# CHAPTER 1

# INTRODUCTION TO BASIC RADAR

The Navy Electricity and Electronics Training Series (NEETS) modules, especially module 18, *Radar Principles*, provide information that is basic to your understanding of this volume. This volume will discuss radar and radar systems as you may encounter them as an Electronics Technician at your command. You should refer to NEETS module 18 and Electronics Installation and Maintenance Book (EIMB), *Radar and Electronic Circuits*, on a regular basis to ensure that you have a complete understanding of the subject matter covered in this volume.

As an Electronics Technician, Second Class, and possible work center supervisor, you must understand the basic radar principles and safety requirements for radar maintenance. However, due to luck of the draw, your first assignment may not afford you exposure to radar systems. Our intention with this volume is NOT to teach you every radar system the Navy uses, but simply to familiarize you with the radars and their general maintenance principles.

You will be able to identify the equipment requirements and general operation of the three basic radar systems covered in chapter 1. You'll become familiar with the nomenclature of specific radars used in the Navy today as we discuss them in chapter 2. Then, armed with all that knowledge you will easily grasp the system concepts addressed in chapter 3. And before you go out to tackle the radar world, chapter 4 will give you necessary safety information specific to radar maintenance.

When you arrive at your next command as a second class with work center responsibilities for a radar maintenance shop, you will be ready.

## BASIC RADAR CONCEPTS

The term *radar* is an acronym made up of the words *radio, detection,* and *ranging.* It refers to electronic equipment that detects the presence, direction, height, and distance of objects by using reflected electromagnetic energy. The frequency of electromagnetic energy used for radar is unaffected by darkness and also penetrates weather. This permits radar systems to determine the position of ships, planes, and land masses that are invisible to the naked eye because of distance, darkness, or weather.

Radar systems provide only a limited field of view and require reference coordinate systems to define the positions of the detected objects. Radar surface angular measurements are normally made in a clockwise direction from **TRUE NORTH,** as shown in figure 1-1, or from the heading line of a ship or aircraft. The actual radar location is the center of this coordinate system.

Figure 1-1 contains the basic terms that you need to know to understand the coordinate system. Those terms are defined in the following paragraph.

The surface of the earth is represented by an imaginary flat plane, known as the **HORIZONTAL PLANE,** which is tangent (or parallel) to the earth's surface at that location. All angles in the up direction are measured in a secondary imaginary plane, known as the **VERTICAL PLANE,** which is perpendicular to the horizontal plane. 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

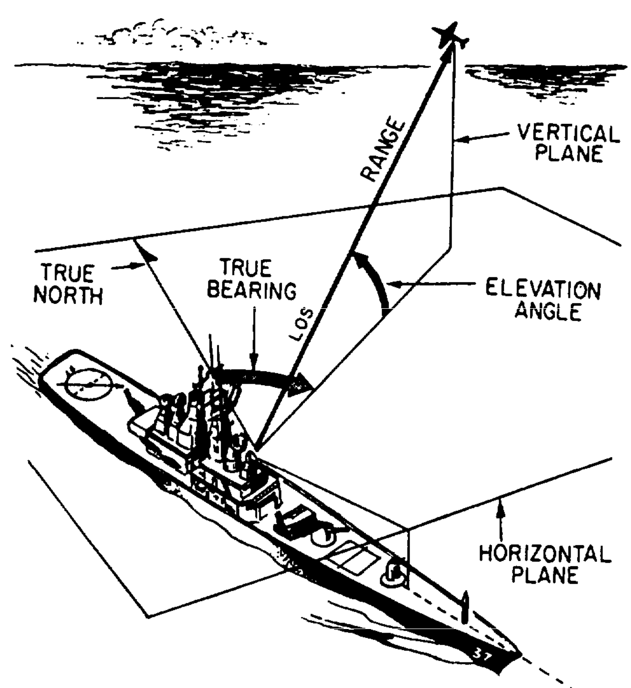


**Figure 1-1.—Radar reference coordinates.**

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. Information based on these terms describes the location of an object with respect to the antenna, giving the operator data on range, bearing, and altitude.

## RANGE/BEARING/ALTITUDE

Using the coordinate system discussed above, radar systems provide early detection of surface or air objects, giving extremely accurate information on distance, direction, height, and speed of the objects. The visual radar data required to determine a target's position and to track the target is usually displayed on a specially designed cathode-ray tube (crt) installed in a unit known as a planned position indicator (ppi).

Radar is also used to guide missiles to targets and to direct the firing of gun systems. Other types of radar provide long-distance surveillance and navigation information.

Bearing and range (and in the case of aircraft, altitude) are necessary to determine target movement. It is very important that you understand the limitations of your radar system in the areas of range, hewing, and altitude.

### 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 range to an object, in nautical miles, can be determined by measuring the elapsed time (in microseconds) during the round trip of a radar pulse and dividing this quantity by the number of microseconds required for a radar pulse to travel 2 nautical miles (12.36). In equation form this is:

$$\textit{range (nautical miles)} = \frac{\textit{elapsed time}}{12.36}$$

**MINIMUM RANGE.—** Radar duplexers alternately switch the antenna between the transmitter and receiver so that one antenna can be used for both functions. The timing of this switching is critical to the operation of the radar and directly affects the minimum range of the radar system. A reflected pulse will not be received during the transmit pulse and subsequent receiver recovery time. Therefore, any reflected pulses from close targets that return before the receiver is connected to the antenna will be undetected.

**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.

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 that can be processed and presented on an indicator.

The prr will determine the frequency that the indicator is reset to the zero range. With the leading edge of each transmitted pulse, the indicator time base used to measure the returned echoes is reset, and a new sweep appears on the screen. If the transmitted pulse is shorter than the time required for an echo to return, that target will be indicated at a false range in a different sweep. For example, the interval between pulses is 610 sec with a repetition rate of 1640 pulses per second. Within this time the radar pulse can go out and come back a distance equal to 610 sec ' 164 yards per sec, or 100,000 yards, which becomes the scope's sweep limit. Echoes from targets beyond this distance appear at a false range. Whether an echo is a true target or a false target can be determined by simply changing the prr.

**RANGE ACCURACY.—** The shape and width of the rf pulse influences minimum range, range accuracy, and maximum range. The ideal pulse shape is a square wave that has vertical leading and trailing edges. A sloping trailing edge lengthens the pulse width. A sloping leading edge provides no definite point from which to measure elapsed time on the indicator time base.

Other factors affecting range are the antenna height, antenna beam width, and antenna rotation rate. A higher antenna will create a longer radar horizon, which allows a greater range of detection. Likewise, a more concentrated beam has a greater range capability since it provides higher energy density per unit area. Also, because the energy beam would strike each target more times, a slower antenna rotation provides stronger echo returns and a greater detection range for the radar.

Given the range information, the operator knows the distance to an object, but information on bearing is still required to determine in which direction from the ship the target lies.

### Bearing

Radar bearing is determined by the echo signal strength as the radiated energy lobe moves past the target. Since search radar antennas move continuously, the point of maximum echo return is determined either 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.

**TRUE BEARING.—** The angle between true north and a line pointed directly at a target is called the *true bearing* (referenced to true north) of a radar target. This angle is measured in the horizontal plane and in a clockwise direction from true north.

**RELATIVE BEARING.—** The angle between the centerline of your own ship or aircraft and a line pointed directly at a target is called the *relative bearing* of the radar target. This angle is measured in a clockwise direction from the centerline.

Both true and relative bearing angles are illustrated in figure 1-2.

Most surface search radars will provide only range and bearing information. If the operator had a need to direct air traffic or to track incoming missiles, the radar would also have to provide altitude.

### Altitude

An operator can determine the altitude of a target by adjusting a movable height line on a height indicator to the point where it bisects the center of the target. The altitude is then displayed by an altitude dial or digital readout. A search radar system that detects altitude as well as range and bearing is called a three-dimensional (3D) radar.

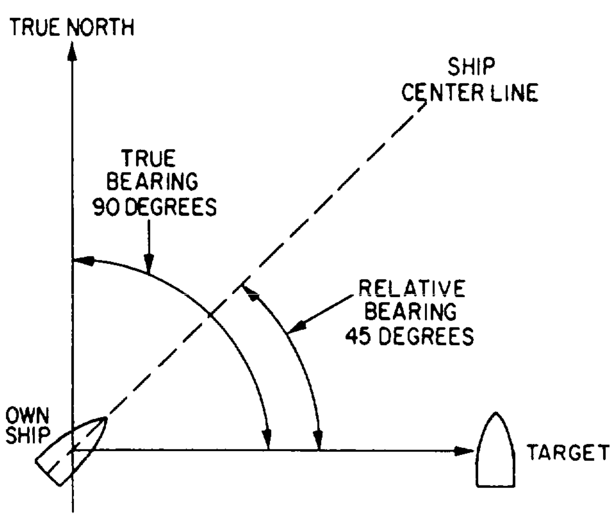


**Figure 1-2.—True and relative bearings.**

Altitude or height-finding radars use a very narrow beam in the vertical plane. This beam is scanned in elevation, either mechanically or electronically, to pinpoint targets. Tracking and weapons-control radar systems commonly use mechanical elevation scanning techniques. This requires moving the antenna or radiation source mechanically. Most air search radars use electronic elevation scanning techniques. Some older air search radar systems use a mechanical elevation scanning device; however, these are being replaced by electronically-scanned radar systems.

## RADAR DETECTING METHODS

Radar systems are normally divided into operational categories based on energy transmission methods. Although the pulse methcd 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.

### Continuous Wave

The continuous wave (cw) method uses the Doppler effect to detect the presence and speed of an object moving toward or away from the radar. The system is unable to determine the range of the object or to differentiate between objects that lie in the same direction and are traveling at the same speed. It is usually used by fire control systems to track fast moving targets at close range.

### Frequency Modulation

With the frequency modulation (fm) method, energy is transmitted as radio frequency (rf) waves that continuously vary, increasing and decreasing, from a fixed reference frequency. Measuring the difference between the frequency of the returned signal and the frequency of the radiated signal will give an indication of range. This system works well with stationary or slowly-moving targets, but it is not satisfactory for locating moving objects. It is used in aircraft altimeters that give a continuous reading of how high the aircraft is above the earth.

### Pulse Modulation

With the pulse modulation method, depending on the type of radar, energy is transmitted in pulses that vary from less than 1 microsecond to 200 microseconds. The time interval between transmission and reception is computed and converted into a visual indication of range in miles or yards. Pulse radar systems can also be modified to use the Doppler effect to detect a moving object. The Navy uses pulse modulation radars to a great extent.

## FACTORS AFFECTING RADAR PERFORMANCE

Radar accuracy is a measure of the ability of a radar system to determine the correct range, bearing, and in some cases, altitude of an object. The degree of accuracy is primarily determined by the resolution of the radar system and atmospheric conditions.

### Range Resolution

Range resolution is the ability of a radar to resolve between two targets on the same bearing, but at slightly 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.

### Bearing Resolution

Bearing, or azimuth, resolution is the ability of a radar system to separate objects at the same range but at slightly different bearings. The degree of bearing resolution depends on radar beamwidth and the range of the targets. The physical size and shape of the antenna determines beamwidth. Two targets at the same range must be separated by at least one beamwidth to be distinguished as two objects.

Earlier in this chapter, we talked about other internal characteristics of radar equipment that affect range performance. But there are also external factors that effect radar performance. Some of those are the skill of the operator; size, composition, angle, and altitude of the target; possible electronic-countermeasure (ECM) activity; readiness of equipment (completed PMS requirements); and weather conditions

### Atmospheric Conditions

Several conditions within the atmosphere can have an adverse effect on radar performance. A few of these are temperature inversion, moisture lapse, water droplets, and dust particles.

Either temperature inversion or moisture lapse, alone or in combination, can cause a huge change in the refraction index of the lowest few-hundred feet of 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 in which the radar waves are bent. The effect of ducting is illustrated in figure 1-3.

Water droplets and dust particles diffuse radar energy through absorption, reflection, and scattering. This leaves less energy to strike the target so the return echo is smaller. The overall effect is a reduction in usable range. Usable range varies widely with weather conditions. The higher the frequency of the radar system, the more it is affected by weather conditions such as rain or clouds.

All radar systems perform the same basic functions of detection, so, logically, they all have the same basic equipment requirements. Next, we will talk about that basic radar system.

## BASIC RADAR SYSTEMS

Radar systems, like other complex electronics systems, are composed of several major subsystems and many individual circuits. Although modern radar systems are quite complicated, you can easily understand their operation by using a basic block diagram of a pulsed radar system.

## FUNDAMENTAL RADAR SYSTEM

Since most radars used today are some variation of the pulse radar system, the units we discuss in this section will be those used in a pulse radar. All other

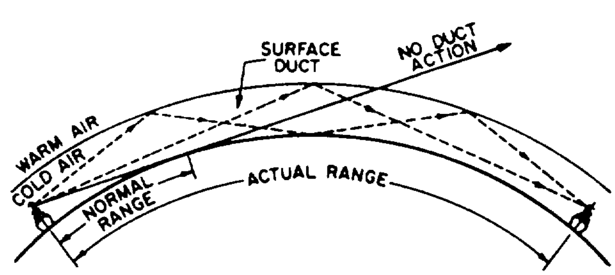


**Figure 1-3.—Ducting effect on the radar wave.**

types of radars use some variations of these units, and we will explain those variations, as necessary in the next chapter. For now, let's look at the block diagram in figure 1-4.

### Modulator

You can see on the block diagram that the heart of the radar system is the modulator. It generates all the necessary timing pulses (triggers) for use in the radar and associated systems. Its function is to ensure that all subsystems making up the radar system operate in a definite time relationship with each other and that the intervals between pulses, as well as the pulses themselves, are of the proper length.

### 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. (You can review the construction and operation of microwave components in NEETS module 11, *Microwave Principles.)*

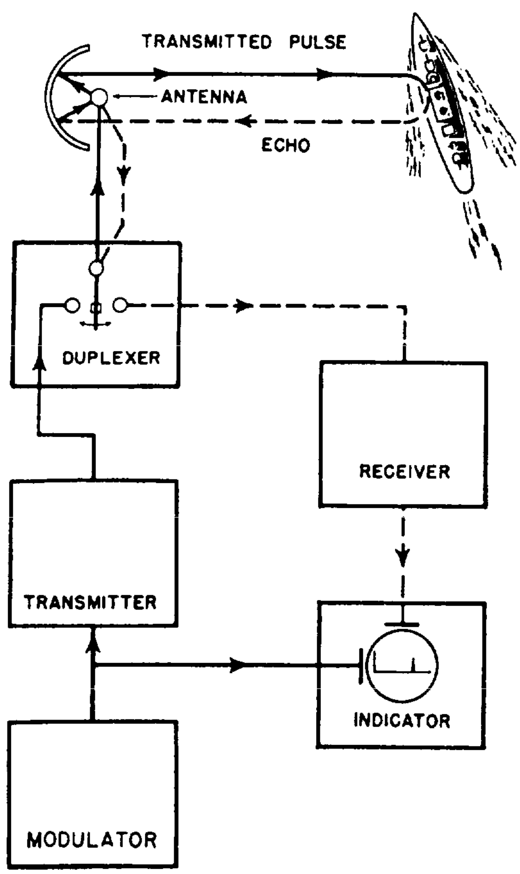


**Figure 1-4.—Block diagram of fundamental radar system.**

### Duplexer

The 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. As we mentioned previously, the switching time is called *receiver recovery time,* and must be very fast if close-in targets are to be detected.

### 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 transmission lines and waveguide from the antenna to the receiver.

### Receiver

The receiver accepts the weak rf echoes from the antenna system and routes them to the indicator as discernible video signals. Because the radar frequencies are very high and difficult to amplify, a superheterodyne receiver is used to convert the echoes to a lower frequency, called the intermediate frequency (IF), which is easier to amplify.

### Indicator

The indicator uses the video output of the receiver to produce a visual indication of target information including range and bearing (or in the case of height-finding indicators, range and height).

## TYPES OF RADAR SYSTEMS

Because of different design parameters, no single radar set can perform all the many radar functions required for military use. The large number of radar systems used by the military has forced the development of a joint-services classification system for accurate identification of radars.

Radar systems are usually classified according to their specific function and installation vehicle. The joint-service standardized classification system divides these broad categories for more precise identification.

Table 1-1 is a listing of equipment identification indicators. You can use this table and the radar nomenclature to identify the parameters of a particular radar set.

If you use the table to find the parameters of an AN/FPS-35, you will see that it is a fixed (F) radar (P) for detecting and search (S). The AN indicates Army/Navy and the 35 is the model number.

Since no single radar system can fulfill all of the requirements of modern warfare, most modern warships, aircraft, and shore installations have several radar sets, each performing a specific function. A shipboard radar installation may include surface search and navigation radars, an air search radar, a height-finding radar, and various fire control radars.

### Surface Search and Navigation

The primary function of a surface search radar is to maintain a 360-degree search for all targets within line-of-sight distance from the radar and to detect and

**Table 1-1.—Table of Equipment Indicators**

| Installation (1st letter) | Type of Equipment (2nd letter) | Purpose (3rd letter) | Miscellaneous Identification |
|---|---|---|---|
| A—Piloted aircraft | A—Invisible light, heat radiation | B—Bombing | X,Y,Z—Changes in voltage, phase, or frequency |
| B—Underwater mobile, submarine | C—Carrier | C—Communications (receiving and transmitting | T—Training |
| D—Pilotless carrier | D—Radiac | D—Direction finder reconnaissance and/or surveillance | (V)—Variable grouping |
| 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 searchlight directing | |
| K—Amphibious | J—Electromechanical or inertial wire covered | H—Recording and/or reproducing (graphic meteorological and sound) | |
| M—Ground, mobile | K—Telemetering | K—Computing | |
| P—Portable | L—Countermeasures | M—Maintenance and/or test assemblies (including tools) | |
| S—Water | M—Meteorologcal | N—Navigational aids (including altimeters, beacons, 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 | | |
| | Y—Data processing | | |

determine the accurate ranges and bearing of surface targets and low-flying aircraft.

The following are some applications of surface search radars:

- Indicate the presence of surface craft and aid in determining their course and speed
- Coach fire control radar onto a surface target
- Provide security against attack at night, during conditions of poor visibility, or from behind a smoke screen
- Aid in scouting
- Obtain range and bearing on prominent landmarks and buoys as an aid to piloting, especially at night and in conditions of poor visibility
- Facilitate station keeping
- Detect low-flying aircraft
- Detect certain weather phenomena
- Detect submarine periscopes
- Aid in the control of small craft during boat and amphibious operations

Navigation radars fall into the same general category as surface search radars. As the name implies, navigation radars are used primarily as an aid to navigate or pilot the ship. This type of radar has a shorter operating range and higher resolution than most surface search radars. Because the navigation and surface search radars share the same general operating characteristics, both radar types can be used simultaneously with one covering longer ranges, while the other covers distances closer to the ship. The use of radars for navigation is discussed further in *Electronics Technician, Volume 5—Navigation.*

So now, with surface search and navigation radars on line, the ship is aware of all surface targets, land masses, and low-flying aircraft. But, to protect itself from fighter planes, incoming missiles, and other targets in the upper skies, the ship requires a different type of radar.

### Air Search

The primary function of an air search radar is to maintain a 360-degree surveillance from the surface to high altitudes and to detect and determine ranges and bearings of aircraft targets over relatively large areas.

The following are some applications of air search radar:

- Early warning of approaching aircraft and missiles, providing the direction from which an attack could come. This allows time to bring anti-aircraft defenses to the proper degree of readiness and to launch fighters if an air attack is imminent.
- Constant observation of movement of enemy aircraft, once detected, to guide combat air patrol (CAP) aircraft to a position suitable for an intercept
- Provide security against attacks at night and during times of poor visibility
- Provide information used for aircraft control during operations requiring a specific geographic track (such as an anti-submarine barrier or search and rescue pattern)

Together, surface and air search radars provide a good early warning system. However, the ship must be able to determine altitude to effectively intercept any air target. This requires still another type of radar.

### Height Finding

The primary function of a height-finding radar (sometimes referred to as a 3D or three-coordinate radar) is to compute accurate ranges, bearings, and altitudes of targets detected by air search radar. This information is used to direct fighter aircraft during interception of air targets.

The height-finding radar is different from the air search radar in that it has a higher transmitting frequency, higher output power, a much narrower vertical beamwidth, and requires a stabilized antenna for altitude accuracy.

The following are some applications of height-finding radar:

- Obtain range, bearing, and altitude data on enemy aircraft and missiles to assist in the guidance of CAP aircraft
- Provide precise range, bearing, and height information for fast and accurate initial positioning of fire control tracking radars
- Detect low-flying aircraft

- Determine range to distant land masses
- Track aircraft over land
- Detect certain weather phenomena
- Track weather balloons

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

In this chapter we looked at general radar operation and the three types of radars most frequently maintained by ETs. Tracking radars, missile-guidance radars, and airborne radars are also critical to Navy readiness; however, they are not normally maintained by ETs and will not be covered in this TRAMAN.

Because there are so many different models of radar equipment, the radars and accessories we describe in this volume are limited to those common to a large number of ships or shore stations. In our discussion of specific equipments in the next chapter, we will purposely leave out older equipment currently installed in the fleet, but scheduled for replacement.