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AIRCRAFT RADAR

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/Figures referred to are appended./

The purpose of this article is to describe briefly the following three radar: (1) Radar in the interceptor, (2) Radar to warn of dangers in the rear, (3) Radar for identifying aircraft.

1. Radar in the Interceptor

The success of fighter planes in action in World War II was largely determined by use of radar. In daytime, fighters were aided by ground-based radar which located friendly and enemy aircraft; ground-based radio gave friendly aircraft detailed instructions concerning the course to follow to meet the enemy. At night, however, such orientation was insufficient: to facilitate attack under night conditions, another instrument in the fighter was required to enable the pilot, after reaching the enemy area, to assume a favorable attacking position and to close on his opponent at proper range.

Such devices, called interceptor radar, were built and installed in two-seater fighters. It was the radar operator's duty to give the pilot necessary directions for contacting the enemy.

The basic units of radar are transmitter, receiver, marker, antenna, and power unit.

The transmitter generates short, high-frequency pulses which are radiated from a transmitting antenna in hemispherical wave fronts; are reflected, then amplified by the receiver and finally delivered to the indicator.

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Let us now examine how early interceptor radar determined the polar coordinates of the target. Figure 1 shows the antenna system and other radar units on the plane. Two receiving antennas are used to determine the elevation angle. One antenna is placed above the wing surface, the other underneath. The directional lobes from the upper and lower antennas are such that the echo pulses reflected from aircraft above the line of flight are received more strongly by the upper antenna, while those from aircraft beneath the line of flight are received more strongly by the lower antenna (Figure 2,a).

Signals reflected from the target and received by the antennas are brought through a switch to the receiver and thence to the elevation indicator (Figure 2,c). By means of the switch, the upper and lower antennas are connected alternately with the receiver. There are also switches in the indicator by means of which incoming signals from the upper antenna produce on the indicator screen pulse pips directed upwards from the axial line, while incoming signals from the lower antenna produce impulse pips directed downwards. The intensity of these signals received by the antennas depends on the position of the target which affects the amplitude of the reflected echo pulses. The greater the deflection of the pulses upwards from the axial line, for example, the higher the target's position.

Pulses from three planes in the same position in relation to the line of flight as those in Figure 2,a are shown on the elevation indicator in Figure 2,b (distance to the first plane, one kilometer; to the second, 2 kilometers; and to the third, 3 kilometers).

The azimuth of the target is calculated in the same manner as the elevation angles by means of two antennas placed on the right and left side of the plane. Directional lobes of these antennas are shown in Figure 2,c.

The three planes shown in Figure 2,b are projected on a horizontal plane as shown in Figure 2,c. Figure 2,d shows the echo pulses from these planes on the azimuth indicator.

To summarize the observations from the elevation indicator and the azimuth indicator: it may be said that plane 2 is on the right and above the line of flight at a distance of 2 kilometers; plane 3 is to the left and below at a distance of 3 kilometers; and plane 1 is one kilometer in front of the fighter.

Let us examine a radar set the marker of which has two indicators. There are also radar markers with a larger number of indicators, but they are not widely used because they make the work of the operator too complicated.

Practical use has been made of markers that permit simultaneously scanning the field of view on only one indicator. In particular, use has been made of markers on indicators in which the plane appears in the form of a ring of luminous dots (Figure 3). The brightness of the various parts of this ring is not uniform and depends on the position of the located plane in relation to the course of the fighter. If the airplane is exactly in front of the fighter, it will appear as a ring of uniform brightness (Figure 3,a). Any deflection of the plane from the axis of the fighter's flight will decrease the brightness of the ring on the side opposite to the airplane's deflection (Figure 3,b). The radius of the ring determines the target range.

The advantage of this marker as compared with those examined earlier is that the operator needs to watch only one screen.

Other types of indicators are also used in interceptor radar. We shall touch upon them in describing more modern apparatus.

Figure 4 shows interceptor radar in which the transmitting antenna is placed on the nose of the plane; the elevation angle antennas are located on the left outer panel and the azimuth antennas are located on the right and left sides of the fuselage. There have been other methods of placing the receiving antennas. One, in particular, is to install all four receiving antennas on the right and left outer panels. Another method is to put the whole antenna system in the nose of the plane (Figures 4 and 5). All these antennas are very large and seriously impair the aerodynamic properties of the airplane.

The first interceptor radar operated on a wave length from one meter to one decimeter. With these rather long waves it was not possible to obtain a sufficiently wide field of search because of the narrow directional lobes and because of limitations in the over-all dimensions of antennas permissible in aircraft. This type of antenna emits pulses in a wide beam and a considerable part of the radiated energy falls on the earth's surface. At distances greater than the fighter's altitude, the signals reflected from the earth completely mask the echo signal from the target (Figures 2 and 3). Hence, the range of detection depends on the altitude. To eliminate this dependence, narrower directional lobes were necessary. This was accomplished by employing centimeter waves.

The antenna of radar operating on centimeter waves is a half-wave radar horn located at the focus of a parabolic reflector. The smaller over-all dimensions of the reflector make it possible to install the antenna inside the nose of the fuselage. The directional lobe of this type of antenna is a narrow beam, only a few degrees wide. But it is difficult to detect a target with such a narrow beam since it covers only a small part of the forward hemisphere. In order that a large part of the field may be scanned by radar, the antenna is rotated.

In this case (Figure 6), the marker indicator has a radial arm or cursor which rotates synchronously with the angular rotation of the antenna beam. Usually the arm is not visible on the indicator; but when echo signals are received from the target, a bright spot at a certain point, corresponding to the distance from the target, will be formed on the arm. When the target is scanned by a rotating beam, luminous points emerge in a number of contiguous radial arms and thus form a small luminous arc. The width of the arc is determined by the amount of the target's divergence from the line of flight. The greater this divergence from the antenna axis, the narrower the arc, since the beam rotates and remains on the target only for a short time. If the fighter is following its target, the target is exposed to radiation throughout the entire rotating sweep of the beam and thus a closed ring will appear on the indicator.

For convenience in observing the target at short ranges from the fighter, the scale of the indicator begins a short space from the center and forms a luminous ring of small diameter (first reading ring). The indicator in Figure 6 also shows the so-called altimeter ring, which is formed by the reflection from the earth's surface of the small undirected side lobes radiating from the radar antenna. Echo signals from the earth's surface produce light spots on the screen. These spots do not materially affect the range of radar detection.

Interceptor radar, which has appeared since World War II, is now much improved. Weight and over-all dimensions have been decreased and they are more reliable and simpler to operate. Among the most important improvements are automatic tracking in attack and an increased scanning field.

Automatic radar tracking greatly increases reliability of aircraft interception under all atmospheric conditions and also decreases probability of missing the target. Increased range makes it possible for the crew to be well prepared for attack.

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This newer radar is installed on the plane in the following positions: antenna, transmitter, and high-frequency parts of the receiver are in the nose; indicator, manual search control and various other control and auxiliary apparatus, near the operator; on the pilot's panel are indicator and devices that show target range and velocity of approach.

The radar antenna is a half-wave dipole, located at the focus of a parabolic reflector. The lobes of maximum power emitted by the antenna are slightly to the sides of the axis. Because of the rotation of the dipole, the radar scanning field is enlarged and the axis of maximum antenna emission describes a cone. In the process of scanning, the antenna reflector turns slowly to the right and left. This increases the radar field of scanning to the sides.

While scanning, the operator examines the air situation by means of his indicator, on which he sees the pulses from all planes within his field of search (Figure 7). Azimuth angles are measured on the indicator along the horizontal axis, and target ranges are measured along the vertical axis. A faint vertical band indicates the angle of deviation of the antenna from the axial line. The band rotates on the screen proportionally to the angle of the antenna reflector.

During search, no targets at all are seen on the indicator in the cockpit; only the horizon line is to be seen (Figure 8). The position of the horizon line shows the pilot his plane's movement: an upward or downward deflection of the horizon line from the horizontal line below the screen indicates that the airplane is pitching or diving; an inclination to left or right denotes left or right banking.

After selecting his target before attack, the operator first determines the position of the antenna in relation to the target by manual control and then shifts to automatic target tracking both for direction and range.

After the automatic target-tracking device is switched in, the target silhouette of the airplane appears on the pilot's indicator (Figure 8). The position of the center of the silhouette shows the pilot the amount of the target's deflection.

Switching devices show simultaneously the target range and the velocity of approach. By watching his instruments, the pilot establishes all aspects of flight and directs his plane in such a manner that the center of the silhouette coincides with the center of the indicator.

The span of the silhouette increases in proportion to the proximity of the enemy. The pilot opens fire at the moment when the wing tips reach the vertical marks on the axial lines of the indicator.

Interceptor radar can be used for purposes other than their primary task. They may serve to guide an airplane to its airdrome and also to permit blind landings.

2. Radar Devices to Warn of Danger in the Rear

For rear hemisphere observation and for warning the crew of enemy approach, so-called rear-warning radar is used. This set is installed both on fighters and bombers. There are two types, one for passive and one for active warning.

Devices for passive warning consist of a receiver and transmitter and operate only after exposure to the enemy interceptor radar. Such instruments are very simple, but their use demands knowledge of the frequency of the enemy interceptor radar. For this reason, the devices for passive warning are rarely used.

Rear-warning sets for active warning are radar sets which detect an enemy by echo signals.

Their basic units are: transmitter with a modulator, receiver, antenna, indicator, and power unit (Figure 9).

The principle of rear-warning radar is analogous to that of interceptor radar.

An antenna installed on the wing is employed for signal and transmission reception.

The method of signaling the crew differs with the type of instrument. The following signaling methods are in use: sounding of electric buzzers; audio signals through the intercommunication system (SPU); flashing signals, and indications on cathode-ray tubes.

For greater reliability in warning the crew, combinations of several types of signaling are sometimes used.

The instruments used in intercom, and the cathode-ray tubes are the only warning devices that indicate in some way the distance of the approaching hostile aircraft.

The defects of the rear-warning devices in use are their small range and inability to identify detected targets.

In view of the fact that the lobe width of the beams radiated from the antenna of rear-warning devices is rather large, strong reflections from the earth's surface can be observed on the instruments. Signals bouncing from the earth unfortunately register on the rear-warning instruments and may thus mislead the crew. Hence, the range of these devices must be intentionally restricted so that they can be employed even at low altitudes.

To protect the rear hemisphere of heavy bombers, more complicated instruments are used. These do not merely warn, but also aid in coordinating fire from the guns. We call such instruments "radar shooting sights." Some of them operate entirely on optical sights and are employed to determine the target range. They carry out automatic target-tracking according to distance. The data supplied by them are fed into a mathematical computor.

3. Radar Devices for Identifying Aircraft

Success in the tactical employment of radar entirely depends upon the ability to identify quickly and positively any target appearing within the radar station's field of scanning. Radar stations without special equipment for identifying aircraft would be completely unable to distinguish friendly aircraft from enemy craft. The aircraft is first judged by type, its flight course, and by data from observation posts. To facilitate further identification of friendly aircraft, various maneuvers are executed by the plane. For example, following commands from the ground station, the airplane to be identified (if friendly) must execute some specific maneuver which has been previously recorded for reference on the radar plotting board or even directly on the indicator. (Thus, the airplane may fly in a square, or weave, etc.)

None of these methods of identification is very satisfactory, because they are indefinite and time consuming. Besides, it is not always possible to employ them. Therefore, it is necessary to construct and install apparatus on the planes themselves which will cause its presence to be immediately registered on friendly radar indicators.

The earliest of these airborne devices was a simple antenna tuned to radar frequency. With aid of a special switch, the antenna was alternately connected and disconnected so that it produced a periodic pattern in the amplitude of the echo signals. By the presence or absence of these echo-pulse code patterns in the radar indicator, friendly aircraft can be distinguished from hostile craft. But this system of identification has many serious defects and was never very widely used.

An improved apparatus made its appearance after this one. Instead of the antenna, a transceiver was used, which was a type of airborne beacon for radar signals.

As long as the airplane is not exposed to radar waves, this transceiver acts as a receiver. When the airplane is exposed to radar waves, the radar pulses are received and then amplified by the receiver and finally cause the transmitter automatically to emit radar identification signals (beacon signals) on a frequency equal to the radar frequency and with an amplitude somewhat greater than that of the echo signals. The beacon signals are propagated immediately after the echo signals and, therefore, appear on the radar indicator, along with the original echo pulses, in the form of pulse pips with an amplitude slightly greater than that of the echo signals (Figure 10).

So that ordinary reflected pulses may be differentiated from beacon signals, the identification apparatus is so constructed that it does not transmit reply or beacon signals on every pulse but skips a certain number of pulses. Thus, unlike echo impulses, the beacon signal pulses alternately appear and disappear (flicker). To prevent the enemy from imitating beacon signals, the apparatus has a coding device which makes it possible to change both the duration of the impulses and their successive alternations according to a fixed schedule. Thus, aircraft identification is carried out, not only through the presence or absence of signals but also through coding.

Such a system we call "joint identification." Detection and identification are here carried out on the same wave. These devices were designed to permit cooperation between radar stations, airborne or ground-based, which differed only slightly in their operational frequencies. With the continual development of radar and the appearance of many stations operating on a great variety of wave lengths, the construction of existing devices had to be changed in order to enlarge their frequency bands.

The chief defects of the identification system in question are as follows:

The system is completely unsatisfactory from the standpoint of universality. Thus, with the use of new wave lengths in radar, it is necessary constantly to increase the weight and volume of airplane equipment, which is obviously limited.

The system is extravagant in operation. Thus, the identification device operates during the whole period of exposure of the airplane to radar, although only a very few reply signals are needed for identification.

Because the same wave length is used in detection and identification, the beacon signals from adjacent aircraft can affect the operation of these devices.

In semi-autonomous beacon systems a partial separation has been made between detection waves and identification waves. This was effected by tuning the aircraft receiver to the radar wave; but the transmitter sends identifying signals on a frequency different from that of the radar apparatus. Special receivers are supplied to receive signals by radar.

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The semi-autonomous beacon system eliminates the defects connected with the possibility of confusion with interrogators but all the other defects in the "joint identification system" also occur in the semi-autonomous system.

Immediately after the semi-autonomous systems, the autonomous beacon systems made their appearance, in which independent (autonomous) frequency ranges were used.

The absolute assignment of a certain band to be used only in identification made it possible to eliminate the chief defect of the previously mentioned systems and to install a great number of identification devices on aircraft. To send reply signals by the autonomous system, there is installed on each plane a device, the "responder," which answers the "interrogator." But for all radar apparatus, whether on the ground or in aircraft, there are also special attachments -- the interrogators or challengers.

The principle on which the autonomous beacon system operates is shown in Figure 11.

After a target has been detected by radar, the interrogator is then switched in. The interrogator is considerably less powerful than the radar apparatus, but is powerful enough to emit inquiry pulses which strike the plane to be identified. But since the pulses of the interrogator are considerably weaker than normal radar pulses, their reflection from the fuselage fade rapidly and cannot be detected by an interrogator.

The responder operates only when the interrogator is switched in. In autonomous systems this eliminates the defect connected with the protracted operation of interrogators used in joint identification systems.

/Figures follow./

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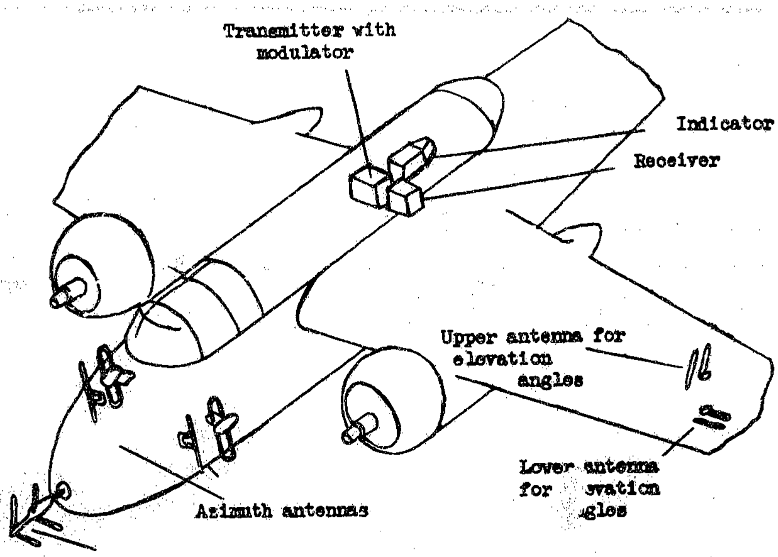


Figure 1

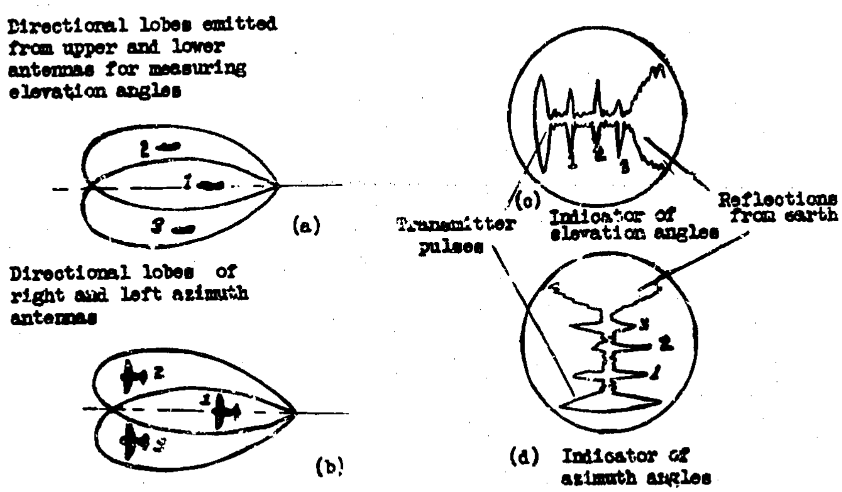
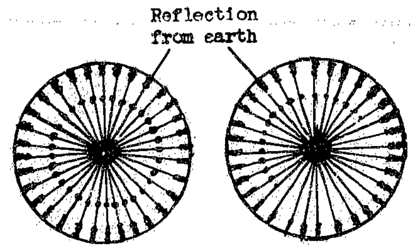


Figure 2



(a) Fighter is immediately behind enemy plane

(b) Enemy is above fighter and to left

Figure 3

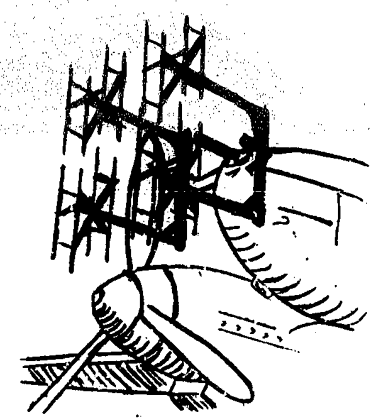


Figure 4

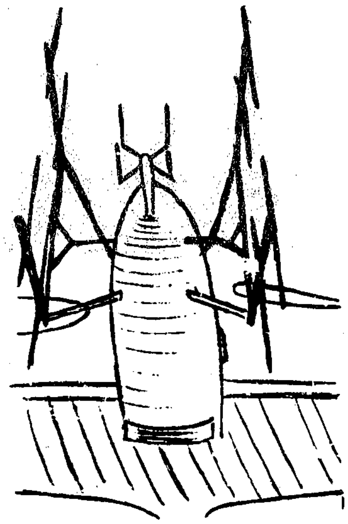


Figure 5

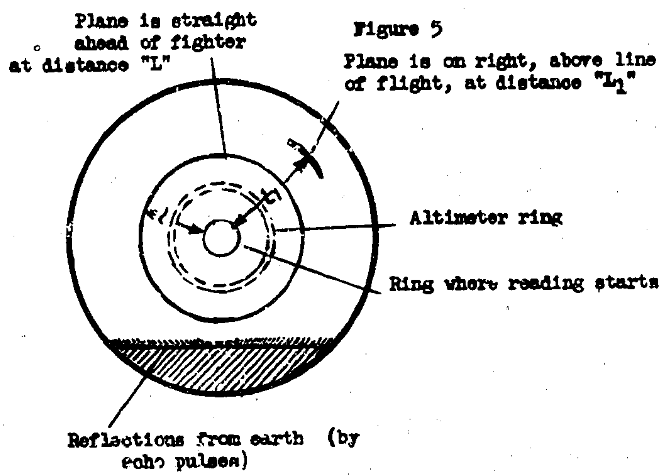


Figure 6

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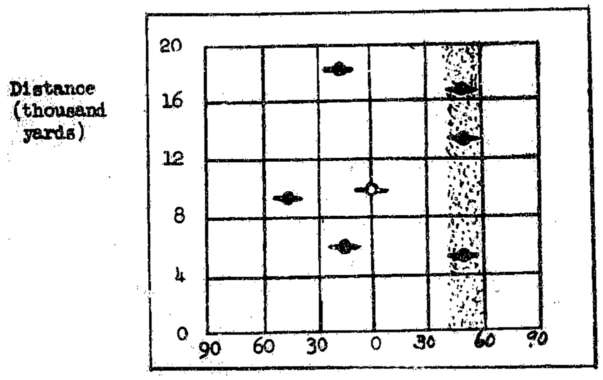

Azimuth in degrees

Figure 7

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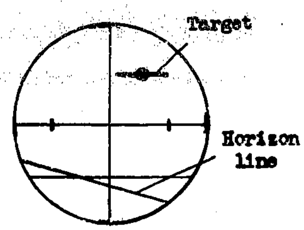

Figure 8

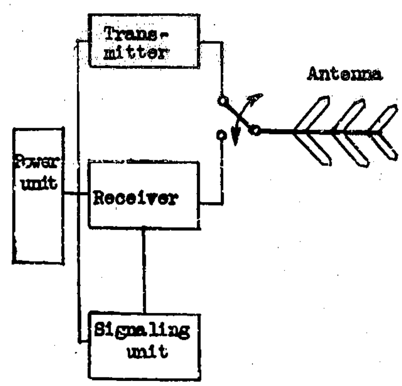

Figure 9

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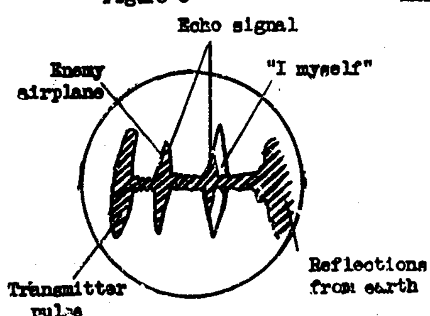

Figure 10

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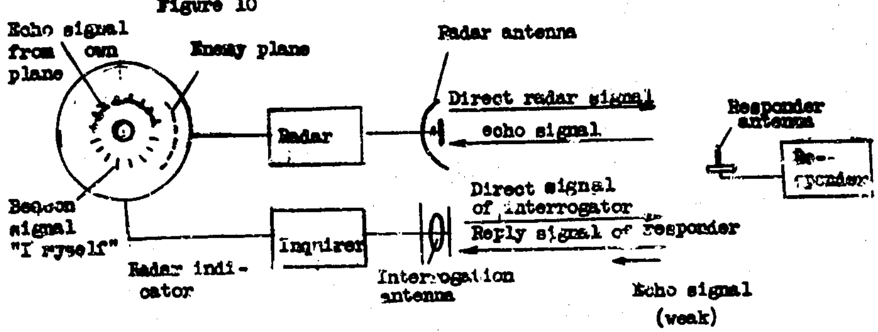

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Figure 11

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