local oscillator signal. The result is a bearing 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:

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

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If the target is on the elevation and bearing axis, the summations will both be zero; therefore, neither the bearing nor elevation channels will receive an input signal. If either of the bearing 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 bearing 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 bearing and elevation channels must be converted to dc error signals for use by automatic bearing and elevation tracking systems. The dc error voltages are applied to the antenna bearing and elevation positioning servos. These servos reposition the antenna until the errors are nulled.

The phase detectors compare the phase of the bearing 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 bearing 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 bearing 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 bearing channel. The phase of the bearing 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 bearing 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.

Q47. 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?

Q48. What happens to the overall gain of a lin-log amplifier as each stage saturates?

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Q49. A monopulse receiver has how many separate channels?

Q50. If a target is on the bearing axis of the radiated beam, what is the input to the bearing IF channel?

Q51. What characteristic of the bearing and elevation output signals determines the direction of antenna movement?

2.5 SUMMARY

The following paragraphs summarize the important points of this chapter.

The **SYNCHRONIZER** is essential to any radar because it controls and times the operation of the entire system. Radar systems may be self-synchronized by triggers from the transmitter or externally synchronized from a master oscillator.

Most modern systems are synchronized by a **MASTER OSCILLATOR**, which may be a **SINEWAVE OSCILLATOR**, an **ASTABLE MULTIVIBRATOR**, or a **BLOCKING OSCILLATOR**.

Each of these oscillators fulfills the basic requirements of a synchronizer, which must be:

- free running
- stable in frequency
- frequency variable (in steps)

The **TRANSMITTER** produces the short-duration, high-power, rf pulses of energy that are radiated into space by the antenna.

The **MODULATOR** controls the radar pulse, width and amplitude.

KEYED-OSCILLATOR TRANSMITTERS produce a high-power output pulse by keying a high power oscillator, such as a **MAGNETRON**.

POWER-AMPLIFIER TRANSMITTERS amplify a low-level pulse to the desired power level using a series of microwave amplifiers such as **TRAVELING-WAVE TUBES** or **KLYSTRONS**.

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The **DUPLEXER** is a device that allows the same antenna to both transmit and receive. Most duplexers use the impedance characteristics of transmission lines and waveguides in conjunction with TR and ATR tubes to route the energy to the correct place. One of the most important functions of the duplexer is isolation of the receiver during transmission.

The **RECEIVER** detects the very small target return echo and amplifies it to a usable level for display on the indicator.

A typical **SUPERHETERODYNE RECEIVER** consists of a low-noise amplifier, a mixer, a local oscillator, an IF amplifier, a detector, and a video amplifier.

Some special purpose receivers are the **MOVING TARGET INDICATOR** and **MONOPULSE RECEIVERS**.

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ANSWERS TO QUESTIONS Q1. THROUGH Q51.

- A1. *Controls system operation and timing.*
- A2. *Timing and control.*
- A3. *Transmitter.*
- A4. *Free-running.*
- A5. *The master oscillator.*
- A6. *Leakage from the duplexer.*
- A7. *Sine-wave oscillator, single-swing blocking oscillator, and master-trigger (astable) multivibrator.*
- A8. *It requires additional shaping circuits.*
- A9. *Blocking oscillators.*
- A10. *Keyed oscillator and power-amplifier chain.*
- A11. *The modulator.*
- A12. *Steep leading and trailing edges.*
- A13. *Line-pulsed.*
- A14. *Capacitor, artificial transmission line, or pulse-forming network.*
- A15. *Pulse width.*
- A16. *Thyratron.*
- A17. *The charging impedance.*
- A18. *600-30,000 megahertz.*
- A19. *Mode skipping and mode shifting.*
- A20. *The magnetron will not oscillate.*

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- A21. *±5 percent.*
- A22. *Frequency stability.*
- A23. *Local oscillator and coherent oscillator.*
- A24. *Multicavity klystron.*
- A25. *Frequency synthesizer.*
- A26. *Oscillations at an undesired frequency.*
- A27. *Electronic.*
- A28. *Tr tube.*
- A29. *Apply keep-alive voltage.*
- A30. *Quarter-wavelength section.*
- A31. *Transmit.*
- A32. *Neither fires.*
- A33. *180 degrees out of phase.*
- A34. *Noise.*
- A35. *Superheterodyne.*
- A36. *Thirty or sixty megahertz.*
- A37. *Local oscillator.*
- A38. *Mixer.*
- A39. *Cascade.*
- A40. *Detector.*
- A41. *IAGC.*
- A42. *Zero.*

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A43. *FTC has no effect on receiver gain.*

A44. *Stationary.*

A45. *Coho lock pulse.*

A46. *Opposite.*

A47. *Amplification is reduced.*

A48. *Decreases.*

A49. *Three.*

A50. *Zero.*

A51. *Phase.*

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3 RADAR INDICATORS AND ANTENNAS

LEARNING OBJECTIVES

After you finish this chapter, you should be able to do the following:

1. Describe the purpose of the A scope, the range-height indicator (rhi), and the plan position indicator (ppi).
2. State the relationship between range and sweep speed and length on a radar indicator.
3. Explain the purpose of timing triggers, video, and antenna position inputs to a radar indicator.
4. List the major units of a ppi and describe their functions.
5. Describe the basic operation of sweep deflection and sweep rotation in a ppi.
6. List and describe the operation of the three range measurement circuits.
7. Describe antenna directivity and power gain characteristics.
8. Describe the focusing action of a basic parabolic antenna.
9. Describe the basic radiation patterns of the most common parabolic reflectors.
10. Describe the basic characteristics of horn radiators.

3.1 INTRODUCTION

Radar systems require an antenna to both transmit and receive radar energy and an indicator system to display the video information generated. This chapter will briefly describe some commonly used indicators and antenna systems. Antenna systems are described in more detail in NEETS, Module 10, Wave Generation, Transmission Lines, and Antennas, and Module 11, Microwave Principles.

3.2 RADAR INDICATORS

The information available from a radar receiver may contain as many as several million separate data bits per second. From these and other data, such as the orientation of the antenna, the indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets. It should provide size, shape, and insofar as possible, indications of the type of targets. A cathode-ray tube (crt) fulfills these requirements to an astonishing degree. The cathode-ray tube's principal shortcoming is that it cannot present a true three-dimensional picture.

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The fundamental geometrical quantities involved in radar displays are the RANGE, AZIMUTH ANGLE (or BEARING), and ELEVATION ANGLE. These displays relate the position of a radar target to the origin at the antenna. Most radar displays include one or two of these quantities as coordinates of the crt face.

The actual range of a target from the radar, whether on the ground, in the water, or in the air is known as SLANT RANGE. The majority of displays use as one coordinate the value of slant range, its horizontal projection (GROUND RANGE), or its vertical projection (ALTITUDE). Since slant range is involved in every radar situation, it inevitably appears in at least one display on every set. Slant range is the coordinate that is duplicated most often when more than one type of display is used. This is partly because displays presenting range have the highest signal-to-noise discrimination and partly for geometrical reasons.

Range is displayed by means of a linear time-base sweep, starting from a given point or line at a definite time in each pulse cycle. Thus, distances along this range sweep actually measure slant range. The sweep speed determines the scale factor, which relates the distance on the tube to actual range. The sweep length is the total distance represented. Distances are expressed in miles (statute or nautical) or yards. The origin of the range sweep may be on or off the tube face.

The angle at which the antenna is pointing, either in azimuth or elevation, may provide two dimensional information in the display; that is, range and azimuth, or range and elevation.

A radar indicator, sometimes called a radar repeater, acts as the master timing device in *analyzing* the return of the video in a radar system. It also provides that capability to various other locations physically remote from the radar system. Each indicator should have the ability to select the outputs from any desired radar system aboard the ship. This is usually accomplished by the use of a RADAR DISTRIBUTION SWITCHBOARD. The switchboard contains a switching arrangement that has inputs from each radar system aboard ship and provides outputs to each repeater. The radar desired is selected by means of a selector switch on the repeater. For the repeater to present correct target position data, the indicator must have the following three inputs from the selected radar:

1. *Trigger timing pulses.* These pulses ensure that the sweep on the repeater starts from its point of origin each time the radar transmits. As discussed earlier, the repeater displays all targets at their actual range from the ship based on the time lapse between the instant of transmission and the instant the target's echo is received.

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2. *The returning echo.* The echo, in rf form, is detected (converted to a video signal) by the radar receiver and applied to the repeater.

3. *Antenna information.* The angular sweep position of a plan position indicator (ppi) repeater must be synchronized to the angular position of the radar antenna to display target bearing (azimuth) information.

The three most common types of displays, called scopes, are the A-scope, the RANGE-HEIGHT INDICATOR (RHI) SCOPE, and the PLAN POSITION INDICATOR (PPI) SCOPE. The primary function of these displays will be discussed in this section. However, detailed descriptions will be limited to the ppi scope, which is the most common display.

3.2.1 The A Scope

The A-scope display, shown in figure 3-1, presents only the range to the target and the relative strength of the echo. Such a display is normally used in weapons control radar systems. The bearing and elevation angles are presented as dial or digital readouts that correspond to the actual physical position of the antenna.

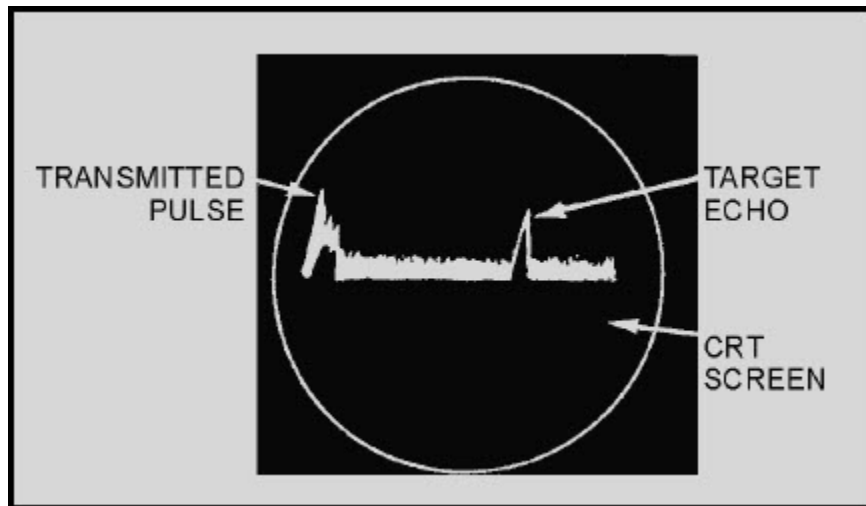


Figure 3-1 A scope

The A-scope normally uses an electrostatic-deflection crt. The sweep is produced by applying a sawtooth voltage to the horizontal deflection plates. The electrical length (time duration) of the sawtooth voltage determines the total amount of range displayed on the crt face.

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The ranges of individual targets on an A-scope are usually determined by using a movable range gate or step that is superimposed on the sweep. Ranging circuits will be discussed in more detail later in this section.

3.2.2 Range-Height Indicator (RHI)

The range-height indicator (rhi) scope, shown in figure 3-2, is used with height-finding search radars to obtain altitude information. The rhi is a two-dimensional presentation indicating target range and altitude. The sweep originates in the lower left side of the scope. It moves across the scope, to the right, at an angle that is the same as the angle of transmission of the height-finding radar. The line of sight to the horizon is indicated by the bottom horizontal line. The area directly overhead is straight up the left side of the scope. Target echoes are displayed on the scope as vertical PIPS or BLIPS (spots of increased intensity that indicate a target location). The operator determines altitude by adjusting a movable height line to the point where it bisects the center of the blip. Target height is then read directly from an altitude dial or digital readout. Vertical range markers are also provided to estimate target range.

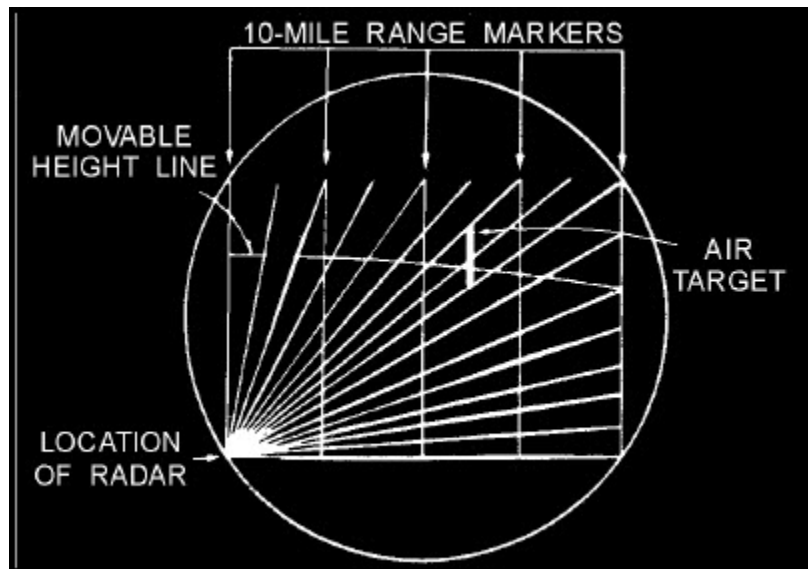


Figure 3-2 RHI scope

Q1. What are the three fundamental quantities involved in radar displays?

Q2. What are the required radar inputs for proper indicator operation?

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Q3. What coordinates are displayed on an rhi scope?

3.2.3 Plan Position Indicator (PPI)

The ppi scope shown in figure 3-3, is by far the most used radar display. It is a polar coordinate display of the area surrounding the radar platform. Own ship is represented as the origin of the sweep, which is normally located in the center of the scope, but may be offset from the center on some sets. The ppi uses a radial sweep pivoting about the center of the presentation. This results in a map-like picture of the area covered by the radar beam. A long-persistence screen is used so that the display remains visible until the sweep passes again.

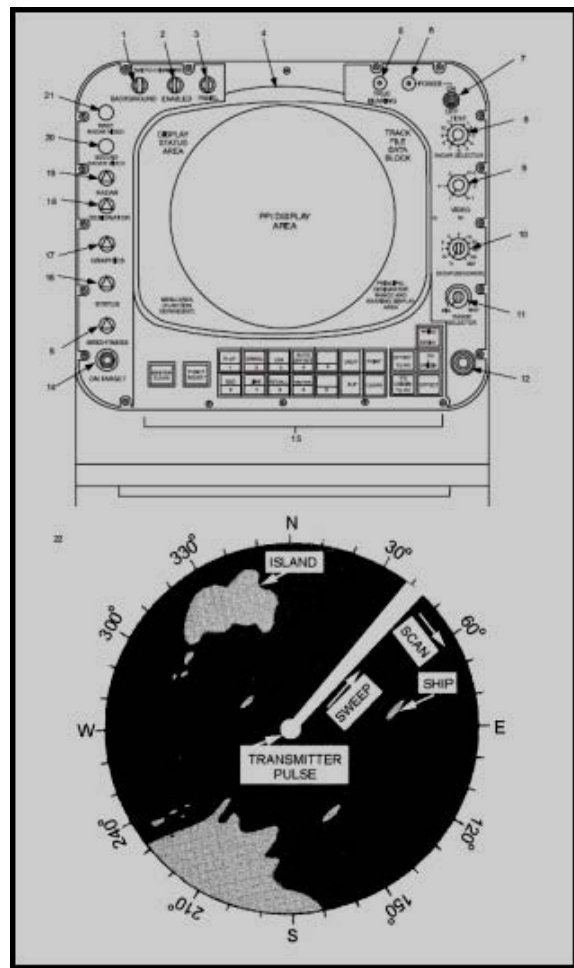


Figure 3-3 PPI scope

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Bearing to the target is indicated by the target's angular position in relation to an imaginary line extending vertically from the sweep origin to the top of the scope. The top of the scope is either true north (when the indicator is operated in the true bearing mode) or ship's heading (when the indicator is operated in the relative bearing mode).

3.2.3.1 PPI Block Diagram

The basic block diagram, figure 3-4, illustrates the major units of a plan position indicator. Synchronization of events is particularly important in the presentation system. At the instant a radar transmitter fires (or at some predetermined time thereafter), circuits which control the presentation on the indicator must be activated. These events must be performed to a high degree of accuracy to ensure accurate range determination. The synchronization of these events is provided by the gate circuit.

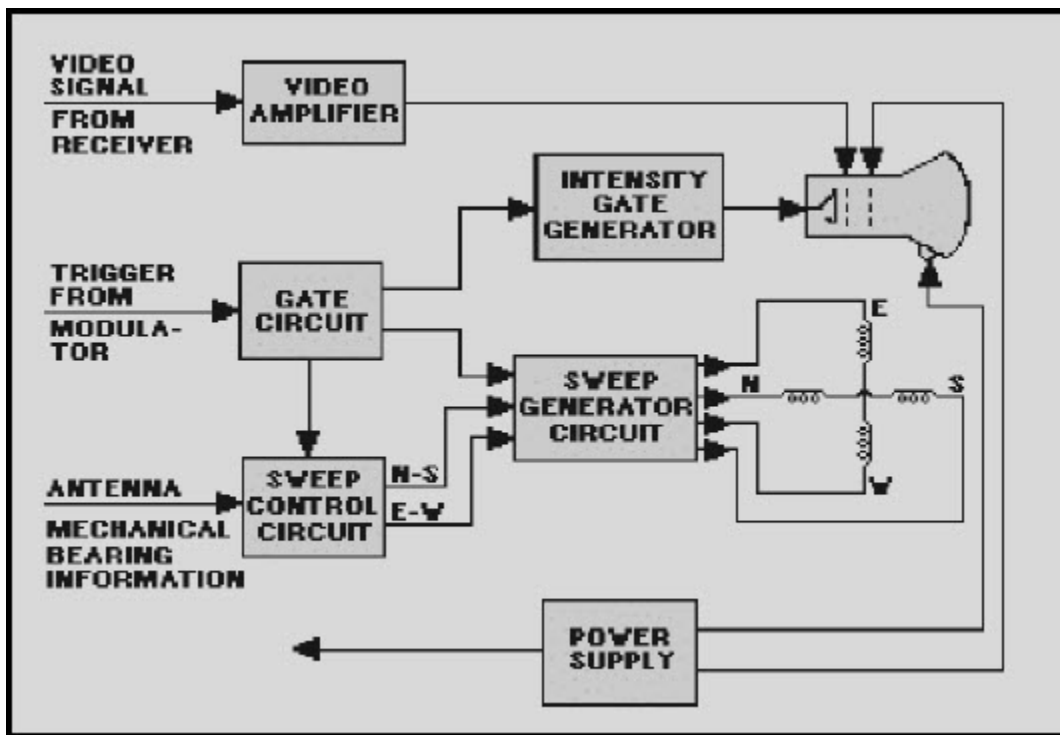


Figure 3-4 Basic ppi block diagram

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GATE CIRCUIT.—The gate circuit develops pulses which synchronize the indicator with the transmitter. The gate circuit itself is synchronized by trigger pulses from the synchronizer. It then provides timing for the intensity gate generator, sweep generator circuit, and the sweep control circuit.

SWEEP CONTROL CIRCUIT.—The sweep control circuit converts mechanical bearing information from the antenna into voltages which control sweep circuit azimuth.

SWEEP GENERATOR CIRCUIT.—The sweep generator circuit produces currents which deflect an electron beam across the crt. Varying voltages from the sweep control circuit are applied to deflection coils. Gate voltages determine sweep rate, and therefore, the effective distance (range) covered by each sweep. Sweep potentials consist of separate north-south and east-west voltages; the amplitudes of these voltages determine sweep azimuth. The sweep generator is synchronized by an input from the gate circuit.

INTENSITY GATE GENERATOR.—The intensity gate generator provides a gate which unblanks the crt during sweep periods. The intensity of the trace appearing on the crt is determined by the dc level of this gate. This circuit is also synchronized by the gate circuit.

VIDEO AMPLIFIER.—The video amplifier circuit amplifies the video signal from the receiver and applies it to the crt intensity-modulating element (control grid).

POWER SUPPLY.—The power supply produces all voltages needed to operate the indicator. It also includes protective devices and metering circuits.

Although not shown in the basic block diagram, many indicators contain circuits which aid in range and bearing determination. These circuits are also synchronized by the gate circuit.

3.2.3.2 Sweep Deflection

In modern indicator systems, electromagnetic deflection of the crt electron beam is preferred to electrostatic deflection. Reasons for this choice are (1) increased control of the beam, (2) improved deflection sensitivity, (3) better beam position accuracy, and (4) simpler construction of the crt.

The primary difference between electromagnetic and electrostatic cathode-ray tubes lies in the method of controlling deflection and focusing of the electron beam. Both types employ electron guns and use electrostatic fields to accelerate and control the flow of electrons. The physical construction of a crt employing electromagnetic deflection is similar to an electrostatic type. The construction of a crt employing electromagnetic deflection is shown in figure 3-5.

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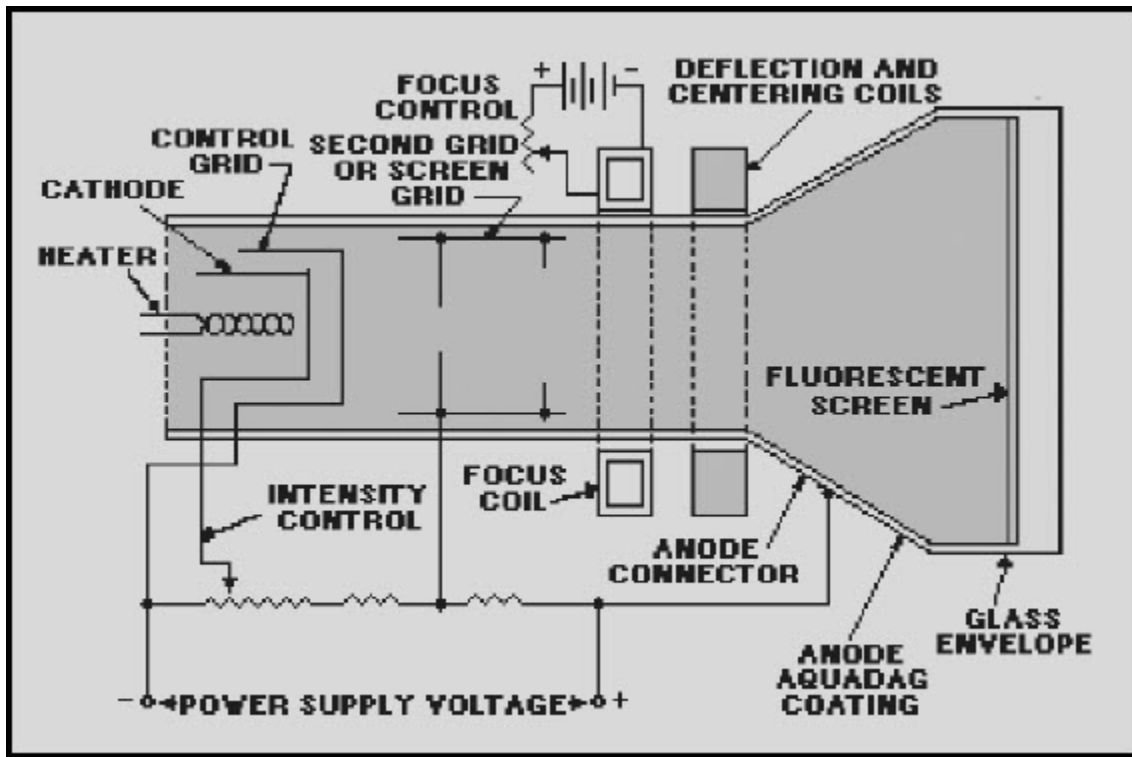


Figure 3-5 Electromagnetic crt construction

The electron gun in figure 3-5 is made up of a heater, cathode, control grid, second or screen grid, focus coil, and anode (composed of a special coating). Focusing the electron beam on the face of the screen is accomplished by the focus coil. A direct current through the windings sets up a strong magnetic field at the center of the coil. Electrons move precisely along the axis of the tube and pass through the focusing field with no deflection. This is because they move parallel to the magnetic field at all times.

Any electron which enters the focusing field at an angle to the axis of the tube has a force exerted on it that is perpendicular to its direction of motion. A second force on this electron is perpendicular to the magnetic lines and is, therefore, constantly changing in direction. These forces cause the electron to move in a helical or corkscrew path shown in figure 3-6. With the proper velocity of the electron and strength of the magnetic field, the electron will be caused to move at an angle which allows it to converge with other electrons at some point on the crt screen. Focusing is accomplished by adjusting the current flow through the focusing coils.

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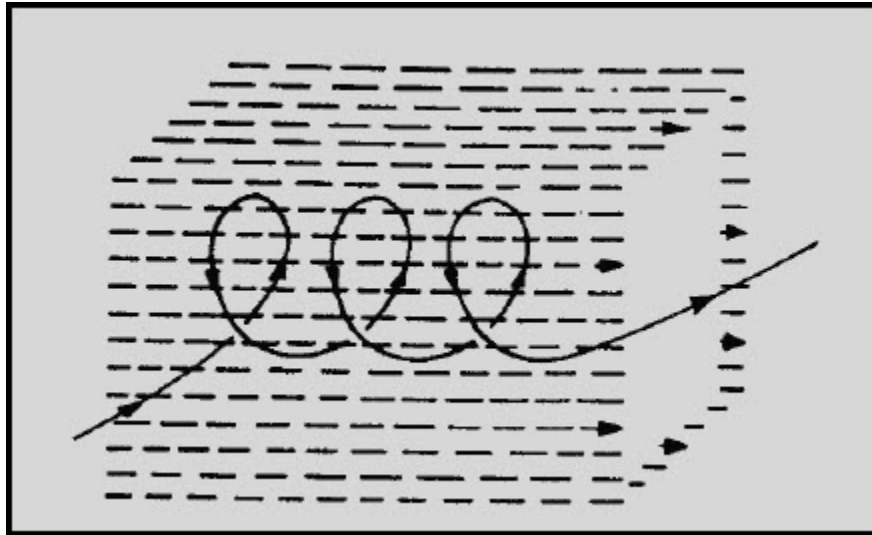


Figure 3-6 Helical motion of electron through a uniform magnetic field

The focused electron beam is deflected by a magnetic field that is generated by current flow through a set of deflection coils, as shown in figure 3-5. These coils are mounted around the outside surface of the neck of the crt. Normally, four deflection coils (**N**, **S**, **E**, and **W**) are used, as shown in figure 3-4. Two coils in series are positioned in a manner that causes the magnetic field produced to be in a vertical plane. The other two coils, also connected in series, are positioned so that their magnetic field is in a horizontal plane. The coils (**N-S**) which produce a horizontal field are called the **VERTICAL DEFLECTION COILS** and the coils (**E-W**) which produce a vertical field are called the **HORIZONTAL DEFLECTION COILS**. This may be more clearly understood if you recall that an electron beam will be deflected at right angles to a deflecting field. The deflection coils are illustrated in view A of figure 3-7. View B shows the **N-S** windings in schematic form.

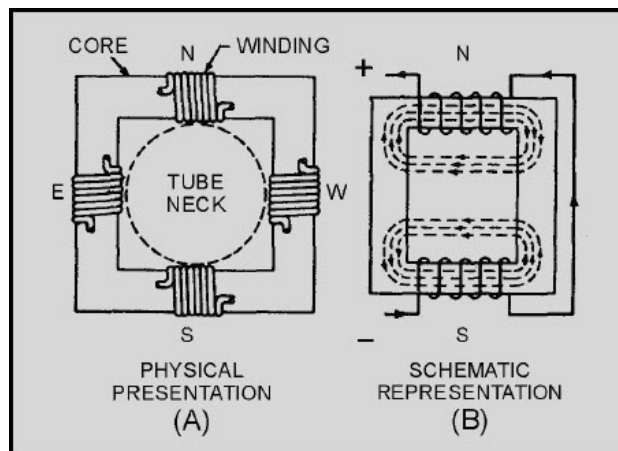


Figure 3-7 Deflection yoke

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Electron deflection in the electromagnetic crt is proportional to the strength of the magnetic fields. Magnetic field strength depends on current in the coils. The sweep circuits associated with electromagnetically deflected cathode-ray tubes must provide currents, rather than voltage, to produce the desired beam deflection.

A sawtooth current is required to produce a linear trace. A deflection coil may be considered equivalent to the circuit shown in view A of figure 3-8. Because of the inductance of the coil, a trapezoidal voltage must be applied across the coil to produce a sawtooth of current through it. This is illustrated in view B. (Refer to NEETS, Module 9, *Wave-Generation and Wave-Shaping Circuits*, for a review of wave shaping.)

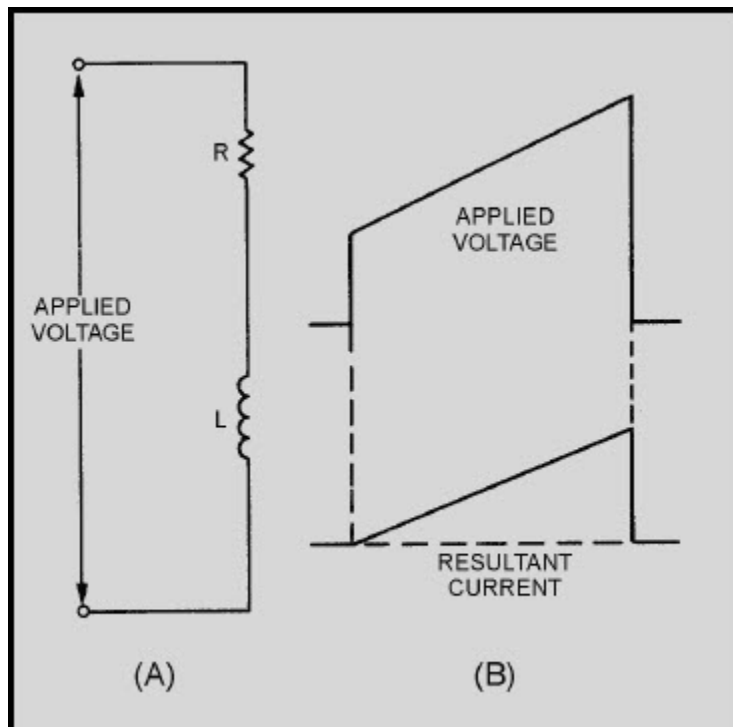


Figure 3-8 Deflection coil equivalent circuit and waveform

3.2.3.3 Sweep Rotation

Azimuth indication of the ppi requires that the range trace rotate about the center of the screen. A very simple means of achieving sweep rotation is to cause the deflection coil to rotate about the neck of the crt in synchronization with the antenna motion. This method, however, has the disadvantages of inaccuracy and maintenance complications inherent to any mechanical gear-train assembly.

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Most modern ppi systems employ fixed deflection coils and use special circuits to electronically rotate the magnetic field. Figure 3-9 illustrates a method of electronically producing a rotating sweep. In view A, a range sweep current, i , is applied to the vertical deflection coils only. The resulting magnetic field, represented by Φ , lies along the axis of these coils. The resulting range trace, shown by the short straight line, is vertical because the electron beam is deflected perpendicular to the magnetic field. In view B, range sweep currents are applied to both sets of coils, and the resultant magnetic field takes a position between the axis of the two sets of coils. Because of this shift of the magnetic field, the range trace is rotated 45 degrees clockwise from its previous position. In view C, the sweep current is applied to the horizontal deflection coils only, and the range trace lies 90 degrees clockwise from its original position. Further rotation is obtained if the polarities of the deflection coil currents are varied in proper sequence, as illustrated in views D and E.

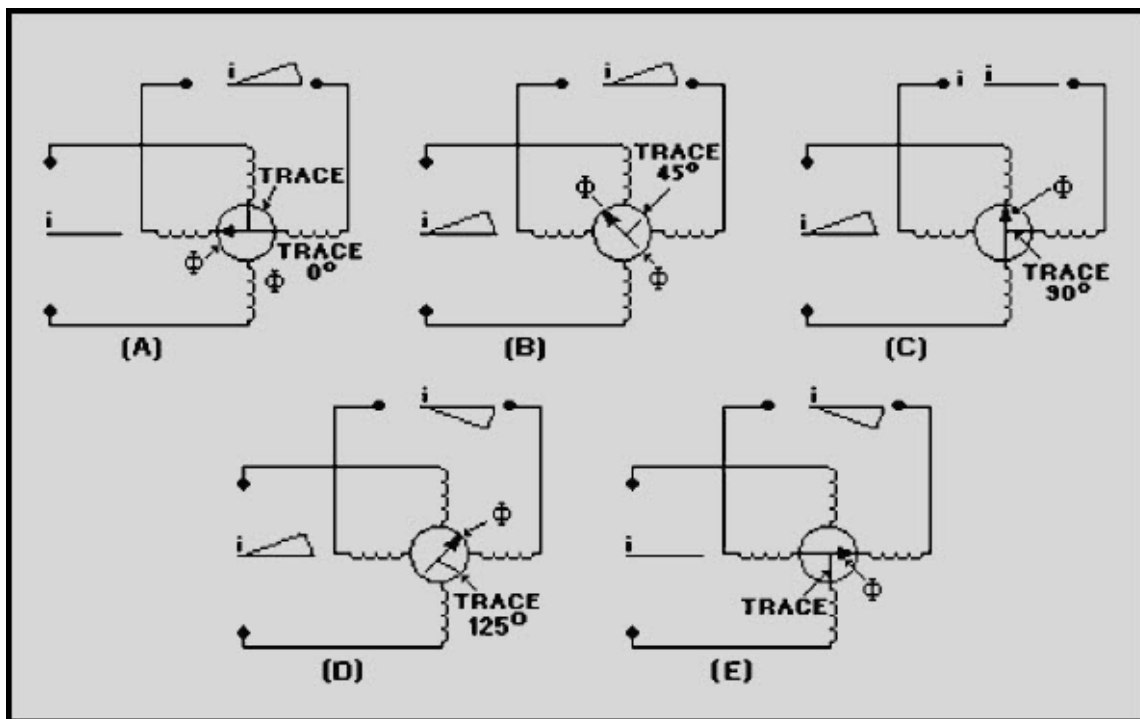


Figure 3-9 Trace rotation

To synchronize sweep rotation with antenna rotation, you must convert antenna azimuth (bearing) information into electrical signals. These signals, usually provided by synchros, control the amplitudes and polarities of the sawtooth sweep currents applied to the deflection coils.

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Figure 3-10 illustrates the waveforms of current required to produce a rotating range sweep. The amplitudes of the sawtooth sweep currents are varied sinusoidally (like a sine wave), corresponding to the rotation of the antenna. Notice that there is a 90 degree phase difference between the amplitude variations of the horizontal and vertical waveforms.

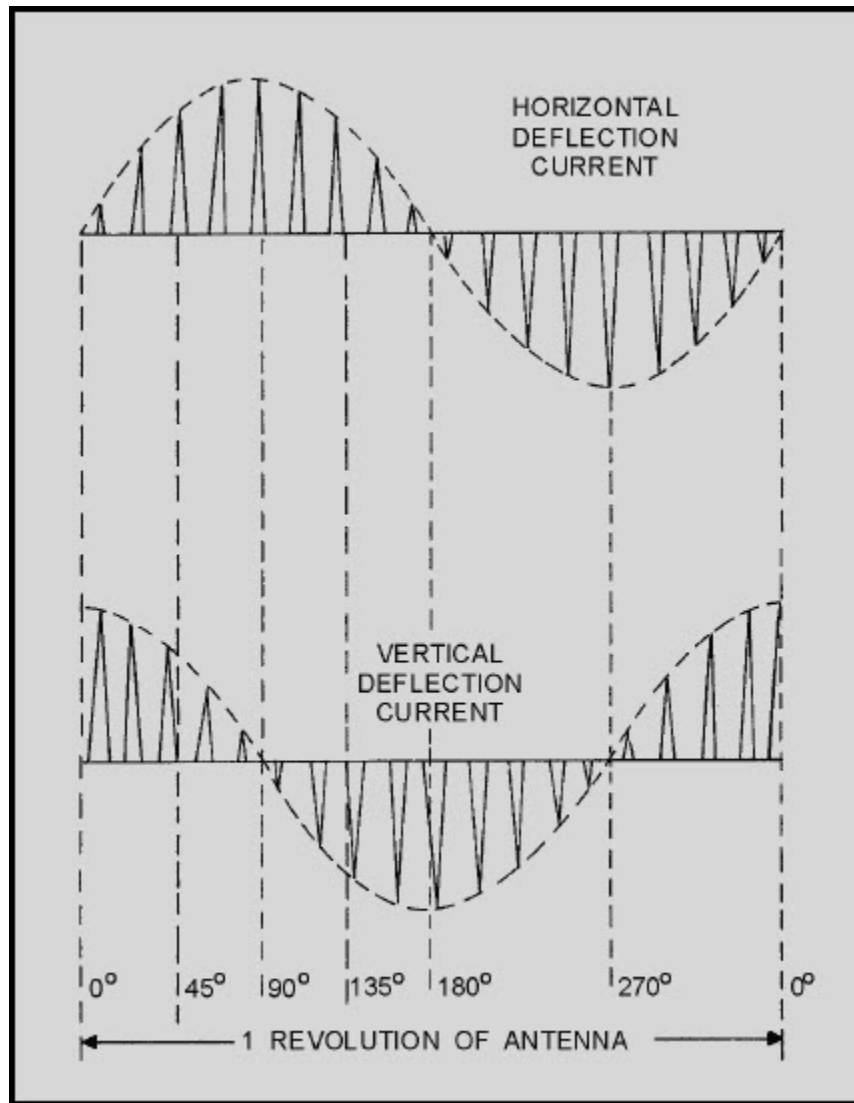


Figure 3-10 Deflection coil currents

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3.2.3.4 CRT Screen Persistence

A ppi requires a crt in which the screen is coated with a long-persistence phosphor. This is necessary because each target reflects energy for only a short period of time during each rotation of the antenna. Therefore, the target indication on the face of the crt must be able to continue to glow during the portion of antenna rotation when the target is not reflecting energy.

Q4. What coordinates are presented on a ppi scope?

Q5. What type of deflection is preferred for a crt electron beam?

Q6. Which of the two types of deflection coils (fixed or rotating) is used most often?

3.2.4 Ranging Circuits

The accuracy of target-range data provided by a radar varies with the use of the radar. For example, a weapons systems radar operating in a search mode is required to be accurate within a small percentage of its maximum range. However, an intercept radar, operating in a tracking mode, must supply range data that is even more accurate; it must be within a few yards of the actual range.

In some applications of radar, the indicator sweep is calibrated by a transparent overlay with an engraved range scale. This overlay enables the operator to estimate the range of targets. In other applications, electronic range marks are supplied to the indicator. They usually appear as vertical pulses on A-scopes and as concentric circles on ppi scopes. The distance between range marks is generally determined by the type of equipment and its mode of operation.

In a weapons systems radar that requires extremely accurate target-range data, a movable range marker may be used. The range marker is obtained from a range-marker generator and may be a movable range gate or range step. When a ppi scope is used, a range circle of adjustable diameter may be used to measure range accurately. In some cases, movement of the range marker is accomplished by adjusting a calibrated control from which range readings are obtained.

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The following discussion describes the operation of three types of range-marker generators: the RANGE-GATE GENERATOR, the RANGE-MARKER GENERATOR, and the RANGE-STEP GENERATOR. The range-gate generator, used in conjunction with a blocking oscillator, generates a movable range gate. The range-marker generator and the range-step generator, used in conjunction with an astable multivibrator, generate fixed range marks and a movable range step, respectively.

3.2.4.1 Range-Gate Generator

Figure 3-11 shows a simplified block diagram of a typical range-gate generator. The pulse-repetition frequency is controlled by a master oscillator, or multivibrator, in which the output is coupled to a trigger thyatron (both in the synchronizer). The output of the trigger thyatron is used to trigger the radar modulator and the scope sweep circuits, thus starting the transmitter pulse and the range sweep at the same instant, referred to as time T_0 .

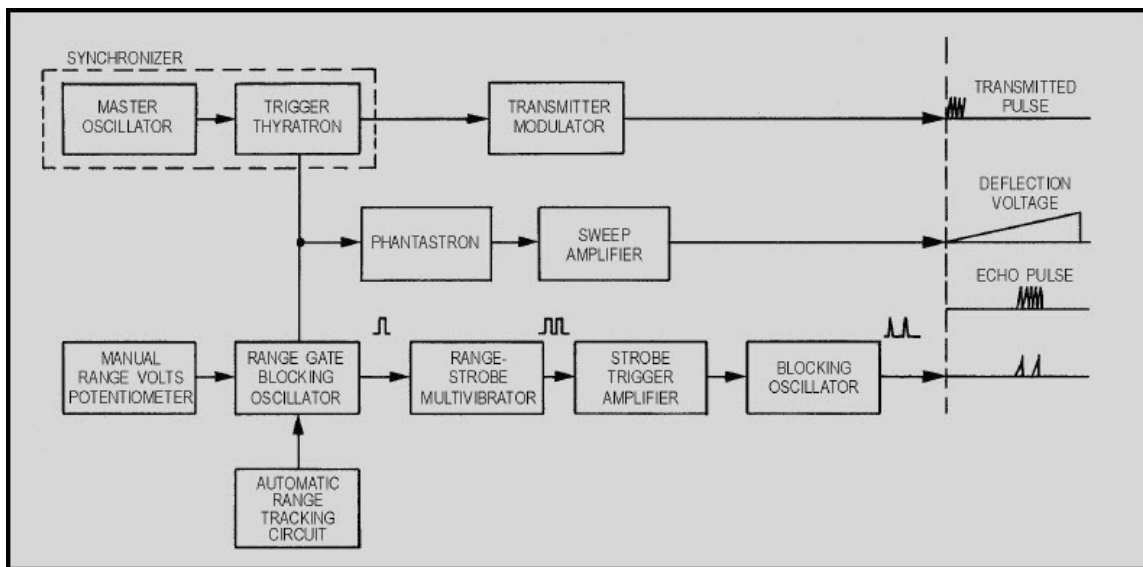


Figure 3-11 Range-gate generator

The PHANTASTRON in the sweep circuits is a variable timing circuit that supplies a sweep sawtooth to the sweep amplifier. The width of the gate and sawtooth is dependent upon the range selected by the radar operator.

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The range-gate circuit receives its input pulse from the trigger thyatron and generates a delayed range-gate pulse. The delay of this pulse from time **T₀** is dependent on either the range of the target when the radar is tracking, or the manual positioning of the range-volts potentiometer when the radar is not tracking (in the search mode). The range-gate triggers the range-strobe multivibrator, from which the output is amplified and sent to the blocking oscillator (which sharpens the pulses), as shown in figure 3-11. This range gate is used to select the target to be tracked. When in the track mode, the range gate brightens the trace or brackets the blip (depending on the system) to indicate what target is being tracked. Range-gate generators are used most often in weapons-control track radar A-scope presentations, but they can also be used with ppi presentations. When used with a ppi presentation, the range gate must be movable in both range and bearing.

The range-gate generator can easily be modified to produce a range strobe instead of a range gate. A range strobe is simply a single brightened spot that is movable both in range and bearing. In operation, the range strobe or range gate control also controls a dial or digital readout to provide a range readout to the operator.

3.2.4.2 Range-Marker Generator

Several types of range-marker generators are in common use. Figure 3-12 shows a simplified version of a circuit that produces both range markers and the basic system timing triggers. The master oscillator in this case is a blocking oscillator that operates at a frequency of 80.86 kilohertz. By dividing 80.86 kilohertz into 1 ($t = 1/\text{frequency}$), we find the time required for one cycle of operation is 12.36 microseconds. Thus the blocking oscillator produces pulses 1 radar mile apart. These are fed to the 5:1 divider circuit. Five of the 1-mile marks are required to produce an output from the divider circuit. These five-mile marks are sent to the indicator for display and to the 10:1 divider circuit. In the latter case, ten of the five-mile marks are required to produce an output from the 10:1 divider. Thus the output triggers are 50 miles apart. These basic timing triggers are for a radar with a range of fifty miles. The period between triggers could be extended through the use of additional dividers for use with longer range systems.

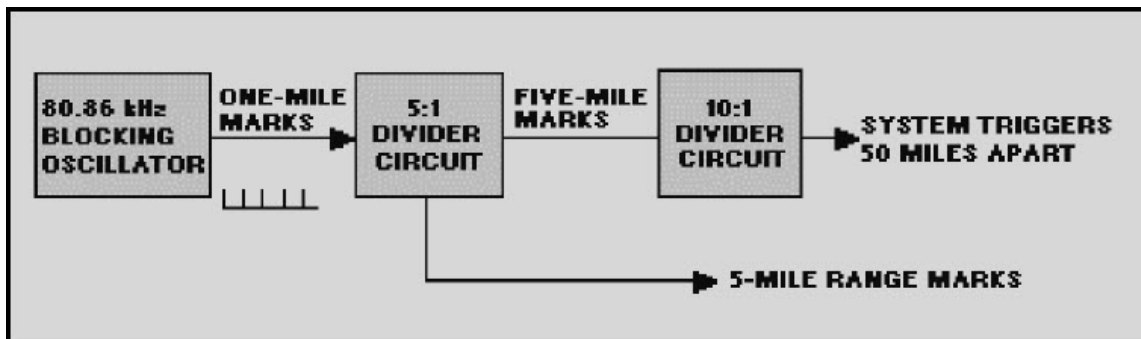


Figure 3-12 Range-marker generator

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Another version of a range-mark generator is shown in figure 3-13. This circuit provides range marks at 1,000-, 2,000-, or 3,000-yard intervals. Generation of the marks begins with the ringing oscillator, which is started by a delayed master trigger from the synchronizer. A ringing oscillator produces a sinusoidal output of a fixed duration and frequency when triggered. The output is synchronized to the input trigger. In this circuit, the trigger causes the oscillator to produce a 162-kilohertz signal that lasts for 4 1/2 cycles. The emitter follower isolates the ringing oscillator from the countdown multivibrator and clips the oscillator output signals. This action allows only the positive half of each sine wave to reach the multivibrator. The positive triggers from the ringing oscillator are at 1,000-yard intervals. This input signal results in an output from the countdown multivibrator of 1,000-, 2,000-, or 3,000-yard range marks, depending on the position of the RANGE MARK SELECT SWITCH.

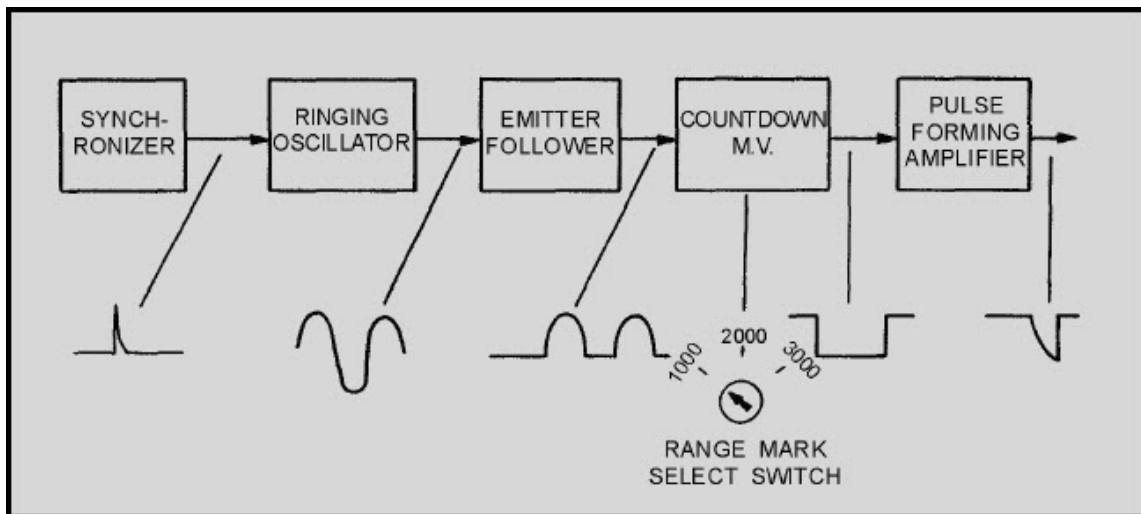


Figure 3-13 Range-marker generator

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3.2.4.3 Range-Step Generator

The range step is often used to determine target range on an A-scope presentation. The appearance of a range step on an A-scope is illustrated in figure 3-14.

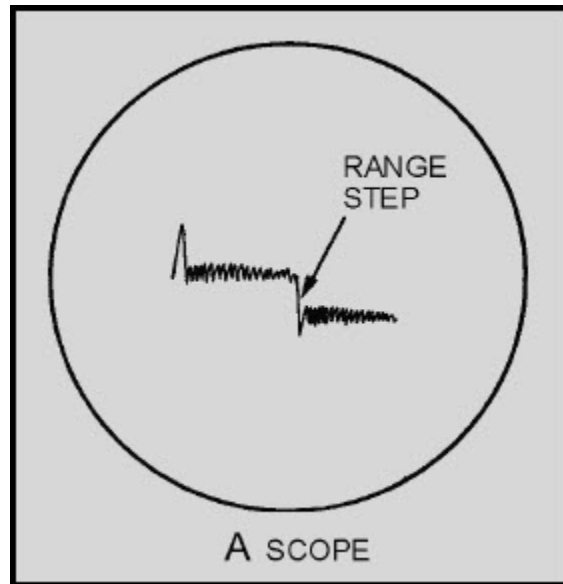


Figure 3-14 Range-step presentation

View A of figure 3-15 is a block diagram of a simple range-step generator consisting of a sawtooth generator, a negative clipper, a range potentiometer, and a limiting amplifier. The position of the range step along the indicator's time base is controlled by the range potentiometer. When the range step coincides with the leading edge of a target's echo pulse, the range can be read directly from a calibrated readout associated with the potentiometer.

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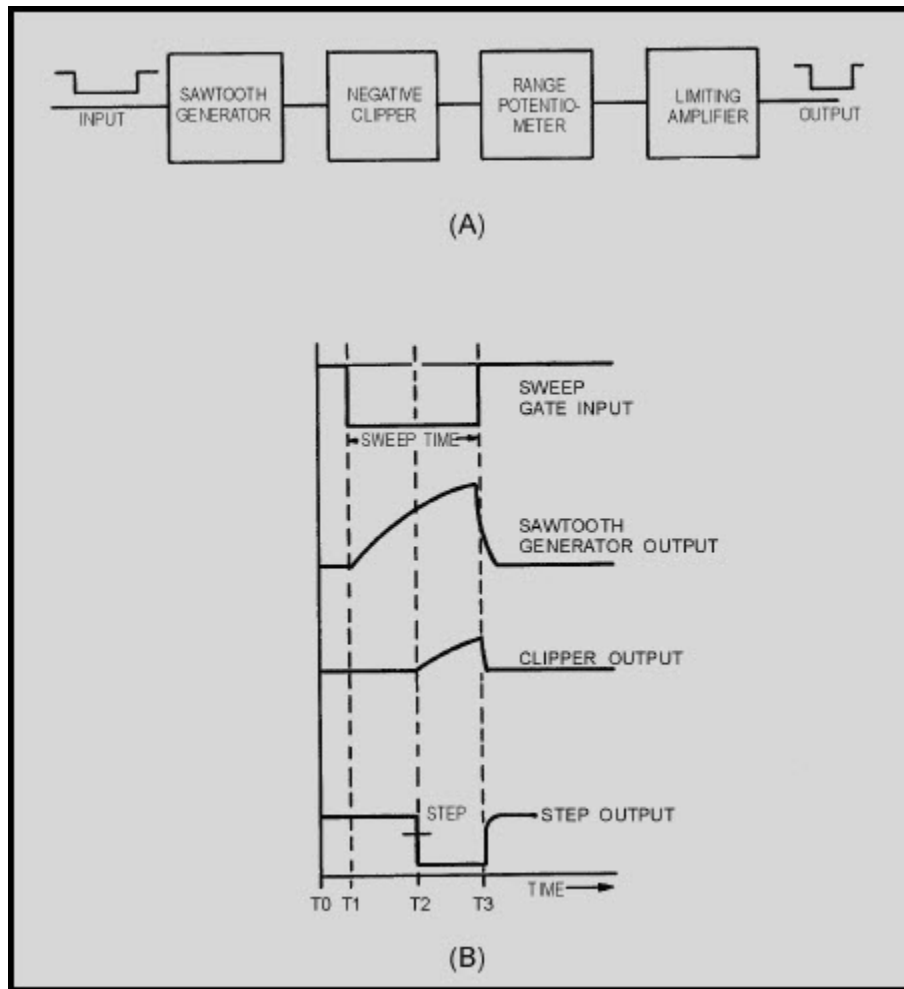


Figure 3-15 Range-step generation

View B shows the time relationships of the voltage waveforms produced by the range-step generator. During the sweep gate, the sawtooth generator produces a sawtooth voltage that is sent to the clipper. The point at which the sawtooth is clipped is controlled by the range potentiometer. The clipped sawtooth is shaped in the limiting amplifier to produce the output voltage waveform. The portion of the output waveform from T1 to T3 is applied to the vertical-deflection plates of the indicator crt to produce the display shown in figure 3-14.

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Q7. What type of ranging circuit is most often used with a radar that requires extremely accurate range data?

Q8. The range sweep in a range-gate generator is started at the same time as what other pulse?

Q9. Range-marker generators produce pulses based on what radar constant?

Q10. What radar scope uses a range step for range measurement?

3.3 RADAR ANTENNAS

In this section, we will briefly review the requirements of radar antennas. Antenna characteristics are discussed in detail in NEETS, Module 10, Wave-Generation, Transmission Lines, and *Antenna* and in Module 11, *Microwave Principles*. A review of these modules would be helpful at this point to prepare you for the following radar antenna discussion.

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 identification friend or foe equipment, and in countermeasures 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.

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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. 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 bearing 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 bearing), or with respect to the bow of a ship or nose of an aircraft containing the radar set (relative bearing). 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 (bearing) 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 3-16. 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 3-16 is 2,000 feet and the angle of elevation is 45 degrees, the altitude is 1,414.2 feet ($2,000 \cdot .7071$). In some radar equipments that use antennas that may be moved in elevation, altitude determination is automatically computed.

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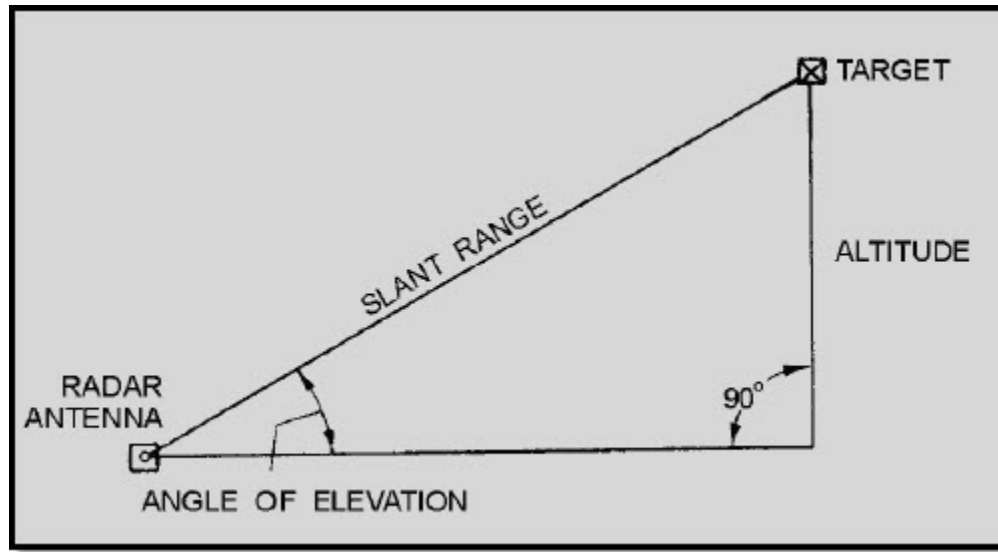


Figure 3-16 Radar determination of altitude

3.3.1 Parabolic Reflectors

A SPHERICAL WAVEFRONT spreads out as it travels and produces a pattern that is neither too sharp nor too directive. On the other hand, a PLANE wavefront does not spread out because all of the wavefront moves forward in the same direction. For a sharply defined radar beam, the need exists to change the spherical wavefront from the antenna into a plane wavefront. 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 3-17, a point-radiation source is placed at the focal point F. The field leaves this antenna with a spherical wavefront. As each part of the wavefront 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.

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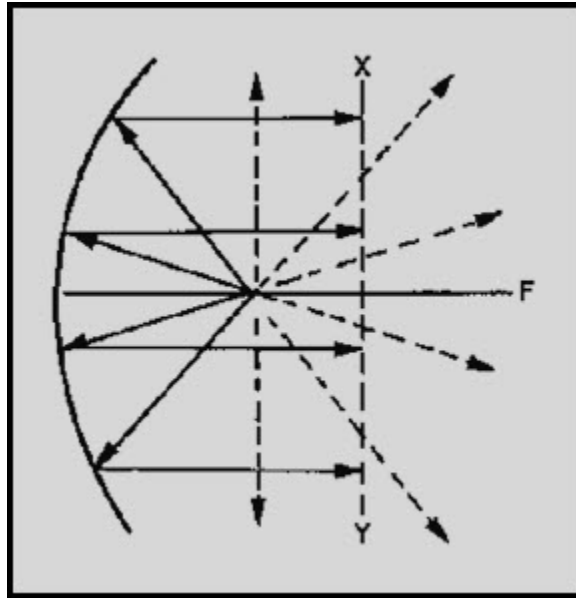


Figure 3-17 Parabolic reflector radiation

If a dipole is used as the source of radiation, there will be radiation from the antenna into space (dotted lines in figure 3-17) 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 through the use of a PARASITIC array, which directs the radiated field back to the reflector, or through the use of a feed horn 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 3-18. Very narrow beams are possible with this type of reflector. View A of figure 3-19 illustrates the parabolic reflector.

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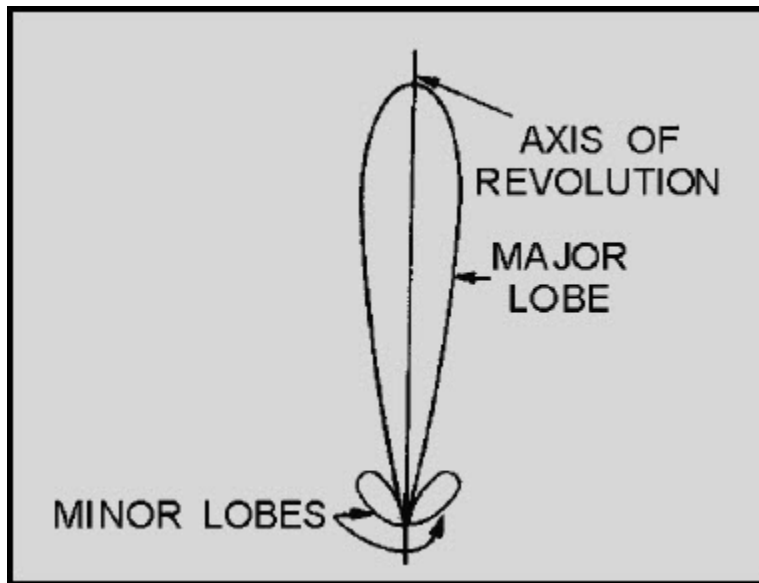


Figure 3-18 Parabolic radiation pattern

3.3.1.1 Truncated Paraboloid

View B of figure 3-19 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.

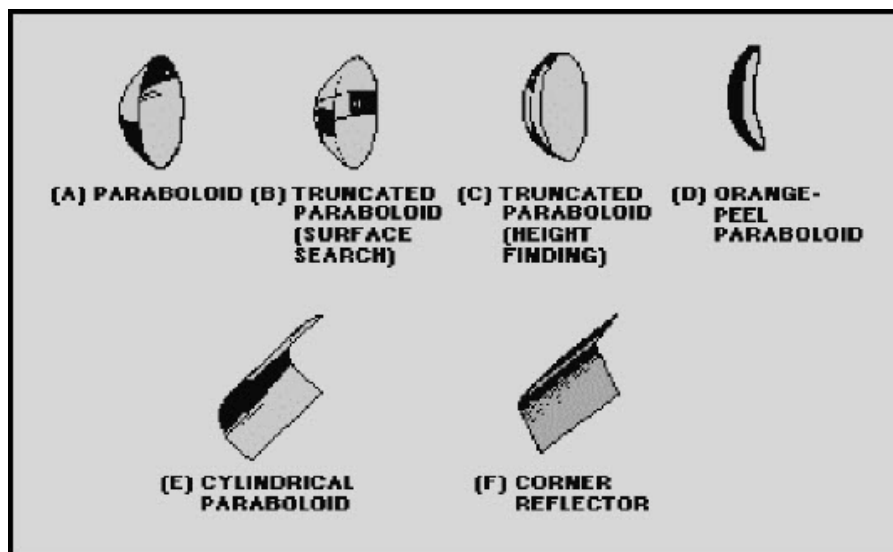


Figure 3-19 Reflector shapes

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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.

3.3.1.2 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 3-19. 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.

3.3.1.3 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 3-19 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 either fed 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.

Q11. Which of the two general classes of antennas is most often used with radar?

Q12. The power gain of an antenna is directly related to what other antenna property?

Q13. A parabolic reflector changes a spherical wavefront to what type of wavefront?

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3.3.2 Corner Reflector

The corner-reflector antenna consists of two flat conducting sheets that meet at an angle to form a corner, as shown in view F of figure 3-19. This reflector is normally driven by a half-wave radiator located on a line which bisects the angle formed by the sheet reflectors.

3.3.3 BROADSIDE ARRAY

The desired beam widths are provided for some vhf radars by a broadside array, such as the one shown in figure 3-20. The broadside array consists of two or more half-wave dipole elements and a flat reflector. The elements are placed one-half wavelength apart and parallel to each other. Because they are excited in phase, most of the radiation is perpendicular or broadside to the plane of the elements. The flat reflector is located approximately one-eighth wavelength behind the dipole elements and makes possible the unidirectional characteristics of the antenna system.

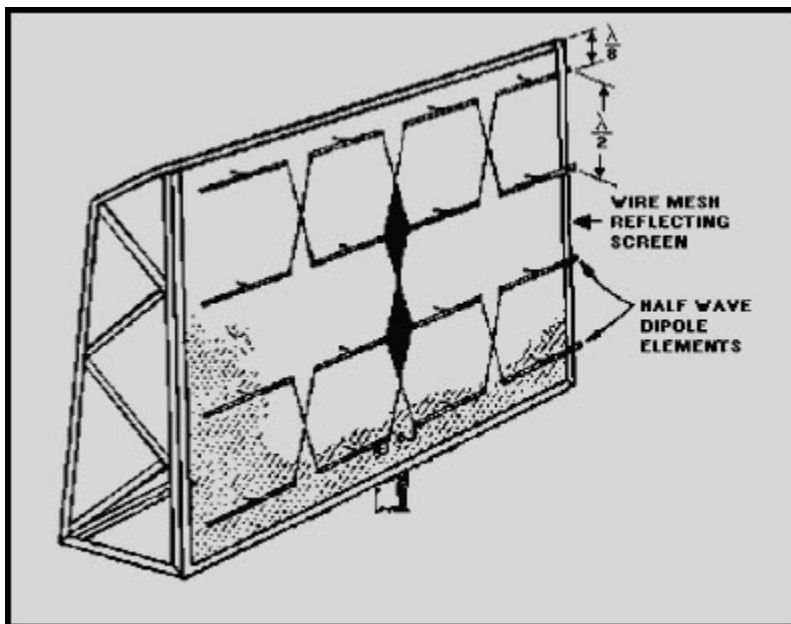


Figure 3-20 Broadside array

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3.3.4 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 3-21. 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.

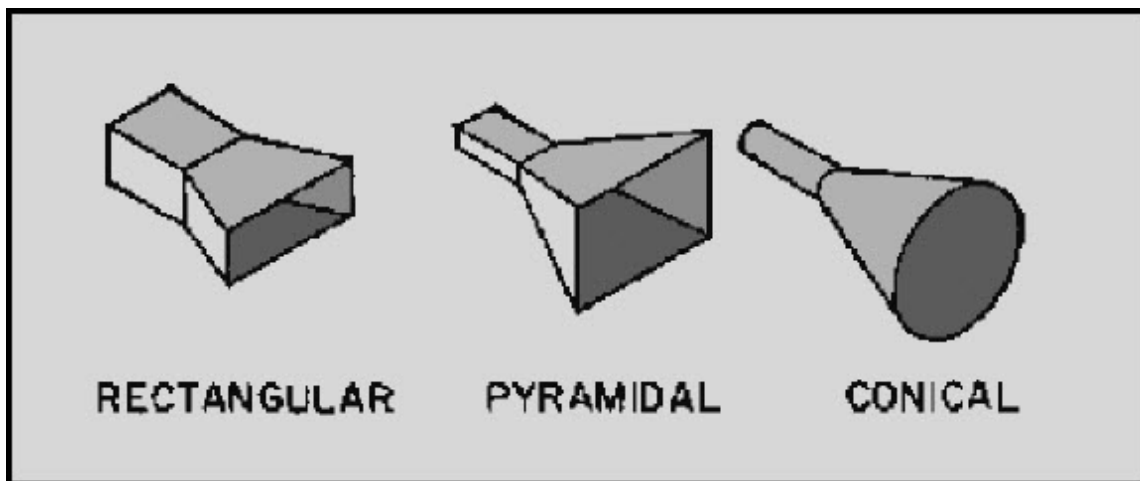


Figure 3-21 Horn radiators

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3.3.5 Feedhorns

A waveguide horn, called a FEEDHORN, may be used to feed energy into a parabolic dish. The directivity of this feedhorn is added to that of the parabolic dish. The resulting pattern is a very narrow and concentrated beam. In most radars, the feedhorn is covered with a window of polystyrene fiberglass to prevent moisture and dirt from entering the open end of the waveguide.

One problem associated with feedhorns is the SHADOW introduced by the feedhorn if it is in the path of the beam. (The shadow is a dead spot directly in front of the feedhorn.) To solve this problem the feedhorn can be offset from center. This location change takes the feedhorn out of the path of the rf beam and eliminates the shadow. An offset feedhorn is shown in figure 3-22.

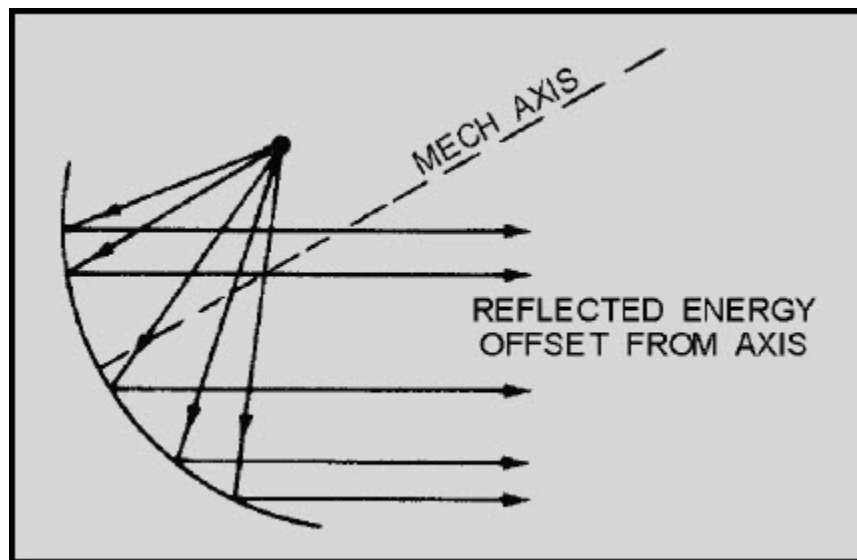


Figure 3-22 Offset feedhorn

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3.3.6 Airborne Radar Antennas

Airborne radar equipment is used for several specific purposes. Some of these are bombing, navigation, and search. Radar antennas for this equipment are invariably housed inside nonconducting radomes, not only for protection but also to preserve aerodynamic design. Some of these radomes are carried outside the fuselage, while others are flush with the skin of the fuselage. In the latter case, the radar antenna itself is carried inside the fuselage, and a section of the metallic skin is replaced by the nonconducting radome. The radar antenna and its radome must operate under a wide variety of temperature, humidity, and pressure conditions. As a result, mechanical construction and design must minimize any possibility of failure. Transmission lines are usually hermetically sealed to prevent moisture accumulation inside them. Such accumulation would introduce losses. Because the low air pressures encountered at high elevations are very conducive to arcing, pressurization of equipment is widely used (the pressure is maintained by a small air pump). In some airborne radar equipments, practically all of the equipment is sealed in an airtight housing, along with the antenna and transmission line. The antenna radome forms a portion of the housing.

Airborne radar antennas are constructed to withstand large amounts of vibration and shock; the radar antennas are rigidly attached to the airframe. The weight of the radar antenna, including the rotating mechanism required for scanning, is kept to a minimum. In addition, the shape of the radome is constructed so as not to impair the operation of the aircraft.

The airborne radar antenna must have an unobstructed view for most useful operation. Frequently, the antenna must be able to scan the ground directly under the aircraft and out toward the horizon. To meet this requirement, the antenna must be mounted below the fuselage. If scanning toward the rear is not required, the antenna is mounted behind and below the nose of the aircraft. If only forward scanning is needed, the antenna is mounted in the nose. When an external site is required, a location at the wing tip is common. A fire-control radar antenna is frequently located near the turret guns or in a special nacelle, where it can scan toward the rear or sides of the aircraft.

Q14. How many major lobes are produced by a paraboloid reflector?

Q15. What type of radiator normally drives a corner reflector?

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Q16. The broadside array consists of a flat reflector and what other elements?

Q17. Horn radiators serve what purpose other than being directional radiators?

3.4 SUMMARY

The following is a brief summary of the important points of this chapter.

A radar **INDICATOR** presents the information (video) from the radar receiver in a usable manner. The display usually consists of one or more of the coordinates of range, bearing, and altitude.

The **CATHODE-RAY TUBE (crt)** is the best available device for displaying the two-dimensional relationship produced by radar coordinates. The most commonly used crt displays are the A-SCOPE, the RHI, and the PPI. The A-scope presents range information only. The rhi displays range and height information. The ppi is the most widely used radar display indicator and presents range and bearing.

The range of a radar contact is determined by special **RANGING CIRCUITS**. The following three basic types of ranging circuits are used.

RANGE-GATE GENERATORS produce a movable gate that measures range based on elapsed time and can be used on A-scope and ppi displays.

RANGE-MARKER GENERATORS produce fixed interval range marks that can be used to estimate the range to a detected target. Range marks appear as an intensified series of vertical dots on an rhi and as concentric circles on a ppi.

The **RANGE-STEP GENERATOR** produces a movable step that is displayed on an A-scope presentation.

RADAR ANTENNAS are usually directional antennas that radiate energy in a one directional lobe or beam. The two most important characteristics of directional antennas are directivity and power gain. Radar antennas often use parabolic reflectors in several different variations to focus the radiated energy into a desired beam pattern. Other types of antennas used with radar systems are the corner reflector, the broadside array, and horn radiators.

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ANSWERS TO QUESTIONS Q1. THROUGH Q17.

- A1. *Range, bearing, and elevation.*
- A2. *Triggers, video, and antenna information.*
- A3. *Range and elevation.*
- A4. *Range and bearing.*
- A5. *Electromagnetic.*
- A6. *Fixed.*
- A7. *Range gate or range step.*
- A8. *Transmitter.*
- A9. *The radar mile (12.36 microseconds).*
- A10. *The A scope.*
- A11. *Directional.*
- A12. *Directivity.*
- A13. *Plane.*
- A14. *One.*
- A15. *Half-wave.*
- A16. *Two or more half-wave dipoles.*
- A17. *Waveguide impedance matching devices.*

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4 RADAR SYSTEM MAINTENANCE

LEARNING OBJECTIVES

After you finish this chapter, you should be able to do the following:

1. Interpret the transmitter frequency spectrum in terms of frequency distribution, power output, receiver response, and an acceptable spectrum curve.
2. Describe the methods for measuring the average and peak power outputs of a radar transmitter.
3. Describe the methods of measuring receiver sensitivity.
4. Define receiver bandwidth in terms of the receiver response curve and state the most common methods of measuring tube recovery time.
5. List the support systems associated with a typical shipboard radar system and describe the basic function of each.
6. State the general rules for the prevention of personnel exposure to rf radiation and X-ray emissions.

4.1 INTRODUCTION TO RADAR MAINTENANCE

The effectiveness of your radar system depends largely upon the care and attention you give it. An improperly adjusted transmitter, for example, can reduce the accuracy of a perfectly aligned receiver; the entire system then becomes essentially useless. Maintenance, therefore, must encompass the entire system for best operation.

Because of the complexity of most radar systems, trying to detail step-by-step procedures for specific maintenance actions in this chapter is impractical. However, the basic procedures for some maintenance actions that are common to most radar systems will be discussed. Also, an overview of support systems for radars will be presented. This will include electrical power, dry-air systems, and liquid cooling systems. Finally, safety precautions inherent to radars are listed.

4.2 TRANSMITTER PERFORMANCE CHECKS

The transmitter of a radar is designed to operate within a limited band of frequencies at an optimum power level. Operation at frequencies or power levels outside the assigned band greatly decreases the efficiency of the transmitter and may cause interference with other radars. Therefore, transmitter performance must be monitored closely for both frequency and output power.

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4.2.1 Transmitter Frequency

Whether of the fixed-frequency or tunable type, the radar transmitter frequency should be checked periodically. If the transmitter is of the fixed-frequency type and found to be operating outside its normal operating band, the problem is probably a defective part. The defective component must be replaced. If the transmitter is tunable, the transmitter must again be tuned to the assigned frequency.

Each time a radar transmitter generates an rf pulse, it produces electromagnetic energy. You should recall from your study of NEETS, Module 12, *Modulation Principles*, that the square wave used to modulate the transmitter carrier wave has (1) the fundamental square-wave frequency and (2) an infinite number of odd harmonics of the fundamental square wave frequency. When this square wave is used to modulate the transmitter carrier frequency, both the fundamental and odd harmonic frequencies of the square wave heterodyne with the transmitter carrier frequency. The heterodyning process produces in each transmitted rf pulse the following frequencies:

1. The fundamental carrier frequency
2. The sum and difference frequencies between the carrier and fundamental square-wave frequencies
3. The sum and difference frequencies between the odd harmonics of the square wave and the carrier frequencies

For a complete discussion of this process, you should review module 12.

Actually, the radar energy is distributed more or less symmetrically over a band of frequencies. This frequency distribution of energy is known as the **FREQUENCY SPECTRUM**. An analysis of frequency spectrum characteristics may be made with a **SPECTRUM ANALYZER**. The spectrum analyzer presents a graphic display of energy versus frequency. An extensive explanation of spectrum analyzer use can be found in the Electronics Installation and Maintenance Book (EIMB), *Test Methods and Practices*, NAVSEA 0967-LP-000-0130.

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4.2.1.1 Spectrum Analysis

When properly performed and interpreted, a spectrum analysis will reveal maladjustments' and troubles that would otherwise be difficult to locate. Therefore, you should be able to perform a spectrum analysis and understand the results.

You may be wondering why we are so interested in the frequency spectrum of an rf pulse. To better understand why, look at the spectrum of a transmitter as compared to the response curve of a receiver in figure 4-1. The receiver's response curve has a broader bandwidth than the transmitted spectrum, which ensures complete coverage. But the receiver responds best to frequencies in the middle of the bandwidth. This causes the receiver response to taper off from both sides of the center frequency until the response passes through the half-power points, as shown on the curve. Usually the receiver response beyond these points is too low to be useful and is not considered. Notice that the spectrum of the transmitter is centered inside the response curve of the receiver, thus yielding maximum efficiency.

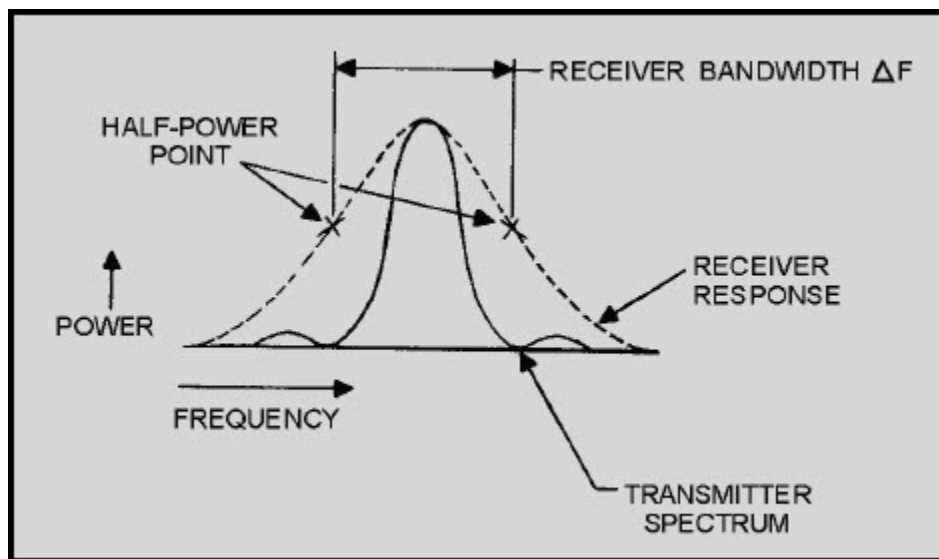


Figure 4-1 Transmitter spectrum compared with receiver response

Any frequency, when modulated by another frequency, will produce a base frequency with sideband frequencies (sum and difference). In other words, the output of a pulsed radar will contain more than one frequency. The output frequency spectrum of the pulsed radar transmitter does not consist of just a single frequency that is turned on and off at the pulse-repetition frequency (prf). Consider the spectrum as a base frequency (carrier) that is modulated by short rectangular pulses occurring at the prf of the radar. Two distinct modulating components are present: One component consists of the prf and its associated harmonics; the other component consists of the fundamental and odd-harmonic frequencies that make up the rectangular modulating pulse.

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The distribution of power over the radar frequency spectrum depends on the amount of modulation. A pulsed radar spectrum is illustrated in figure 4-2. The vertical lines represent the modulation frequencies produced by the prf and its associated harmonics; the lobes represent the modulation frequencies produced by the fundamental pulse frequency and its associated harmonics. The amplitude of the main lobe falls to zero on each side of the carrier. The side lobes are produced by the odd harmonics of the fundamental pulse frequency. The zero points are produced by the even harmonics of the fundamental pulse frequency. In an ideal spectrum each frequency above the carrier has its counterpart in another frequency below the carrier. These frequencies are equally spaced and have equal power. Therefore, the pattern is symmetrical about the carrier. The main lobe, of course, contains the major portion of the transmitted rf energy.

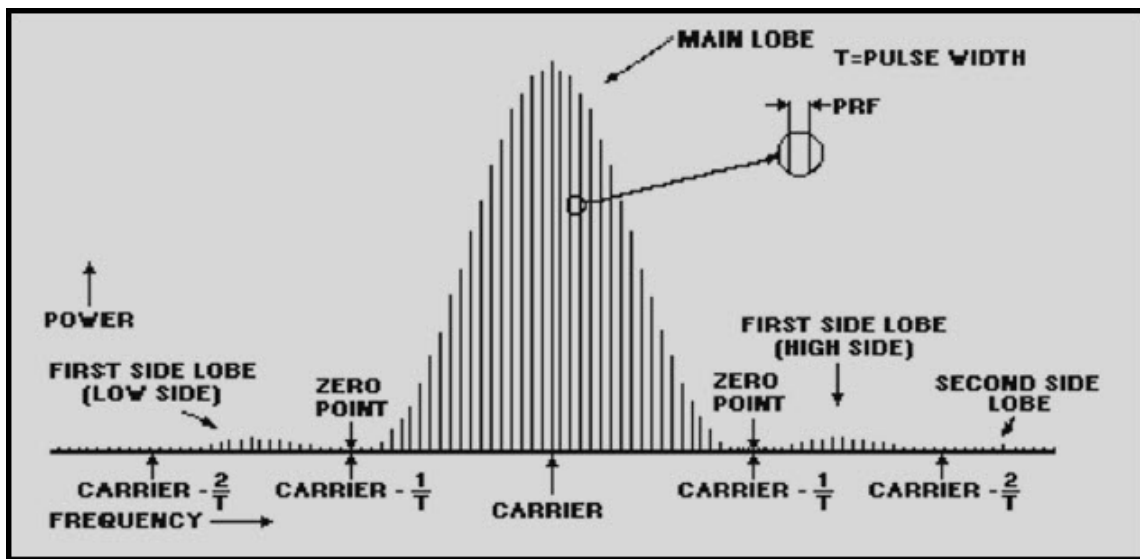


Figure 4-2 Spectrum of a pulse-modulated carrier

A radar transmitter in good condition should produce a spectrum curve similar to the curves shown in view A or B in figure 4-3. Good curves are those in which the two halves are symmetrical and contain deep, well-defined minimum points (minima) on both sides of the main peak.

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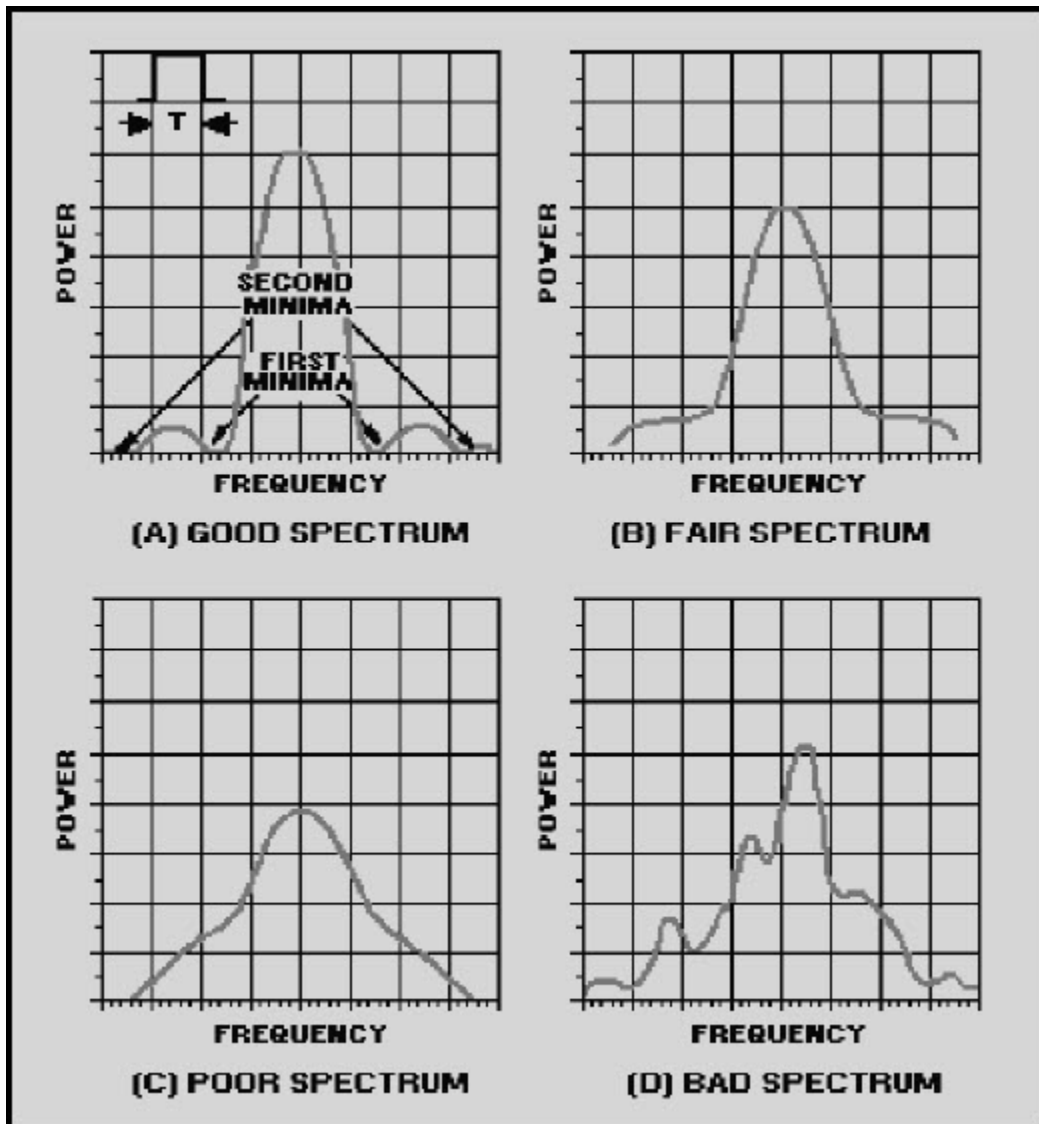


Figure 4-3 Comparison of radar spectra

A curve without well-defined minima, as in the curve shown in view C, indicates that the transmitter output is being frequency modulated during the pulse. This condition may occur when a pulse without sufficiently steep sides or a flat peak is applied to the transmitter. It may also occur when a transmitter tube is unstable or is operated without proper voltage, current, or magnetic field.

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An extremely irregular spectrum, as in the curve in view D, is an indication of severe frequency modulation. This condition usually causes trouble with the receiver automatic frequency control (afc) as well as a general loss of signal strength. You can often improve a faulty spectrum by adjusting the transmission line stubs or by replacing the transmitter tube. When the spectrum has two large peaks that are quite far apart, it indicates that the transmitter tube is DOUBLE MODING (shifting from one frequency to another). This could be caused by standing waves in the transmission line or a faulty transmitter tube. Standing waves may be caused by a faulty line connection, a bad antenna rotating joint, or obstructions in the line. (Standing waves are described in NEETS, Module 10, *Wave Propagation, Transmission Lines, and Antennas*.)

In the case of a good or fair spectrum curve with sharply defined minimum points on both sides of the main lobe, the distance between these two points is proportional to the duration of the transmitted pulse.

The device most commonly used to check the frequency spectrum of a radar transmitter is the spectrum analyzer.

4.2.1.2 Frequency-Measuring Devices

Devices used to determine the basic carrier frequency of a radar transmitter are the ELECTRONIC FREQUENCY COUNTER, the WAVEMETER, and the ECHO BOX. One or more of these devices may be included in a special RADAR TEST SET designed for a specific system or type of radar. Radar test sets quite often consist of several types of test equipment. This combination of test equipments enables both transmitter and receiver performance checks to be carried out with one test instrument. Electronic frequency counters, frequency meters, and wavemeters are discussed in NEETS, Module 16, *Test Equipment*. The echo box is discussed in the next section. The specific equipments and procedures required to measure the frequency of any radar system are found in the associated system technical manuals and related PMS documents.

Q1. The spectrum of a radar transmitter describes what characteristic of the output pulse?

Q2. Where should the transmitter spectrum be located with respect to the receiver response curve?

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Q3. The ideal radar spectrum has what relationship to the carrier frequency?

Q4. The display screen of a spectrum analyzer presents a graphic plot of what two signal characteristics?

4.2.1.3 The Echo Box

The ECHO BOX is an important test instrument for indicating the overall radar system performance. The echo-box test results reflect the combined relative effectiveness of the *transmitter* as a transmitter of energy and the receiver as a *receiver* of energy.

The echo box, or RESONANCE CHAMBER, basically consists of a resonant cavity, as shown in view A of figure 4-4. You adjust the resonant frequency of the cavity by varying the size of the cavity (the larger the cavity the lower the frequency). A calibrated tuning mechanism controls the position of a plunger and, therefore, the size of the cavity. The tuning mechanism is adjusted for maximum meter deflection, which indicates that the echo box is tuned to the precise transmitted frequency. The tuning mechanism also indicates on a dial (figure 4-5, view A) both the coarse transmitted frequency and a numerical reading. This reading permits the technician to determine the transmitted frequency with greater accuracy by referring to a calibration curve on a chart (figure 4-5, view B).

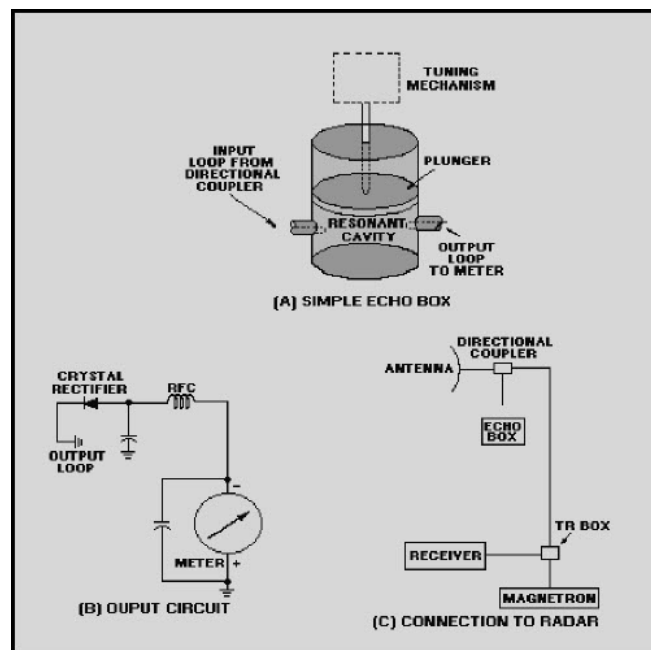


Figure 4-4 Echo box

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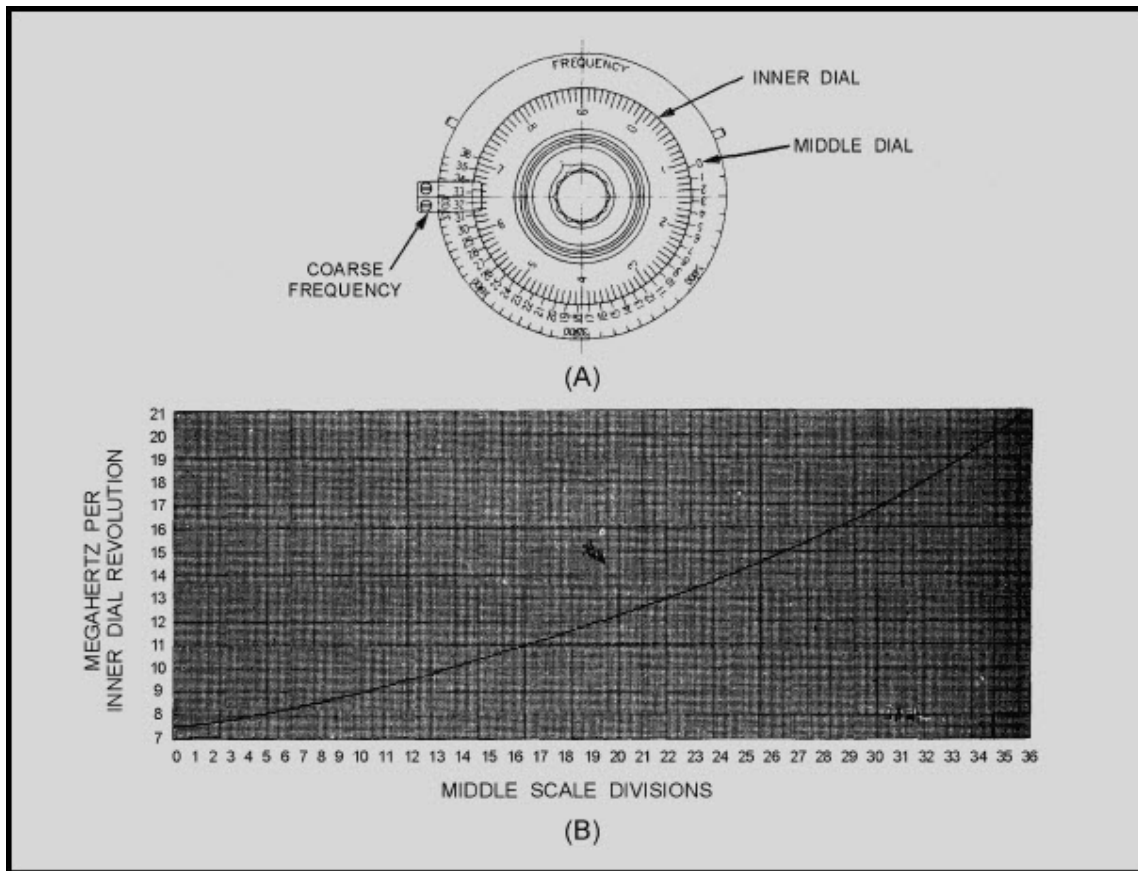


Figure 4-5 Reading the echo box dial

Energy is coupled into the cavity from the radar by means of an rf cable connected to the input loop. Energy is coupled out of the cavity to the rectifier and meter by means of the output loop. You can vary the amount of coupling between the echo box and the crystal rectifier by changing the position of the output loop. A schematic diagram of the output circuit is shown in figure 4-4, view B. The energy picked up by the loop is rectified, filtered, and applied to the meter. The method of connecting the echo box in a radar system is shown in figure 4-4, view C.

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4.2.2 Ring Time Measurements

Some of the energy generated by the radar transmitter is picked up by the echo box by means of the directional coupler. This energy causes oscillations (known as RINGING) within the echo box that persist for some time after the end of the radar pulse, much in the fashion of an echo that persists in a large room after a loud noise. As this echo dies down, a part of it is fed back into the radar receiving system, again by means of the directional coupler. The ringing causes a saturating signal to appear on the radar indicator (figure 4-6). The longer this ringing extends, the better the performance of the radar.

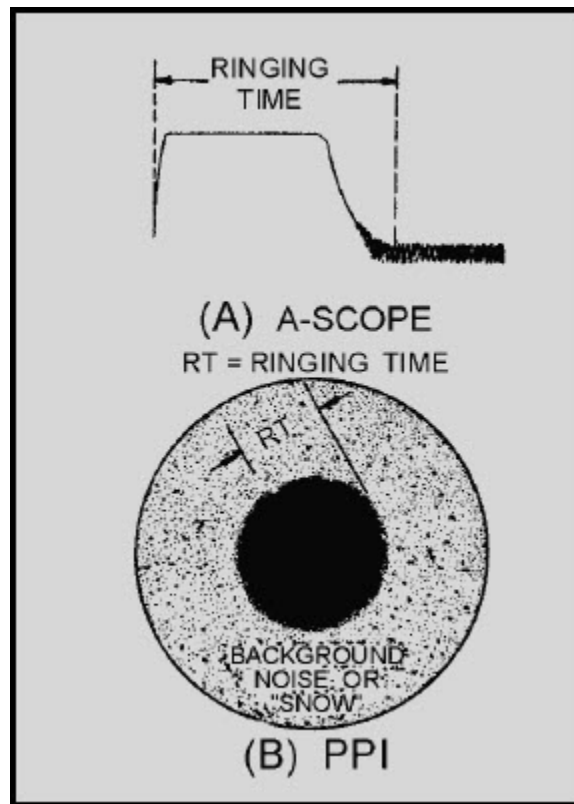


Figure 4-6 Ring time saturation of A-scope and ppi

The length of time the echo box *should* ring under the particular conditions of the test is called the EXPECTED RING TIME. You may determine whether or not the radar is performing well by comparing the expected ring time with the ring time observed.

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The ring time to be expected on a good radar depends on the particular type of radar being tested; on the way the echo box is installed - that is, whether a directional coupler or a pickup dipole is used; on the length and type of cable used; on the individual ringing ability of the particular echo box in use; on the frequency of the radar; and on the temperature of the echo box at the time of the test. Corrections are made for all of these factors according to the procedure given in the technical manual for the echo box being used.

You may use an echo box without correction to detect a *change* in the performance of a radar. You simply log and compare the ring time from day to day. You should recognize that these readings do not permit the comparison of a particular radar with a standard of performance; however, you can use the readings to tell whether or not its performance is deteriorating.

Because ring time measurements are the most valuable single feature of the echo box, they must be measured properly. Ring time measurements are made on the A-scope or on the ppi.

In measuring the ring time, you should make sure the echo-box ringing (not some fixed-target echo or block of echoes) is being monitored. You can determine this condition by adjusting the radar gain control and noting if the ring time varies on the scope. The echo box ringing will change in duration; fixed target echoes, however, will not change duration.

To obtain the best results, you should repeat every ring time measurement at least four times; then average the readings. You should take special care to ensure that all readings are accurate. If two or more technicians use the same echo box, they should practice together until their ring time measurements agree.

4.2.3 Transmitter Power Measurement

Because high peak power and radio frequencies are produced by radar transmitters, special procedures are used to measure output power. High peak power is needed in some radar transmitters to produce strong echos at long ranges. Low average power is also desirable because it enables transmitter components to be compact, more reliable, and to remain cooler during operation. Because of these considerations, the lowest possible duty cycle ($pw \times prf$) must be used for best operation. The relationships of peak power, average power, and duty cycle were described in chapter 1. Peak power in a radar is primarily a design consideration. It depends on the interrelationships between average power, pulse width, and pulse-repetition time.

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You take power measurements from a radar transmitter by sampling the output power. In one sampling method, you use a pickup horn in front of the antenna. Air losses and weather conditions make the horn placement extremely critical and also affect the accuracy of the sample. A more accurate and convenient method can be used. In this method, you sample the output power through a directional sampling coupler located at the point in the transmitter where a power reading is desired. Power-amplifier transmitters usually have sampling couplers after each stage of amplification.

Some radar sets have built-in power-measuring equipment; others require the use of general purpose test equipment or a special test set. In any case, the measuring instruments are most often referenced to 1 milliwatt; readings are taken in dBm (a discussion of the decibel measurement system was presented in NEETS, Module 11, *Microwave Principles*).

When taking power measurements, you must allow for power losses. You must add the directional coupler attenuation factor and the loss in the connecting cable to the power meter reading. The sum is the total power reading. For example, the directional coupler has an attenuation factor of 20 dB, the connecting cable has a loss rating of 8 dB, and the reading obtained on the power meter is 21 dBm. Therefore, the transmitter has an output power that is 49 dBm ($21 + 20 + 8$). Power readings in dBm obtained by the above procedure are normally converted to watts to provide useful information. Although the conversion can be accomplished mathematically, the procedure is relatively complex and is seldom necessary. Most radar systems have a conversion chart, such as the one shown in figure 4-7, attached to the transmitter or the test equipment. As you can see on the chart, 49 dBm is easily converted to 80 watts average power.

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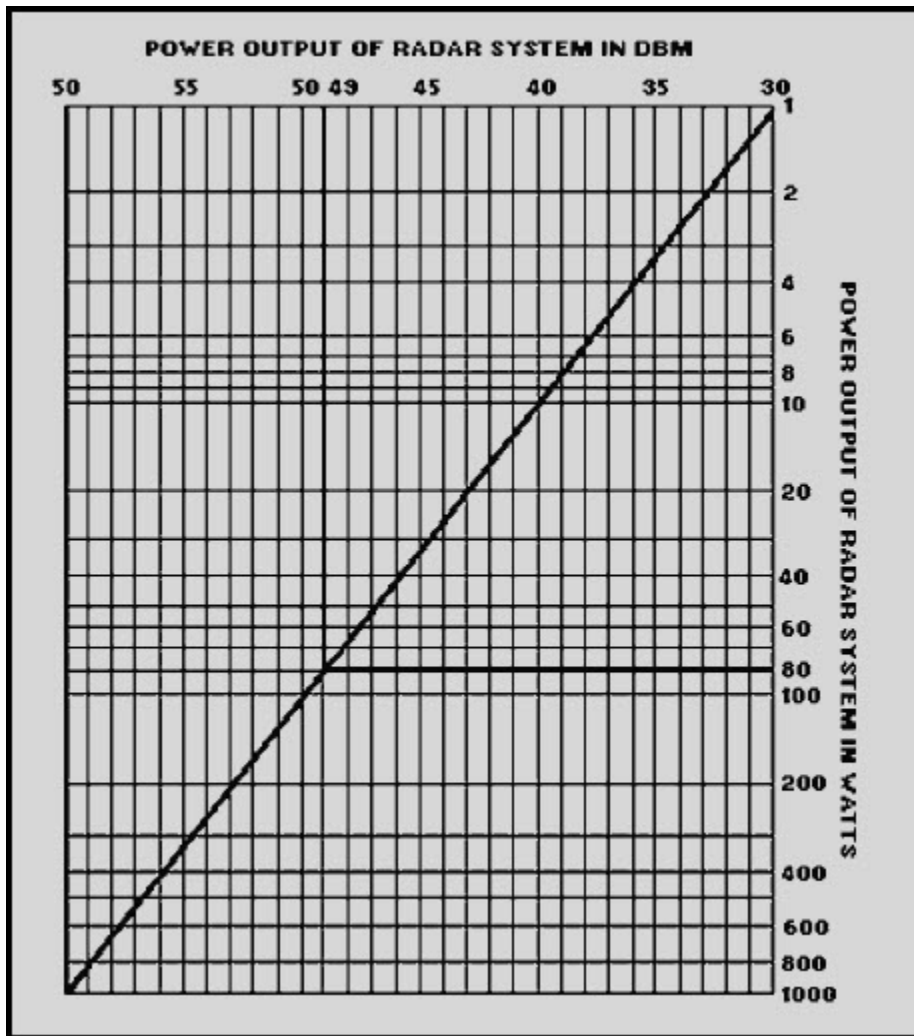


Figure 4-7 Conversion of power in dBm to watts (average)

You can convert average power to peak power by dividing average power by the duty cycle of the radar. If the radar in the above example has a duty cycle of 0.001, then the peak power can be calculated with the following formula:

$$\begin{aligned} \text{peak power } (P_{pk}) &= \frac{\text{average power } (P_{avg})}{\text{duty cycle}} \\ &= \frac{80 \text{ watts}}{0.001} \\ &= 80,000 \text{ watts or } 80 \text{ kilowatts} \end{aligned}$$

Many radar systems have charts available to convert average power to peak power.

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Q5. The peak power of a radar depends on the interrelationship of what other factors?

Q6. Transmitter power readings are most often referenced to what power level?

4.3 RECEIVER PERFORMANCE CHECKS

The performance of a radar receiver is determined by several factors, most of which are established in the design engineering of the equipment. In the paragraphs that follow, factors concerned with maintenance are considered. Important factors are (1) receiver sensitivity, which includes noise figure determination and minimum discernible signal (m_{ds}) measurement; (2) tr recovery time; and (3) receiver bandwidth.

Many radar systems contain circuits that serve special functions. Three of these special circuits are instantaneous automatic gain control (iagc), sensitivity time control (stc), and fast time constant (ftc). These circuits may be found in combination or alone, depending on the purpose of the radar. When the test methods and procedures about to be described are used, these special functions should not be used. If an automatic frequency control (afc) circuit is included in the radar, it may be permitted to operate during receiver tests. A good way you can check afc circuit operation is to complete the tests specified for manual tuning and then switch to afc. If the afc circuit operation is normal, test indications should not differ.

4.3.1 Receiver Sensitivity

Insufficient detection range in a radar system can be caused by decreased sensitivity in the radar receiver. This condition results mainly from the great number of adjustments and components associated with the receiver. A decrease of receiver sensitivity has the same effect on range performance as does a decrease of transmitter power. For example, a 6 dB loss of receiver sensitivity shortens the effective range of a radar just as much as a 6 dB loss in transmitter power. Such a drop in transmitter power is evident and is easy to detect. On the other hand, a 6 dB loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is difficult to detect unless accurate measurements are made.

Figure 4-8 shows a comparison of radar system performance versus maximum range. The system performance loss in dB includes both transmitter and receiver losses. You should note that with a loss of 5 dB in both receiver and transmitter (a total of 10 dB), only 55 percent of the maximum range of the system is realized.

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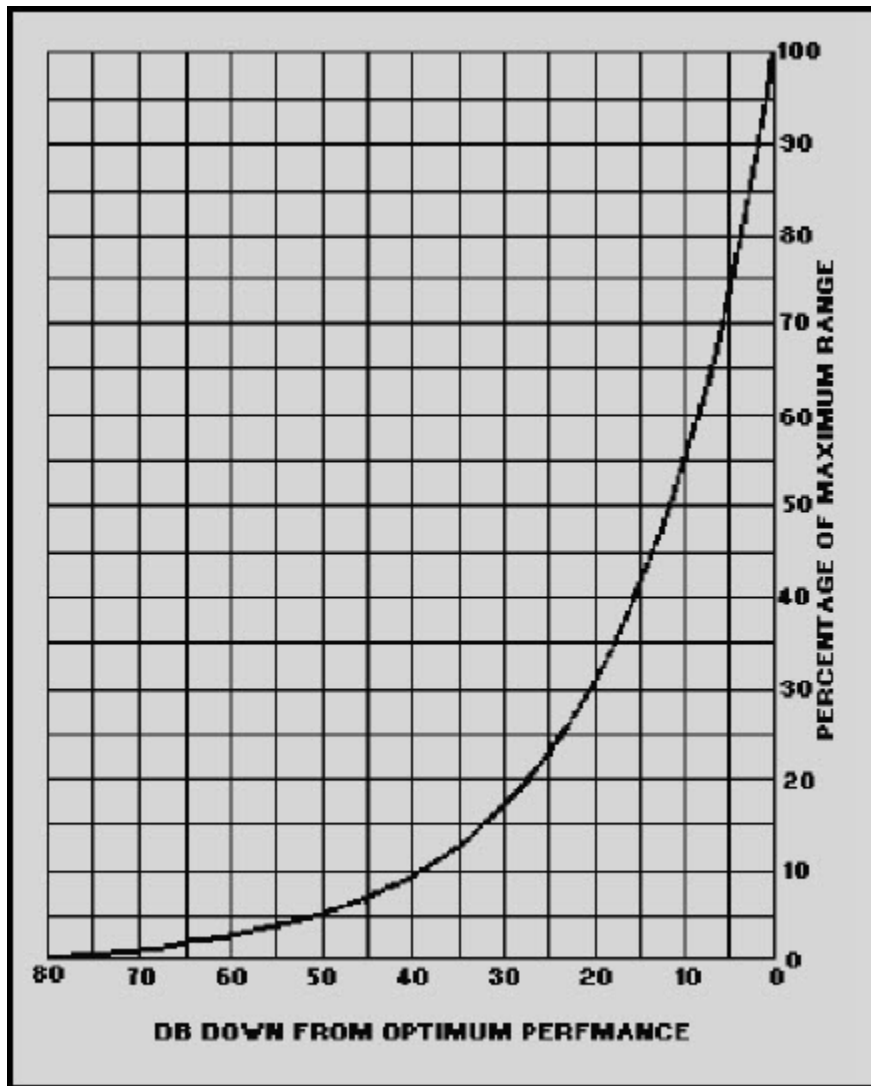


Figure 4-8 System performance versus maximum range

The sensitivity of the radar receiver is a measure of its ability to pick up weak signals. The greater the sensitivity of the receiver, the better the receiver picks up weak signals. You can determine receiver sensitivity by measuring the power level of the MINIMUM DISCERNIBLE SIGNAL (m_{ds}). M_{ds} is defined as the weakest signal that produces a visible receiver output (on a scope). Its value is determined by the receiver output noise level (noise tends to obscure weak signals). Because m_{ds} measurement depends on the receiver noise level, measuring either m_{ds} or noise level (called NOISE FIGURE) will indicate receiver sensitivity.

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Many radar systems have built-in receiver sensitivity test circuits. These test circuits indicate the sensitivity of the receiver to the technician or operator.

To measure the mds, you must measure the power of a test pulse in which the level is just sufficient to produce a visible receiver output. If a radar receiver has the mds level specified in the maintenance manual, then the noise figure should also be correct. Therefore, measurement of the mds is a satisfactory substitute for a noise-figure determination and is less complicated.

Because receiver sensitivity readings are taken periodically for comparison purposes, the identical pulse length must be used for each measurement. Maintenance instructions for the radar set usually specify the correct pulse length to be used in receiver sensitivity tests. In most cases, it is the same as the transmitter pulse length.

Before any measurements of receiver sensitivity can be made, the receiver must be accurately tuned to the transmitter frequency. If the receiver frequency differs from the transmitter frequency, the most likely cause is an improperly adjusted or malfunctioning local oscillator or transmitter frequency drift. Such problems can be caused by heat or aging components. Local oscillator tuning procedures differ widely according to the type of radar system; therefore, you should follow the tuning procedures in the system maintenance manuals.

Two basic methods are used to measure radar receiver sensitivity. One is the PULSE METHOD, in which a pulse of measured amplitude and width is coupled to the receiver. In the second method, you use an fm generator to vary the signal generator output frequency across the receiver bandwidth. This latter method ensures the test signal is within the bandpass of the receiver.

The sensitivity of the receiver is equal to the sum of the reading on the signal generator and the attenuations of the connecting cable and directional coupler. Receiver sensitivity is expressed as a negative dBm; for example, -90 dBm expresses the sensitivity of a receiver that can detect a signal 90 dB less than the 1-milliwatt reference level. A typical receiver sensitivity reading on a modern radar should be in the vicinity of -105 dBm.

4.3.2 Receiver Bandwidth Test

Receiver bandwidth is defined as the frequency spread between the half-power points on the receiver response curve. Receiver bandwidth is specified for each radar, but wide variations are often tolerated. If either the bandwidth or the shape of the receiver response curve is not within tolerances, a detailed check of circuit components may be necessary. A considerable change in the value of circuit components is required to alter the response. You should check receiver response after any extensive repair to an IF amplifier.

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Figure 4-9 shows a typical response curve of a radar receiver. The half-power points are shown as 3 dB below maximum response. Since the curve is plotted in terms of voltage, these points are also represented by the 70.7 percent voltage points as shown in the figure.

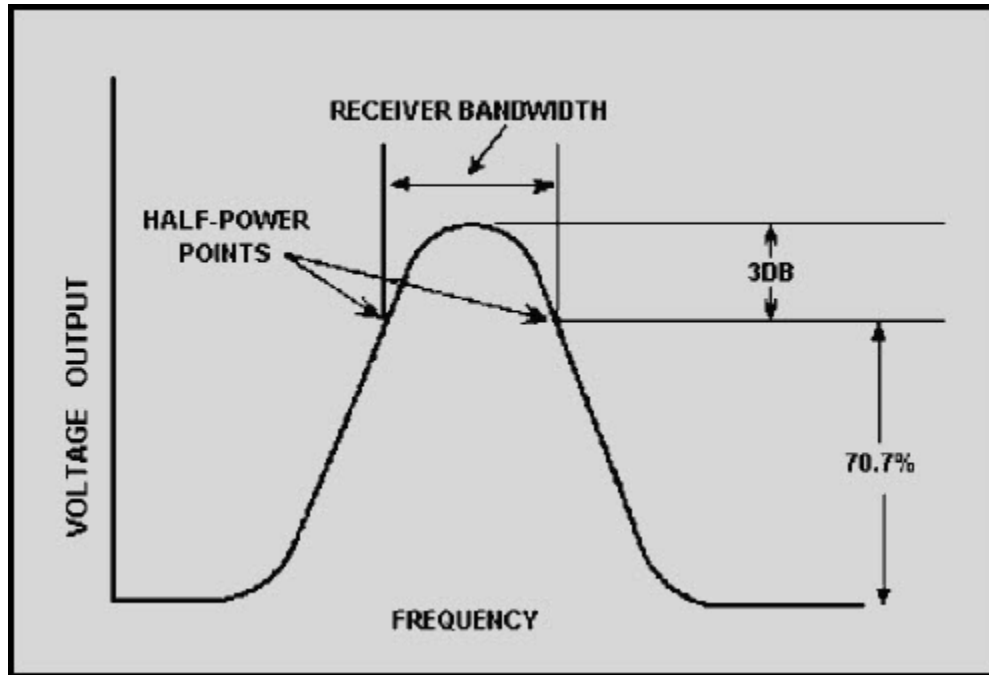


Figure 4-9 Typical receiver response curve

4.3.3 Tr Recovery Time

The time required for tr recovery is determined by the time taken by the tr switch (tube) to deionize after each transmitter pulse. It is usually defined as the time required for the receiver to return to within 6 dB of normal sensitivity after the end of the transmitter pulse. However, some manufacturers use the time required for the sensitivity to return to within 3 dB of normal sensitivity. Tr recovery time is a factor that limits the minimum range of a radar because the radar receiver is unable to receive until the tr switch is deionized. In various radars, the recovery time may differ from less than 1 microsecond to about 20 microseconds.

The primary function of the tr switch is to protect the sensitive crystal detectors from the powerful transmitter pulse. Even the best tr switches allow some power to leak through; but when the switch is functioning properly, leakage power is so small that it does not damage the crystal. However, the useful life of a tr tube is limited because the amount of leakage to the receiver increases with use.

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To ensure efficient performance, some technicians make a policy of replacing the tr tube after a certain number of hours of use. A better practice is to measure the tr recovery time at frequent intervals and make a graph or chart. A graph or chart will immediately disclose any change in performance. Figure 4-10 shows how the recovery time is correlated with leakage power. Note that the end of the useful life of the tr tube is indicated by an increase in recovery time.

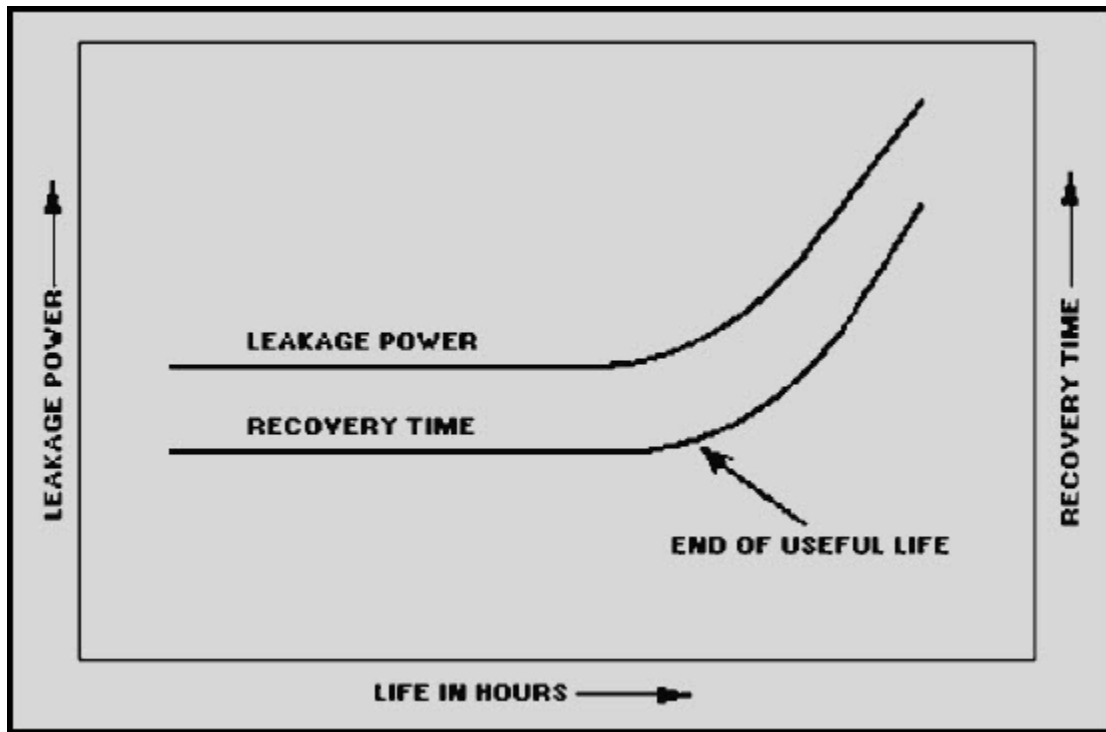


Figure 4-10 Tr recovery time versus leakage power

This method of checking the condition of a tr tube is reliable because recovery time increases before leakage power becomes excessive. In practice, a tr tube is replaced when any sharp increase in recovery time becomes apparent.

Ambient temperature also has an effect on recovery time. The colder a tr tube, the greater its recovery time. When tests are conducted under widely varying temperature conditions, this effect must be considered.

One method you can use in testing a tr tube is to measure the KEEP-ALIVE current. This current keeps the tr tube partially ionized, which makes the firing more instantaneous and thus helps protect the receiver crystals. The keep-alive current is normally about 100 microamperes but falls off as the end of the tr tube life approaches. You can also measure the keep-alive voltage between the plate of the tr tube and ground when the voltage source is known to have the correct output. You then record this voltage for use as a reference for future checks. However, these checks are not as reliable as recovery time testing.

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Specific procedures for measuring tr leakage and recovery time can be found in the equipment technical manuals.

Q7. A loss of receiver sensitivity has the same effect on range performance as what other loss?

Q8. You determine receiver sensitivity by measuring the power level of what signal?

Q9. When measuring receiver sensitivity, what quantities must you add to the dBm reading obtained on the signal generator or test set?

4.3.4 Standing Wave Measurements

(You may want to refer to NEETS, Module 10, Wave Propagation, Transmission *Lines, and Antennas* for a review of standing waves before going further.) Measurements of standing waves can indicate the approximate operating frequency, the presence of defective transmission-line sections, and the condition of the antenna. Standing waves present on transmission lines and waveguides indicate an impedance mismatch between a transmitter or receiver and its antenna. When this condition occurs, the transfer of energy between these units becomes inefficient. Reflection of energy at the load end of a transmission line results in a wave that travels toward the generator end. This reflected wave varies continuously in phase in much the same way that the incident wave varies in phase. At certain points, a half wavelength apart, the two waves are exactly in phase; the resultant voltage is at maximum. At points a quarter wavelength from the maximums, the two waves are in opposition and voltage nodes (null points) are produced. The ratio of maximum-to-minimum voltage at such points is called the VOLTAGE STANDING WAVE RATIO (vswr). The ratio of maximum-to-minimum current along a transmission line is the same as the vswr. A high vswr (1.5 to 1 or higher) indicates that the characteristic impedance of a transmission line differs greatly from the terminating impedance; a low vswr (1 to 1 is best) indicates a good impedance match between the transmission line characteristic impedance and the terminating impedance.

For radar applications, a low vswr is desired for the following reasons: (1) Reflections in the transmission line cause improper transmitter operation and can result in faulty pulsing (this effect is most pronounced when the line is long, as compared with a wavelength of the transmitted energy); (2) arc-over may occur at the maximum voltage points; and (3) hot spots can occur in the transmission line and cause mechanical breakdown. Since transmission lines for radar equipment are normally coaxial cables or waveguides, slotted lines or directional couplers must be used for standing-wave measurements.

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Q10. Receiver bandwidth is defined as those frequencies spread between what two points of the receiver response curve?

Q11. The end of the usefulness of a tri tube is indicated by an increase in what quantity?

4.4 SUPPORT SYSTEMS

When you think of radar equipment with its complex electronic circuitry and other sophisticated equipment, you may forget that the entire radar relies on other systems. These other systems are referred to as SUPPORT SYSTEMS and are not normally thought of as part of the radar. These support systems include ELECTRICAL POWER, DRY-AIR, and LIQUID-COOLING SYSTEMS. Without these support systems, radars could not function. Therefore, you must be aware of these support systems and understand their relationship to your radar equipment.

4.4.1 Electrical Power

Let us now look at a typical ship's power distribution system. The power system on your ship or aircraft is probably similar in many ways. We will briefly discuss an overall power distribution system and the areas that are closely related to radar equipment.

4.4.1.1 Power Distribution System

Most ac power distribution systems in naval vessels are 440-volt, 60-hertz, 3-phase, 3-wire, ungrounded systems. The ac power distribution system consists of the power source, equipment to distribute the power, and the equipment which uses the power. A partial distribution chart is shown in figure 4-11.

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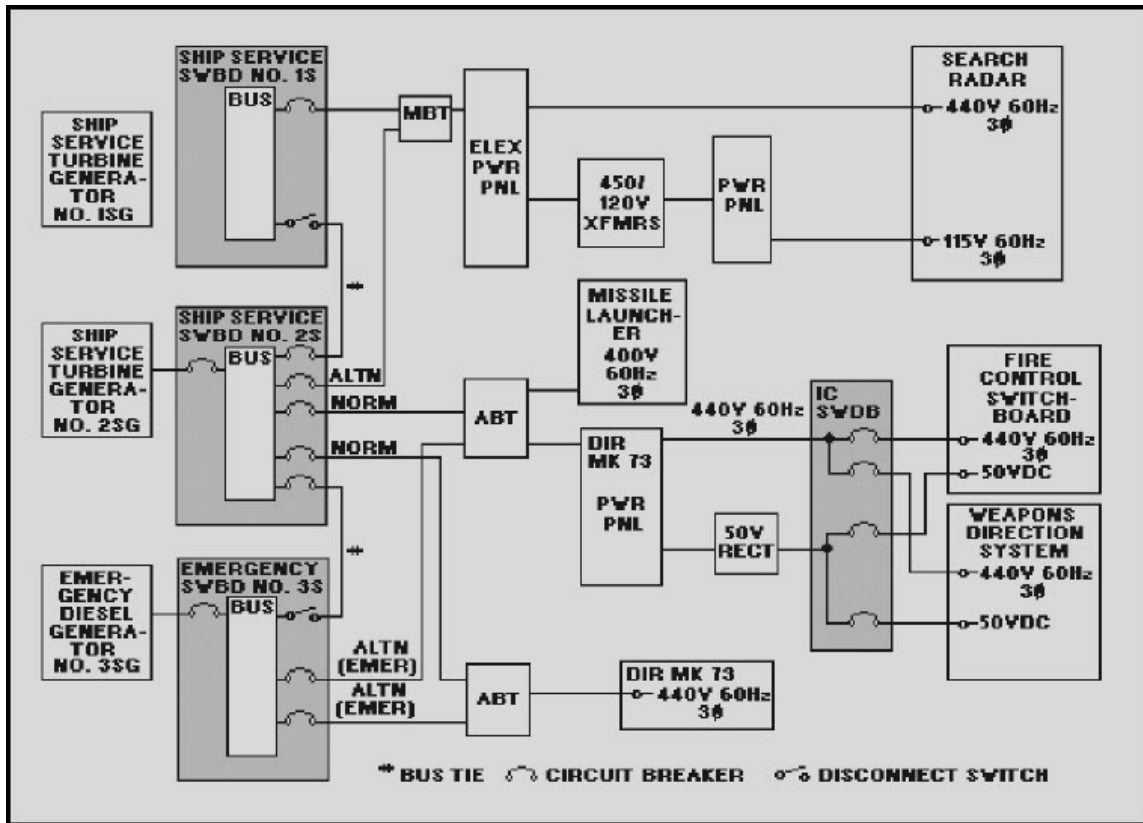


Figure 4-11 60 Hz distribution

The power source can be the ship service turbine generator or the emergency diesel generator. Power is normally distributed through the ship service distribution switchboards and power panels. Some large ships also use load centers (not shown) that function as remote switchboards.

Power is used by any equipment that requires electrical power for its operation (lights, motors, director power drives, radar equipment, weapon direction equipment, computers, etc.). The maintenance of the ship service generators, the emergency generators, and distribution switchboards is the responsibility of the ship's engineers (machinist's mates, electrician's mates, enginemen, etc.).

4.4.1.2 Emergency Power

If power from the ship service distribution system is interrupted, the emergency power distribution system is activated. The emergency system supplies an immediate and automatic source of electrical power to selected loads that are vital to the safety and defense of the ship. This system includes one or more emergency diesel generators and switchboards. The emergency generator is started automatically when a sensor detects the loss of normal power.

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4.4.1.3 Bus Transfer Equipment

Bus transfer equipment is installed on switchboards, at load centers, on power panels, and on loads that are fed by both normal and alternate and/or emergency feeders (figure 4-11). Either the normal or alternate source of the ship's service power can be selected. Emergency power from the emergency distribution system can be used if an emergency feeder is also provided.

Automatic bus transfer (ABT) equipment is used to provide power to vital loads, while nonvital loads can be fed through manual bus transfer (MBT) equipment. For example, the interior communications (IC) switchboard is fed through an ABT in which the alternate input is from the emergency switchboard. A search radar might be fed through an MBT.

4.4.1.4 Miscellaneous Power

Many other supply voltages are used in radar systems and subsystems. They are usually used as reference voltages for specific functions. When you are missing a power input to your equipment, work backwards from the load to the source. Usually, the power panels and bus transfer units that feed the equipment are located nearby, possibly in the same space or in a passageway.

Keep in mind that technicians have corrected many suspected casualties merely by restoring a minor power input or signal reference, sometimes after hours of troubleshooting.

Q12. Most shipboard distribution systems use ac power that has what number of phases?

Q13. How is emergency power applied when normal power is lost?

Q14. What device is used to switch power from the normal source to an alternate source for nonvital users?

Q15. What procedure should you use when a power input to your equipment is missing?

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4.4.2 Dry-Air Systems

Some radars depend on inputs of dry air for proper operation. Radar dry air is normally supplied by the ship's central dry-air system. This system produces high-pressure (hp) air and low-pressure (lp) dry air for distribution to user equipment, such as a search or a fire control radar.

4.4.2.1 Electronics Dry-Air Branch

The electronics dry-air branch is fed from the vital service lp air main through the Type II (desiccant) or Type III (combination refrigerant and desiccant) dehydrators, as shown in figure 4-12. The purpose of the electronics dry-air branch is to provide several electronic equipments with air that is dry enough for proper operation. Microwave components, such as waveguides, cavities, and power amplifiers, require dry air to prevent arcing and internal corrosion. The electronics dry-air branch must satisfy the dry-air requirements of the electronic user equipment. Dry air of less than the required specifications will degrade equipment performance. It may also incur major repairs, overhaul, or replacement of expensive electronic components.

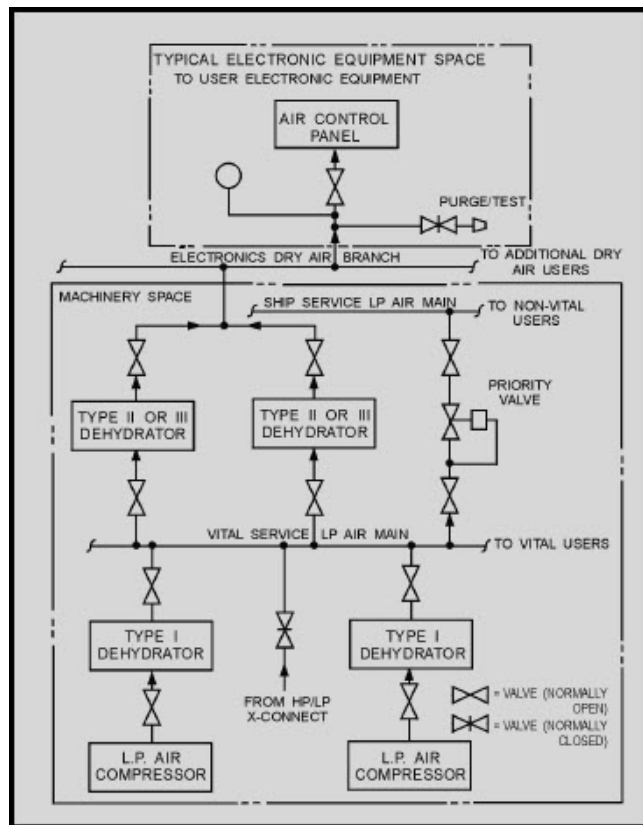


Figure 4-12 Typical lp air system layout

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4.4.2.2 Air Control Panel

The dry-air distribution system (figure 4-12) delivers dry air to each air control panel of the user equipment. The air control panels are used to control and regulate the dry-air pressure to that required by the electronic user equipment.

The air control panel (figure 4-13) provides a means of monitoring the dry-air supply to the user equipment. The type of control panel used varies, depending on the outlet pressure and flow rate required.

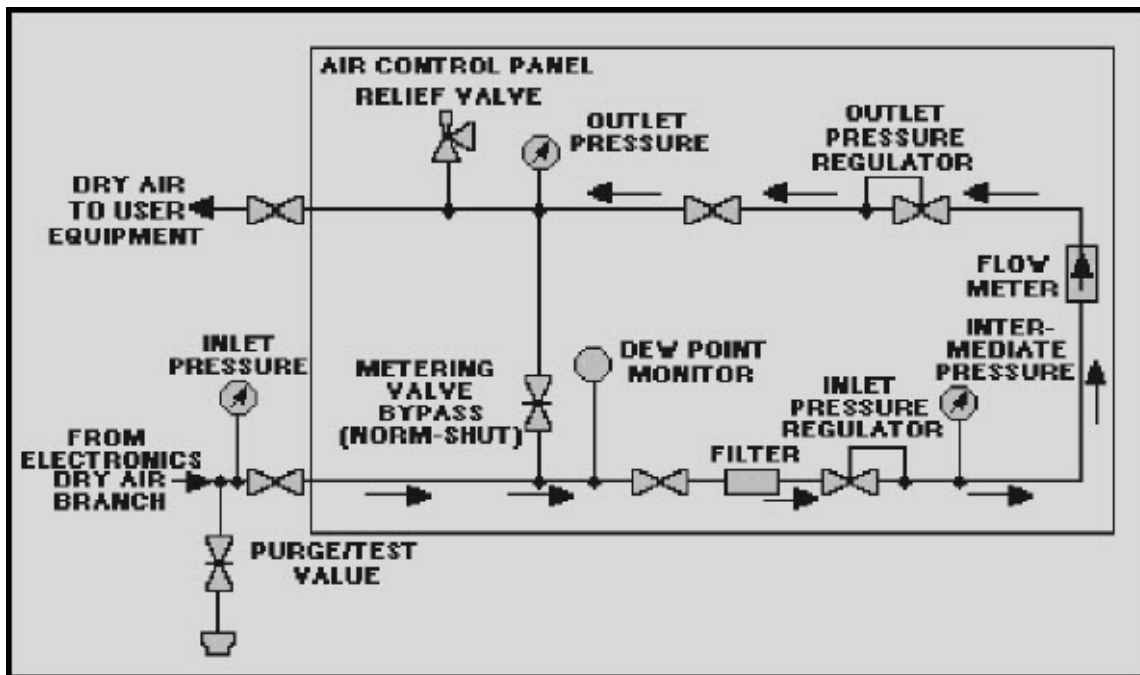


Figure 4-13 Air control panel flow diagram

The dew point (related to moisture content) and the flow of the 1p dry air can be monitored at the air control panel. Also, the dry-air pressure can be monitored at the input to the control panel, at the input to the flowmeter (in which accuracy is calibrated at a certain pressure), and at the output of the control panel. A filter is installed to trap particles that affect proper pressure regulation. A metering valve bypass and a pressure relief valve are provided in case of malfunctions. The metering valve bypass permits manual control of air pressure to the user equipment.

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4.4.2.3 Electronic Equipment Dehydrators

Dehydrators or compressor-dehydrators are supplied as part of various radars. Many of them were provided prior to installation of properly configured central dry-air systems. These dehydrators are intended for emergency use in the event of the failure of the central dry-air system. In a typical configuration (figure 4-14), the outlet air from the local dehydrator is connected between the air control panel outlet and the user equipment or radar by a three-way valve.

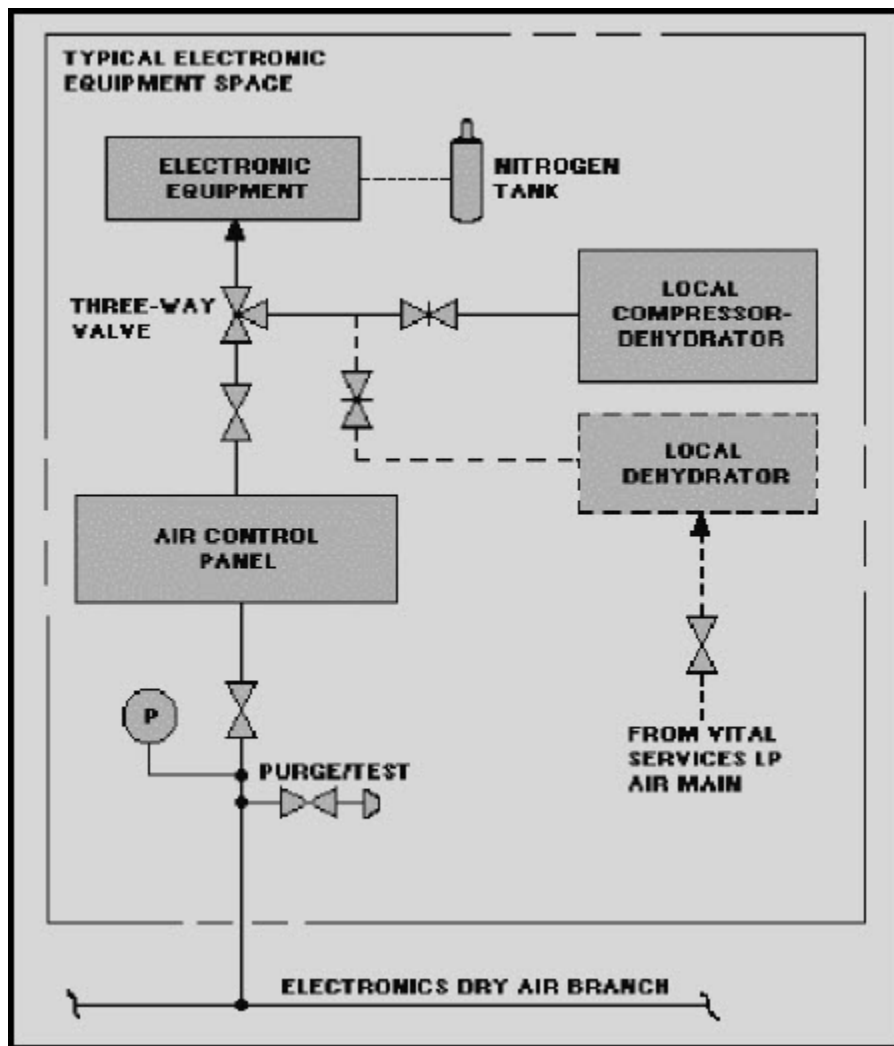


Figure 4-14 Typical local dehydrator interface

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Local dehydrators depend on the ship's lp air for an inlet supply, while the local compressor dehydrators can operate independently of the ship's air supply. Some units of electronic equipment that have local dehydrator units are pressure interlocked within the dehydrator unit. When the outlet air pressure is below a set value, the interlock prevents the equipment from going to a full OPERATE condition. When the central dry-air system is used, the pressure interlock is bypassed.

Some radars provide a tank of nitrogen as an emergency source that can be connected in place of dry air. Special safety precautions must be taken when you handle compressed gases because of the possibility of explosion. Nitrogen does not support life; when released in a confined space, it can cause asphyxiation.

Q16. What is the normal source of dry air for a radar system?

Q17. What is the major difference between the electronics dry-air branch and the vital service lp air main?

Q18. What is the air control panel designed to control?

4.4.3 Cooling Systems

Radar equipment, particularly the high-power transmitters, generate large amounts of heat. This heat must be dissipated to prevent damage to the equipment and to prevent erratic circuit operation. Most radar equipment rooms have high-capacity air-conditioning systems to control the ambient room temperature; however, equipment cabinets must have additional cooling to control the internal temperature. In the case of transmitters (and other high-voltage circuits), individual components may require cooling.

Cabinets that generate relatively small amounts of heat may only require a system of fans or blowers to maintain constant air circulation. In some cases the air is circulated through a liquid-cooled heat exchanger located inside the cabinet.

Most low-power amplifier tubes are air cooled; most high-power tubes, such as klystrons, crossed field amplifiers, and magnetrons, are liquid cooled.

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The main source of power and heat in a power amplifier package is the high-voltage power supply. Part of the power produced by the power amplifier is transmitted in the form of rf energy; the remainder of the power eventually converts to heat, and cooling is required to dissipate the heat.

Radars that use blowers for cooling will usually have an airflow sensing switch. If the blower fails, the switch will open and remove power from appropriate power supplies. Radars employing liquid cooling normally distribute the liquid into a large number of separate paths, because the flow requirements are quite dissimilar. Each of the various paths will have a low flow interlock. If one of the liquid cooling paths becomes restricted, the low flow interlock switch will open and remove power from the radar.

Liquid cooling systems also include pressure gauges and switches, temperature gauges, and over temperature switches. Many systems have pressure or flow regulators. Some systems include audio and/or visual alarms that energize before damage actually occurs. In some cases this allows the problem to be cooled without turning off the equipment.

Figure 4-15 illustrates a typical transmitter cooling system showing the many protective devices.

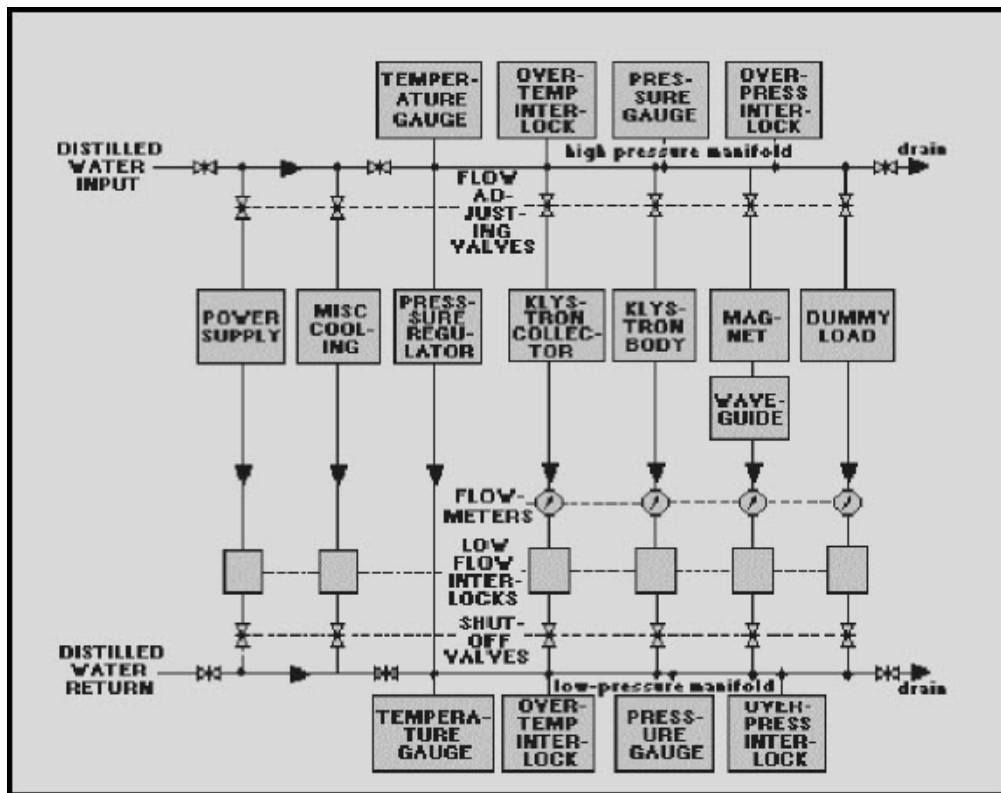


Figure 4-15 Typical transmitter cooling system

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Distilled water is one of the best mediums for cooling high-power components, and, in many cases, the only medium that may be used.

For a distilled-water-cooling system to operate satisfactorily, the temperature, quantity, purity, flow, and pressure of the water must be controlled. This control is provided by various valves, regulators, sensors, meters, and instruments that measure the necessary characteristics and provide the required regulation.

Liquid-cooling systems consist of a sea water or a chilled (fresh) water section that cools the distilled water circulating through the electronic equipment. The main components of cooling systems are piping, valves, regulators, heat exchangers, strainers, circulating pumps, expansion tanks, gages, and demineralizers. Other specialized components are sometimes necessary to monitor cooling water to the electronic equipment.

A typical liquid-cooling system is composed of a PRIMARY LOOP and a SECONDARY LOOP (figure 4-16). The primary loop provides the initial source of cooling water and the secondary loop transfers the heat load from the electronic equipment to the primary loop. The source of cooling water for the primary loop is either sea water from a sea water supply or chilled water from the ship's air conditioning plant. The cooling water used in the secondary loop is distilled water. Ultrapure systems are maintained by a demineralizer and use double-distilled water obtained through the Navy Supply System.

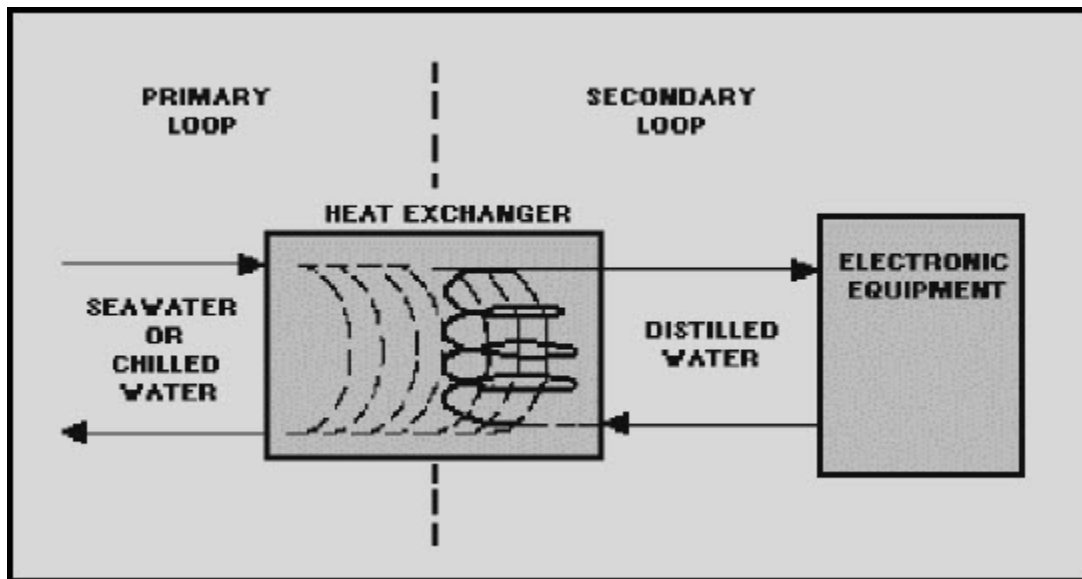


Figure 4-16 Liquid cooling system block diagram

Additional information about liquid cooling systems can be found in *Basic Liquid Cooling Systems for Shipboard Electronic Equipment Technician's Handbook*, NAVSEA 0948-LP-122-8010.

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Q19. What type of cooling is used to control ambient room temperature?

Q20. A typical liquid-cooling system is composed of what loops?

Q21. What loop of a cooling system is often supplied by sea water?

4.5 SAFETY

Many safety and health hazards are involved with operating and maintaining high-power radars. These hazards result from high levels of rf radiation, X-ray emissions, the necessity of working aloft, and the generation of extremely high voltages.

Navy professionals are very safety conscious and, as a result, the number of accidents that occur on the job is small. Most of the safety precautions applicable to radar are published in radar technical manuals. Many of the safety regulations included in technical manuals are the result of actual experiences. Therefore, you should give them careful thought and strict observance.

4.5.1 RF Radiation Hazards

Radar peak power may reach a million watts or more. Rf radiation hazards exist in the vicinity of radar transmitting antennas. These hazards are present not only in front of an antenna but also to the sides and sometimes even behind it because of spillover and reflection. At some frequencies, exposure to excessive levels of radiation will not produce a sufficient sensation of pain or discomfort to warn you of injury. If you suspect any injury, see your ship's doctor or corpsman. Be sure to acquaint yourself with the actual radiation hazard zones of the radars on your ship.

Personnel should observe the following precautions to ensure that persons are not exposed to harmful rf radiation:

- Visual inspection of feedhorns, open ends of waveguides, and any other opening that emits rf energy should not be made unless the equipment is properly secured and tagged for that purpose.
- Operating and maintenance personnel should observe all rf radiation hazard signs posted in the operating area.

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- All personnel should observe rf radiation hazard (radhaz) warning signs (figure 4-17) that point out the existence of rf radiation hazards in a specific location or area. (You may encounter other types of rf radiation hazard signs, depending on the situation.)
- Ensure that radiation hazard warning signs are available and posted.
- Ensure that those radar antennas that normally rotate are rotated continuously while radiating or are trained to a known safe bearing.
- Ensure that those antennas that do not normally rotate are pointed away from inhabited areas (ships, piers, and the like) while radiating.
- Dummy loads should be employed where applicable in transmitting equipment during testing or checkout.

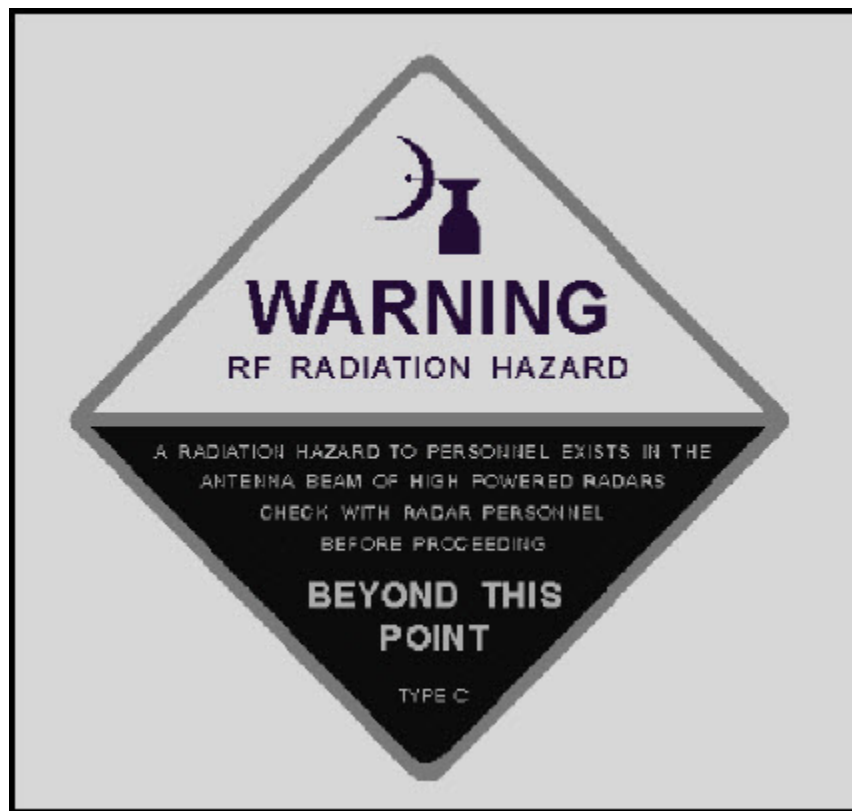


Figure 4-17 Sample of one type of radhaz sign

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4.5.2 X-Ray Emissions

X rays may be produced by the high-voltage electronic equipment in radars. X rays can penetrate human tissue and cause damage of a temporary or permanent nature. Unless the dosage is extremely high, no ill effects will be noticeable for days, weeks, or even years after the exposure.

The sources of these X rays are usually confined to magnetrons, klystrons, and cathode-ray tubes. Personnel should not linger near any of these types of equipments when the equipment covers have been removed. Klystrons, magnetrons, rectifiers, or other tubes that employ an excitation of 15,000 volts or more may emit X rays out to a few feet; thus, unshielded personnel standing or working close to the tubes will be endangered.

When performing maintenance on X-ray emitting devices, you should take the following precautions:

- Observe all warning signs (figure 4-18) on the equipment and all written precautions in the equipment technical manuals.

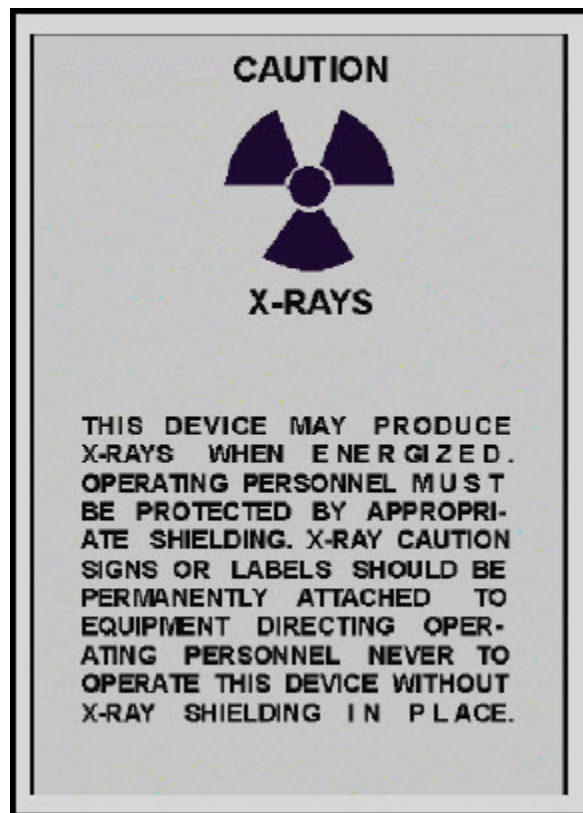


Figure 4-18 X-ray caution label

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- Unless called for in the technical manual, do not bypass interlocks to permit the servicing of operating equipment with the X-ray shield removed.
- Be sure to replace all protective X-ray shielding when servicing is complete.

4.6 SUMMARY

This chapter has presented information on radar maintenance procedures. The information that follows summarizes the important points of this chapter.

Transmitter **PERFORMANCE CHECKS** are essential for you to maintain an efficient radar system. The transmitter output must be monitored closely for both frequency and power.

Transmitter energy is distributed symmetrically over a band of frequencies known as the **SPECTRUM**.

The **SPECTRUM ANALYZER** and the ECHO BOX are two instruments used to check transmitter performance.

One of the more important measurements that can be performed with the echo box is RING TIME. Ring time gives a relative indication of both transmitter output power and receiver sensitivity.

Transmitter **OUTPUT POWER MEASUREMENTS** are a good indication of overall transmitter operation. POWER MEASUREMENTS are usually of average power read in dBm. The average power dBm reading must be converted to watts and the peak power calculated.

RECEIVER PERFORMANCE CHECKS determine receiver sensitivity, tr recovery time, and receiver bandwidth. You usually measure receiver sensitivity by measuring the MINIMUM DISCERNIBLE SIGNAL (mds) using the pulse method.

TR RECOVERY time is the time required for the tr tube to DEIONIZE after each transmitted pulse. You should keep a graph of tr recovery time to determine when the tr tube should be replaced. If not replaced in a timely manner, a weak tr tube will allow damage to the radar receiver. Few radars can function without SUPPORT SYSTEMS. These support systems include ELECTRICAL POWER, DRY-AIR, and LIQUID-COOLING SYSTEMS.

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The radar technician should learn the source and distribution routes for **NORMAL** and **EMERGENCY POWER** for the radar.

The **DRY AIR** needed for electronic equipment can be supplied by the ship's electronics dry-air system through an air control panel or from local dehydrators.

Radar transmitters generate large amounts of heat. Most of this heat is dissipated by a combination of **AIR CONDITIONING**, **CABINET AIR BLOWERS**, and a **DISTILLED-WATER COOLING** system.

Personnel working on radars should always be aware of the hazards of **RF RADIATION** and **X-RAY EMISSION**.

All posted **SAFETY PRECAUTIONS** should be strictly observed.

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ANSWERS TO QUESTIONS Q1. THROUGH Q21.

- A1. *Frequency distribution.*
- A2. *In the center.*
- A3. *Symmetrical above and below the carrier frequency.*
- A4. *Power and frequency.*
- A5. *Average power, pulse width, and prt.*
- A6. *1 milliwatt.*
- A7. *Transmitter power loss.*
- A8. *Minimum discernible signal (mds).*
- A9. *Attenuations of the directional coupler and the connecting cable.*
- A10. *Half-power points.*
- A11. *Recovery time.*
- A12. *Three.*
- A13. *Automatically.*
- A14. *Manual bus transfer (MBT) unit.*
- A15. *Work backwards from the load to the source.*
- A16. *Ship's central dry-air system.*
- A17. *Degree of dehydration.*
- A18. *Pressure.*
- A19. *Air conditioning.*
- A20. *Primary and secondary.*
- A21. *The primary loop.*

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APPENDIX A

GLOSSARY

A-SCOPE—A radar display on which slant range is shown as the distance along a horizontal trace.

ACQUISITION—Operational phase of a fire-control or track radar during which the radar system searches a small volume of space in a prearranged pattern.

AIR-CONTROL PANEL—Panel that monitors the dry-air input at each user equipment.

ALTITUDE—Vertical distance of an aircraft or object above a given reference, such as ground or sea level.

AMBIGUOUS RETURNS—Echoes that exceed the prt of a radar and appear at incorrect ranges.

AMPLITRON—See Crossed-Field Amplifier.

ANTENNA BEAM WIDTH—Width of a radar beam measured between half-power points

ANTENNA SYSTEM—Routes rf energy from the transmitter, radiates the energy into space, receives echoes, and routes the echoes to the receiver.

ANTIJAMMING CIRCUIT—Electronic circuit used to minimize the effects of enemy countermeasures, thereby permitting radar echoes to be visible on the indicator.

ANTITRANSMIT-RECEIVE TUBE (atr)—Tube that isolates the transmitter from the antenna and receiver. Used in conjunction with tr tube.

ARTIFICIAL TRANSMISSION LINE—An LC network that is designed to simulate characteristics of a transmission line.

ASYMMETRICAL MULTIVIBRATOR—Multivibrator that generates rectangular waves.

AUTOMATIC GAIN CONTROL—Circuit used to vary radar receiver gain for best reception of signals that have widely varying amplitudes.

AVERAGE POWER—Output power of a transmitter as measured from the start of one pulse to the start of the next pulse.

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AZIMUTH—Angular measurement in the horizontal plane in a clockwise direction.

BALANCED MIXER—Waveguide arrangement that resembles a T and uses crystals for coupling the output to a balanced transformer.

BEAM—See Lobe.

BEARING RESOLUTION—Ability of a radar to distinguish between targets that are close together in bearing.

BEAT FREQUENCIES—Difference and sum frequencies which result from combining two different frequencies.

BLIP—See Pip.

BLOCKING—A condition in an amplifier, caused by overdriving one or more stages, in which the amplifier is insensitive to small signals immediately after reception of a large signal.

BROADSIDE ARRAY—An antenna array in which the direction of maximum radiation is perpendicular to the plane of the array.

BUFFER AMPLIFIER STAGE—Amplifier stage that isolates one circuit from another.

CARRIER FREQUENCY—The frequency of an unmodulated transmitter output.

CARRIER-CONTROLLED APPROACH—Shipboard radar system used to guide aircraft to safe landings in poor visibility conditions.

CLUTTER—Confusing, unwanted echoes that interfere with the observation of desired signals on a radar indicator.

COHERENCE—A definite phase relationship between two energy waves, such as transmitted frequency and reference frequency.

COHERENT OSCILLATOR—In cw radar this oscillator supplies phase references to provide coherent video from target returns.

CONICAL SCANNING—Scanning in which the movement of the beam describes a cone, the axis of which coincides with that of the reflector.

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CONTACT—In radar, an object that reflects rf energy; target.

CORNER REFLECTOR—Two flat reflectors that meet at an angle and are normally fed by a half-wave radiator.

CROSSED-FIELD AMPLIFIER—High-power electron tube that converts dc to microwave power by a combination of crossed electric and magnetic fields.

CYLINDRICAL PARABOLIC REFLECTOR—A parabolically shaped reflector that resembles part of a cylinder.

DEFLECTION COILS—In a cathode-ray tube, coils used to bend an electron beam a desired amount.

DEIONIZATION TIME—In a spark gap, the time required for ionized gas to return to its neutral state after the spark is removed.

DESIGNATION—Operational phase of a fire- control or track radar during which the radar is directed to the general direction of a desired target.

DIFFERENCE FREQUENCY—See Beat Frequency.

DIODE DETECTOR—A demodulator that uses one or more diodes to provide a rectified output with an average value that is proportional to the original modulation.

DIRECTIONAL ANTENNA—An antenna that radiates most effectively in only one direction.

DIRECTIVITY—Ability of an antenna to radiate or receive more energy in some directions than in others. The degree of sharpness of the antenna beam.

DISCRIMINATOR—A circuit in which amplitude variations are derived in response to phase or frequency variations.

DISTILLED WATER—Water that has been purified through a process of evaporation and condensation.

DOPPLER EFFECT—In radar, the change in frequency of a received signal caused by the relative motion between the radar and the target.

DOPPLER FREQUENCY—Difference between transmitted and reflected frequencies; caused by the Doppler effect.

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DOUBLE-MODING—In a transmitter output tube, the abrupt and random change from one frequency to another.

DRY-AIR SYSTEM—Provides dehumidified air for electronic equipment that is moisture critical.

DUCTING—Trapping of an rf wave between two layers of the earth's atmosphere or between an atmospheric layer and the earth.

DUPLEXER—A radar device that switches the antenna from the transmitter to the receiver and vice versa.

DUTY CYCLE—In a transmitter, ratio of time on to time off.

ECHO—The rf signal reflected back from a radar target.

ECHO BOX—A resonant cavity device that is used to check the overall performance of a radar system. It receives a portion of the transmitted pulse and retransmits it back to the receiver as a slowly decaying transient.

ELECTRICAL POWER SYSTEM—Provides the necessary input power.

ELECTRONIC COUNTER-COUNTERMEASURES (ECCM) CIRCUITS—See Antijamming Circuits.

ELECTRONIC EQUIPMENT DEHYDRATOR—Provides alternate dry-air input in the event of failure of the central dry-air system. May include a compressor.

ELECTRONIC FREQUENCY COUNTER—An instrument that counts the number of cycles (pulses) occurring during a precise time interval.

ELECTRONIC SCANNING—Scanning in which the axis of the beam is moved, relative to the antenna axis, in a desired pattern.

ELECTRONICS DRY-AIR BRANCH—A common line for providing dry air to various electronic equipment, such as search radar, fire-control radar, and repeaters.

ELEVATION ANGLE—The angle between the horizontal plane and the line of sight.

EMERGENCY POWER—Temporary source of limited electrical power used upon the loss of the normal power source.

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EXTERNALLY SYNCHRONIZED RADAR—Radar system in which timing pulses are generated by a master oscillator external to the transmitter.

FAST-TIME-CONSTANT CIRCUIT—Differentiator circuit in the first video amplifier that allows only the leading edges of target returns, no matter how small or large, to be used.

FEEDBACK—The return of a portion of the output of a circuit to its input.

FEEDHORN—A horn radiator used to feed a reflector.

FIRST DETECTOR—See Mixer.

FREQUENCY COMPENSATION NETWORK—Circuit modification used to improve or broaden the linearity of its frequency response.

FREQUENCY SCANNING—Varying the output frequency to achieve electronic scanning.

FREQUENCY SPECTRUM—In a radar, the entire range of frequencies contained in an rf pulse or signal.

FREQUENCY SYNTHESIZER—A bank of oscillators in which the outputs can be mixed in various combinations to produce a wide range of frequencies.

GAIN—Any increase in the strength of a signal.

GATED AGC—Circuit that permits automatic gain control to function only during short time intervals.

GLOW DISCHARGE—Discharge of electricity through a gas in an electron tube.

GROUND CLUTTER—Unwanted echoes from surrounding land masses that appear on a radar indicator.

GROUND RANGE—The distance on the surface of the earth between a radar and its target. Equal to slant range only if both radar and target are at the same altitude.

GROUND-CONTROLLED APPROACH—Radar system used to guide aircraft to safe landings in poor visibility conditions.

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GUIDANCE RADAR—System which provides information that is used to guide a missile to a target.

HALF-POWER POINT—A point on a waveform or radar beam that corresponds to half the power of the maximum power point.

HARD-TUBE MODULATOR—A high-vacuum electron tube modulator that uses a driver for pulse forming.

HEIGHT-FINDING RADAR—Radar that provides target altitude, range, and bearing data.

HITS PER SCAN—The number of times an rf beam strikes a target per antenna revolution.

HORIZONTAL PLANE—Imaginary plane that is tangent (or parallel) to the earth's surface at a given location.

HORN ANTENNA—See Horn Radiator.

HORN RADIATOR—A tubular or rectangular microwave antenna that is tapered and is widest at the open end.

HYBRID RING—A circular waveguide arrangement with four branches. When properly terminated, energy is transferred from any one branch into any two of the remaining three branches.

HYBRID MIXER—See Balanced Mixer.

IF AMPLIFIER—Usually a narrow-bandwidth IF amplifier that is tuned to one of the output frequencies produced by the mixer.

INDEX OF REFRACTION—The degree of bending of an rf wave when passing from one medium to another.

INDICATOR—Equipment that provides a visual presentation of target position information.

INSTANTANEOUS AUTOMATIC GAIN CONTROL (IAGC)—Circuit that can vary the gain of the radar receiver with each input pulse to maintain the output peak amplitude nearly constant.

INTERMEDIATE FREQUENCY (IF)—A lower frequency to which an rf echo is converted for ease of amplification.

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KEEP-ALIVE CURRENT—See Keep-Alive Voltage.

KEEP-ALIVE VOLTAGE—Dc voltage applied to a triode gap electrode to produce a glow discharge that allows the tube to ionize faster when the transmitter fires.

KEYED-OSCILLATOR TRANSMITTER—A transmitter in which one stage is used to produce the rf pulse.

KEYER—See Synchronizer.

KLYSTRON POWER AMPLIFIER—Multicavity microwave electron tube that uses velocity modulation.

LIN-LOG AMPLIFIER—Amplifier in which the response is linear for weak signals and logarithmic for large signals.

LINE OF SIGHT—Straight line from a radar antenna to a target.

LINE-PULSING MODULATOR—Circuit that stores energy and forms pulses in the same circuit element, usually the pulse-forming network (PFN).

LIQUID-COOLING SYSTEM—Source of cooling for high-heat producing equipments, such as microwave components, radar repeaters, and transmitters.

LOBE—An area of greater signal strength in the transmission pattern of an antenna.

LOGARITHMIC RECEIVER—Receiver that uses a linear logarithmic amplifier (lin-log) instead of a normal linear amplifier.

LOW-NOISE AMPLIFIER—See Preamplifier.

MAGIC T—See Balanced Mixer.

MAGNETRON OSCILLATOR—Electron tube that provides a high power output. Theory of operation is based on interaction of electrons with the crossed electric and magnetic fields in a resonant cavity.

MASTER OSCILLATOR—In a transmitter, the oscillator that establishes the carrier frequency of the output.

MECHANICAL SCANNING—The reflector, its feed source, or the entire antenna is moved in a desired pattern.

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MINIMUM DISCERNIBLE SIGNAL (MDS)—The weakest signal that produces a usable signal at the output of a receiver. The weaker the signal, the more sensitive the receiver.

MIXER—In radar, a circuit that combines the received rf signal with a local-oscillator signal to effectively convert the received signal to a lower IF frequency signal.

MODE SHIFTING—In a magnetron, shifting from one mode to another during a pulse.

MODE SKIPPING—Rather than firing on each successive pulse as desired, the magnetron fires randomly.

MODES—Operational phases (of a radar).

MODULATOR SWITCHING DEVICE—Controls the on (discharge) and off (charge) time of the modulator.

MODULATOR—Produces a high-voltage pulse that turns the transmitter on and off.

MONOPULSE (SIMULTANEOUS) LOBING—Radar receiving method using two or more (usually four) partially overlapping lobes. Sum and difference channels locate the target with respect to the axis of the antenna.

MONOPULSE RADAR—A radar that gets the range, bearing, and elevation position data of a target from a single pulse.

MONOPULSE RECEIVER—See Monopulse Lobing.

MOISTURE LAPSE—Abnormal variation of moisture content at different altitudes because of high moisture located just above large bodies of water.

MOVING TARGET INDICATOR—A device that limits the display of radar information to moving targets.

NAUTICAL MILE—The length of a minute of arc of a great circle of the earth (6,076 ft.)

NAUTICAL RADAR MILE—See Radar Mile.

NOISE—In radar, erratic or random deflection or intensity of the indicator sweep that tends to mask small echo signals.

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NOISE FIGURE—The ratio of output noise to input noise in a receiver.

NUTATING—Moving an antenna feed point in a conical pattern so that the polarization of the beam does not change.

OMNIDIRECTIONAL ANTENNA—An antenna that radiates equally in all directions (nondirectional).

ORANGE-PEEL PARABOLOID—A section of a complete circular paraboloid that is narrow in the horizontal plane and wide in the vertical plane.

PARABOLIC REFLECTOR—An antenna reflector in the shape of a parabola. It converts spherical wavefronts from the radiating element into plane wavefronts.

PARALLEL-CONNECTED DUPLEXER—Configuration in which the tr spark gap is connected across the two legs of the transmission line one-quarter wavelength from the T junction.

PARASITIC ARRAY—An antenna array containing one or more elements not connected to the transmission line.

PEAK POWER—Maximum power of the rf pulse from a radar transmitter.

PERSISTANCE—The length of time a phosphor dot glows on a crt before disappearing.

PHANASTRON—A variable-length sawtooth generator used to produce a sweep on an A-scope.

PIP (BLIP)—On a crt display, a spot of light or a base-line irregularity representing the radar echo.

PLANE WAVEFRONTS—Waves of energy that are flat, parallel planes and perpendicular to the direction of propagation.

PLANNED-POSITION INDICATOR—A radar display in which range is indicated by the distance of a bright spot or pip from the center of the screen and the bearing is indicated by the radial angle of the spot.

POWER GAIN—In an antenna, the ratio of its radiated power to that of a reference.

POWER-AMPLIFIER (CHAIN) TRANSMITTER—Transmitter that uses a series of power amplifiers to create a high level of power.

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PREAMPLIFIER (PREAMP)—An amplifier that raises the output of a low-level source for further processing without appreciable degradation of the signal-to-noise ratio.

PRIMARY LOOP—In a cooling system, the primary source of cooling for the distilled water.

PROBE COUPLER—A resonant conductor placed in a waveguide or cavity to insert or extract energy.

PULSE WIDTH—Duration of time between the leading and trailing edges of a pulse.

PULSE-FORMING NETWORK (PFN)—An LC network that alternately stores and releases energy in an approximately rectangular wave.

PULSE-REPETITION RATE (PRR)—Average number of pulses per unit of time; pulse rate.

PULSE-REPETITION FREQUENCY (PRF)—The rate at which pulses are transmitted, given in hertz or pulses per second; reciprocal of pulse-repetition time.

PULSE-REPETITION TIME (PRT)—Interval between the start of one pulse and the start of the next pulse; reciprocal of pulse-repetition frequency.

RADAR—An acronym for RAdio Detecting And Ranging.

RADAR ALTIMETER—Airborne radar that measures the distance of the aircraft above the ground.

RADAR BEAM—The space in front of a radar antenna where a target can be effectively detected or tracked.

RADAR DISTRIBUTION SWITCHBOARD—An electrical switching panel used to connect inputs from any of several radars to repeaters.

RADAR MILE—Time interval (12.36 microseconds) for rf energy to travel out from a radar to a target and back to the radar; radar nautical mile.

RADAR TEST SET—Combination of several test circuits and equipment used to test various characteristics of a radar.

RANGE—The length of a straight line between a radar set and a target.

RANGE-HEIGHT INDICATOR—A radar display on which slant range is shown along the X axis and height along the Y axis.

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RANGE-GATE—A movable gate used to select radar echoes from a very short-range interval.

RANGE MARKER—A movable vertical pulse on an A-scope or ring on a ppi scope used to measure the range of an echo or to calibrate the range scale.

RANGE RESOLUTION—Ability of a radar to distinguish between targets that are close together.

RANGE STEP—On an A-scope sweep, vertical displacement used to measure the range of an echo.

RECEIVER—In radar, a unit that converts rf echoes to video and/or audio signals.

RECEIVER SENSITIVITY—The degree to which a receiver can usefully detect a weak signal; the lower limit of useful signal input to the receiver.

RECOVERY TIME—In a radar, the time interval between the end of the transmitted pulse and the time when echo signals are no longer attenuated by the tr gap.

REFLECTING OBJECT—In radar, an air or surface contact that provides an echo.

REFLEX KLYSTRON—A microwave oscillator that is tuned by changing the repeller voltage.

REFRACTION—The bending of rf waves as the waves pass through mediums of different density.

REFRACTIVE INDEX—In a wave-transmission medium, the ratio between the phase velocity in free space and in the medium.

REGENERATION—See Feedback.

RELATIVE BEARING—Bearing of target measured in a clockwise direction from "dead ahead" of a ship or plane.

RESONANCE CHAMBER—See Echo Box.

RETURN—The rf signal reflected back from a radar target; echo.

RF RADIATION HAZARD—Health hazard caused by exposure to electromagnetic radiation or high energy particles (ions). Abbreviated RADHAZ.

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RING TIME—In radar, the time during which the output of an echo box remains above a specified level.

RINGING—Rf oscillations caused by shock excitation of a resonant circuit (cavity).

SEA CLUTTER—Unwanted echoes from the irregular surface of the sea that appear on a radar indicator.

SEARCH RADAR SYSTEM—Early-warning device that searches a fixed volume of space.

SECOND DETECTOR DEMODULATOR—The part of the receiver that separates the audio or video component from the modulated intermediate frequency.

SECOND-SWEEP ECHOES—See Ambiguous Returns.

SECONDARY LOOP—In a cooling system, the loop that transfers the heat from the heat source (electronic equipment) to the primary loop; usually distilled water.

SELF-SYNCHRONIZED RADAR—A type of radar in which the timing pulses are generated within the transmitter.

SENSITIVITY TIME CONTROL (STC)—A circuit that varies the gain of a receiver as a function of time.

SERIES-CONNECTED DUPLEXER—Configuration in which the tr spark gap is connected in series in one leg of the transmission line one-half wavelength away from the T-junction.

SHADOW—A dead spot (minimum radiation) caused by the physical obstruction of transmitted waves by a feed horn.

SINGLE-ENDED MIXER—See Unbalanced Crystal Mixer.

SINGLE, STATIONARY-LOBE SCANNING SYSTEM—Antenna (with a single, stationary beam) that is rotated to obtain 360-degree coverage.

SLANT RANGE—See Range.

SPECTRUM ANALYZER—A test instrument that provides a visual display of the frequency distribution of a transmitter output.

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SPHERICAL WAVEFRONTS—Waves of energy that spread out in concentric circles.

STABILITY—In a magnetron, the ability to maintain normal operating characteristics.

STATUTE MILE—15,280 ft.

STUB—A short section of transmission line connected in parallel with the main transmission line.

SCINTILLATION—Apparent change in target reflectivity. Motion of the target causes radar pulses to bounce off different parts of the target, such as fuselage and wingtip.

SUPERHETERODYNE RECEIVER—A type of receiver that uses a mixer to convert the rf echo to an IF signal for amplification.

SUPPORT SYSTEM—For a radar, a system that provides an auxiliary input, such as dry air, electrical power, or liquid cooling.

SYMMETRICAL MULTIVIBRATOR—Circuit that generates square waves.

SYNCHRONIZER—Circuit that supplies timing signals to other radar components.

TARGET—In radar, a specific object of radar search or detection.

TARGET RESOLUTION—The ability of a radar to distinguish between two or more targets that are close to each other.

THREE-DIMENSIONAL RADAR (3D)—Measures the range, bearing, and altitude of a target.

THYRATRON—Gas tube used as a modulator switching device.

TIMER—See Synchronizer.

TR RECOVERY TIME—Time required for a fired tr or atr tube to deionize to a normal level of conductance.

TRACK—Operational phase of a fire-control or track radar during which the radar beam is kept on the target.

TRACK RADAR—Radar that provides continuous range, bearing, and elevation data by keeping the rf beam on the target.

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TRANSMIT-RECEIVE TUBE (TR)—Gas-filled rf switch that is used as a duplexer.

TRANSMITTER—Equipment that generates, amplifies, and modulates electromagnetic energy.

TRANSMITTER FREQUENCY (CARRIER FREQUENCY)—The frequency of the unmodulated output of a transmitter.

TRAVERSE (BEARING) SIGNAL—In a monopulse radar system, the combination of individual lobe signals that represents target offset direction and amplitude from the antenna axis.

TRIGGER GENERATOR—See Synchronizer.

TRIGGER PULSES—In radar, pulses that are used to initiate specific events.

TRUE BEARING—Angle between a target and true north measured clockwise in the horizontal plane.

TRUE NORTH—Geographic north.

TRUNCATED PARABOLOID—A paraboloid reflector that has been cut away at the top and bottom to increase beam width in the vertical plane.

TWO-DIMENSIONAL RADAR (2D)—Measures the range and bearing to a target.

UNBALANCED CRYSTAL MIXER—Circuit consisting of a section of coaxial transmission line one half wavelength long that is tuned to the difference (intermediate) frequency between the local oscillator and rf echo signals.

VERTICAL PLANE—Imaginary plane that is perpendicular to the horizontal plane.

VIDEO ENHANCEMENT FEATURES—See Antijamming Circuits.

VOLTAGE STANDING WAVE RATIO (VSWR)—In a waveguide, the ratio of the electric field at a maximum point to that of an adjacent minimum point.

WAVEGUIDE DUPLEXER—Consists of tr and atr tubes housed in a resonant cavity attached to a waveguide system.

WAVEMETER—An instrument for measuring the wavelength of an rf wave.

X-RAY EMISSION—Penetrating radiation similar to light, but with shorter wavelength, that can penetrate human tissue.

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ASSIGNMENT 1

Textbook assignment: Chapter 1, "Radar Fundamentals".

- 1-1. Radar uses what form of energy to detect ships, planes, and land masses?
1. Sound waves
 2. Visible light
 3. Infrared radiation
 4. Electromagnetic energy
- 1-2. What radar measurement of an object is referenced to true north?
1. Height
 2. Surface angle
 3. Vertical angle
 4. One-way distance
- 1-3. The elevation angle to the target is the angle between which of the following references?
1. Ship's heading and line of sight
 2. Vertical plane and line of sight
 3. Horizontal plane and line of sight
 4. Vertical plane and horizontal plane
- 1-4. Electromagnetic energy travels through air at approximately what speed?
1. 984 feet per microsecond
 2. 186,000 statute miles per second
 3. 162,000 nautical miles per second
 4. Each of the above is correct
- 1-5. For an object that is detected 15 miles from a radar set, what is the approximate time required for the rf energy to travel to and return from the object?
1. 7 microseconds
 2. 185 microseconds
 3. 271 microseconds
 4. 927 microseconds

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- 1-6. The minimum range of a radar depends on the length of time of the transmitter pulse (pulse width) and recovery time. During this period, the radar can NOT receive energy. A radar set with a pulse width of 5 microseconds and a recovery time of 0.2 microseconds has a minimum range of approximately
1. 614 yards
 2. 787 yards
 3. 852 yards
 4. 4,100 yards
- 1-7. Of the following radar characteristics, which has NO effect on maximum range capability?
1. Recovery time
 2. Carrier frequency
 3. Receiver sensitivity
 4. Pulse-repetition frequency
- 1-8. Which of the following characteristics of a radar system determines the degree to which the radiated energy is affected by atmospheric conditions?
1. Pulse peak power
 2. Carrier frequency
 3. Receiver sensitivity
 4. Pulse-repetition frequency
- 1-9. Pulse-repetition time is described as the
1. reciprocal of pulse width
 2. period of time from the beginning to the end of a transmitter pulse
 3. period of time required for the pulse to travel to the target and return
 4. period of time from the beginning of one transmitter pulse to the beginning of the next
- 1-10. Which of the following terms describes radar returns that exceed the prt of the radar?
1. Clutter
 2. Ambiguous
 3. Reciprocal
 4. Acquisition

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1-11. What type of transmitter power is measured over a period of time?

1. Peak
2. Return
3. Average
4. Reciprocal

1-12. Which of the following formulas can be used to compute the duty cycle of a radar set?

1. $\frac{\text{prt}}{\text{pw}}$
2. $\frac{\text{pw}}{\text{prt}}$
3. $\frac{\text{peak power}}{\text{average power}}$
4. $\text{average power} \times \text{peak power}$

IN ANSWERING QUESTIONS 1-13 AND 1-14, ASSUME THAT A RADAR SET HAS THE FOLLOWING CHARACTERISTICS: AVERAGE POWER = 700 WATTS
PULSE WIDTH = 3.5 MICROSECONDS PRF = 400 HERTZ

1-13. What is the peak power (in kilowatts) for this radar set?

1. 500
2. 1,500
3. 2,000
4. 2,500

1-14. What is the pulse-repetition time (in microseconds) for this radar set?

1. 1,500
2. 2,000
3. 2,500
4. 4,000

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- 1-15. For a radar set with a pulse width of 25 microseconds and a prf of 600 pulses per second, what is the duty cycle?
1. 0.015
 2. 0.024
 3. 0.15
 4. 0.24
- 1-16. What is the maximum radar horizon distance for a radar set with an antenna 100 feet above the surface of the earth?
1. 8 miles
 2. 12.5 miles
 3. 80 miles
 4. 125 miles
- 1-17. A radar set with a prf of 1,000 pps and an antenna rotation rate of 15 rpm produces what maximum number of pulses per degree?
1. 2.7
 2. 11.1
 3. 14.4
 4. 36
- 1-18. The relative bearing of a radar echo is measured with respect to which of the following reference points?
1. True north
 2. Magnetic north
 3. Centerline of your own ship
 4. The position of the antenna
- 1-19. Altitude- or height-finding radar systems require a beam with which of the following characteristics?
1. Narrow in the vertical plane
 2. Narrow in the horizontal plane
 3. Broad in the horizontal plane
 4. Broad in the vertical plane

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- 1-20. Target resolution is the ability of a radar to distinguish between targets that are at nearly the same range and/or bearing. Range resolution is dependent on which of the following factors?
1. Peak power and beam width
 2. Pulse width and beam width
 3. Pulse width and target size
 4. Peak power and target size
- 1-21. What is the approximate range resolution (in yards) of a radar set with a pulse width of 15 microseconds and a peak power of 2 kilowatts?
1. 10
 2. 24
 3. 1,093
 4. 2,460
- 1-22. The width of a radar beam and range to a detected object are the determining factors in which of the following radar system characteristics?
1. Range resolution
 2. Bearing resolution
 3. Beam half-power points
 4. Altitude detection accuracy
- 1-23. Which of the following factors has/have the greatest effect on the accuracy of a pulse radar?
1. Resolution
 2. Average power
 3. Atmospheric conditions
 4. Each of the above
- 1-24. To detect nearby objects, the output pulse of a radar transmitter should possess which of the following characteristic shapes?
1. Narrow and square
 2. Narrow with a sloping trailing edge
 3. Wide and trapezoidal
 4. Wide and square

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- 1-25. Refractions and speed changes are known to occur in electromagnetic wavefronts. These phenomena are caused by which of the following conditions?
1. Temperature
 2. Vapor content
 3. Atmospheric pressure
 4. All of the above
- 1-26. Temperature inversions and/or moisture lapses in the atmosphere may extend or reduce the range of a radar by creating
1. ducts
 2. ionic layers
 3. surface waves
 4. reflective layers
- 1-27. In a pulse radar system, which of the following components should you expect to find?
1. Synchronizer and transmitter
 2. Duplexer and antenna system
 3. Receiver and indicator
 4. All of the above
- 1-28. In a pulse radar system, what component controls timing throughout the system?
1. Power supply
 2. Synchronizer
 3. Indicator
 4. Receiver
- 1-29. What component of the transmitter supplies the trigger pulse, which acts as a switch to turn the klystron on and off?
1. Magnetron
 2. Modulator
 3. Indicator
 4. Power supply

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- 1-30. Which of the following radar components allows the use of one antenna for both transmitting and receiving radar energy?
1. Synchronizer
 2. Modulator
 3. Duplexer
 4. Mixer
- 1-31. To make amplification of received rf energy easier, the returning rf signal is converted to a lower, intermediate frequency. What component of the radar system performs this function?
1. A duo-diode duplexer
 2. A three-stage synchronizer
 3. A cross-field amplifier
 4. A superheterodyne receiver
- 1-32. The sweep frequency of a radar indicator is determined by what parameter of the radar system?
1. Duty cycle
 2. Pulse width
 3. Carrier frequency
 4. Pulse-repetition frequency
- 1-33. The type and method of scanning used by a radar system depend upon which of the following radar system design considerations?
1. Antenna size
 2. Type of radar
 3. Purpose of the radar
 4. All of the above
- 1-34. In a single stationary-lobe scanning system, complete azimuth coverage is achieved by which of the following methods?
1. Multiple overlapping beams
 2. An omnidirectional antenna
 3. A continuously rotating antenna
 4. Very wide, flat beams

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- 1-35. Which of the following methods can be used to achieve radar-beam scanning?
1. Mechanical
 2. Electronic
 3. Combined mechanical and electronic
 4. Each of the above
- 1-36. In a conical-scan antenna, nutation of the radar beam is usually accomplished by which of the following methods?
1. By moving the reflector
 2. By moving the feed point
 3. By varying the signal phase at the feed point
 4. By moving both the feed point and the reflector
- 1-37. At any given distance from the antenna, the radar beam axis of a conical-scan antenna follows what pattern?
1. A circle around the scan axis
 2. An ellipse in the vertical plane
 3. An ellipse in the horizontal plane
 4. Two circles covering the scan axis in figure eights
- 1-38. In a monopulse scanning radar, the relative position of a target with respect to the radar-beam axis is determined by comparing which of the following signal components?
1. The phases of the radiated rf energy
 2. The phases of the returning rf energy
 3. The amplitudes of the returning rf energy in each horn
 4. The amplitudes of the returning rf energy in each successive pulse
- 1-39. In a monopulse scanning system, which of the following feedhorn signal combinations makes up the bearing signal?
1. $(A + D) - (A + C)$
 2. $(A + B) - (C + D)$
 3. $(A + C) - (B + D)$
 4. $A + B + C + D$

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1-40. In a monopulse scanning system, which of the following combinations make up the range signal?

1. $(A + D) - (A + C)$
2. $(A + B) - (C + D)$
3. $(A + C) - (B + D)$
4. $A + B + C + D$

1-41. Monopulse receivers use what signal as a phase reference?

1. Range
2. Traverse
3. Elevation
4. Angle-tracking

1-42. In the cw radar transmission method, the Doppler effect provides which of the following target information?

1. Speed of the target
2. Presence of the target
3. Both 1 and 2 above
4. Relative bearing of the target

1-43. The frequency of the returned signal increases when a target is approaching and decreases when a target is moving away in which of the following types of radar systems?

1. Search
2. Doppler
3. Pulse-modulation
4. Frequency-modulation

1-44. Continuous-wave radar that uses the Doppler effect is best used in detecting which of the following types of targets?

1. Stationary
2. Past-moving
3. Targets with a high degree of range resolution
4. Targets with a high degree of bearing resolution

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- 1-45. Range information can be obtained in a Doppler radar by which of the following methods?
1. Sweeping the transmitter frequency
 2. Using two separate transmitters
 3. Both 1 and 2 above
 4. Using two separate antennas
- 1-46. Frequency-modulated radars transmit a wave that continuously changes in frequency about a center frequency. Using frequency modulation, the range to a target is determined by using which of the following methods?
1. By comparing the frequency of the transmitted signal with the returned frequency from the target
 2. By comparing the magnitude of transmitted pulses with the magnitude of returned pulses
 3. By comparing the velocity of the received energy with the velocity of the transmitted energy
 4. By measuring the Doppler shift that occurs in the returning signal
- 1-47. Which of the following statements describes the advantage of using pulse modulation (pm) rather than continuous wave (cw) in a radar system?
1. Pm may be used to detect moving targets; cw is effective only against stationary targets
 2. Pm may be used to determine relative velocity much more accurately than cw
 3. Pm does not require frequency stabilization of the carrier wave; cw does
 4. Pm does not depend on target motion; cw does
- 1-48. In Doppler radar, some definite relationship must exist between the transmitted frequency and the reference frequency. For what purpose is this relationship used?
1. To detect the heterodyning signal
 2. To detect the continuous-wave signal
 3. To detect the Doppler shift of the received signal
 4. To detect the frequency shift of the transmitted frequency

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- 1-49. Which of the following JETDS classifications identifies a shipboard fire control radar set?
1. AN/SPS-39
 2. AN/SPG-55
 3. AN/APG-12
 4. AN/MRC-20
- 1-50. For most military applications, which of the following radar systems is/are used?
1. Track radar only
 2. Search radar only
 3. Both track and search radars are used
 4. Moving-target indicators
- 1-51. Detection of surface and low-altitude air targets is the primary purpose of which of the following types of radar?
1. Surface search
 2. Height finding
 3. Fire control
 4. Air search
- 1-52. Which of the following are typical characteristics of surface-search radars?
1. High pulse-repetition rates
 2. Narrow pulse widths
 3. High frequencies
 4. All of the above
- 1-53. Long-range aircraft detection is provided by which of the following types of radar?
1. Track
 2. Air search
 3. Fire control
 4. Surface search
- 1-54. Which of the following are characteristics of a typical air-search radar?
1. Low frequency
 2. Narrow pulse width
 3. High pulse-repetition rate
 4. All of the above

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- 1-55. Which of the following types of radar provides accurate range, bearing, and altitude of aircraft?
1. Air search
 2. Guidance
 3. Height-finding
 4. Surface search
- 1-56. Which of the following radars would most likely be used to direct CAP aircraft during an intercept?
1. Track radar
 2. Fire-control radar
 3. Surface-search radar
 4. Three-coordinate radar
- 1-57. The range capability of a 3D radar is limited by which of the following characteristics?
1. Low prf
 2. Long prt
 3. Low output power
 4. High operating frequency
- 1-58. Fire control radars must be directed to the general location of a desired target. This is because of which of the following characteristics?
1. Low output power level
 2. Low degree of accuracy
 3. Narrow beam pattern
 4. Poor resolution
- 1-59. When a fire-control radar antenna approaches the general direction of a target, the radar enters which of the following modes of operation?
1. Acquisition
 2. Designation
 3. Lock-on
 4. Track

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- 1-60. Which of the following characteristics is/are typical of a fire-control radar
1. Very high prf
 2. Very narrow pw
 3. Very narrow beam
 4. All of the above
- 1-61. Complete control of a beam-rider missile requires what minimum number of radar beams?
1. 1
 2. 2
 3. 3
 4. 4

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ASSIGNMENT 2

Textbook assignment: Chapter 2, "Radar Subsystems".

- 2-1. Which of the following units of a radar system determines timing for all units of the radar?
1. Automatic tracker
 2. Synchronizer
 3. Transmitter
 4. Receiver
- 2-2. Which of the following classifications describes a radar system that uses a master oscillator to produce timing pulses?
1. Externally synchronized
 2. Self-synchronized
 3. Unsynchronized
 4. Free-running
- 2-3. Which of the following oscillators may be used as the master oscillator in a radar system?
1. A stable multivibrator
 2. Sine-wave oscillator
 3. Blocking oscillator
 4. Each of the above
- 2-4. Which of the following oscillators, used in a synchronizer to provide timing trigger pulses, does NOT require a pulse shaping circuit in its output?
1. Phase-shift oscillator
 2. Square-wave oscillator
 3. Sine-wave oscillator
 4. Blocking oscillator
- 2-5. A radar system in which timing triggers are determined by the pulse-repetition rate of the modulator uses what type of synchronization?
1. Self
 2. External
 3. Free-running
 4. Stable blocked

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- 2-6. Which of the following radar indicator functions is/are controlled by gate pulses from the synchronizer?
1. Sweep duration
 2. Sweep initiation
 3. Range-mark generator gating
 4. All of the above
- 2-7. Indicator sweep voltage in a radar is normally initiated at which of the following times?
1. At the same time as the transmitter trigger
 2. Before the transmitter trigger
 3. After the transmitter trigger
 4. Each of the above
- 2-8. The flyback retrace of a radar system indicator is prevented from appearing on the cathode-ray tube by removing the
1. negative-intensity gate pulse applied to the control grid
 2. positive-intensity gate pulse applied to the control grid
 3. negative-intensity gate pulse applied to the cathode
 4. positive-intensity gate pulse applied to the cathode
- 2-9. Which of the following characteristics is NOT a requirement of a basic radar system timing circuit?
1. It must be free-running
 2. Frequency must be variable
 3. It must develop random frequencies
 4. It should provide a stable frequency
- 2-10. Which of the following circuits converts square waves to positive and negative triggers?
1. A negative limiter
 2. A positive limiter
 3. A long-time-constant RC differentiator
 4. A short-time-constant RC differentiator

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- 2-11. Which of the following circuits is used to remove either the negative or positive triggers from the output of a sine-wave oscillator?
1. A clipper
 2. A limiter
 3. An LC network
 4. A differentiator
- 2-12. When the master oscillator in a multivibrator timer is asymmetrical, the output of the master oscillator is in the form of
1. rectangular waves
 2. negative pulses
 3. square waves
 4. sine waves
- 2-13. The positive and negative output pulses of the astable multivibrator are sent to the indicator for which of the following purposes?
1. To intensify the crt beam
 2. To gate the range-marker generator
 3. Both 1 and 2 above
 4. To gate the transmitter output
- 2-14. Which of the following oscillators generates sharp trigger pulses without additional circuitry?
1. Sine-wave oscillator
 2. Wien-bridge oscillator
 3. One-shot multivibrator
 4. Single-swing blocking oscillator
- 2-15. A radar transmitter is triggered directly by high voltage pulses from what unit?
1. The timer
 2. The antenna
 3. The indicator
 4. The modulator

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- 2-16. The peak power of a transmitted rf pulse depends on which of the following factors?
1. Width of the modulator pulse
 2. Amplitude of the modulator pulse
 3. Prf of trigger pulses from the timer
 4. Delay time between trigger and modulator pulse outputs
- 2-17. The transmitter range timing circuit must be triggered at the instant the transmitted pulse leaves the transmitter. For which of the following reasons is this timing so important?
1. To ensure accurate range
 2. To ensure long range targets are detected
 3. To ensure that the target is "painted" on the crt by each transmitted pulse
 4. To keep the magnetron oscillating at a fixed frequency
- 2-18. For proper operation of the magnetron, the modulator pulse must have which of the following characteristics?
1. A flat top
 2. A steep leading edge
 3. A steep trailing edge
 4. All of the above
- 2-19. In order that nearby targets may be detected, which of the following characteristics must the transmitted pulse have?
1. A steep leading edge
 2. A steep trailing edge
 3. A sloping leading edge
 4. A sloping trailing edge
- 2-20. Compared to the hard-tube modulator, the line-pulsing modulator has which of the following advantages?
1. It is more complex
 2. It is more efficient
 3. It is more sensitive to voltage changes
 4. It requires a higher power-supply voltage

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- 2-21. The modulator of a radar basically consists of a power supply, a switch, a storage element, and a/an
1. IF strip
 2. oscillator
 3. transmitter
 4. charging impedance
- 2-22. Which of the following devices can be used as the storage element in a radar modulator?
1. A capacitor
 2. A pulse-forming network
 3. An artificial transmission line
 4. Each of the above
- 2-23. A signal introduced at the input end of an artificial transmission line moves through the circuit to the output end and is reflected back to the input. The output end of an artificial transmission line appears to the input signal as what type of circuit?
1. Open
 2. Short
 3. Inductive reactance
 4. Capacitive reactance
- 2-24. The discharge pulse from the artificial transmission line causes a voltage of what magnitude to appear across the primary of the pulse transformer?
1. Twice the original charge voltage
 2. One-half the original charge voltage
 3. The same as the original charge voltage
 4. One-fourth the original charge voltage
- 2-25. What parameter, if any, of the output pulse from an artificial transmission line is affected by the inductance and capacitance of each section of the line?
1. Width
 2. Amplitude
 3. Frequency
 4. None of the above

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- 2-26. A pulse-forming network exhibits electrical behavior similar to which of the following devices?
1. A resistance-capacitance network
 2. An artificial transmission line
 3. A capacitor
 4. An inductor
- 2-27. The requirements of a modulator switch are to (1) reach full conduction quickly, (2) consume low power, (3) start and stop conduction suddenly, and (4) conduct high currents and handle high voltages. Which of the following tubes meets these requirements?
1. A tetrode
 2. A thyatron
 3. A magnetron
 4. A beam-powered amplifier
- 2-28. What modulator circuit characteristic determines the charging rate of the storage element?
1. Resistance
 2. Capacitance
 3. Charging impedance
 4. Pulse-repetition frequency
- 2-29. Which of the following types of instability are common to magnetron oscillators?
1. Mode skipping
 2. Mode shifting
 3. Both 1 and 2 above
 4. Magnetic fluctuation
- 2-30. Which of the following magnetron characteristics can be caused by low magnetic field strength?
1. Low power output
 2. Excessive plate current
 3. Incorrect operating frequency
 4. All of the above

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- 2-31. Which of the following maximum tuning ranges is typical for a tunable magnetron?
1. ± 10 percent around the center frequency
 2. ± 5 percent around the center frequency
 3. 1 to 5 percent above the center frequency
 4. 1 to 10 percent below the center frequency
- 2-32. Compared to the keyed-oscillator transmitter, power-amplifier transmitters are used more often with mti radar systems because power-amplifier transmitters provide
1. better stability
 2. lower output power
 3. higher output power
 4. greater frequency range
- 2-33. Which of the following tubes should be used as the power amplifier in a radar transmitter?
1. The magnetron
 2. The thyratron
 3. The reflex klystron
 4. The multicavity klystron
- 2-34. Which of the following components determines the pulse width of a power amplifier transmitter?
1. The modulator
 2. The mixer-amplifier
 3. The local oscillator
 4. The power-amplifier tube
- 2-35. The intermediate stages of a power amplifier transmitter have operating power only during which of the following times?
1. When the coherent rf pulse is applied
 2. When the local oscillator signal is applied
 3. During the time the modulator pulse is applied
 4. Immediately after the coherent rf pulse is removed

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- 2-36. Using a frequency synthesizer instead of a heterodyning mixer as the frequency generating source for a power-amplifier transmitter is an advantage because the frequency synthesizer
1. is more stable
 2. is simpler to construct
 3. produces a single frequency
 4. produces discrete frequencies over a wide band
- 2-37. Unwanted oscillations in an rf amplifier transmitter are prevented because of which of the following pulse relationships?
1. The rf pulse is wider than the modulator pulse
 2. The rf pulse is narrower than the modulator pulse
 3. The rf pulse frequency is equal to the local oscillator frequency
 4. The rf pulse frequency is less than the local oscillator frequency
- 2-38. A power-amplifier transmitter that transmits a broad band of frequencies typically uses which of the following tubes as the final stage?
1. A crossed-field amplifier
 2. A multicavity klystron
 3. A magnetron
 4. A twt
- 2-39. What is the primary function of the radar duplexing system?
1. To prevent the formation of standing waves in the waveguide system
 2. To permit the use of one antenna for transmission and reception
 3. To increase the effective range of the radar
 4. To increase antenna directivity
- 2-40. A defective duplexer in a radar will most likely cause damage to which of the following components?
1. The receiver
 2. The waveguide
 3. The magnetron
 4. The local oscillator

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- 2-41. Why is it desirable that the duplexer quickly connect the receiver to the antenna after the transmitted pulse?
1. So that line-match will remain balanced
 2. So that the transmitter power dissipated will be minimum
 3. So that echoes from nearby targets will be received
 4. So that echoes from nearby targets will not prolong ionization
- 2-42. The action of tr-atr circuits depends upon the impedance characteristics of which of the following lengths of transmission line segments?
1. 1 wave length
 2. 1/2 wave length
 3. 1/4 wave length
 4. 1/8 wave length
- 2-43. Which of the following requirements is/are essential for proper tr spark gap operation?
1. High impedance during arc time
 2. Low impedance during arc time
 3. High impedance prior to arc time
 4. Both 2 and 3 above
- 2-44. What is the purpose of introducing water vapor into a tr tube?
1. It increases recovery time
 2. It prevents early ionization
 3. It decreases deionization time
 4. It increases the gap breakdown potential
- 2-45. Keep-alive voltage is applied to the tr tube for which of the following reasons?
1. To maintain ionization within the tube after the breakdown voltage is removed
 2. To ensure that the tube will rapidly return to the deionized state
 3. To maintain a glow discharge within tube so that firing will occur rapidly
 4. To prevent breakdown within the tube prior to pulse transmission so that firing will not be premature

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- 2-46. Atr tubes generally have a longer duty life than tr tubes because atr tubes do NOT use
1. radioactive materials and chemically active gas
 2. chemically active gas and keep-alive voltages
 3. keep-alive voltages and radioactive materials
 4. keep-alive voltages and pure inert gas
- 2-47. In a series-connected duplexer, what spark gap, if any, fires during reception?
1. The tr only
 2. The atr only
 3. Both the tr and atr
 4. None of the above
- 2-48. Indirectly coupled waveguide duplexers are normally connected to the main waveguide by which of the following devices?
1. A two-wire line
 2. A coaxial cable
 3. A short quarter-wave stub
 4. A short section of waveguide
- 2-49. The direct-coupled waveguide duplexer is connected to the waveguide at the location of
1. minimum current flow
 2. minimum magnetic field intensity
 3. maximum magnetic field intensity
 4. maximum electric field intensity
- 2-50. In a hybrid-ring duplexer, the fields at the entrance of an arm must have what phase relationship to propagate energy down the arm?
1. 0 degrees
 2. 90 degrees
 3. 180 degrees
 4. 270 degrees

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- 2-51. Which of the following are requirements of a microwave receiver?
1. Amplify extremely high-frequency pulses
 2. Detect and amplify pulses in the microvolt range
 3. Detect pulses with a duration of a few microseconds
 4. All of the above
- 2-52. The maximum range at which a radar receiver can detect an object is limited by which of the following factors?
1. Noise
 2. Signal distortion
 3. Receiver bandwidth
 4. Transmitter frequency
- 2-53. An effective radar receiver should have a gain factor that is in which of the following ranges?
1. 10^1 to 10^2
 2. 10^3 to 10^4
 3. 10^6 to 10^8
 4. 10^9 to 10^{10}
- 2-54. An overdriven amplifier stage in a receiver may cause which of the following conditions?
1. Blocking
 2. Inaccurate ranges
 3. Increased sensitivity
 4. Large signal distortion
- 2-55. The intermediate frequency is produced in what stage of a microwave receiver?
1. The mixer
 2. The IF amplifier
 3. The second detector
 4. The local oscillator
- 2-56. What section of a radar receiver usually determines the overall bandwidth?
1. The mixer
 2. The IF amplifier
 3. The video amplifier
 4. The local oscillator

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- 2-57. What component in a receiver afc circuit produces an output voltage proportional in amplitude and polarity to any change in the intermediate frequency?
1. The mixer
 2. The IF amplifier
 3. The discriminator
 4. The local oscillator
- 2-58. An efficient local oscillator must have which of the following characteristics?
1. Tunable frequency
 2. Stable output frequency
 3. Operation in the 4,000 megahertz range
 4. All of the above
- 2-59. Which of the following devices would be used as a local oscillator in a radar receiver?
1. A magnetron
 2. A crystal diode
 3. A reflex klystron
 4. A parametric amplifier
- 2-60. Which of the following advantages is gained by using a crystal mixer in a microwave receiver?
1. Less noise
 2. Reduced saturation
 3. Increased overall gain
 4. Improved oscillator stability
- 2-61. The resonant circuit at the output of an unbalanced crystal mixer serves which of the following purposes?
1. It amplifies the IF signal
 2. It produces the IF signal
 3. It eliminates unwanted signals
 4. It amplifies the local oscillator signal

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- 2-62. The balanced transformer connected to the crystals of a balanced mixer has a secondary that is tuned to what frequency?
1. The desired IF
 2. The local oscillator frequency
 3. The afc discriminator frequency
 4. The transmitter carrier frequency
- 2-63. The IF amplifier stage of a radar receiver determines which of the following receiver characteristics?
1. The gain
 2. The effective bandwidth
 3. The signal-to-noise ratio
 4. All of the above
- 2-64. The detector in a radar receiver converts the IF pulses into what form?
1. Video pulses
 2. Square waves
 3. Dc voltage levels
 4. Continuous-wave signals
- 2-65. Agc automatically adjusts the gain of the receiver by controlling which of the following quantities?
1. Detector bias
 2. IF amplifier bias
 3. Mixer output signal level
 4. Video amplifier output signal level
- 2-66. A radar receiver uses iagc for which of the following purposes?
1. To reduce the amplitude of echoes from distant targets
 2. To prevent full amplification of strong signals
 3. To permit full amplification of weak signals
 4. Both 2 and 3 above

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- 2-67. In a radar receiver, which of the following purposes is served by using stc?
1. Prevents full amplification of echoes from nearby targets
 2. Permits full amplification of echoes from distant targets
 3. Both 1 and 2 above
 4. Prevents target echoes within a selected range from being received
- 2-68. In the input of the first video amplifier of a radar receiver, the differentiator circuit performs which of the following functions?
1. Ftc
 2. Ggc
 3. Afc
 4. Igc
- 2-69. The primary function of the mti system is to display which of the following types of targets?
1. Moving targets only
 2. Motionless targets only
 3. Moving and motionless targets during each sweep
 4. Moving and motionless targets during alternate sweeps
- 2-70. Delaying the received signals in the mti system permits them to be combined with the next set of received signals so that only desired signals are displayed. The signals displayed are formed by which of the following methods?
1. Division
 2. Addition
 3. Subtraction
 4. Multiplication
- 2-71. In the mti system, what is the purpose of the coho lock pulse?
1. To synchronize the coho and transmitted frequency phase relationship
 2. To control the transmitter pulse repetition frequency
 3. To synchronize the phase of the timing circuits with the phase detector
 4. To control the polarity of the coherent video

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2-72. The amplitude of coherent video is determined by the phase difference between which of the following signals?

1. Coho reference and transmitted pulse
2. Coho reference and coho lock pulse
3. Coho reference and IF echo
4. IF echo and received echo

2-73. The purpose of the mti system timing circuits is to

1. synchronize the coho and transmitted frequency phase relationship
2. control the transmitter pulse repetition frequency
3. synchronize the phase of the video balancer with the phase detector
4. select the polarity of the coherent video

2-74. The lin-log amplifier provides (a) a linear output voltage for what amplitude of input signal and (b) a logarithmic output voltage for what amplitude of input signal?

1. (a) Low (b) low
2. (a) Low (b) high
3. (a) High (b) high
4. (a) High (b) low

2-75. What channel in a monopulse receiver is used as the reference channel?

1. IF
2. Range
3. Bearing
4. Elevation

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ASSIGNMENT 3

Textbook assignment: Chapter 3, "Radar Indicators and Antennas" and Chapter 4, "Radar Maintenance".

- 3-1. Which of the following geometrical quantities is/are used as coordinates for radar displays?
1. Range
 2. Bearing
 3. Elevation
 4. All of the above
- 3-2. Of the following target parameters, which would most likely be displayed on all radar sets?
1. Altitude
 2. Slant range
 3. Ground range
 4. All of the above
- 3-3. Which of the following quantities determines total distance represented on a crt display.
1. Crt size
 2. Sweep speed
 3. Sweep length
 4. Echo spacing
- 3-4. To correctly represent the location of a target, a radar repeater must receive which of the following quantities?
1. Video
 2. Timing pulses
 3. Antenna information
 4. All of the above
- 3-5. The A-scope crt normally uses what type of sweep deflection?
1. Mechanical
 2. Electrostatic
 3. Electromagnetic
 4. Electromechanical

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- 3-6. The rhi scope provides the operator with information concerning the target's
1. range only
 2. altitude only
 3. range and altitude
 4. range and bearing
- 3-7. Own ship position is at the center of the scope in which of the following radar displays?
1. A-scope
 2. B-scope
 3. Rhi scope
 4. Ppi scope
- 3-8. Synchronization of events in ppi circuitry is of special importance for which of the following reasons?
1. To ensure that bearing readings are accurate
 2. To ensure that range readings are accurate
 3. To ensure the deflection coils do not overheat
 4. To ensure the power supply is activated at the instant the transmitter fires
- 3-9. Pulses used to synchronize the ppi with the transmitter are developed in which of the following circuits?
1. Gate
 2. Sweep control
 3. Sweep generator
 4. Intensity gate generator
- 3-10. Which of the following circuits produces currents that deflect the electron beam across the crt?
1. Gate
 2. Sweep control
 3. Sweep generator
 4. Intensity gate generator

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- 3-11. Electromagnetic deflection is preferred over electrostatic deflection in ppi scopes because it provides which of the following advantages?
1. Better control of the beam
 2. Better beam position accuracy
 3. Better deflection sensitivity
 4. All of the above
- 3-12. Focusing is accomplished in an electromagnetic crt by varying the
1. potential on the deflection plates
 2. potential between the first anode and the cathode
 3. current through the coil around the neck of the tube
 4. do bias current in the deflection coils
- 3-13. Because the electromagnetic crt uses magnetic deflection, the sweep circuits must provide the deflection coils with which of the following signals?
1. Linear trace current
 2. Trapezoidal voltage
 3. Sinusoidal voltage
 4. Direct current
- 3-14. In a ppi scope that uses electromagnetic deflection, the amplitudes and polarities of the sawtooth currents are determined by which of the following inputs?
1. Target position and speed
 2. Antenna rotation speed
 3. Antenna position
 4. Both 2 and 3 above
- 3-15. On the screen of a ppi scope, range markers appear as
1. vertical pulses
 2. radial grid lines
 3. concentric circles
 4. horizontal grid lines

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- 3-16. The range sweep in a range-gate generator is started at the same time the transmitter fires. A pulse from which of the following circuits causes this timing?
1. Receiver
 2. Indicator
 3. Transmitter
 4. Synchronizer
- 3-17. When used with a ppi presentation, a range gate must have which of the following characteristics?
1. Movable in range
 2. Movable in bearing
 3. Both 1 and 2 above
 4. Fixed in range and bearing
- 3-18. Range-markers are produced on the basis of which of the following timing constants?
1. Radar mile
 2. Transmitter prf
 3. Receiver bandwidth
 4. Transmitter pulse width
- 3-19. To read range directly, the range step is placed in what position relative to an echo pulse?
1. The range step is centered on the echo pulse
 2. The range step coincides with the leading edge of the echo pulse
 3. The range step coincides with the trailing edge of the echo pulse
 4. The range step covers the entire echo pulse
- 3-20. Compared to omnidirectional antennas, directional antennas provide which of the following advantages?
1. Power gain and selectivity
 2. Power gain and directivity
 3. Sensitivity and selectivity
 4. Sensitivity and directivity

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- 3-21. If the vertical beam width of a radar antenna is decreased, what will be the effect on (a) power gain and (b) vertical directivity?
1. (a) Decrease (b) decrease
 2. (a) Decrease (b) increase
 3. (a) Increase (b) increase
 4. (a) Increase (b) decrease
- 3-22. An array of twelve dipoles are set in the same position as a reference dipole and are fed with the same line. The power gain will be
1. less than unity
 2. one-twelfth the reference
 3. twelve times the reference
 4. dependent on the directivity of the array
- 3-23. If the slant range and altitude of a target are known, which of the following coordinates can be computed using trigonometric functions?
1. Elevation angle
 2. True-bearing angle
 3. Relative-bearing angle
 4. All of the above
- 3-24. To convert diverging waves into parallel waves, where must the radiating element be placed in relation to a parabolic reflector?
1. At the focal point of the reflector
 2. $1/4$ wavelength from the reflector
 3. $1/2$ wavelength from the reflector
 4. At the focal point of the hemispherical shield
- 3-25. What is the function of the hemispherical shield of the parabolic reflector?
1. To polarize all reflected waves in the vertical plane
 2. To polarize all reflected waves in the horizontal plane
 3. To convert the spherical waves radiated by the dipole into vertical lines of rf energy
 4. To reflect rf energy radiated forward of the dipole back to the parabolic reflector

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- 3-26. Which of the following types of parabolic reflectors has a focal line rather than a single focal point?
1. Truncated
 2. Rotational
 3. Orange-peel
 4. Cylindrical
- 3-27. A broadside array causes maximum energy to be radiated perpendicular to the plane of the dipole for which of the following reasons?
1. Because dipoles are excited in phase with each other
 2. Because dipoles are parallel to each other
 3. Because dipoles are $1/2$ wavelength apart
 4. Because dipoles are $1/8$ wavelength away from the reflector
- 3-28. The directivity of a horn radiator is dependent on which of the following physical dimensions of the horn?
1. The shape
 2. The length
 3. The mouth size
 4. All of the above
- 3-29. Feedhorn shadows can be eliminated by taking which of the following actions?
1. By making the horn smaller
 2. By making the reflector smaller
 3. By offsetting the horn from the center of the reflector
 4. By putting the horn behind the reflector
- 3-30. Airborne radars have unique physical design requirements. Which of the following functions is performed by the radome?
1. It serves as the antenna
 2. It provides aerodynamic shape
 3. It protects the antenna from low air pressure
 4. All of the above

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- 3-31. If a fixed-frequency radar transmitter is found to be off its normal operating band, which of the following corrective actions should be taken?
1. Retune the transmitter
 2. Change the assigned frequency
 3. Replace the defective part causing the error
 4. Check the frequency again, an error has been made
- 3-32. If a transmitter carrier wave is modulated by a square wave, what maximum number of different frequencies will be produced?
1. An infinite number
 2. 2
 3. 3
 4. 4
- 3-33. Which of the following statements describes a radar transmitter frequency spectrum?
1. The distribution of energy over a band of frequencies
 2. The distribution of energy over time
 3. The prf multiplied by the duty cycle
 4. The pulse width versus peak power
- 3-34. What total number of modulating components are present in the output spectrum of a pulse radar transmitter?
1. 1
 2. 2
 3. 3
 4. 4
- 3-35. An ideal radar frequency spectrum would be best described in which of the following ways?
1. It is symmetrical
 2. It has a wide lobe
 3. It has narrow side lobes
 4. It has no minimum points

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- 3-36. In a good spectrum curve the distance between the two minima is proportional to which of the following transmitter parameters?
1. Prt
 2. Prf
 3. Peak power
 4. Pulse width
- 3-37. The echo box is a good instrument for measuring overall radar system performance because it indicates the combined effectiveness of which of the following components?
1. Antenna and duplexer
 2. Transmitter and antenna
 3. Transmitter and receiver
 4. Receiver and synchronizer
- 3-38. Oscillations in an echo box are known as ringing. Which of the following conditions cause this ringing?
1. A weak transmitter
 2. A saturated receiver
 3. A normally operating receiver
 4. A normally operating transmitter
- 3-39. What constitutes the single most useful measurement you can make with the echo box?
1. Ring time
 2. Duty cycle
 3. Power distribution
 4. Frequency distribution
- 3-40. Desirable transmitter output power characteristics include what relative levels of (a) peak power and (b) average power?
1. (a) Low (b) low
 2. (a) Low (b) high
 3. (a) High (b) high
 4. (a) High (b) low

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- 3-41. Most transmitter power readings are referenced to which of the following quantities?
1. 1 microwatt
 2. 1 milliwatt
 3. 1 watt
 4. 1 kilowatt
- 3-42. Which of the following factors determines the overall performance of a radar receiver?
1. Bandwidth
 2. Sensitivity
 3. Recovery time of the tr
 4. All of the above
- 3-43. Of the following receiver special circuits, which one is used during sensitivity tests?
1. Afc
 2. Agc
 3. Ftc
 4. Iagc
- 3-44. The ability of a receiver to detect weak signals can be determined by which of the following measurements?
1. Noise figure
 2. Minimum discernable signal
 3. Both 1 and 2 above
 4. Bandwidth
- 3-45. When several mds checks are to be taken over a period of time, the length of the test pulse used in the tests should
1. be the same on each check
 2. be different on each check
 3. vary with the transmitter pulse length on each check
 4. vary with the noise figure on each check

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- 3-46. When expressing the sensitivity of a radar receiver, which of the following quantities is used?
1. The signal generator reading
 2. The combined attenuation value of the connecting cable and directional coupler
 3. The sum of both 1 and 2 above
 4. The attenuation value of the signal generator
- 3-47. Tr recovery time places limits on which of the following quantities?
1. Minimum range
 2. Maximum range
 3. Receiver bandwidth
 4. Receiver sensitivity
- 3-48. Which of the following methods is/are used to determine the effectiveness of a tr tube?
1. Measure the keep-alive current
 2. Measure the keep-alive voltage
 3. Graph the correlation between recovery time and leakage power
 4. All of the above
- 3-49. The presence of standing waves on a transmission line indicates which of the following conditions?
1. Excessive output power
 2. An impedance mismatch
 3. Excessive pulse width
 4. Excessive prf
- 3-50. Of the following conditions, which would be a likely indication of a high vswr?
1. Insufficient reflection
 2. Cold spots in the transmission line
 3. Arc-over at the maximum points
 4. All of the above

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- 3-51. Most primary shipboard ac distribution systems provide which of the following types of electrical power?
1. 60 Hz, 3 phase, ungrounded
 2. 60 Hz, 1 phase, ungrounded
 3. 400 Hz, 1 phase, ungrounded
 4. 400 Hz, 3 phase, ungrounded
- 3-52. If your equipment is missing a certain voltage input, which of the following actions should you take first?
1. Call an electrician
 2. Energize the emergency generator
 3. Check the input to the switchboard
 4. Check the power panel that feeds your equipment
- 3-53. What is the normal source of dry air for a shipboard radar system?
1. Compressed-air bottles
 2. Central dry-air system
 3. Dehumidifying ovens
 4. Local dehydrators
- 3-54. The air control panel is designed to regulate
1. flow
 2. purity
 3. pressure
 4. dew point
- 3-55. Which of the following units may be available as an emergency back-up to the central dry-air system?
1. Nitrogen tank
 2. Local dehydrator
 3. Local compressor-dehydrator
 4. Each of the above
- 3-56. Which of the following methods is used to cool radar system components?
1. Air blowers
 2. Liquid-cooling loops
 3. Air-conditioning systems
 4. Each of the above

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- 3-57. A radar cooling system has a low-flow alarm in the sea-water loop. What is the primary purpose of this alarm?
1. It allows correction before damage occurs
 2. It increases the flow in the distilled water loop
 3. It removes power from the system
 4. It increases the sea-water pressure
- 3-58. Which of the following characteristics of cooling water for electronic equipment must be carefully controlled?
1. Purity
 2. Pressure
 3. Quantity
 4. All of the above
- 3-59. For which of the following reasons do personnel sometimes develop a false sense of security concerning exposure to radiation?
1. Rf radiation does not always produce pain
 2. Rf radiation is visible only at night
 3. Only search radars are hazardous
 4. Rf hazards occur only at night
- 3-60. Injury from X-rays would most likely result from which of the following actions?
1. Standing near unshielded high voltage components
 2. Working alone on low-voltage power supplies
 3. Bypassing interlocks on shielded equipment
 4. Working too close to a crt with a potential of 1,500 volts