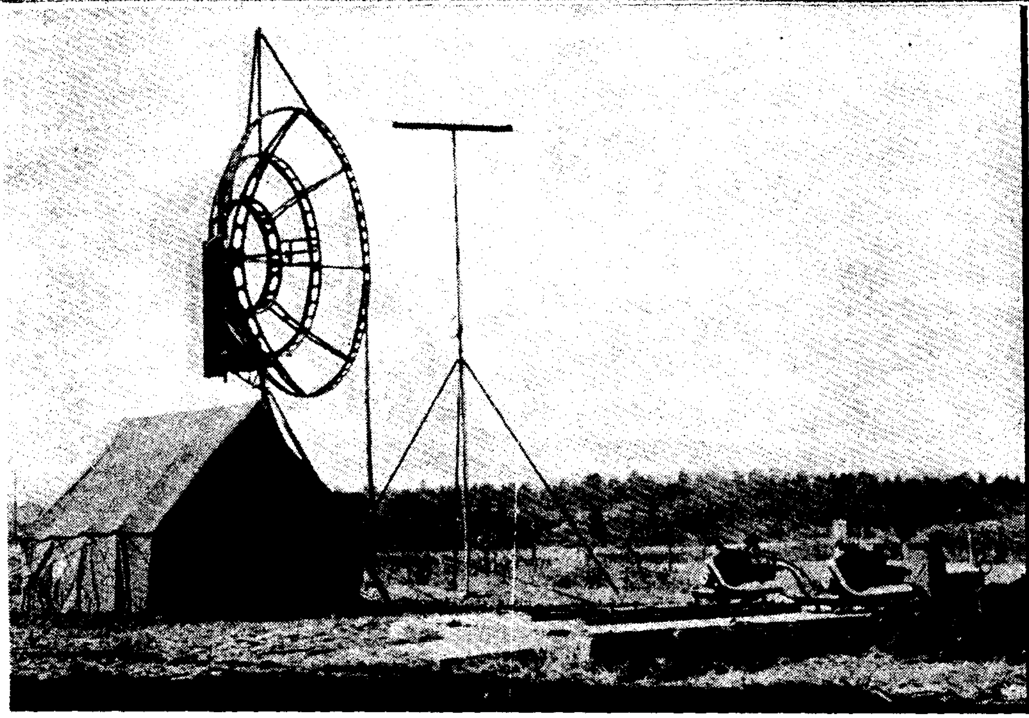

FIG. 1—Typical setup of the TPS-3 radar

RADAR

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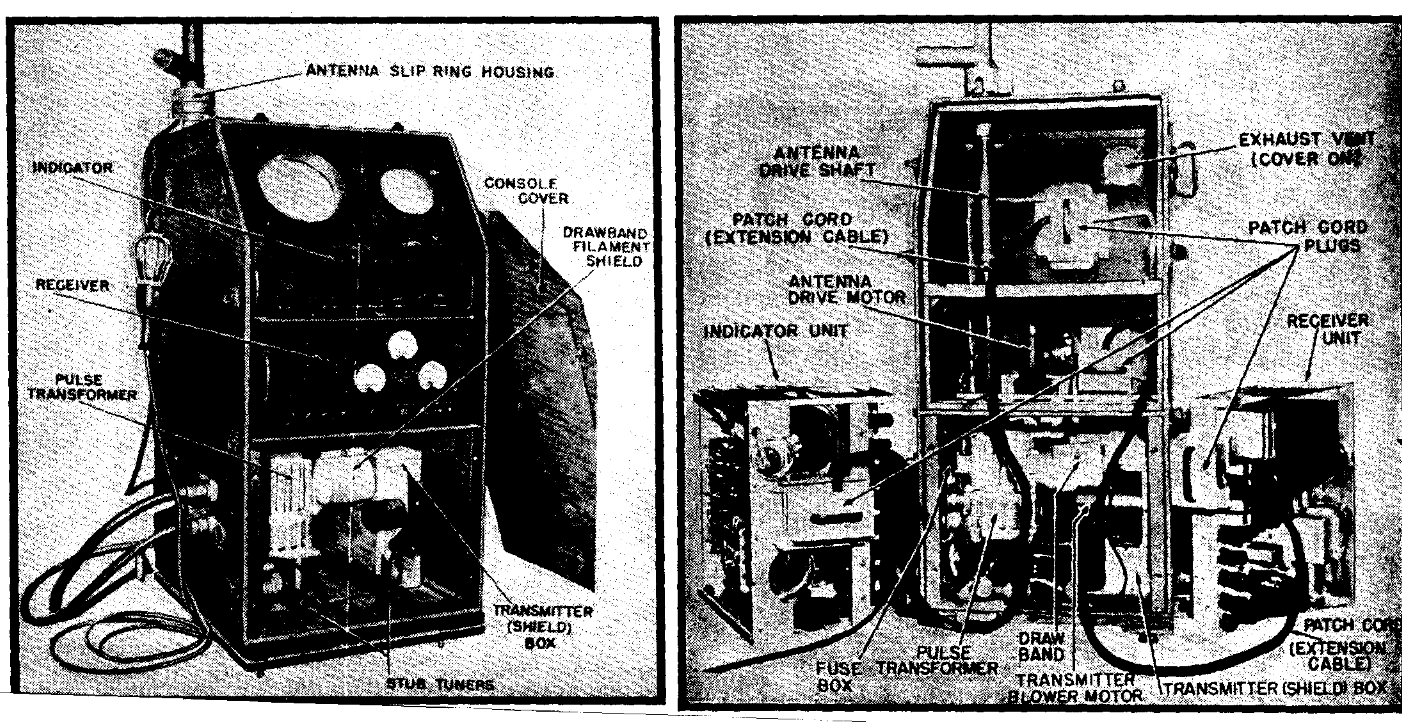
PRIOR TO AMERICA'S entry in the war, available radar equipment operated on 100 and 200 mc. This equipment had been set up at the Panama Canal, but it was felt that additional measures were necessary to avoid surprise raids by low-flying aircraft against which the existing radars were least effective.

A plan was set up to construct a small number of radar sets which were to be mounted on small boats anchored in the vicinity of the Canal entrances. It was felt that in these advance locations they would provide a radar screen making surprise raids impossible. After considerable experimentation, it was decided to construct these sets to operate on a frequency of 600 mc and, accordingly, a model was built up of components already developed by the Signal Corps and an installation was made on the motor vessel "Nordic."

Tests of this equipment were so successful that it was immediately apparent that extremely long ranges and low angle coverage were obtainable in this frequency band even from a set only 15 feet above sea level, and that with the components available a very lightweight medium-warning radar could be constructed. At the request of Col. William Cody and others of the AAF, the Signal Corps was asked to repackage this equipment into a lightweight assault-type radar that could be both air transportable and hand-carried and have a range of well over 100 miles on bombardment aircraft.

To prove that the first laboratory model was air transportable it was flown from Newark Airport to Florida on February 27, 1943, in a B-18 and was set up and operating

FIG. 2—A view of the console and, at the right, of the console with the indicator and receiver units removed, showing the maintenance cable system



ON 50 CENTIMETERS

Combining high power with light weight, the TPS-3 radar detects approaching bombers at 120 miles, yet can be carried by hand and set up by a four-man crew. This first of two articles on the equipment furnishes an important example of 600-mc technique

at the test site on March 1, 1943. The next two weeks were spent in calibrating and determining operational performance of this equipment in comparison with three other lightweight equipments. At the conclusion of the tests it was definitely determined that the AN/TPS-3 (then known as the 602-T8) had a range in excess of 110 miles and could be mass-produced. This performance was sufficient to indicate an immediate combat requirement. The model was flown back to Camp Evans, Belmar, N. J., on March 18, 1943. The engineers responsible for the design of the equipment took all of the information available to a manufacturer, along with the model, so that production might start as soon as possible. Nine hundred sets were ordered, and the first started coming off the production line about a year later.

To cover the interim period it was necessary to produce on a crash basis a small number of sets for immediate air shipment to critical theater areas. Accordingly, it was decided to construct 12 models within the Camp Evans Signal Laboratory. These 12 models were completed in three months with the aid of GI crews who later formed the operating teams for the equipment and were flown directly to the theaters.

electronics
WAR REPORT

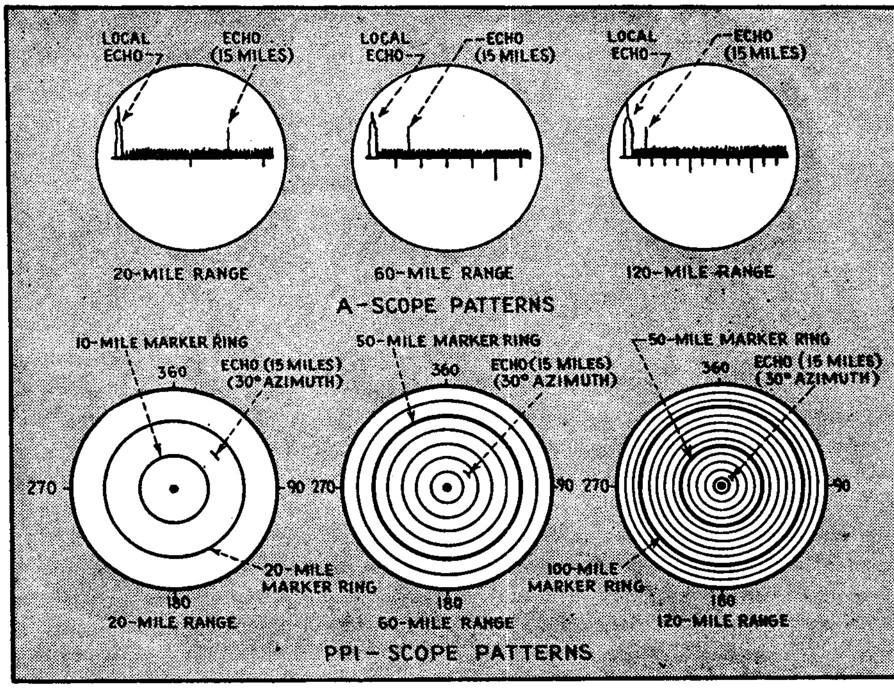


FIG. 3—A-scope and PPI-scope patterns

The production models of this set found their way to all the theaters of the war. The first 25 were produced in time to take an active part in the Normandy invasion.

General Description

The AN/TPS-3 was designed chiefly for medium-long-range early warning against aircraft. It is composed of units which are small and light enough to be either transported by air or hand-carried. Its total weight (including spare parts and power units) when packed for air transport is 1200 lbs. Maximum weight of any single component is 200 lbs. The set can be completely assembled and put on the air by a crew of four men within thirty minutes of arrival at a site. A typical installation is shown in Fig. 1.

The major component is a console which houses the receiver, the transmitter, the indicator, part of the modulating system and part of the r-f system. This unit is shown in Fig. 2. The console is normally housed in a tent which is provided with the set and acts as both a lightproof covering and a shelter. A section of transmission line with very heavy steel walls plugs into the top of the console and forms a pedestal upon which a 10-ft parabolic-reflector antenna system is mounted. This section of transmission line is braced by two wooden struts whose ends are buried in the ground. The top of the parabolic reflector is further secured by three guy wires and the entire structure is so made that the antenna can rotate continuously in either direction or be inched slowly for accurate azimuth orientation.

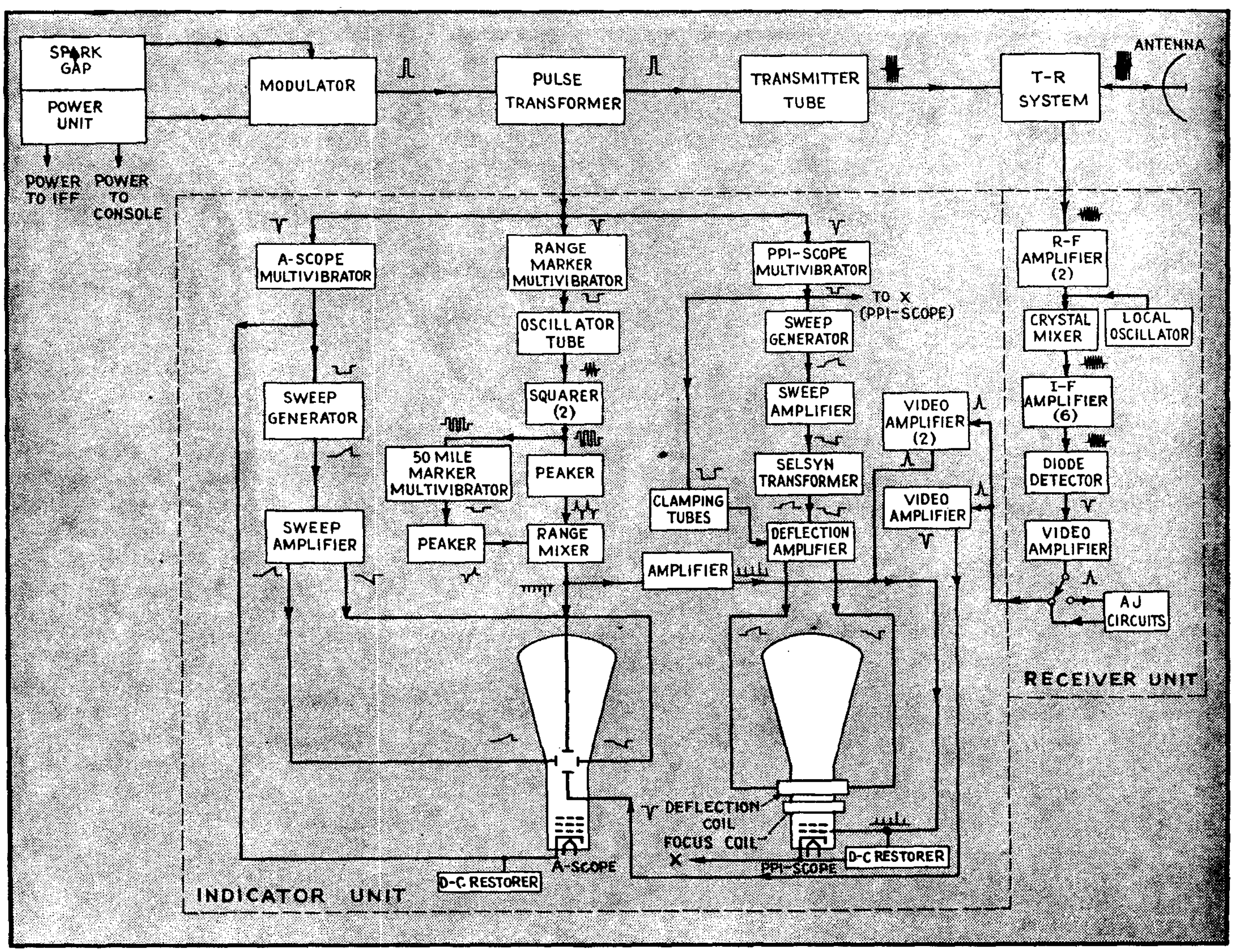
The power unit and modulator are kept 50 ft from the tent and are connected to the console by means of cables. The power unit is a single-cylinder gasoline engine driving a 400-cycle alternator and a d-c generator mounted on the same shaft. The radar components of the set use 400-cycle power, thus effecting a great saving in weight and size. The d-c generator produces 28 volts that is used to drive fan motors and the antenna turning motor.

Unlike the SCR-268 previously described in ELECTRONICS, the AN/TPS-3 provides only range and azimuth information. This information is displayed on the indicator on two cathode-ray tubes used in an A-scope and in a PPI-scope. The A-scope resembles an ordinary test oscilloscope and presents a horizontal sweep line with the signal appearing as vertical deflections along this line. The PPI presentation employs a sweep line which starts at the center of the tube and sweeps outward toward the edge. This sweep line is made to rotate about the center of the tube in synchronism with the rotation of the antenna and therefore indicates the position of the antenna. Signals are applied to this tube by intensity modulation so that they appear as bright dots on a dark background. Both of these tubes indicate the range of the target by the distance of the signal from the beginning of the sweep line. The PPI tube measures azimuth by noting the position of the sweep line when a signal appears. The two forms of presentation are shown in Fig. 3.

The pulse rate of the set is 200 pulses per second. The interval between pulses is 5000 microseconds. Using a sub-multiple of the alternator frequency for timing the pulses provides a clear and steady picture on the indicators with a minimum of filter weight. The transmitted radio-frequency power and the sensitivity of the receiver are such that the radar set will "see" a medium-size aircraft at 120 miles. The total time necessary to cover this 120 miles is approximately 1300 microseconds, and this amount of time is all that is used on each sweep of the cathode-ray tube. The remainder is dead time.

Figure 4 is a block diagram showing the flow of signals through the equipment. The modulator, in conjunction with a rotary spark wheel, mounted on the power unit, produces high voltage d-c pulses which are synchronous with the 400-cycle power supply at half its frequency.

FIG. 4—Block diagram of the complete TPS-3 radar



These pulses are applied to the transmitter, which converts them to pulses of 600-mc energy. They are then radiated from the antenna, which is coupled to the transmitter by means of a coaxial line. When one of these pulses strikes an object some of the energy is reflected. Measurement of range is facilitated by injecting into both cathode-ray tubes a series of markers spaced 107 microseconds apart, and also synchronized with the transmitted pulses. These markers represent 10-mile intervals and provide the scale by means of which the range is measured.

Antenna and Propagation

The antenna used with the AN/TPS-3 is a 10-ft parabolic reflector with a radiator at its focus. This produces a free-space beam which is about 10-deg wide at its half-power points. Consider such an antenna situated at height *h* above a plane earth as shown in Fig. 5. Assume a reflecting target at point *p* at a great distance from the antenna. The antenna will appear as a point source as seen from *p*. The radiation pattern shows the free-space pattern of the antenna. It is obvious that energy can reach the point *p* from the antenna by traveling two paths, one directly from the antenna and the second reflected from the ground. These will be called the direct ray and the reflected ray. The angle made by the direct ray with the horizontal is almost exactly equal to the angle made by the reflected ray and the horizontal. Therefore, the amount of energy reaching point *p* along each of these two paths will be almost equal. However, because the distances along the two paths are not equal, the phase of the direct ray and the reflected ray at point *p* will in general not be the same. Therefore, the total energy at point *p* is the vector sum of the energies reaching it along the direct path and reflected path.

In order to determine this total energy it is not necessary to know the length of each path but merely the difference between the path lengths, which will determine the difference between the phases of the direct and reflected rays at point *p*. It may be assumed that the earth is a perfect reflector. At the point of reflection there is a 180-deg change of phase. Because radio energy travels with the speed of light, 180-deg phase differences occur every half-wavelength in space. Therefore, in order for the direct ray and reflected ray to arrive in

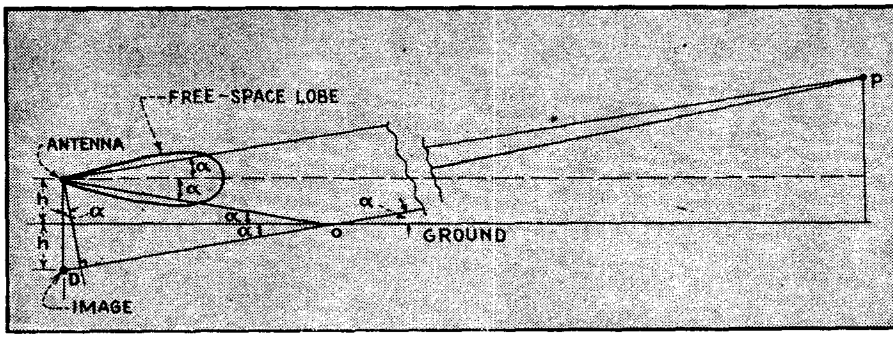


FIG. 5—Determination of reflected energy maxima and minima

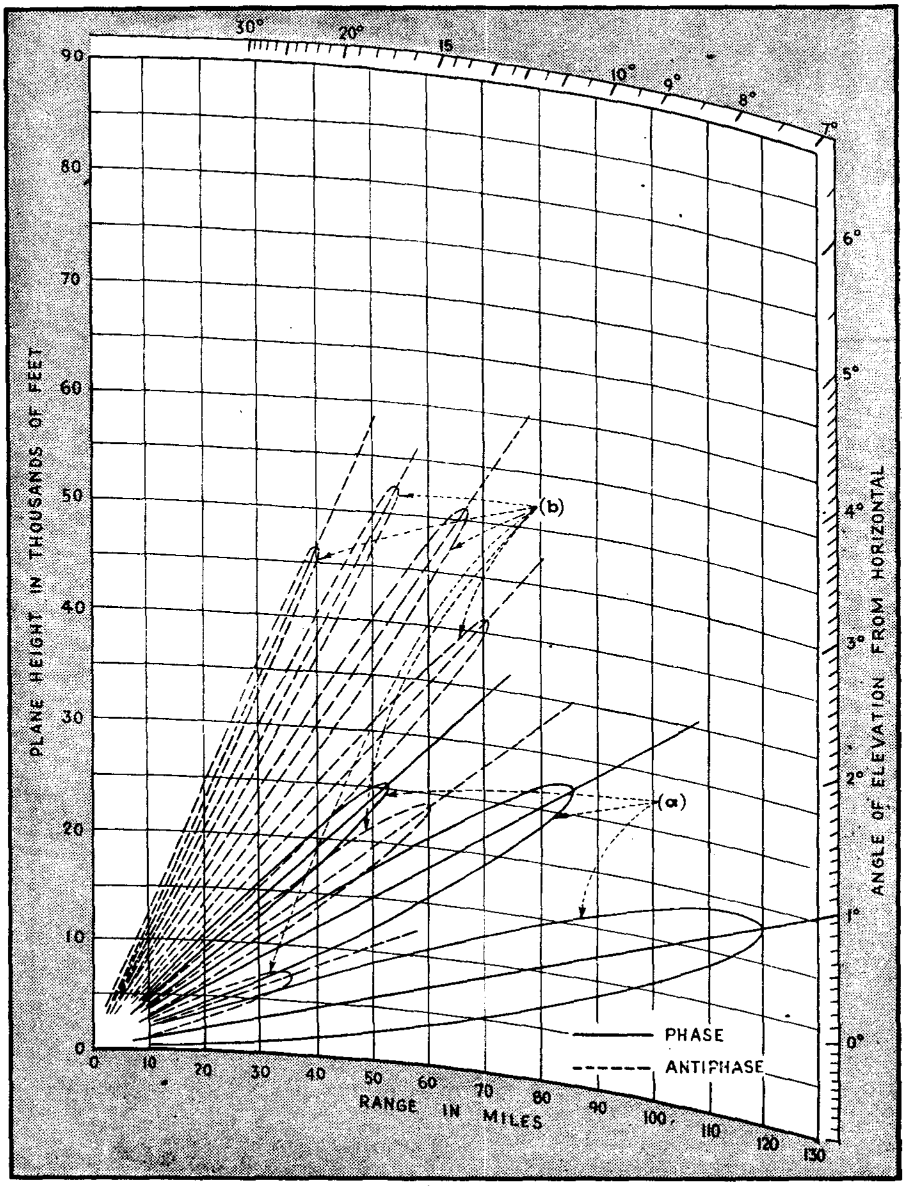


FIG. 6—Complete coverage pattern, with the antenna horizontally polarized and having a 24-ft effective height

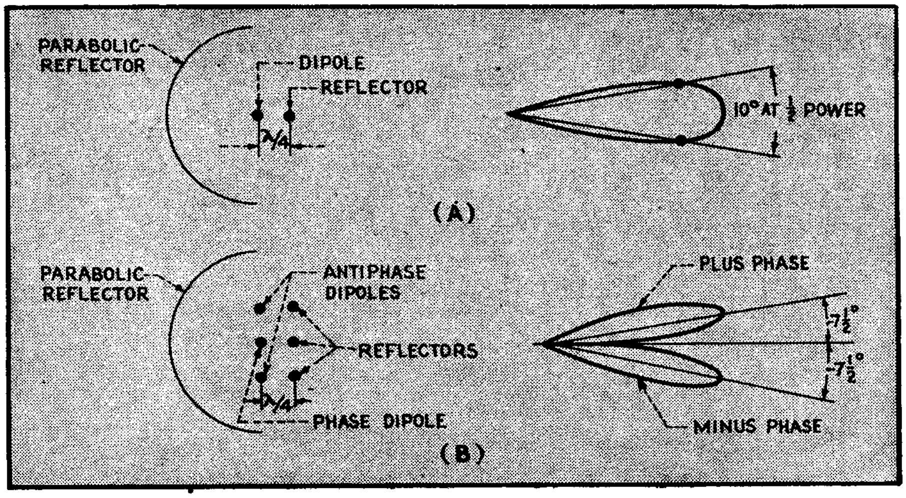


FIG. 7—Free-space patterns for the two TPS-3 radar antenna connections

phase at point p and add algebraically the path difference must be a half wave. Whenever the path differs from a half wave or some odd multiple of a half wave, the total energy at point p will be slightly less than the sum of the direct and reflected ray. Whenever the path difference is an even multiple of a half wave, the energy at point p will be zero, because the direct and reflected wave arrive 180 deg out of phase.

To find this path difference it is only necessary to extend line op through the point of reflection to a point directly under the antenna. It can be seen that the extension of op will intersect a vertical line through the antenna at a point the same distance below the surface of the earth as the antenna is above the surface of the earth. This point is called the image antenna and can be considered to be radiating energy toward point p with the same intensity as the true antenna but opposite in phase. A perpendicular is then dropped from the antenna to the extension of op and the distance D then represents the path difference. While there may be some objections to this procedure on geometrical grounds the distance op is so large compared with $2h$ that for all practical purposes the results are correct.

If point p is moved up and down the vertical line it will be seen that the distance D varies greatly, passing through several odd and even multiples of half-wave lengths. This means that the distribution of energy along the vertical line through p will pass through maxima and minima. The first maximum will occur when D is equal to a half-wavelength. The relationship between the angle of this first maximum and the height of the antenna for the small angles involved is then $\alpha = \lambda/4h$ since $D = \lambda/2$ for maximizing, where λ is the wavelength and h the height of the antenna. The first minimum occurs where $D = 1$ wavelength and will therefore be twice the angle of the first maximum. The resulting complete radiation pattern is shown in Fig. 6 at (a). The succeeding lobes get shorter and shorter because although each one of them is the sum of direct and reflected ray, each of these rays gets smaller and smaller in energy value as the angle α is increased and finally reach zero when the direct and reflected paths are tangent to the free-space radiation pattern. This means that the envelope of the complete radiation pattern will be the same as the free-space radiation pattern, although the length of the longest lobe will be twice the length of the free-space lobe because it is the sum of two rays, each of which is nearly equal to the maximum energy in the free-space radiation pattern.

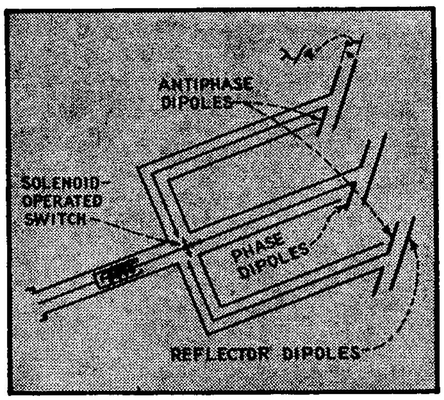


FIG. 8—Triple-head antenna system

From the complete radiation pattern it can be seen that there are large areas where no radio energy is present. This would allow enemy aircraft to fly into these areas without being detected. Many schemes have been used to overcome this deficiency in early warning radar sets. The one adopted for the AN/TPS-3 is known as the phase-antiphase system. Looking again at Fig. 5 it can be seen that if point p is at a minimum and by some means the reflected ray could be moved 180 deg out of phase with the direct ray, point p would immediately become a maximum. This phase shift is the basis of the phase-antiphase system. The antenna is arranged so that by means of switching it can produce either the free-space pattern shown in Fig. 7A or the free-space pattern shown in Fig. 7B; in the latter case the upper lobe is 180 deg out of phase with the lower lobe.

The antiphase radiation pattern is shown in Fig. 6 at (b). Here the lobes are small at the low angles, pass through a maximum, and are small again at the high angles. This occurs because the energy in the free-space pattern is low at small angles, reaches a maximum at about 7½ deg, and then decreases again. Superimposing the phase and antiphase coverage patterns gives a pattern of the total coverage of the radar set. Contours can be drawn representing the loci of point where the energy is just sufficient so that the amount reflected from a medium-sized aircraft will be detectable by the receiver. Such contours represent the maximum range.

From the discussion on formation of maxima and minima it can be seen that the coverage diagram can be greatly altered by changing either the frequency or the height of the antenna. The height of the antenna is usually restricted by mechanical considerations and features of the terrain. Therefore, to get low-angle coverage as high a frequency as possible is used. That is why 600 mc gives more efficient low-angle coverage than the lower-frequency radar sets. Higher frequencies would give still better low angle coverage.

Radio-Frequency System

As stated previously, the AN/TPS-3 employs a 10-ft parabolic reflector. It is also provided with two different antenna feeds that can be used interchangeably. One is a simple halfwave dipole at the focus of the parabolic reflector, with a parastically excited halfwave reflector a quarter wave in front of it. This combination produces a single free-space lobe such as that shown in Fig. 7A. The purpose of the reflector is to prevent direct radiation from the dipole, and results in an increase in gain.

The second type of antenna feed is the one used to produce phase and antiphase patterns. This array consists of three dipoles spaced vertically a quarter wave apart in the plane of the focus, with center dipole at the focal point. Each one of these dipoles has its associated half-wave parasitic reflector a quarter wave in front of it. These three dipoles are so arranged that either the center dipole alone or the two outside dipoles may be driven. When the center dipole alone is driven the result is a single free space lobe such as shown in Fig. 7A. The outside dipoles are so connected that they are fed 180 deg out of phase, which is very simply arranged by connecting the left side of the upper dipole to the center conductor and the right side of the lower dipole to the center conductor and then feeding the pair in parallel from a common point. When these two dipoles are driven the result is a split pattern such as that shown in Fig. 7B, with the upper lobe 180 deg out of phase with the lower lobe.

The switching between the phase dipole and the antiphase dipoles is done by means of a solenoid-operated plunger which is controlled from a switch on the panel of the radar set. The plunger merely connects the center conductor of the transmission line to either the center dipole or the outside dipoles as shown in Fig. 8.

The antenna radiators are connected to the transmission line by means of a 50-ohm rigid coaxial line. In order that this line be flat, or without appreciable standing wave, every precaution is taken to match the antenna radiator to this line. This is done by means of quarter-wave transformers consisting of sections of inner conductor of different diameter from the diameter of the inner conductor of the transmission line itself. By properly choosing the diameter and position of such a quarter-wave transformer, the antenna radiator can be matched to the transmission line.

The requirement of a flat line precludes the use of insulating beads as supports for the inner conductor, since many beads in the line would produce reflections and, therefore, standing waves. Instead of beads, quarter-wave stubs are used to support the inner conductor. A section of transmission line, short-circuited at one end and a quarter-wave long, has an extremely high impedance looking into the open end. When such a section is shunted across the line it does not produce any appreciable reflection. Such quarter-wave stubs, spaced at intervals along the transmission lines, can be used to support the inner conductor. However, since a stub is a sharply tuned resonant circuit it can be used only at one frequency. The AN/TPS-3 operates over a band from 590 to 610 mc, so that provision must be made for allowing the transmission line to pass this band of frequencies without appreciable reflections. This is done by making the characteristic impedance of the support stubs 100 ohms as compared to 50 ohms for the transmission line proper.

Another interesting feature of this transmision line is the rotary joint. The antenna must be able to rotate continuously, so the transmission line must be broken at some point and means provided to pass energy from the stationary to the rotating side. This breaking is done

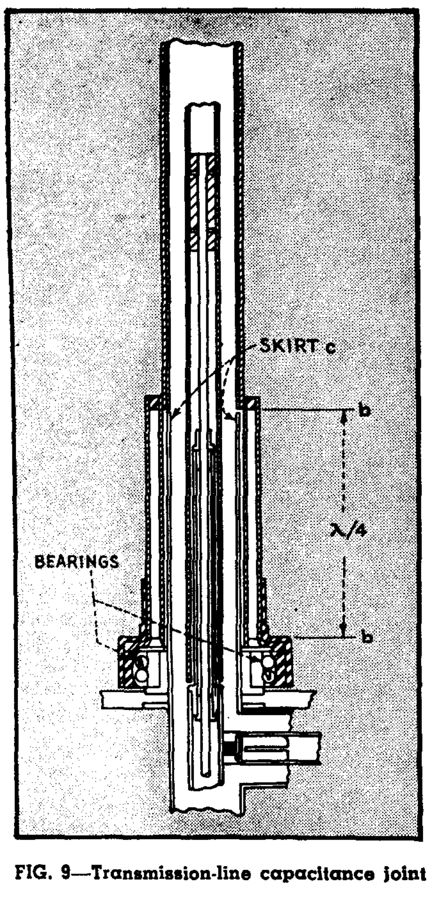


FIG. 9—Transmission-line capacitance joint

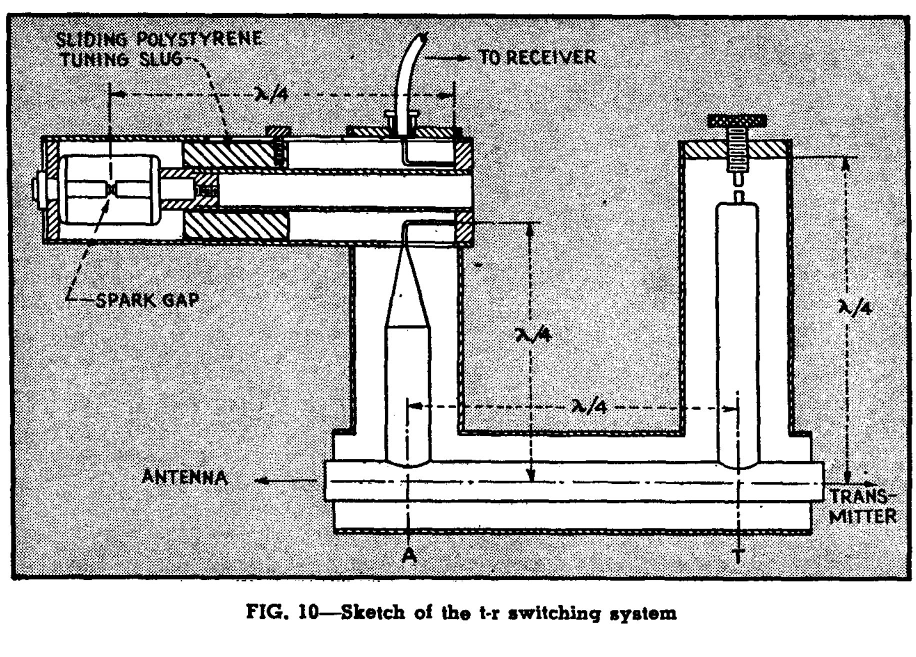


FIG. 10—Sketch of the t-r switching system

by means of a capacitance joint. A sketch is shown in Fig. 9.

The sections *bb* can be considered as forming a transmission line of very low characteristic impedance by themselves. Because this line is open circuited at the antenna end and is a quarter wave long, it is effectively short circuited at the transmitter end. The transmitter energy therefore passes from the stationary to the moving part. The function of the skirt *c* is for broad banding and also allows the bearing to be placed at a zero-current point. This bearing carries the total thrust load of the super-structure.

The inner conductor functions in essentially the same manner except that it is unnecessary to fold the line back upon itself in a skirt as in the case of the outer conductor. In the inner conductor, the ¼-inch rod extending beyond the rotary joint itself performs the same function as the skirt in the outer conductor. Oilite bearings are used on the inner conductor.

Moving down the transmission line toward the transmitter, the next interesting feature is the t-r or transmit-receive system. As shown in the block diagram (Fig. 4) the transmitter and receiver are connected to the same antenna. Some means must be provided to protect the input of the receiver from the high power present in the line when the transmitter is operating and to prevent the received signal from being dissipated in the transmitter instead of flowing into the receiver. This is accomplished by a combination called a receiver-disconnect switch and a transmitter-disconnect switch. The combination of these two components is called the t-r system. A functional diagram is shown in Fig. 10. The transmitter-disconnect switch consists of a quarter-wave section of line with a spark gap in the end. When the spark gap fires, this quarter-wave section is short circuited and therefore presents a very high impedance at its open end. When the spark gap is not firing, the quarter-wave section is open circuited and presents a short circuit at the transmission line. A quarter wavelength toward the antenna from the transmitter-disconnect switch is the receiver-disconnect switch. This consists of a high-Q cavity a quarter wavelength long, short-circuited at one end with a spark gap between the center conductor and ground at the open end. The transmission line and the receiver are both coupled into this cavity by means of loops. When the spark in this cavity is firing, the cavity is detuned and the receiver is decoupled from the transmission line. When the spark gap is not firing the cavity is tuned and energy passes freely from the transmission line to the receiver.

The operation is as follows:

When the transmitter is operating, a high voltage is present in the line. This fires the spark gap in the transmitter-disconnect switch, which then acts as a quarter-wavelength short-circuited stub and has no effect on the line. A high voltage is also built up in the cavity of the receiver-disconnect switch, firing its spark gap as well. This effectively decouples the receiver from the transmission line. When a received signal comes down the transmission line from the antenna, the voltage is extremely small. This voltage is far too small to fire either the spark gap in the transmitter-disconnect switch or the spark gap in the receiver-disconnect switch. The transmitter disconnect switch will therefore be an open-circuited wavelength and will appear to be a short circuit at the transmission line end. A quarter wavelength toward the antenna, at the point where the receiver-disconnect switch ties in, this will be reflected as an open circuit. Therefore, no energy will flow toward the transmitter. On the other hand, the receiver-disconnect switch is now a high-Q tuned cavity. The received energy will therefore flow freely from the transmission line cavity into the receiver.

The transmission line is connected to the transmitter through a network which provides a means of matching impedances. This network consists of two stubs of variable lengths spaced 3/5 of a wavelength apart. These are known as tuning stubs. Since a short-circuited stub of variable lengths acts as a pure variable reactance either capactive or inductive, depending on its length, such a stub when properly placed may be used to match a transmitter of arbitrary impedance to a transmission line. However to avoid the mechanical difficulty of properly placing this stub on the transmission line two stubs are used and spaced 3/5 of a wavelength apart. By properly adjusting the length of these stubs, any impedance from infinity to one half the impedance of the line can be matched to the line.

The next and concluding installment on the AN/TPS-3 will describe the transmitter, modulating system, receiving and indicating system.

Acknowledgments

Responsibility for the construction of the AN/TPS-3 was directly assigned to J. W. Marchetti, who was assisted by William P. Goldberg as civilian engineer in charge. Many individuals of the Camp Evans Signal Laboratory contributed in the design of various features of this equipment. The modulator, indicators, and transmitter were turned over to a group headed by Dr. John E. Gorham. Within this group H. P. Pacini was responsible for the design of the indicators and I. Sager for the modulator. The transmitting tube, which was designed by the first named author, required very little additional development, since it had been in semi-production for some time and required only minor changes to adapt it for use in a lightweight radar set being styled for mass production. Later, when the set went into production, Dr. Gorham handled the manufacturing problems incidental to the construction of the transmitting tube. The physical arrangement of the set was due to William J. Smith and he further played a large part in the overall coordination. The major part of the mechanical design of this set was due to Arthur H. Hood.

The VT-158 vacuum tube, which is the heart of the set, is unique in that it includes all of the transmitter under vacuum in a single envelope, thus minimizing seal losses and arcing. The first model of this tube was built by H. A. Zahl in 1939 at the suggestion of Major General Roger B. Colton. The personal interest shown by General Colton, and his many valuable suggestions during the design of all elements of this radar, in no small way contributed to its success.