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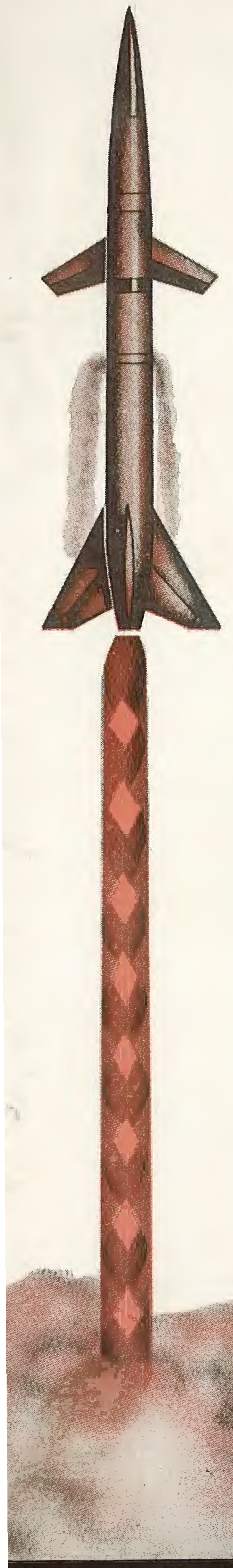
"Missile Away!"

THE NEW MEXICO - WEST TEXAS SECTION
OF THE AMERICAN ROCKET SOCIETY



MICROWAVE RELAY
STATION
(U. S. Army photo)

Alamo Lookout Microwave Relay Station.

RADAR DATA FOR OPTICIAL TRACKING

By PERRY L. WHITE
White Sands Signal Corps Agency

How the "chain radar system" supplies space position information to optical tracking instruments. Optical stations which are located beyond line of sight of launching areas or lose track of targets behind clouds can be pointed "on target" from radar data originating from a remote source.

VARIOUS groups at White Sands Proving Ground are constantly seeking practical means of improving and extending optical coverage of long-flying, supersonic missiles. Optical focal lengths have been increased, automatic tracking systems for optical instruments have been worked on, and radar acquisition data has been furnished to optical instrumentation sites. It is with the last named of these three approaches to the problem, that this article is concerned.

The heart of the acquisition system is the White Sands Signal Corps Agency's Chain radar system. This system has been in use at the proving ground for several years. It consists of four permanent radar control stations, located roughly 30 miles apart, from north to south, on the 120-mile-long missile testing range.

Assume that a missile is fired straight northward from a launching site near the southern range boundary. From the instant of take-off, the missile is tracked by "C" Station, the chain radar station nearest the launching site. "C" Station is now in command of the radar system. But as the missile speeds farther and farther uprange, control is passed from each station, in turn, to the next station to the north. Command is transferred the instant that it becomes apparent that another station is obtaining flight data superior to that being obtained by the controlling station.

The command station transmits missile space position data via a microwave link to the Alamo Lookout Radio Relay Station, atop a 9,288 ft. mountain. From the Relay Station, the data is microwaved to the other chain stations and radioed (VHF) to widely dispersed optical instrumentation sites. The chain stations receiving the data, apply parallax corrections, locate the target in space, and proceed to track.

Before transmission from a station in command of the system, all space position data is referenced to a common coordinate system. Thus all receiving stations, optical or radar, use only one set of parallax constants, regardless of which station is serving as the primary data source.

Each chain radar station is equipped with several radar sets. However, only one set can feed data to the chain at any given time. At a master chain station, the chain commander sits at a chain console during tracking operations. By means of information presented on the console, the commander can not only place any station in command of the chain system but can also select one particular radar set at that station as the data source for the entire system.

In this connection, a device for automatically selecting the command station and the best performing radar at that station has been considered desirable. To meet this need, the Signal Corps Engineering Laboratories have recently let a study contract to Cook Research Laboratories, Chicago, Ill., to investigate the feasibility of developing such a device. This presumably would be a small computer that could evaluate each radar's tracking performance, carefully weigh other factors, and select the radar producing the best chain data during any particular portion of a missile flight.

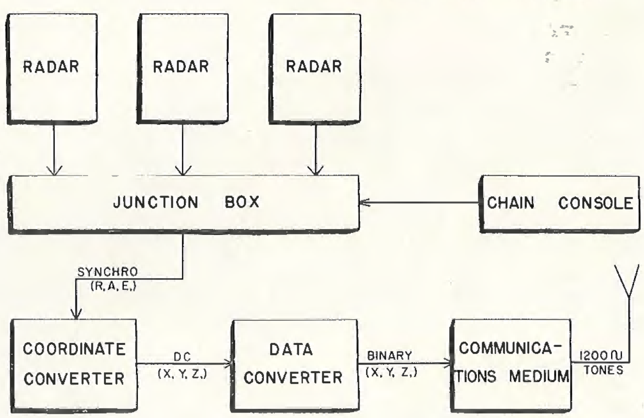
At the present time the chain commander chooses what appears to be the best performing radar by observing both a status board on the chain console made up of a multi-colored display of lights and the space position plot of the missile trajectory. The chosen radar feeds range, azimuth, and elevation data in the form of A.C. voltages to a synchro type analog computer. This computer, commonly referred to as an A.C. Coordinate Converter, transforms this polar data to the cartesian coordinates x, y, and z, applies parallax constants, and sets scale factors. Its output is three D.C. voltages, proportional to the x, y, and z coordinates of the missile's space position.

To digress briefly, the chain system is presently being extensively field tested to determine whether its accuracy and reliability can be increased significantly by replacing A.C. with D.C. type converters. Theoretically, the D.C. method, using radar sine-cosine and range potentiometers as the primary source of data, in place of A.C. synchros, will increase the accuracy, precision, and reliability of the chain data.

The output of the Coordinate Converter, i.e. the three D.C. voltages proportional to x, y, and z, are fed to the Data Converter. This instrument, a 16-digit analog-to-digital converter, transforms the D.C. voltages to binary numbers, applies parallax data as necessary, and feeds the binary numbers in the form of 1200 cycle tone bursts to the communications medium.

It should be interposed here that only the first 13 least significant digits are used for data transimssion, a method providing a potential accuracy of .01% of maximum range. At present the three higher significant digits are not used. However, they could be used for data transmission and parallax purposes should it become necessary to extend the range.

BLOCK DIAGRAM— CHAIN RADAR SYSTEM TRANSMITTING STATION



From the chain station in command, the 1200 cycle tone bursts, representing the missile's position in the x, y, and z planes, are microwaved to the Radio Relay Station. The signals are then re-transmitted by either microwave or VHF radio links to all range stations using acquisition data. When necessary, the signals can be further relayed from the VHF receiver stations to more remote stations via telephone lines.

Present-day stations furnishing acquisition data to optical instruments, are equipped with a VHF communications receiver, an AN/TSQ-1 receiver, and a

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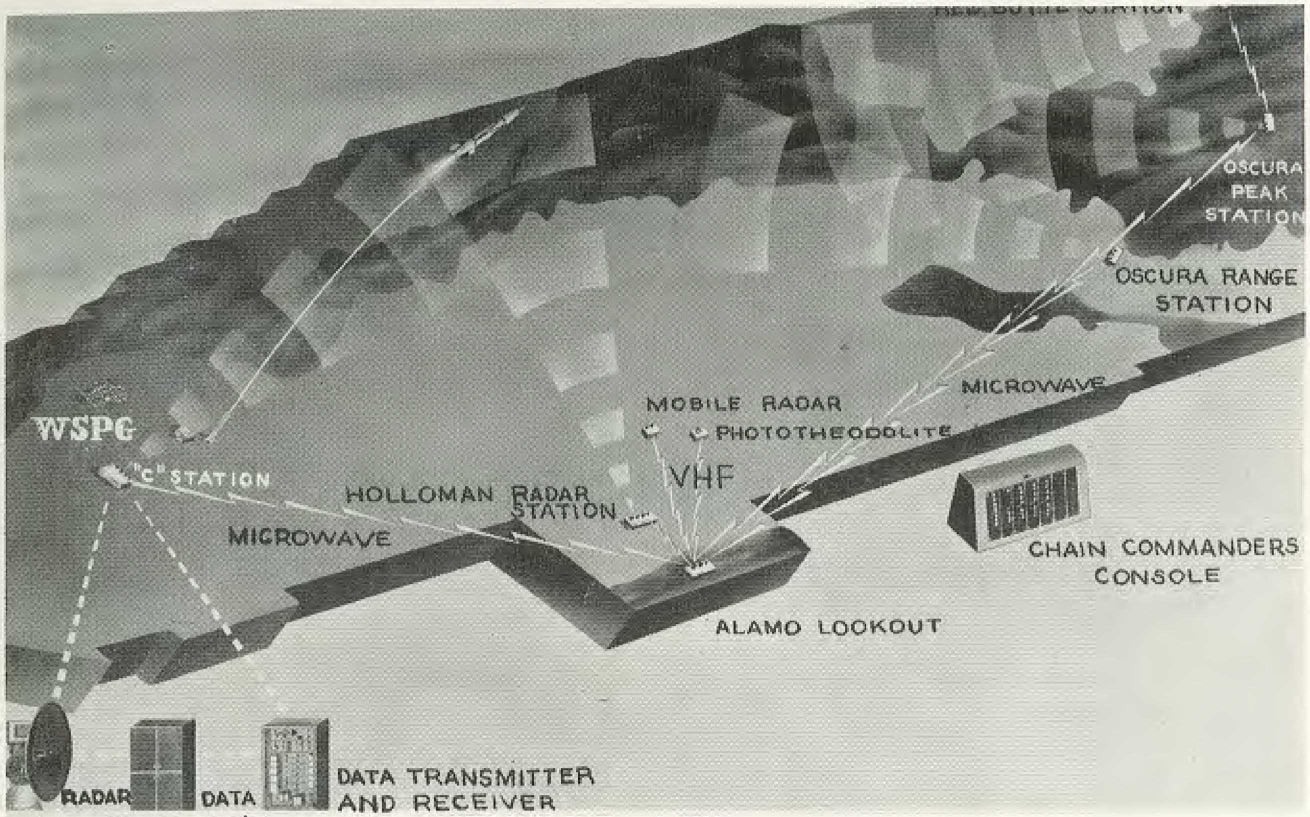


A schematic drawing of the principle of chain radar operation, showing the location of chain stations at WSPG, plus the microwave relay links. The chain commander can, by consulting his console, put any radar station in control of the chain to feed data all over the WSPG range.

D.C., analog type, Coordinate Converter. The VHF receiver reproduces the original 1200 cycle tone burst at its output and feeds it to the TSQ-1 receiver. The TSQ-1, a binary-to-analog converter, which is equipped to handle 16 digits in the same manner as the transmitter, accepts the 1200 cycle tone burst, applies station parallax digitally, and produces three D.C. voltages proportional to the x, y, and z position of the missile with respect to the receiving station. These three voltages along with a D.C. reference voltage are then fed to the D.C. Coordinate Converter. The Coordinate Converter transforms the incoming data from cartesian to polar coordinates, applies proper scale factors, and produces the three necessary shaft rotations. Each shaft rotation is presented at the output in the form of a D.C. voltage and a synchro position.

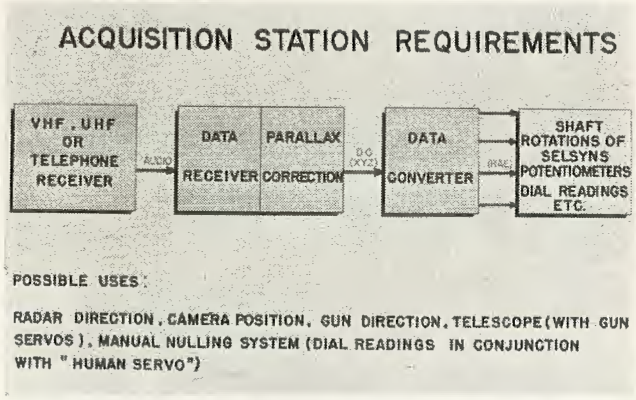
Incidentially, this D.C. Coordinate Converter, developed at Evans Signal Laboratory, has not been conclusively field tested. However, its conversion accuracy appears to be within specifications requiring that the static angular standard deviation should not exceed 1 mil, and under dynamic conditions, should not exceed 2 mils at shaft speeds up to 6 rpm; that static range accuracy should be within 150 yards; and that velocity lag should not exceed 60 yards at velocities up to 20,000 yards per second. The Coordinate Converter also has facilities for adding parallax should it be used with instruments not containing this feature. However, at the proving ground, it is not normally used for parallaxing data.

Outputs of the D.C. Coordinate Converter are normally fed to two types of optical instruments: the IGOR (Intercept Ground Optical Recorder) and the Askania Cine-Theodolite. The IGOR is used to photograph the interception of an aerial target by an anti-aircraft missle. The Askania is used to photograph missiles throughout flight. Both instruments make use of telescopic lenses.

The IGOR cameras receive synchro data from the D.C. Coordinate Converter. To make this possible, cameras on the IGOR are modified to house two synchros which receive azimuth and elevation data respectively. Since circuits for both types of data are identical, only the operation of the azimuth circuit need be explained.

The stator of the azimuth synchro on the camera is wired in parallel with the stator of the output synchro at the converter. The rotor of the camera synchro is geared to the camera azimuth drive shaft. A resistance bridge containing a galvanometer is across the output of this rotor. This circuit is capable of detecting small differences in shaft rotation between the two synchro rotors. The galvanometer indicates the magnitude and direction of the error between the two shafts. Thus, the galvanometer readings indicate to the operators whether the IGOR is on target.

The means used to feed acquisition data to Askania cine-theodolites is much the same as in the case of the IGOR, except that the synchros in the camera are re-



placed with linear potentiometers. Also, the Askania cameras receive D.C. voltage from the Coordinate Converter representing shaft rotation.

A systems evaluation program has recently been begun on the acquisition equipment described in this article. Sufficient data has not yet been gathered to justify conclusions as to over-all accuracy of the acquisition system. However, evidence that the system is serving its purpose very well does exist. The Optical Group of the Flight Determination Laboratory, White Sands Proving Ground, is continuing to make use of this system as an aid in optically instrumenting many types of missile programs.

Although this fact and other evidence indicate that the system is doing a very adequate job at White Sands Proving Ground, it is probable that additional work would be necessary to adapt it to longer range proving grounds. For example, range capability would have to be extended, and increased accuracy would be required. In addition, it would be desirable to devise servo driven optical instruments, thus eliminating the need for human operators, particularly in hazardous or isolated areas. • • •

A Signal Corps technician checks the recording instruments where a continuous record of chain operation is plotted, enabling engineers to assess the operation of the system.

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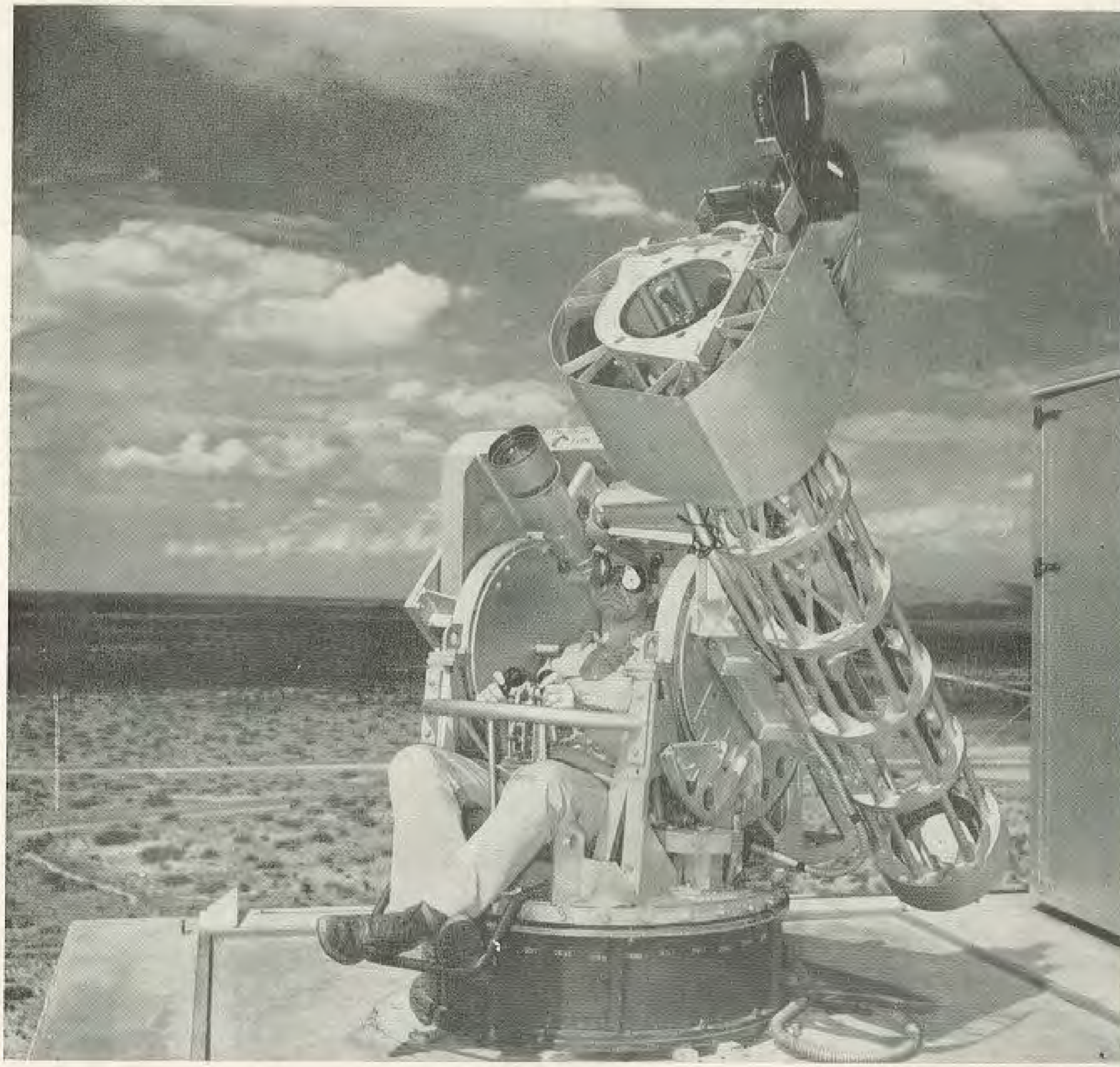
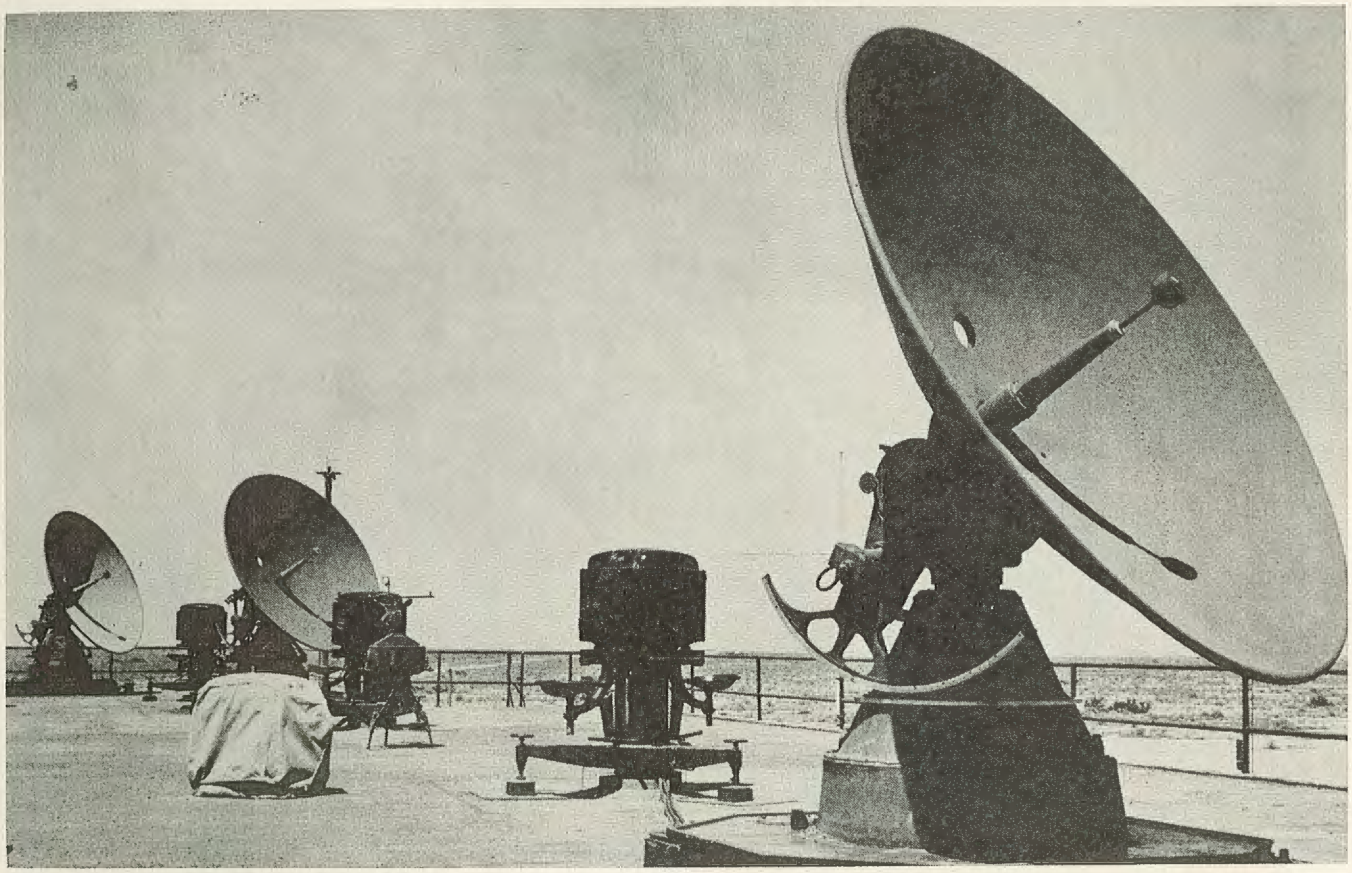


TRACKING
TELESCOPE III
(U. S. Army Photo)

Electronic Instrumentation



Fundamentals of RADAR

by
DUDLEY M. COTTLER
White Sands Signal Corps Agency
White Sands Proving Ground

Many sciences band together to permit a guided missile to go aloft in search of its target. Not least among these is the electronic science of radar which can not only guide a missile but also perform the important function of showing human beings where the target is . . . and where the missile is!

THE term radar is one which was coined from the expression "Radio Detection And Ranging." Successful radar systems were developed independently in the United States, England, France, and Germany during the years 1930 to 1940. It was Heinrich Hertz however, who in 1886 discovered radio waves and established that these waves had optical properties identical to ordinary visible light. He also showed that radio waves are reflected from solid objects. In 1922, Marconi championed the use of short waves for radio detection. In 1925, the pulse-ranging technique was put to use by Breit and Tune of Carnegie Institution of Washington for the measurement of the ionosphere heights. The next logical step in the sequence was the development of radar. In November, 1938, a radar set later to be known as SCR-268, designed and built by the Signal Corps Laboratories, was tested by a Coast Artillery Board for control of antiaircraft guns and searchlights. In early 1939, the Naval Research Laboratories were giving extensive fleet tests to radar equipment installed on the USS New York. The British, in 1936, began an installation of five early warning radars near London which were based on an experimental radar system suggested by Sir Robert Watson-Watt. Tremendous impetus to radar development was given by the onset of World War II. Development of new equipment still continues.

A simplified radar set is made up of some fundamental major components. They are an antenna or antennas, a transmitter, a receiver, an indicator and a timing device. (See Fig. 1 and 2).

With this equipment we are interested in making at least two measurements for search radar equipment, namely, range and azimuth to a target; the third measurement of elevation or height being furnished by an auxillary radar known as a height-finder.

However, a gun-laying radar or precision tracking radar must measure all three parameters, namely, range, azimuth angle, and elevation angle.

The measurement of range is primarily based on the velocity of propagation for radio waves. If we transmit a very short burst of radio frequency energy and measure the elapsed time required for this burst of energy to reach a target and be reflected back to the radar set, we can then determine the total distance of the round trip, if we assume a propagation velocity. The distance to the target would then be, of course, half the round trip distance. The normal propagation velocity used is $C = 3 \times 10^{10}$ cm/sec, which is the free space value. However, the problem of tracking in the earth's atmosphere or through it as the case for rockets requires a different value for precision range measurement. This variation is due to the changing dielectric constant caused usually by a change of moisture content with height. As a result we get refraction, again an optical characteristic, hence a slightly curved radar beam which yields a larger range measurement than the actual range. This effect can be compensated for in the time generator if we use a new average propagation value. The methods of connection for precise range measurement will be covered in a later article. Since the variation occurs in the fourth decimal place, we will continue to use 3×10^{10} cm/sec for this article. This value is also equal to 328 yards/microsecond for the round trip or 164 yards/microsecond for the one-way trip. Then numerically if the elapsed time between transmission of energy and receipt of the echo is 10 microseconds, then the target is 1,640 yards

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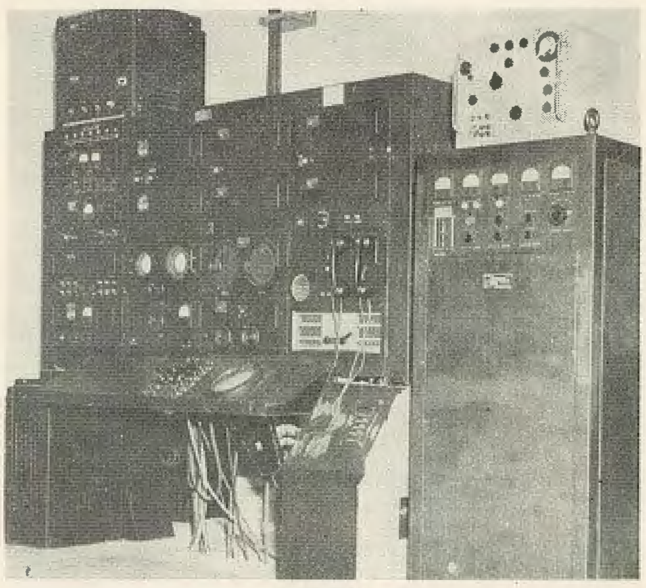

A typical radar operator's console with all controls, screens, and power supplies grouped together for easy operation and maintenance. (U. S. Army photo.)

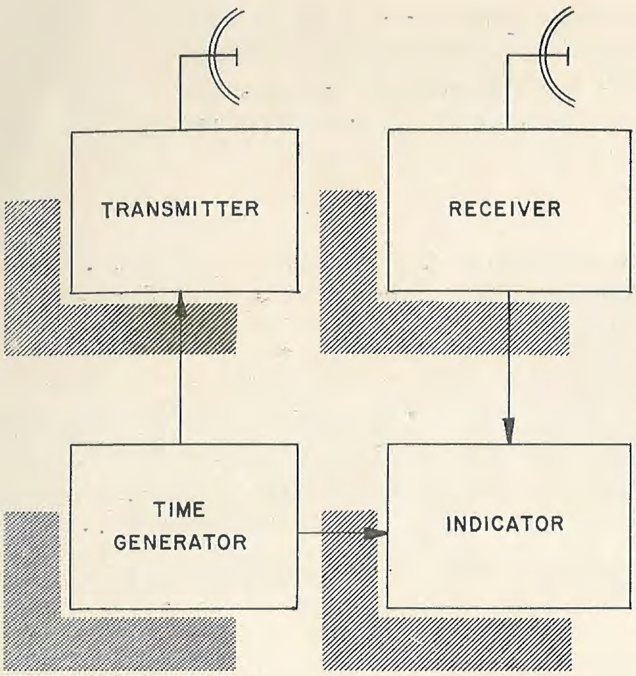

Fig. 1: The block diagram of a radar system with two separate antennas, one for transmitting and another for receiving the reflected pulse.

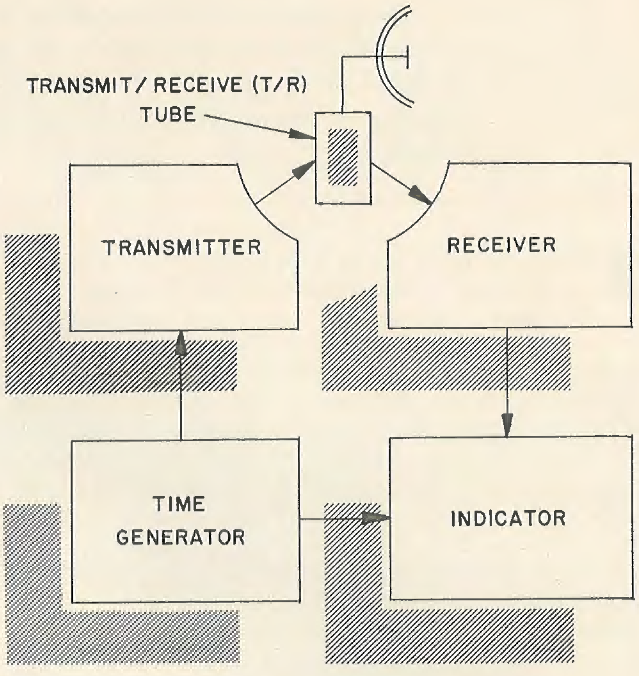

Fig. 2: A common type of radar system using only one antenna for both transmitting and receiving. The t/r tube switches the antenna at a rapid rate, allowing it to send a pulse and then pick up the reflected echo.

away. This distance can be displayed on the indicator which contains a cathode ray tube (CRT) and associated circuitry. In one particular type of scanning known as "A scan", the beam of the CRT is caused to begin a sweep from left to right at the instant a transmitted pulse is sent out by the transmitter. The sweep crosses the face of the tube at a uniform and predetermined rate. When the echo is received by the receiver, the beam of the CRT is deflected from its horizontal course for the duration of the received signal. The CRT normally has a scale on a bezel or electronic range machine calibrated directly in range so that the operator can read the range at anytime during the tracking operation. (See Fig. 2).

The transmission of pulse energy is a cyclic process and is known as the pulse repetition frequency or PRF. The PRF normally determines the maximum range at which the measurement of range can be effectively accomplished without ambiguity. If a second pulse leaves the transmitter and a new sweep starts (the sweep start and transmitted pulse are normally synchronized by the timing generator) prior to the return of the echo from the first pulse, then an incorrect range measurement will be made unless the operator can interpret the indicator reading. There are special circuits which can be used to blank out unwanted information, but are not incorporated in our simplified radar set. The duration of the burst of RF energy from the transmitter is known as the pulse width. This value is one microsecond for long range search type radar sets. The widths of the pulse is determined by a number of factors.

The longer the pulse duration, the greater the quantity of energy transmitted in one pulse for a given peak power output. Therefore, the capability of the particular transmitter tube will be the limiting factor on energy transmitted. The pulse width, peak power, and pulse repetition rate all enter into computation of average power consumption and transmission of the transmitting tube. Normally low repetition rates (on the order of 100 to 400 pulses per second) are used in search systems to allow for long-range tracking. The length of pulse duration will also affect the detection of very close targets. A 10 microsecond pulse width will prevent the detection of a target within 1,640 yards, since some energy from the transmitter will block the receiver for that time. Actually this undetectable range is usually higher because the receiver will not recover to full sensitivity immediately after the transmitted pulse. Therefore, for gun laying equipment, the pulse duration is usually less than one microsecond to allow for tracking of close targets.

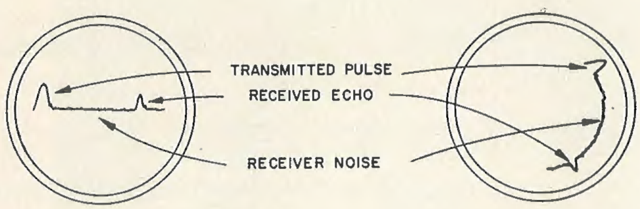

Fig. 3: An "A" scan on the left, one of the earliest types of radar presentations. On the right, a "J" scan or circular scan, a later innovation.

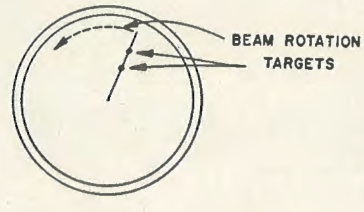

Fig. 4: The "PPI" or "Plan Position Indicator" scan.

We now have been able to measure range by the use of a time measurement. If our time generator contained a 100,000 cycle per sec. oscillator then the period for one cycle would be 10 microseconds or a radar equivalent of 1,640 yards. By causing the CRT beam to move across the face of the tube in one cycle or 10 microseconds we have been able to set up a time or range base of 1,640 yards. If we divided this sweep or base into 300 equal parts we would then be able to measure 1/300 of 1,640 yards or approximately 5 yards, which is equivalent to 1/30 of a microsecond.

Our next problem is to measure bearing or azimuth angle. The relationship of radio waves and optics have led the way toward the design of highly directional antennas similar to the beam produced by a flashlight. The use of ultra high frequencies have reduced antenna sizes to physical realities. A ten foot parabolic reflector at 3000 megacycles has a beam width of approximately 2½ degrees measured at the half power points of the antenna pattern. This means that the antenna must be pointing at a target within the 2½ degree beam width before an echo can be received. The strongest echo is received when the antenna points directly at the target and decreases in signal strength as the antenna moves off the target. Thus the bearing of the target can be determined by noting the bearing of the antenna at the time the strongest return signal is received. One of the basic methods for making this angular measurement makes use of an indicator called a Plan Position Indicator or PPI. By causing a sweep to start in synchronization with transmitted pulse at the center of the CRT and move toward the circumference radially, we can have a visible bearing indicator. The presence of a target is indicated by intensification of the beam at the range from the center equivalent to the position of the target. The radial CRT beam is caused to rotate about its center in synchronization with the antenna so it rotates in the horizontal plane in order to scan a 360° area about its center. (See Fig. 3). Intensification of the CRT beam at any point on its length while it is being rotated indicates the presence of either an airborne or ground target at that bearing depending on the type of antenna being used.

In the event that a radar set has an antenna radiating pattern which is fan type; i. e. narrow in the horizontal plane and wide in the vertical plane (typical of search sets) or let us say 2° in horizontal plane and

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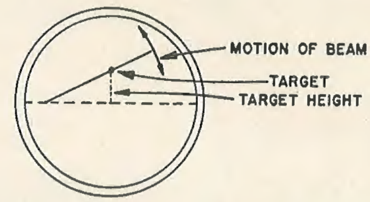

Fig. 5: The Height Finder Scan used to determine both the distance and altitude of a radar target.

30° in vertical plane it would be impossible to determine elevation angle of the target to better than 30° accuracy. If we have an auxilliary radar set with an antenna which has a vertical beam width of 2° and a horizontal beaw width of 30°, then we could scan this antenna in the vertical plane as compared to the previous antenna which scanned in the horizontal plane. By using the same technique as in the PPI, we now have a Range-Height Indicator or RHI. The starting point of the beam is shifted off center to allow more CRT beam length. (See Fig. 4). This type of radar set is known as a Height Finder.

Gun laying radar sets must be capable of measuring bearing or azimuth angle and elevation angle with one antenna. This is accomplished by the flashlight type beam produced by a full parabolic antenna similar to the type described previously which has a beam width of 2½° in horizontal and vertical planes. Since the signal strength return from the target decreases if the antenna goes off target in either azimuth or elevation, we have a suitable source of information which can operate a servomechanism designed to drive the antenna in the direction of maximum received signal in both azimuth and elevation planes.

We have now discussed the basic parameters which are obtained from a radar set normally, range, azimuth and elevation. Further articles will cover applications of the radar set to electronic instrumentation in the rocket field including capabilities of radar in terms of accuracy of measurements.