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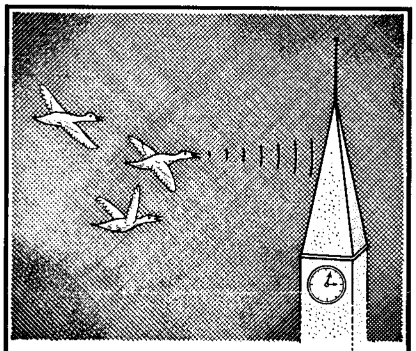
Introduction to Radar Techniques

Part 1. The Radar System

By the Engineering Department, Aerovox Corporation

THE use of Radio Detection And Ranging, more commonly abbreviated "RADAR", played an important part in determining the outcome of World War II. Although overshadowed in the final stages of the hostilities by the more spectacular atomic bomb, few military tacticians doubt that radar played a more decisive role in securing Allied victory. Even more important is the fact that this electronic instrument is finding an ever-widening sphere of usefulness in peace time applications. Radar has become a permanent part of the field of radio, not only as a dependable aid to marine and airborne navigation, but also as a valuable adjunct to meteorological stations throughout the world. Its use as a traffic control device for measuring the speed of automobiles traveling on highways has also been announced. Such uses are only a few of the many which will ultimately be found for this principle. Radio technicians in coastal areas have already found a lucrative field of endeavor in the installation and maintenance of marine radar equipment on fishing boats and ferries. In short, radar has emerged from the laboratories and military field of operations, and has become a part of the everyday civilian scene. For these reasons, this issue of the AEROVOX RESEARCH WORKER, as well as several succeeding ones, will be devoted to a discussion of the fundamental principles of radar. This series will be interspersed from time to time with articles on other subjects of a timely nature to maintain variety.

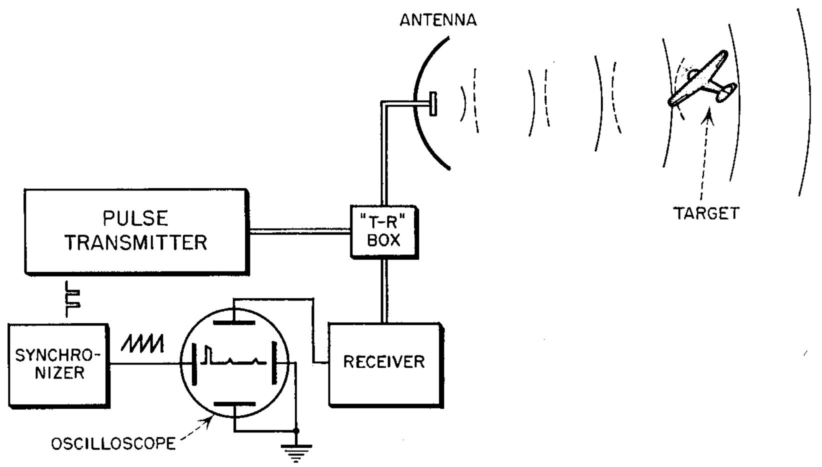


EARLY AIRBORNE RADAR

FIG.1

Historical Notes

Historically, the use of the basic radar principle, i.e., the detection of surrounding objects or obstacles by echoes reflected from them, is not new. In nature, the radar system has been used for as long as wild geese and other migratory birds have navigated through darkness and overcast by "honking" or making other sounds whose echoes warn of approaching obstacles. See Fig. 1. Bats too, are credited with masterful blind navigation by uttering a series of short, supersonic squeaks and interpreting the echoes from these in terms of range and bearing information. Man has utilized the same scheme to some extent in navigating rivers and harbors. Old skippers of ferries, river boats, and coastwise steamers have been known to develop a remarkable faculty for determining their bearings despite fog or darkness by listening to distinctive echoes of the boat's whistle bouncing off shore



COMPONENTS OF ELEMENTARY RADAR SET

FIG. 2

lines or passing craft. Many such men of long experiences and practiced ear claim to be able to differentiate between rocky or wooded coast lines, as well as glean a good estimate of the size and type of a passing vessel, by the nature of the returned echo.

The first use of electronic radar is attributed to Sir Watson-Watt in England, in 1935, although the technique of detecting the echoes of short pulses of radio frequency and energy had been used much earlier (1925) by Breit and Tuve to measure the height of the ionosphere. This work suggested the possibility of obtaining echoes from aircraft and other objects smaller than the ionosphere to a score of workers in several major countries. As a result, successful radar systems were developed almost simultaneously during the late thirties in France, England, Germany, and America.

The Basic Radar System

The fundamental elements of a radar system are shown in Fig. 2. Very short pulses of radio frequency energy which recur at regular intervals are generated by the transmitter. These intense "bursts", which may be only one *millionth* of a second in duration, are radiated by the antenna in a narrow beam. These waves propagate through space with the speed of light and, upon striking a reflecting object, are returned to the receiver as an echo. The output of this receiver is connected to the vertical plates of an oscilloscope. The horizontal plates of this 'scope are driven by a linear, saw-tooth sweep generator which is synchronized with the transmitter pulses in such a manner that the sweep starts across the face of the 'scope at the time of each transmitter pulse. Received echoes then form small vertical "pips" on the base line which represent reflecting objects at distances indicated by their positions on the time base. See Fig. 3.

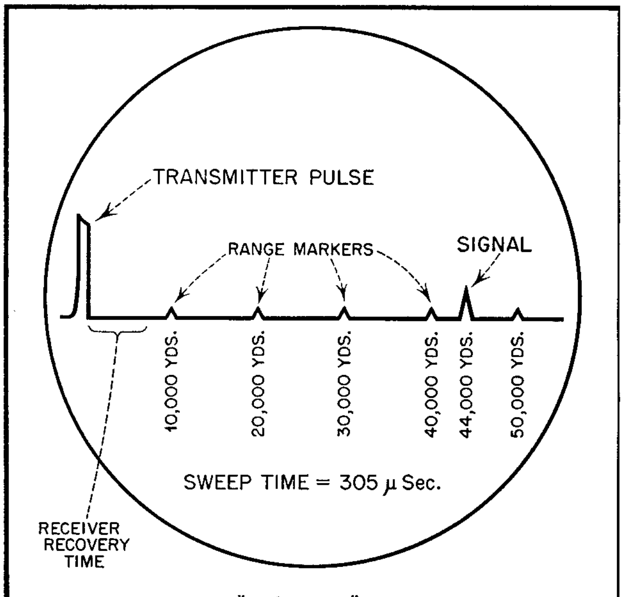
Since radio waves travel in space at a constant velocity, the range of a target indicated on the display oscilloscope may be accurately determined by measuring the time elapsed between the transmission of a pulse and the reception of an echo. This is easily done since the 'scope sweep is linear with time and so can be calibrated directly in range. The range of a target in yards is thus related to the echo time by:

$$(1) \qquad \text{Range (yds.)} = \frac{327.5\,t}{2}$$

Where: t is the echo delay time in microseconds (μ sec.)
327.5 is the free-space velocity of radio waves (yds./sec.)

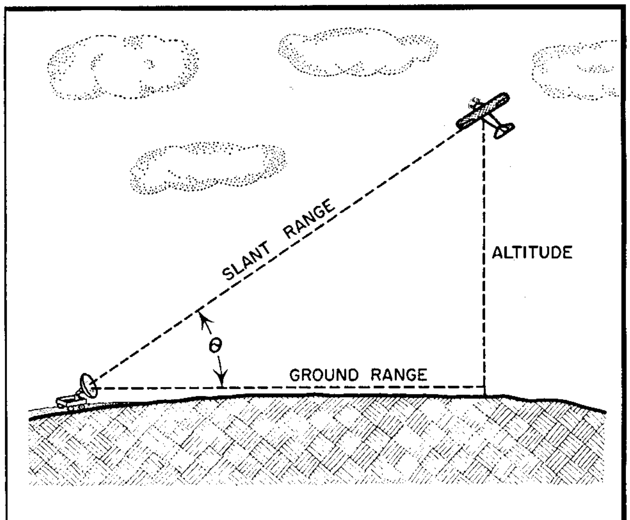
Note that the distance traveled by the waves (velocity times time) is divided by the factor 2 for the actual radar range since the waves must travel this distance twice going to the target and returning.

To facilitate measuring range, the time base is frequently provided with *range markers,* as illustrated in Fig. 3. These range calibration points are formed by feeding a pulse signal into



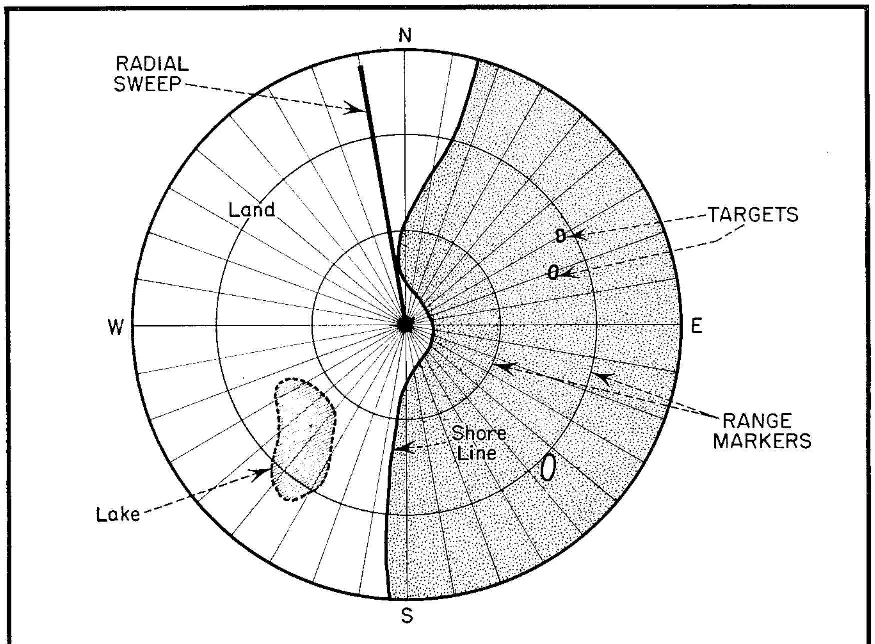
DETAILS OF "A-'SCOPE" PRESENTATION

FIG. 3



ALTITUDE = (SLANT RANGE) (Sin θ)
GROUND RANGE = (SLANT RANGE) (Cos θ)

FIG. 4



TYPICAL "PPI" PRESENTATION

FIG. 5

the vertical deflection plates. The repetition rate of these pulses is chosen to correspond to time intervals which represent convenient increments of range, such as 5000 or 10,000 yards. Markers of this type insure accurate ranging, even when the time base departs from linearity.

The angular bearing, or *azimuth,* of the target is determined by the directional position of the antenna. Information on the elevation of aircraft is obtained in the same manner. The range indicated in this case is called the "slant range". The ground range and altitude are then gotten by simple trigonometry, as shown in Fig. 4. The accuracy of these measurements is limited by the beam width of the antenna pattern. In practice, beam widths of less than one degree are achieved by using large, highly directional antennas and very short operating wavelengths.

Although some radar sets have used separate antennas for the functions of transmitting and receiving, the arrangement illustrated in Fig. 2 is much more convenient. Both transmitting and receiving is done with the same antenna by using a system of automatic switching known as "duplexing". By this method, the receiver is effectively disconnected from the common transmission line during the "on" time of the transmitter and so is protected from overload and burnout damage by the high power transmitter pulses. Between transmitter pulses, the receiver is automatically connected to the line and the transmitting tube is isolated to prevent its absorbing some of the received signal. Duplexing is usually accomplished by using a gas-filled switching device known as a "transmit-receive tube" or, more simply, a "T-R box". The functioning of duplexing devices will be more fully discussed in a subsequent issue.

The method of displaying information illustrated in Fig. 3, known as an "A-'scope" presentation, is only the simplest of many possible types. Although used universally on early radar equipments, it was soon replaced or supplimented by more advanced kinds. One of the most useful of these is the *Plan Position Indicator,* or "PPI", depicted in Fig. 5. This type displays a map of the terrain surrounding the radar set in polar coordinates, with the set at the center of the oscilloscope face. To do this, a radial sweep originates at the center of the tube and is rotated angularly about this point in synchronism with the position of the antenna, which is continuously scanned in azimuth. Received signals are used to intensity modulate the electron beam so that a bright spot is "painted" at the range and azimuthal position of each target. The use of long persistance phosphors enable the 'scope to retain these images until renewed by another antenna scan. The radial sweep is produced by a rotating electromagnetic deflection system which is synchronized with the antenna angle by an electrical or mechanical linkage. Presentations of the PPI type are especially useful for navigational radar.

Limits of Radar Performance

The range of a radar equipment is determined by many design factors. The minimum range at which a target may be detected is limited by the duration of the transmitted pulse and the *recovery time* of the duplexing system. If the transmitted pulse is too long, echoes from objects at close range will be returned while the transmitter is still operatng and the receiver is blocked by the TR system. Since the TR tube requires a finite time to recover after each pulse is sent, the receiver also remains inoperative for a short time after the completion of the pulse. The result is a "blind spot" in the immediate vicinity of the radar set which is usually of little consequence, since long range operation is the most important in most applications.

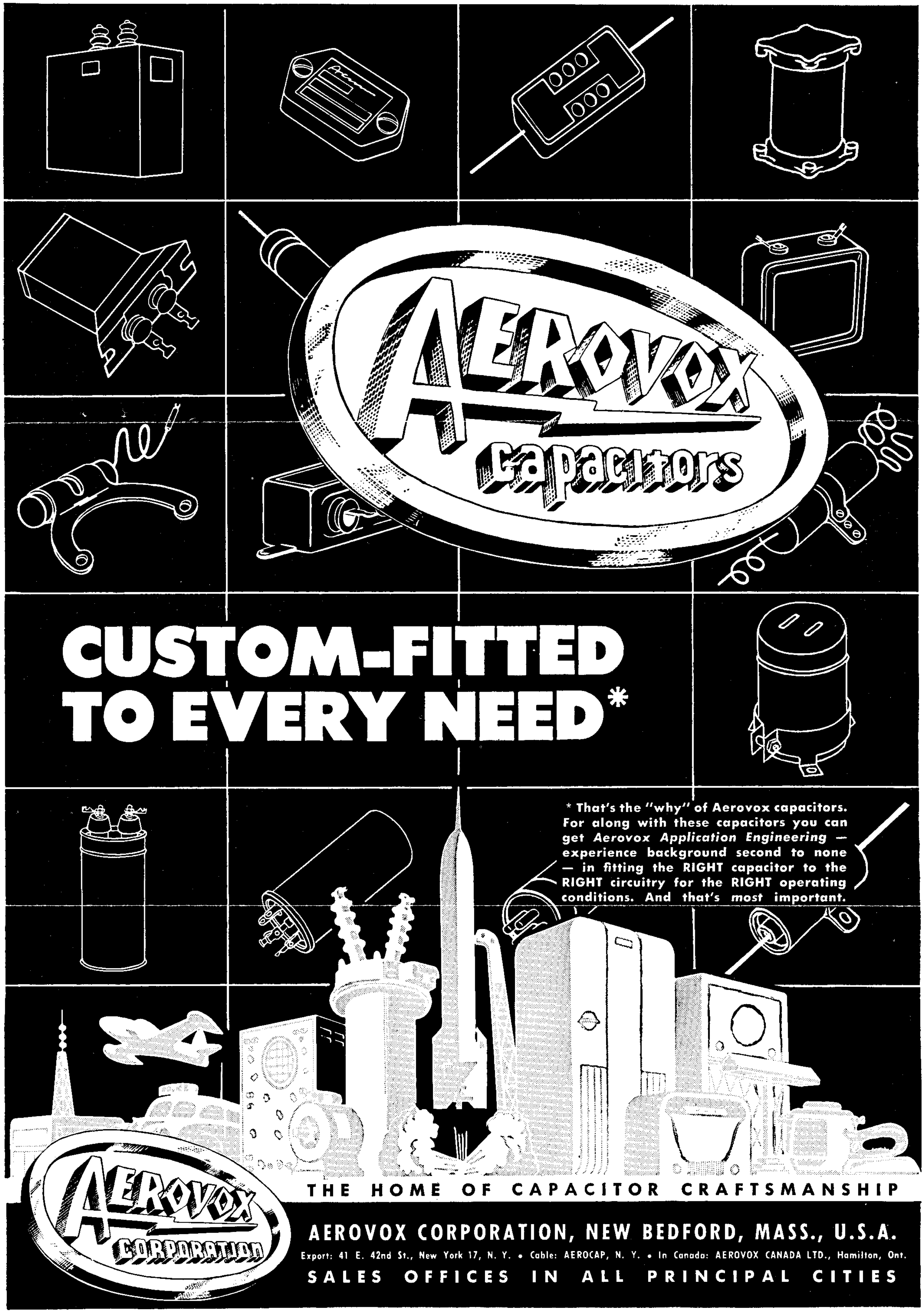
The maximum range obtainable from a radar set of a given design depends upon such factors as transmitter power, size of the target, gain of the antenna, sensitivity of the receiver, operating wavelength, etc. These factors have been related by what is commonly called the "radar equation":

$$(2) \qquad R_{max} = \sqrt[4]{\frac{P\delta A^2 f^2}{4\pi S_m \lambda^2}}$$

Where:

R_{max} is the maximum range in miles
P is the peak transmitter power (watts)
δ is the reflecting area of the target
A is the antenna aperture (sq. ft.)
f is an antenna illumination factor (between .5 and 1.0)
S_m is the minimum signal the receiver will detect (watts)
λ is the operating wavelength (ft.)

By means of this relationship, radar system designers can reasonably predict the performance of a proposed equipment. Note that the range varies as the *fourth* root of the other factors. This arises since the signal traverses the path twice, so that the received signal is inversly proportional to the forth power of the distance rather than the familiar inverse square law of one-way transmission. For this reason, very high transmitter powers and very sensitive receivers are needed for satisfactory radar operation. Fortunately, the pulsing technique required for ranging also makes possible the generation of peak powers of far greater magnitude than could be obtained by continuous wave oscillators. Pulse powers of hundreds of kilowatts are in common use. Subsequent issues of this series will discuss means of generating and radiating such energy.



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