applications. A crystal-controlled vacuum tube oscillator can be used in timers to generate the master timing frequency. This device is used because its output frequency is dependent on the predetermined physical characteristics of the quartz crystal which are altered very little by atmospheric or temperature changes. Since range measurement in the radar is based on extremely accurate time measurements, the circuits in the timer must be very stable.

13. TRANSMITTER

a. The purpose of the transmitting system is to produce high-powered, radio-frequency energy for very short predetermined periods of time. The pulse repetition frequency is determined by the time. A typical transmitter is composed of a driver, modulator, high-voltage rectifier, and magnetron, as shown in figure 4.

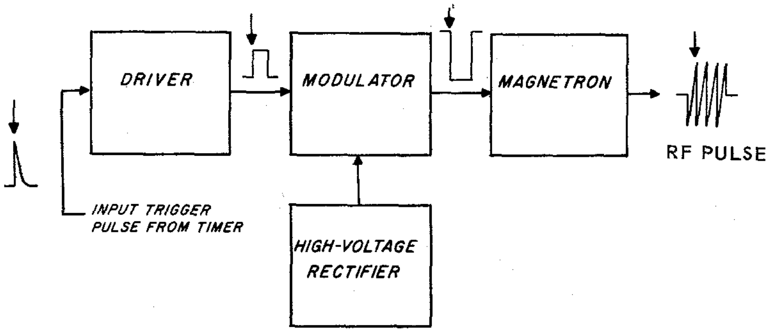

Figure 4. Transmitter block.

b. The manner in which the modulator controls the high voltage that it applies to the magnetron is governed by the driver. The driver stages amplify, shape, and establish the polarity and pulse duration of the trigger pulses that originated in the timer. Correct shaping insures that the pulse of voltage applied to the magnetron will cause it to oscillate at a stable frequency for a definite period of time.

c. The circuit which pulses the magnetron, or connects the high-voltage rectifier to the magnetron, is called the modulator. Its name is derived from the fact that it varies the current through the magnetron from zero to about 30 amperes within an almost instantaneous time. The modulator conducts each time that a pulse is received from the driver. When the modulator conducts, a high-voltage pulse of short duration is applied to the magnetron.

d. The stable high voltage and power required by the magnetron is provided by the high-voltage rectifier and its associated filter circuits. Filter circuits allow the magnetron to be pulsed without affecting the output of the high-voltage rectifier, which in turn would affect the magnetron frequency.

e. The high-frequency, high-powered oscillator used in most radars is the magnetron. A high-voltage pulse applied to the magnetron from the modulator causes it to oscillate and generate a high power output for only a short period of time, usually from about

1/3 to 4 microseconds, depending upon the type of radar. The output frequency of this oscillator is primarily established by the magnetron's physical dimensions, which may be varied to obtain a change in frequencies over a narrow band. The output rf pulse can also be affected by the shape of the pulse which is applied into the magnetron. The output of the magnetron is transferred directly to the antenna for transmission into space.

14. ANTENNA

a. The function of the antenna system is to take the energy from the transmitter, radiate it in a directional beam, pick up the returning echo, and pass it to the receiver with minimum loss. The antenna system may be considered to include the transmission lines from the transmitter to the antenna array, the antenna array itself, the transmission line from the antenna array to the receiver, and any antenna-switching device and receiver-protective device that may be present (fig 5).

b. When a radar receiver is operated in close proximity to a powerful radar transmitter, a certain amount of signal inevitably finds its way into the receiver directly from the transmitter by way of the stray capacitance of the input circuit leads. In certain instances, such signals resulting from the main transmitted pulse must be entirely eliminated from the output of the receiver. Therefore the receiver must be gated or turned off during the pulse time so that it may be completely insensitive.

c. It may be desirable to couple a small amount of the transmitted rf energy to the receiver for timing purposes. However, the signal available from the transmission line is so strong that the receiver input circuit may be burned out. Because of the sensitivity of the receiver, the strong signal may also cause blocking of tubes which employ RC grid circuits. This blocking occurs because the strong signal will overdrive the tubes, causing grid current to flow which charges the capacitors. After the signal is removed, the charge remains for some time, providing a bias which keeps the tubes below cutoff. Both of these conditions place a limit on the permissible amount of transmitted pulse that can reach the receiver, and are the reasons for employing receiver-protective devices.

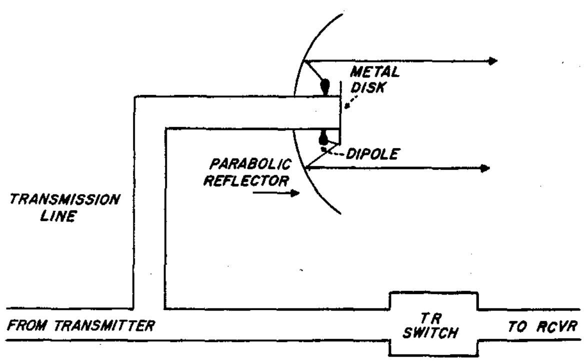

Figure 5. Antenna system.

d. Radio-frequency energy may be transferred from point to point by transmission lines in much the same way as industrial power is transferred by means of high-tension powerlines. However, at high frequencies the two-wire transmission lines (fig 6(1)) used for power frequencies and the lower radio frequencies are no longer practicable. The most common types of transmission systems are the coaxial line and the waveguide. The coaxial line, as the name implies, consists of two tubes with a common axis (fig 6(2)). The outer tube surrounds the inner tube and is separated from it by an insulating material such as dry air. The operation of this line is similar to that of an ordinary transmission line, but with less radiation loss along the line. The waveguide is a pipe, either rectangula or circular in cross section (fig 6(3) and (4)). Transmission is effected by causing the waves of energy to be reflected back and forth along the pipe in a forward direction. The construc tion of the waveguide is much simpler than the coaxial line, since the inner conductor with its various supporting elements has been eliminated. Because of its simple construction, the waveguide can handle high voltages more efficiently than the coaxial line. The dimensions of the waveguide depend upon the wavelength and it becomes rather bulky above 10-centimeter wavelengths (3,000 megacycles); a coaxial line is used with longer wavelengths.

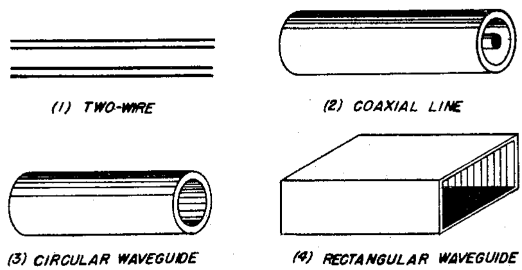

Figure 6. Types of transmission lines.

e. A radar system employs a single antenna and an antenna switch capable of connecting the antenna to the transmitter during the transmission time and to the receiver during the remainder of the pulse cycle. The switch is necessary to protect the receiver from the transmitter during the pulse time and also to isolate the transmitter during the receiving time. Otherwise, the weak receiver echoes might be wholly or partially lost. The transmitted pulse width and the repetition frequency of the system eliminate the possibility of using a mechanical switch.

(1) A system for using a single antenna for both transmission and reception should be as efficient as possible; all of the energy produced by the transmitte should reach the antenna, and all of the received energy should reach the receiver. This efficiency is most easily obtained by matching the antenna to the characteristic impedance of the transmission line. During transmission of the pulse, the transmitter should be matched to the transmission line and the receiver must present an open circuit, or high impedance to the transmission line. During the reception time the conditions should be reversed.

(2) The problem of switching is usually simplified because most transmitters have a different output impedance when they are on than when they are off. If properly matched to the transmission line during the pulse, the transmitter will be mismatched for the receiving time and the transmission line

will be resonant. Figure 7 illustrates a typical elementary system in which the receiver and transmitter are connected by branch lines to the antenna feed line. The junction of the three lines is known as the T-junction. During the off period, the switch in the receiver branch is closed and the transmission

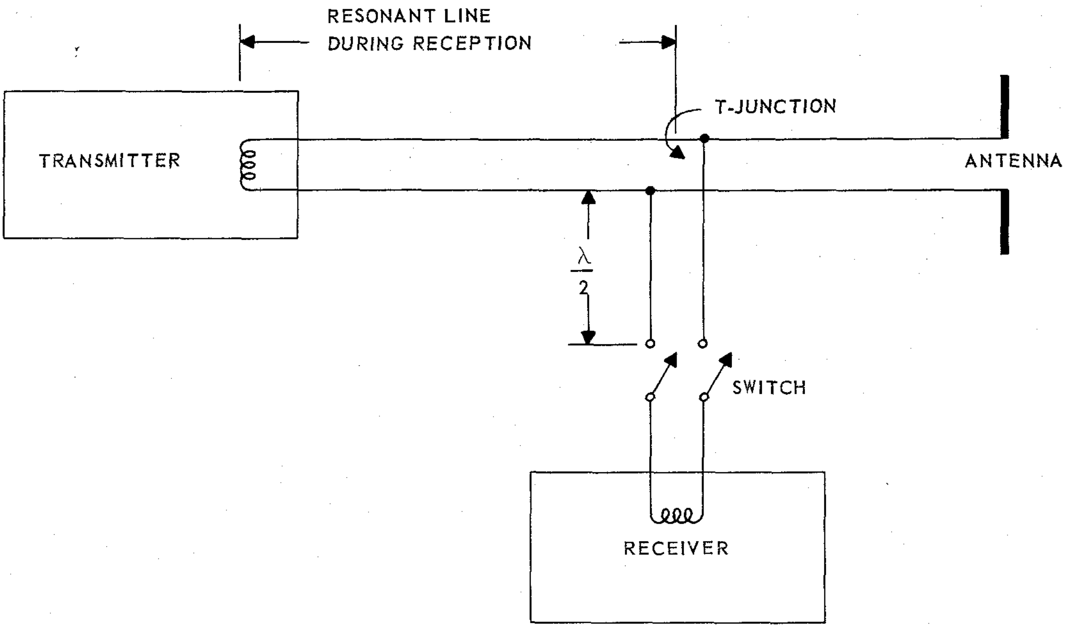

Figure 7. Elementary switching system.

line from antenna to receiver is properly matched. The resistance seen from the T-junction looking toward the transmitter can be controlled by the length of the resonant section between them. If the transmitter impedance decreases when it is turned off, the length should be a quarter-wavelength, or some odd multiple thereof, in order to see a high impedance. The high impedance presented by the transmitter and its feed line to the T-junction is in parallel with the relatively low characteristic impedance of the remainder of the transmission line system, but being high, has little effect. If the transmitter impedance increases when it is turned off, the resonant-line length should be a half-wavelength, or a multiple thereof.

(3) When the transmitter is turned on to transmit the next pulse, it again will be properly matched to the antenna. The open switch (fig 7) will prevent the pulse from reaching the receiver, and will cause a mismatch to the line between the switch and T-junction. By using some multiple of a half-wavelength, the open circuit of the switch will be presented as an open circuit across the transmitter-antenna line.

(4) In a broad sense the switching problem consists of providing what amounts to a double-pole, single-throw switch (fig 7) for connecting the antenna

alternately to the transmitter and to the receiver. The switching device must be capable of acting within a time interval of a few microseconds, as the receiver should be in the antenna circuit immediately after the transmission of the pulse in order to detect close-range targets. This microsecond timing requires that the device be electronic in type. Under various operational circumstances it may take the form of rf amplifiers, klystrons, spark gaps, resonant transformers, spark-gap tubes, and (in waveguides) resonant slits. It is commonly known as the TR (transmit-receive) switch or TR box. Other terms frequently encountered are duplexer, reprod, and, in certain instances, polyplexer.

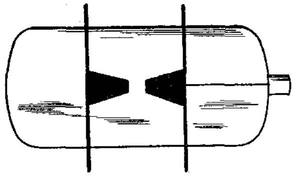

Figure 8. TR tube.

(5) The TR tube (fig 8) consists of two conical-shaped metal electrodes inclosed in a glass envelope that is mounted in a resonant cavity. When excited by the transmitted energy, it causes an arc to be formed between the two electrodes. This action electrically blocks the line to the receiver and causes all of the energy to be conveyed to the antenna. As soon as the transmitted pulse has passed, the TR tube returns to its normal condition. Electrical characteristics of the line cause the magnetron to appear as an open circuit, and the very weak echo signals pass into the receiver system.

(6) ATR (antitransmit-receive) and TR tubes are resonant cavities, whose resonant frequency corresponds to the transmitter frequency. They are filled with gas under a low pressure. In the case of the TR tube, spark gaps shorten the time required for ionization and provide maximum protection for the receiver. The ATR tubes prevent the reflections (rf energy echoes) from entering the magnetron. Since the energy contained in these echoes is not sufficient to cause arcing of the TR tube, the energy enters and travels through the TR tube to the preselector. During the transmitting cycle, the rf energy traveling down the waveguide finds an open circuit at the TR tubes, but the transmitted power enters the resonant cavities, causing oscillation. The power in the cavities, which is great because of the energy contained in the transmitted pulse, causes the gas in the cavities to ionize. This reflects a short circuit across the ATR cavities, and the rf energy continues down the waveguide.

f. The principal types of radiators employed in the radar antenna system include the stacked-dipole array with untuned reflector, the dipole with tuned reflectors and directors (Yagi), the dipole with parabolic reflector, and various arrangements of dielectric radiators used in conjunction with waveguides.

(1) The stacked-dipole array may be composed of one or more banks of dipoles and may be adapted for lobe switching. The entire assembly usually can be rotated in either azimuth or elevation, or both.

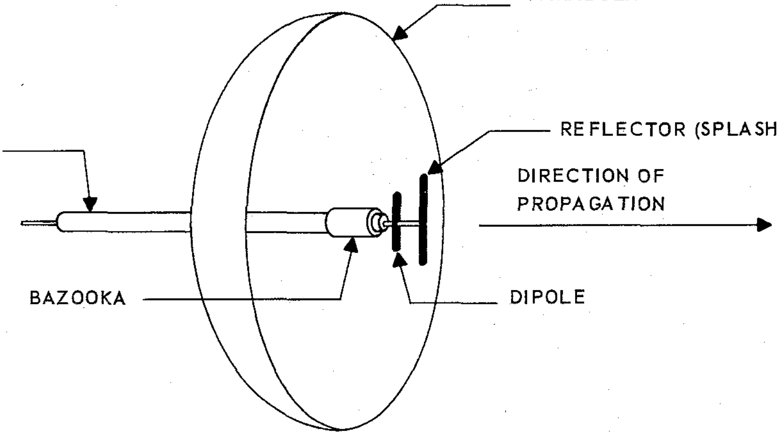

Figure 9. Dipole with parabolic reflector.

(2) A Yagi array can be of a type utilizing both director and reflector parasitic antennas in conjunction with a driven element. Only the driven element is connected to the transmission line. The other elements are excited parasitically, picking up energy from the driven element and reradiating it with such a phase relation with respect to the driven dipole that the field is reinforced in the forward direction.

(3) Figures 5 and 9 show the parabolic reflector type of antenna, which is a practical means of producing a narrow beam pattern in the region of the microwavelengths. The reflection of rf energy by the parabola or dish is closely analogous to the reflection of light by a parabolic mirror. The dish is large in comparison with the operating wavelength; in general, the larger the reflector, the narrower the beam pattern. The rf energy is fed to a dipole located at the focal point of the parabola. A parasitic reflector is placed about one-quarter wavelength in front of the dipole to reflect practically all of the radiated energy back to the dish from which it is reflected ahead in the form of a narrow beam. Modifications of this type of radiating system include cylindrical and other types of parabolas. Parabolic reflectors are frequently used in conjunction with waveguides.

(4) A bank of dielectric radiators can be fed by waveguides. These radiators may be considered merely as extensions of the waveguides and are designed to provide the proper termination to transfer the energy from the waveguides to space.

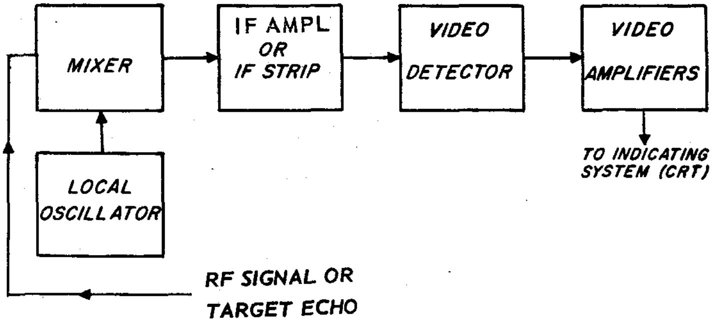

Figure 10. Receiver system.

15. RECEIVER SYSTEM

a. The function of the receiver is to take the weak echoes from the antenna system, amplify them sufficiently, detect the pulse envelope, amplify the pulses, and feed them to the indicator. The receivers used in radars are capable of accepting weak echoes and increasing their amplitudes by a factor of 20 or 30 million. Since radar frequencies are not easily amplified, a superheterodyne receiver changes the radio frequency to an intermediate frequency for amplification. Stability of operation is maintained in the microwave range of frequencies by careful design, and the overall sensitivity of the receiver is greatly increased by the use of many intermediate-frequency stages. Special types of tubes having low interelectróde capacitances have also been developed for use in rf, local-oscillator, and if stages.

b. Figure 10 illustrates the receiver components of the radar system. The rf amplifier may not be present in the higher frequency ranges and thus the received signal may be fed directly to the mixer. In this case it is desirable to use as short a receiver input transmission line as the design requirements allow. Thus the mixer and local oscillator may be located close to the T-junction of the transmission line in order that the received rf energy may be converted to the lower intermediate frequency before being relayed to the remaining receiver components. One or two stages of if amplification are sometimes located immediately after the mixer-local oscillator stage, functioning as a preamplifier to offset the considerable attenuation encountered in coupling the very weak received signal to the remote receiver components. The components of the radar receiver may be distributed throughout the system in such a manner that their physical identity becomes lost.

16. INDICATOR

a. The indicator uses the received signals to produce a visual indication of desired information. The cathode-ray oscilloscope is an ideal instrument for the presentation of radar data since it not only shows a variation of a single quantity such as voltage, but gives an indication of the relative values of two or more synchronized variations. The usual indicator is basically the same in function as the low-frequency test oscilloscope.

The focusing intensity and positioning controls are similar. The sweep frequency of the radar indicator is determined by the pulse-repetition frequency of the system and the sweep duration is established by the setting of the range-selector switch (fig 11).

(1) The simpler systems of data presentation generally use the electrostatic cathode-ray tube in which the electron beam is made to follow some pattern by controlled differences in potential between pairs of deflecting plates.

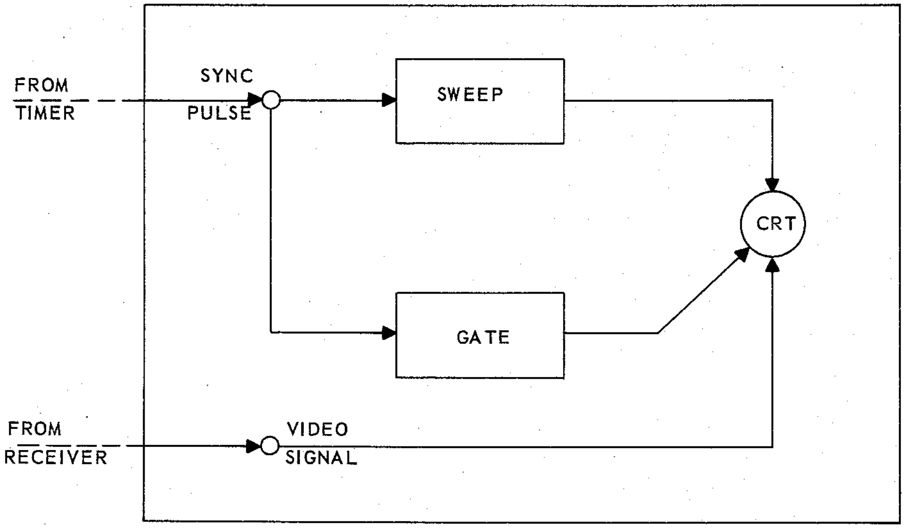

Figure 11. Basic components of radar indicator.

(2) The more highly refined systems of data presentation generally utilize the electromagnetic cathode-ray tube with a long-persistence screen. The position of the electron beam at any instant is determined by causing it to pass through a magnetic field produced by controlled currents through deflecting coils mounted outside the tube. If intensity modulation is used, the bias is such that the tube is held just beyond cutoff, and the video output of the receiver is applied to either the grid or cathode with such polarity as to release the beam and allow the trace to appear on the screen. Thus the bright spots on the screen represent returning echoes detected by the radar receiver.

b. The A-scan (fig 12) uses an electrostatic cathode-ray tube with a linear sweep applied to the horizontal deflecting plates to establish a time base, and with the video output of the receiver applied to the vertical deflecting plates. Since the sweep is linear with time, a scale calibrated in range may be placed on the oscilloscope screen. This scale permits the reading of range directly. Since the antenna beam is highly directive, the maximum received echo appears when the antenna is pointing directly at the target. Thus, by rotating the antenna until the echo pulse produces maximum deflections on the screen, an indication of direction in azimuth or elevation can be obtained.