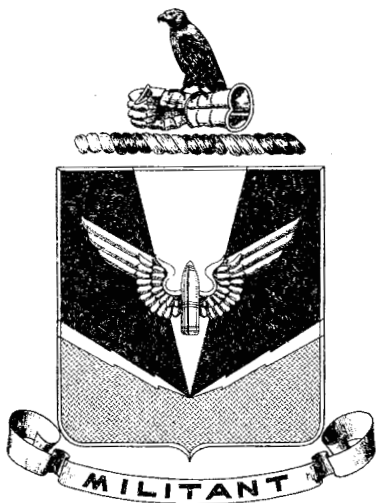


U.S. ARMY

ST 44-188-1

INTRODUCTION TO RADAR



U.S. ARMY AIR DEFENSE SCHOOL

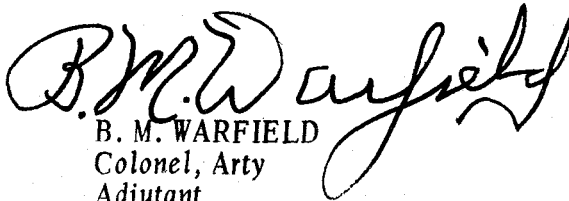
FORT BLISS, TEXAS

NOTE: Supersedes ST 44-188-1, Sep 58

MAY 1960

U.S. ARMY AIR DEFENSE SCHOOL
Fort Bliss, Texas

This publication is provided for resident and extension course instruction at the U.S. Army Air Defense School only. It reflects the current thought of this School and conforms to printed Department of the Army doctrine as closely as possible.


B. M. WARFIELD
Colonel, Arty
Adjutant

CONTENTS

	Par	Page
CHAPTER 1. INTRODUCTION		
Purpose	1	1
Scope	2	1
CHAPTER 2. HISTORY OF RADAR		
Early methods of warning	3	2
Radar development	4	2
CHAPTER 3. THEORY OF RADAR		
Characteristics of radar waves	5	4
Radar methods	6	4
Determination of range	7	5
Determination of azimuth	8	5
Determination of elevation	9	6
Radar transmission	10	7
CHAPTER 4. THE BASIC RADAR SYSTEM		
Fundamental elements	11	10
Timer	12	11
Transmitter	13	13
Antenna	14	14
Receiver system	15	19
Indicator	16	19
Indicator scope ranging	17	23
Power supply	18	25
CHAPTER 5. TYPES OF AIR DEFENSE RADARS		
General	19	26
Defense acquisition radar	20	26
Battery acquisition radar	21	26
CW (continuous wave) acquisition radar and cw track radar	22	26
Target-track radar (TTR) and missile- track radar (MTR)	23	27
Special purpose radars	24	27
CHAPTER 6. THE ELECTROMAGNETIC FREQUENCY SPECTRUM		
Radiant energy frequencies	25	28
Graphic presentation	26	28
CHAPTER 7. SUMMARY AND QUESTIONS		
Summary	27	30
Discussion questions	28	31

CHAPTER 1

INTRODUCTION

1. PURPOSE

The purpose of this publication is to provide a reference which gives the background necessary to understand the theory of radar.

2. SCOPE

This publication covers the history, development, and basic theory of radar operation.

HISTORY OF RADAR

3. EARLY METHODS OF WARNING

a. The earliest armies recognized the importance of knowing the whereabouts of their enemies. They stationed men at lookout points so that they would be aware of the approach of their enemy without revealing their own positions. Down through the centuries, man's principal early warning system has been a lookout stationed at a high vantage point. The invention of the high-powered telescope increased the range of early warning for a particular vantage point, but the position selected as a lookout point was still restricted in range due to the need for communication with the main body of troops. As communication systems progressed from the drum to the telephone and radio, it readily can be seen how early warning progressed proportionally.

b. With the advent of airplanes, visual means of detection were not dependable, particularly on cloudy days and at night. A device that could detect unseen targets was needed. One method included the use of listening devices which detected and amplified engine noises to an audible level, long before they could be heard by the unaided human ear. These devices were able to determine the direction of the approach by utilizing the binaural or two-ear effect of the human auditory system. This method was cumbersome and would be completely useless in the age of supersonic flight. As aircraft increased their speed and altitude, it became evident that new equipment must be developed which could detect and locate fast-moving high-flying targets and track them automatically. This resulted in the development of radar.

4. RADAR DEVELOPMENT

a. The word radar, formed from the initial letters in radio detection and -ranging, indicates a method of employing radio waves to detect and locate material objects. The location of an object is accomplished by determining the distance and direction from the radar equipment. The measurement of three coordinates is generally required - range, azimuth, and elevation.

b. The invention of radar cannot be ascribed to a particular person or organization. Earliest credit belongs to the first radio physicist, Heinrich Hertz, who, in 1887 revealed experiments that proved radio waves were reflected like light rays and could be formed into beams by metallic mirrors similar in shape to mirrors that reflect light. In 1922 Marconi urged the use of short waves for purpose of detection. During the same year Dr. A. Hoyt Taylor and L. C. Young of the U.S. Naval Research Laboratory at Anacostia, D.C. noted that signals received on 60 megacycles were subject to occasional rapid variations in signal strength and finally identified the cause to be the passage of boats on nearby Anacostia River. Dr. Taylor suggested that surface vessels might be detected by this means. In 1925 Drs. Bruit and Tuve of the Carnegie Institute first employed the principles of pulse radar in measuring the height of the ionosphere.

c. In 1930, Dr. Taylor resumed his research at the U.S. Naval Research Laboratory and began a definite program leading to a device to detect the enemy and give knowledge of his movements. In 1932, the Secretary of the Navy communicated all information to the Secretary of War in the belief that radar would prove essential to anti-aircraft activities of the Army. In 1934 a cw source of radio waves at a frequency of about 3,000 mc and about 1/2 watt of power was tested by the Army Signal Corps Laboratories. Harbor traffic was detected at distances of less than a mile. In July 1934, Major Blair, director of the Army Signal Corps Laboratories, reported that consideration was being given to "the scheme of projecting an interrupted sequence of trains of oscillations against the target and attempting to detect the echoes during the interstices between the projections." This was one of the first proposals to use pulses in a radio detection device.

d. Early in 1935, Sir Robert Watson-Watt of the National Physical Laboratory in England made the same proposal independently. In May, pulse equipment had been constructed by Watson-Watt and coworkers that tracked aircraft. In December 1936, Army Signal Corps research turned wholly to pulse systems. Work began on the first U.S. Army radar set, the SCR-268, designed to direct searchlights to aircraft and for the measurement of slant range. Work on the radar set was completed in May 1937. The British embarked on a program of large scale early-warning radar development that resulted, in 1937, in the establishment of radar stations on the Thames estuary. These stations operated on a frequency of 25 mc. They were put on a 24-hour watch in September 1938. The British were far in advance of the rest of the world in radar development during this period.

e. In 1939, radar equipment designed and built by the Naval Research Laboratories was installed on the U.S.S. New York and was tested during battle maneuvers. In 1940, England developed a multicavity magnetron which met the requirements of high peak power and high frequency. The magnetron was an important milestone in the development of the high-power, high-frequency techniques of present-day radar. British and American interests were pooled in 1940-41, and joint work on radar began in early 1941. In the late spring of 1941, the U.S. destroyer Semmes was equipped with a search-type radar which employed a PPI presentation. During 1941, the first radar was built which would track an aircraft automatically in azimuth and elevation; the principles of this equipment were incorporated in the design of the SCR-584. Later, automatic range tracking was developed and employed in the SCR-784 providing fully automatic tracking in range, azimuth, and elevation.

f. The first public announcement of the existence of radar was made in June 1941 when an appeal was made for American technicians to man British radars. A description of the radar principle was released in May 1943. The total expenditure for radar research development, and procurement during 1941-1945 was 2.7 billion dollars. The work on radar development continued at a slower pace after the war ended, and was directed toward industrial and commercial uses. All large commercial aircraft are now equipped with radar to measure absolute altitude, to aid navigation, and to detect mountains and other objects along their course. Ground control approach (GCA) equipment has been perfected to the point where air traffic may be handled with the same speed and safety in bad weather as in clear weather. GCA equipment was used during the Berlin airlift to maintain 24-hour operation regardless of the weather. The range detection capabilities of radar equipment have been greatly increased in recent years.

THEORY OF RADAR

5. CHARACTERISTICS OF RADAR WAVES

a. Radar is an application of radio principles by means of which it is possible to detect the presence of objects, determine their direction and range, and recognize their character.

b. Detection is accomplished by directing a beam of radio-frequency energy over a region to be searched. When the beam strikes a reflecting object, energy is reradiated. A very small part of this reradiated energy is returned to the radar system. A sensitive receiver can detect the echo signal and, therefore, the presence of the object or target. The determination of the actual range is based on the fact that radio-frequency energy travels at the constant velocity of light, 186,000 miles (328 million yards) per second. Making the receiving system directional, the direction, or azimuth of the target, may be determined.

6. RADAR METHODS

a. Continuous-wave (cw) method. When radio-frequency energy which is transmitted continuously strikes an object which moves toward or away from the source of energy, this energy is reflected and its frequency is changed. The change in frequency is known as the doppler effect. The difference in frequency between the transmitted and reflected energy is measured to determine the presence and speed of the moving target. This method works well with fast-moving targets, but does not work satisfactorily with those targets which are slow or stationary.

b. Frequency-modulation method. If the frequency of the transmitted energy is varied continuously and periodically over a specified band, the frequency of the energy being radiated by the antenna differs from that received from the target. This difference occurs because of the time required for the energy to reach the target and return. The frequency difference depends on the distance traveled, and can be used as a measure of range. Moving targets produce a frequency shift in the returned signal because of the doppler effect which affects the accuracy of range measurement.

c. Pulse-modulation method. The radio-frequency energy can also be transmitted in short pulses whose time duration may vary from 1 to 50 microseconds. If the transmitter is turned off before the reflected energy returns from the target, the receiver can distinguish between the transmitted pulse and the reflected pulse. After all reflections have returned, the transmitter can again be turned on and the process repeated. The receiver output is applied to an indicator which measures the time interval between the transmission of the energy and its return as a reflection. Since the energy travels at a constant velocity, the time interval becomes a measure of the distance traveled, or range. Since this method does not depend on the relative frequency of the returned signal, or on the motion of the target, difficulties experienced in the cw and frequency-modulation methods are not present. The pulse-modulation method is used almost

universally in military and naval applications. Therefore, it is the only method which will be discussed in this text.

7. DETERMINATION OF RANGE

a. The successful employment of pulse-modulated radar systems depends primarily on the ability to measure distance in terms of time. Radio-frequency energy, once it has been radiated into space, continues to travel with constant velocity. When it strikes a reflecting object there is no loss in time, but merely a redirecting of the energy. Its velocity is that of light, or in terms of distance traveled per unit of time, 186,000 land miles per second, 162,000 nautical miles per second, or 328 yards per microsecond.

b. The constant velocity of radio-frequency energy is applied in radar to determine range by measuring the time for a pulse to travel to a target and return. The speed of the radar pulse is so great that the second is a rather useless unit of measure and must be further subdivided into millionths of a second, or microseconds. The radar pulse, traveling at a speed of 328 yards per microsecond, will reach a target 164 yards away and return in 1 microsecond. The figure, 164 yards per microsecond, is an important unit in radar system measurements and is known as radar range time.

c. The minimum range of a radar will be determined by the time it takes the receiver to recuperate from the pulse width and the strong transmitted pulse. Peak power developed by the radar transmitter, size and reflecting characteristics of targets, receiver sensitivity, and the length of the listening period between pulses will all be limiting factors as far as the maximum range of a particular radar is concerned.

d. In order to employ the time-range relationship, the radar system must have a time-measuring device. In addition, since there may be more than one target in the region under search, some means of separating and identifying pulses must be included. The cathode-ray oscilloscope is well suited to such a task, since it retains the information on its screen and also forms a time scale. The time scale is provided by using a linear sweep to produce a known rate of motion of the electron beam across the screen of the cathode-ray tube.

8. DETERMINATION OF AZIMUTH

a. The measurement of the direction of a target from the radar system is usually given as an angular position. The angle may be measured from true north if the installation is stationary, or with respect to the heading of a vessel or aircraft containing the radar set. The angle at which the echo signal returns is measured by utilizing the directional characteristics of the radar antenna system.

b. The dimensions of the individual element (the dipole) cause it to send out more energy in some directions than in others. When several elements are used together to form an antenna system, the energy is further concentrated. Radar antennas are constructed of radiating elements, reflectors, and directors to produce a single narrow beam