The AEROVOX Research Worker

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 22, NO. 5 MAY, 1952 Subscription By Application Only

Introduction to Radar Techniques

Part 5. The Antenna and Duplexing System

By the Engineering Department, Aerovox Corporation

THIS is the concluding issue in the series of RESEARCH WORKER articles dealing with the fundamentals of the basic radar system. It is concerned with the radar antenna system and the electronic switching means employed to enable the same antenna and transmission line to be shared between the radar transmitter and receiver. "Duplexing", as this function is called, is common only to radar practice and has its only counterpart in the "antenna changeover" switch of communications radio. The other specialized components of the typical radar system were discussed in the October, November, December, and April issues.

Because of the very short wavelengths used in modern radar (about 1 to 25 centimeters), the antennas employed are capable of very high gains. This high gain is a useful byproduct of the high directivity required to obtain accuracy in determining the position of a radar target. In order that the azmuth and elevation of a target be indicated with precision, the width of the antenna pattern must be small. Therefore, if the total energy radiated by the antenna is concentrated in a narrow cone, the radiated signal strength on the axis of that cone will be hundreds of times greater at a given point in space than if an omni-directional antenna were used.

The gain of a highly directional antenna, such as the paraboloid, as a function of its aperture area in square wavelengths, is given by:

(1) $$G = \frac{8A}{\lambda^2}$$

Where:

G is the power gain of the antenna.
A is the antenna aperture (cm^2).
λ is the operating wavelength (cm).

From this it may be seen that the gain for a given area is inversely proportional to the operating wavelength *squared*. Thus, an antenna of a given area will have 100 times more gain at 1 centimeter than it has at 10 centimeters. For this reason, antenna gain is relied upon to compensate for the lower r.f. powers available at the shorter wavelengths used for modern radar.

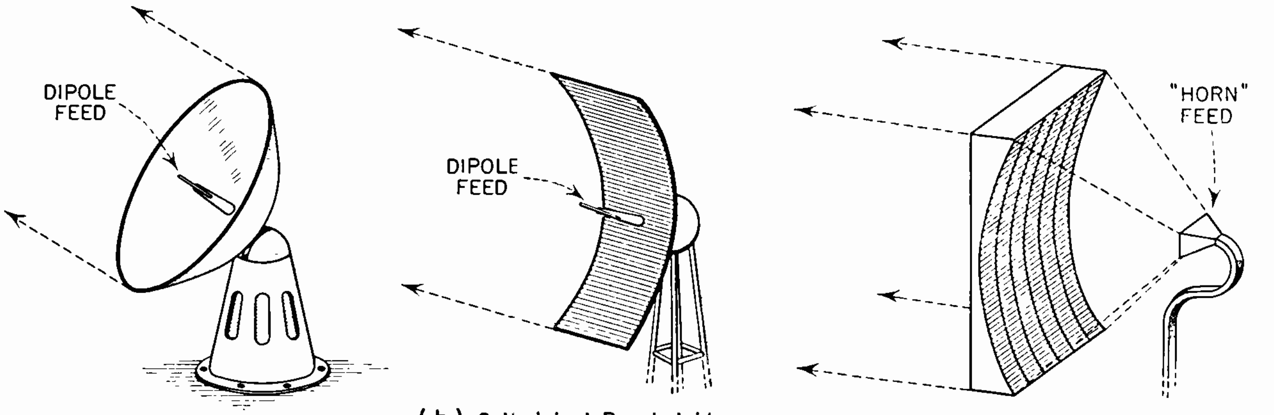
Fig. 1 depicts several forms of basic microwave antennas commonly employed for radio detection and ranging. Of these, the paraboloid (Fig. 1a.) has been used the most extensively to date. In this design, a parabolic reflector made of sheet metal, perforated metal, or screen, is *illuminated* uniformly over its surface by r.f. energy radiated from a source at the focal point. This source, usually called a "feed", may be a small dipole or a waveguide horn. The divergent radiation from this source is focussed by reflection from the parabolic surface into a nearly parallel ray like that of a searchlight. See Fig. 2. Beamwidths as narrow as ½ degree at the half power points are produced in this manner. The theoretical beamwidth is related to the wavelength and diameter of the parabola as:

(2) $$\theta = 70\frac{\lambda}{D}$$

Where:

θ is the half-power beamwidth in degrees.
λ is the operating wavelength (cms)
D is the diameter of the parabola (cms).

In some applications, it is necessary to produce a radar antenna having a radiation pattern which is narrow in elevation but wide in azmuth, or *vice versa.* This is usually accomplished by the use of a *cylinderical* parabola, or a "cut" parabola, as shown in Fig. 1b. Unlike the complete paraboloid, this antenna is high-



(a) Full Paraboloid (b) Cylindrical Paraboloid (c) Waveguide Lens

TYPICAL RADAR ANTENNAS

FIG. 1

ly directional in one plane only, i.e., the plane of its greater aperture dimension. By "shaping", or using various sections of a full paraboloid, the pattern in both the vertical and horizontal planes can be controlled to fit any given application. Equation 2 may be used to predict the approximate beamwidth in either plane by using the diameter of the parabola in that plane.

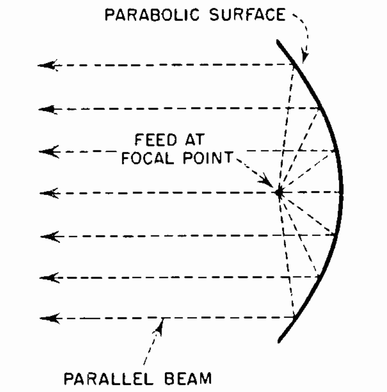
A third general type of antenna, which is finding increasing microwave radar application, as well as widespread use in microwave radio relay systems, is the *waveguide lens* type illustrated in Fig. 1c. This design makes use of the fact that a mosaic of waveguides of different lengths can act as a lens to focus radio waves in a manner similar to the focussing of light waves by a glass optical lens. This comes about because the radio frequency waves travel at a different velocity through the waveguides than they do in free space, just as light travels at a different velocity in the glass lens. As a result, rays which enter one end of the waveguide mosaic lens may be converged, diverged, or rendered nearly parallel, as with an optical lens. An important difference, however, is that the contours for waveguide lenses are opposite those of the glass lenses which perform the corresponding functions, as shown in Fig. 3. This reversal is due to the fact that radio waves travel *faster* in the matallic guide than in air, whereas light waves travel *slower* in glass than in air. Hence, the wave fronts are refracted differently by the same contour.

The same kind of "feed" systems may be employed to illuminate lens antennas as are used for parabolas. The lens antenna has several advantages over the parabola, including less wind resistance for a given aperture and the fact that the feed point is behind the antenna, rather than in front of it. This places fewer restrictions on the feed system to prevent distortion of the radiated pattern. The gain and half-power pattern widths of a metal lens antenna are the same as those of a parabola of equal dimensions, as given by Equations (1) and (2).

The Duplexing System

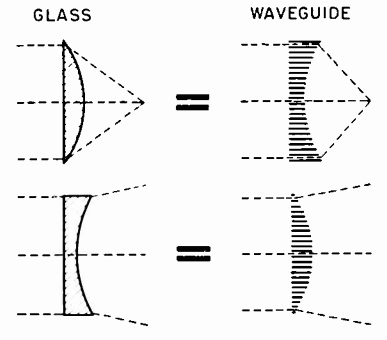
Even with the most powerful transmitters and the most sensitive receivers available, the successful operation of a radar set requires the highest antenna gain and directivity possible. Since this, in turn, means antennas having large physical dimensions, it is highly desirable to use the same antenna for both transmitting and receiving. In this way the gain of a single large antenna is utilized twice. To do this, however, it is neccessary to connect the antenna to the transmitter for a few *millionths* of a second while the pulse is sent out, and then switch it to the receiver during the "listening period" between pulses. This function is called "duplexing" and is accomplished by gas filled devices known as "Transmit-Receive" tubes, or more simply, "T-R" tubes. The duplexing system must prevent the very high peak power of the transmitter from damaging the sensitive crystal mixer input stage of the receiver while at the same time "recovering" fast enough after each pulse to enable the receiver to receive echoes from nearby targets. The duplexing system must also make provisions to prevent the weak received signals from being absorbed in the magnetron transmitting tube.

To fulfill these requirements, modern duplexing systems make use of the large power difference between the transmitted signal and the received echoes. Since the transmitter power is of the order of *kilowatts* or *megawatts*, while the received signa's from distant targets is more typically



FOCUSING ACTION OF PARABOLOID ANTENNA

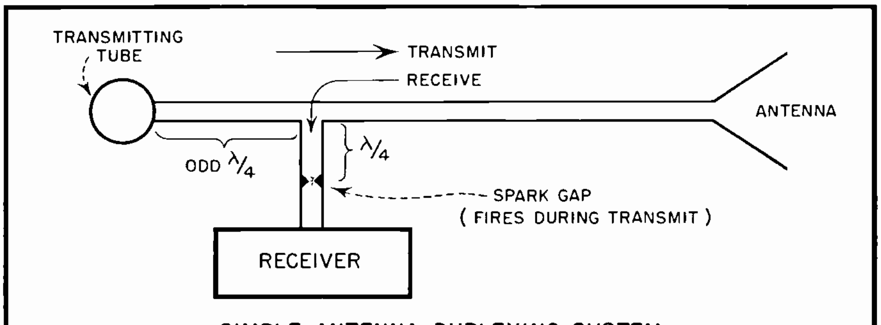
FIG. 2



COMPARISON OF OPTICAL AND WAVEGUIDE LENSES

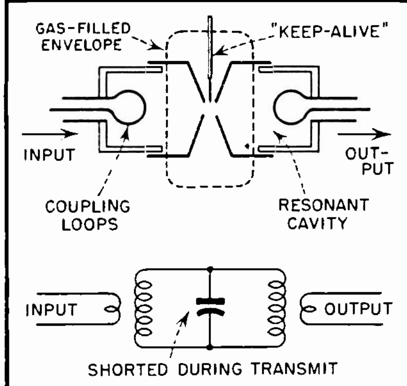
FIG. 3

measured in *micro-microwatts,* a switching device which will discriminate between such extremes of power is used. Fig. 4 illustrates an elementary duplexer utilizing this principle. Here a spark gap is placed across the branch line leading to the receiver and set to break down at high power but remain inoperative at low power. Since the discharge in the gap constitutes a virtual short circuit across the transmission line, very little transmitter power reaches the receiver. If the distance from the junction point to the gap is one-quarter wave-length, the impedance of the branch line appears very high when the gap is "fired" and all of the power goes through to the antenna. When the transmitter pulse ends, the gap is extinguished and, since any received signal is much too weak to initiate a breakdown in the spark gap, signals flow freely to the receiver. If the length of transmission line between the receiver arm and the magnetron is properly chosen, the received signals will encounter a high impedance in traveling toward the magnetron and hence will flow mainly into the receiver.



SIMPLE ANTENNA DUPLEXING SYSTEM
FIG. 4

In actual practice, the simple duplexing system of Fig. 4 is employed only with refinements. To obtain adequate crystal protection, the voltage at which the gap fires must be reduced. This is done in T-R tubes by enclosing the spark gap in an envelope which is filled with a gas, such as hydrogen, under pressure. A third electrode, known as a "keep-alive", is also introduced into the hollow cone forming half of the gap. The function of the keep-alive electrode, which is maintained at a high d.c. voltage with respect to the cone, is to produce a small gas discharge within the cone. The presence of this keep-alive discharge greatly reduces the time required for the main gap to fire when the r.f. pulse arrives. A third refinement consists of making the gap part of a tuned circuit which is resonant at the transmitter frequency. This increases the voltage across the gap and further reduces the time required for the tube to fire.



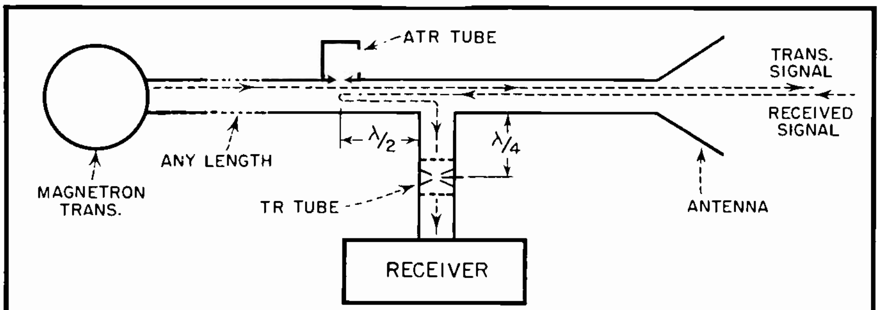
"TR" BOX AND SIMPLE EQUIVALENT CIRCUIT
FIG. 5

Figure 5 shows a typical T-R tube in its resonant cavity and a simple lumped-constant equivalent circuit. The T-R box acts as a band pass filter when the gap is not ionized during receiving, and the signal is attenuated only about 1 db. in passing from one coupling loop to the other. When high power ionizes the gas, however, the band-pass properties of the cavity resonator are destroyed since the effect is the same as short circuiting the capacitance in the equivalent circuit. Under these conditions the attenuation is about 60 db and very little power is coupled from one loop to the other. The important properties of the T-R switch are the *ionization time*, the *leakage power* which reaches the receiver through the fired device, and the *recovery time* neccessary to allow the gas to deionize so that signals can reach the receiver. These properties are controlled by varying the T-R gas filling and water vapor content, the cavity "Q", the keep-alive voltage, etc.

As was mentioned above, provisions must be made in a duplexing system to insure that a large portion of the received signal is not lost in the transmitting tube which terminates the line from the antenna. In early duplexing systems, use was made of the fact that the non-oscillating magnetron tube does not match the line impedance very closely, so that most of the power is reflected. The T-R junction was then placed at a point on the transmission line where the impedance toward the magnetron was high. This system worked but placed undue restrictions on the position of the T-R junction and the "cold" impedance of the magnetron. It has been replaced in most cases by the use of a device known as an "anti T-R" tube, or an "ATR".

Figure 6 depicts a duplexing system using an ATR tube in conjunction with a T-R tube for effective antenna switching. The ATR tube is a resonant, gas-filled device constructed in a manner similar to that of the T-R tube, but with only one coupling loop or iris. It is placed on the transmission line between the magnetron and the T-R in such a manner that it has no effect on the passage of the transmitted signal when it is ionized, but constitutes a high series impedance to the received signal in the unfired condition. The line length between the T-R and the ATR is then chosen so that the received signal "sees" a high impedance toward the magnetron regardless of the cold impedance of the latter.

T-R and ATR tubes are used in a wide variety of forms adaptable to both coaxial transmission lines and waveguides.



OPERATION OF MODERN DUPLEXING SYSTEM
FIG. 6

As old as

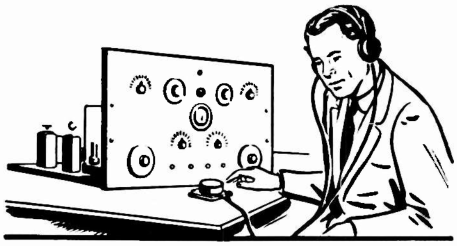
RADIO

yet as young as

ELECTRONICS...

AEROVOX

CAPACITORS



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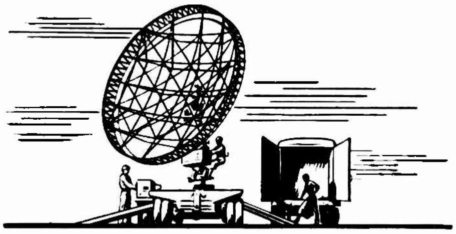

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