The SCR-584 Radar

--- Part I ---

The most versatile of the ground-based radars, SCR-584 stopped the buzz bombs by guiding antiaircraft batteries automatically to an accuracy of 0.06 degree. Technical features include conical scanning, 300-kw pulses at 10-cm wavelength, and range-timing accuracy to 0.01 microsecond

HIGH on the list of the electronic achievements of the war is the SCR-584 radar. A microwave set developed primarily for accurate fire control of 90-mm anti-aircraft batteries, the 584 served this basic purpose from Anzio to the end of the war. It also served as an early-warning radar against approaching enemy aircraft, as a ground control for low-flying fighter aircraft in the advance across France, and detected the motion of enemy transportation along roads and the flight of enemy shells and mortars in the Italian campaign. Technically, also, SCR-584 merits a high place. It is among the most powerful of the portable radars, and is outstanding in the accuracy of its indications. In short, this radar is one of the most highly-engineered electronic devices in existence.

The need for a radar to control the fire of anti-aircraft guns was felt before the war, and the SCR-268 (ELECTRONICS, September 1945, page 100) was applied to this use in the early days. But greater accuracy, obtainable only by the use of shorter wavelengths, was required. The military needs were presented to the Radiation Laboratory at M.I.T. by the Coast Artillery Corps (then the parent body of the Anti-aircraft Command) in January, 1941. By April, the prototype equipment had been erected on the roof of Building 6 at M.I.T. and was successfully tracking aircraft the following month. Since the need for portability was evident, the equipment was then transferred by the Radiation Lab group to a truck, known as XT-1, and demonstrated in November of the same year.* After coordination at the Signal Corps Laboratories, the XT-1 was given its service test by the Coast Artillery at Fort Monroe in February 1942. This test having been passed successfully, manufacturers were called in to bid on production and a year later, in May 1943, the first production model of SCR-584 was delivered to Camp Davis. Its first active service was at the Anzio beachhead in February 1944. In all, no fewer than 1,710 SCR 584 radars

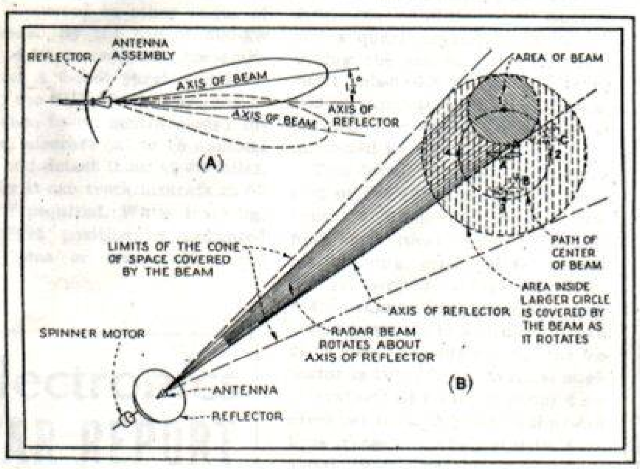


FIG. 1—(A)—Conical scanning is obtained by rotating an offset beam about the axis of the reflector. (B)—The effect of conical scanning is to create a sinusoidal error signal when the target lies off the axis of the reflector

*Among the personnel at the Radiation Laboratory and in military organizations who contributed to the design and production of the SCR-584 are: H. B. Abajian, Col. W. S. Bowen, B. Chance, L. L. Davenport, H. D. Doolittle, I. A. Getting, Sidney Godet, A. Grass, D. T. Griggs, G. B. Harris, C. E. Ingalls, Col. J. E. McGraw, L. N. Ridenour, C. W. Sherwin, Lt. Col. J. A. Slattery, L. J. Sullivan, A. H. Warner, and the late Lt. Col. Paul Watson.

Production model SCR-584 in operation at 68th CA (AA) Bn (C Battery) in the Nettuno Area, Italy, for antiaircraft gunfire control, camouflaged against detection and sandbagged for protection

The original model, developed and built in the Radiation Laboratory in 1941 and known as XT-1. This was the first radar capable of following a target automatically without human aid

were delivered, at an average cost (including spare parts) of approximately $100,000 each.

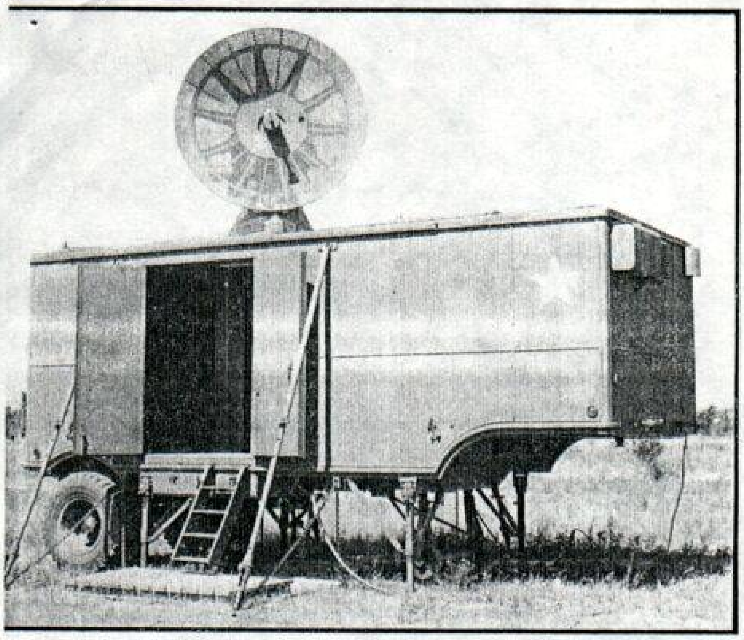
Basic Specifications

The specifications of the SCR-584 are listed in the accompanying table, the significance of the data being discussed in other pages of this issue. By the use of 300-kw pulses of 10-cm radiation, transmitted from a 6-foot paraboloidal reflector, the SCR-584 is designed to track (i.e., follow continuously) individual aircraft out to 18 nautical miles, and detect them at 40 miles. Actually it can track aircraft at 50 miles if required. While tracking, the target position is indicated within plus or minus 25 yards in range, and 0.06 degrees in azimuth and elevation. The range indication, while looking at a stationary target, may be reset to an accuracy of 2 yards, which represents a timing accuracy of about 0.01 microsecond. The key to this outstanding performance lies in the use of conical scanning for angular determination of the target position and a quartz-crystal oscillator for timing the echoes. The use of a short pulse (0.8 microsecond long) and an expanded cathode-ray sweep permits the echo pulses to be measured precisely.

Two forms of scanning (the motion of the radiated beam through space) are employed: helical scanning and conical scanning. In helical scanning, employed for searching for aircraft before they come within range of the guns, the paraboloid is swung in a circle at a rate of 6 rpm. Simultaneously the reflector is tilted in the vertical angle (elevation) at a rate of about 4 degrees per turn. A point on the beam thus traces out a helical path, from about 10 degrees below the horizontal to the zenith, over any 20° sector. Since the beam itself is 4 degrees wide (7 degrees when the conical scanning is in operation) all points of space are passed over by the beam during each full helical scan. If an aircraft target is within range, the radar will surely detect it.

SPECIFICATIONS

Wavelength	10-11 cm
Frequency	2,700-2,900 mc
Reflector	6-foot paraboloid
Pulse Power	300 kw
Pulse width	0.8 microsecond
Pulse rate	1,707 pps
Receiver bandwidth	1.7 mc
Receiver noise figure	15 db
Beam width	4 degrees (not spinning)
Beam width	7 degrees (spinning)
Search scan	6 rpm helical
Track scan	1,400 rpm conical
Azimuth range	360 degrees
Elevation range	— 10 to + 89 degrees
Maximum range, search	40 miles
Maximum range, track	18 miles
Minimum range	500-1,000 yards
Range accuracy	± 25yd (dynamic)
Range accuracy	± [illegible]d (static)
Angular accuracy	± 1 mil = 0.06 degree



Overall view of the SCR-584. The paraboloid can be lowered into the trailer during transportation

reflected signal is approximately sinusoidal, with a frequency equal to the rotation rate. Finally, if the target is at position C, the same sinusoidal variation occurs, but is shifted 90° in phase relative to that of position B. When the target has some intermediate position between B and C, the phase angle has a corresponding intermediate value.

The reflected pulses are thus modulated in amplitude. The amplitude of the modulation increases as the target departs from the axis of the cone, and the phase angle indicates the direction of the departure. By translation of these quantities into appropriate motor controls the antenna is directed so as to keep the target centered on the axis of the cone. So sensitive is this control that a departure from the cone axis of a few hundredths of a degree is immediately perceived and corrected. Moreover, the hunting of the radiator while following the target position is restricted to a probable error of one mil, or 0.06 degree.

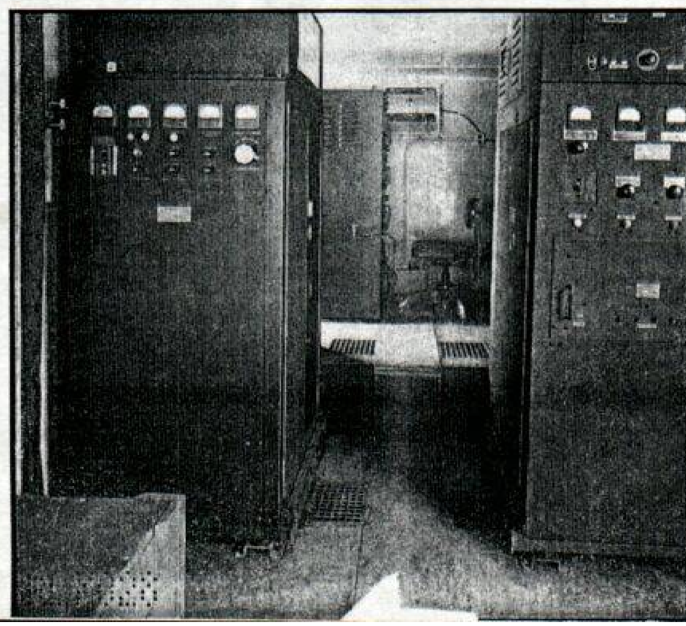
Once the target is detected and is within range of the guns the radar function is shifted from search to track. In tracking, the axis of the antenna points automatically and continuously at the target, while the radar transmits range and angular data to the associated gunfire computer. This automatic function is accomplished by the use of conical scanning, illustrated in Fig. 1A. The radiation is off-set electrically from the focus of the reflector and the dipole radiator is rotated about the focus by an auxiliary motor at a rate of 1400 rpm. The offset causes the axis of the radiated beam to depart from the axis of the paraboloid by about 1.25 degrees, and as it rotates, the beam traces out a cone as shown.

When the target lies on the axis of this cone (at point A in Fig. 1B) the signal intercepted has a constant value throughout the rotation. Consequently the reflected pulses are of constant amplitude, except for changes due to fading, polarization effects, etc. But if the target is off this axis, say at point B, the signal intercepted is a maximum at position 3, a minimum at position 1 and has intermediate values at positions 2 and 4. The variation in the intercepted and

General Operating Principles

The components of the SCR-584 are shown in the block diagram in Fig. 2. The operation starts in the timing unit, which contains a crys-

Looking forward in the trailer, the 22-kilovolt rectifier is at the left, and the modulator (including magnetron transmitter) at the right. These two units develop pulses of 300-kw peak power at a rate of 1707 per second



tal oscillator and four frequency-dividing multivibrator stages which produce the basic pulse rate of 1,707 pulses per second. Several waveforms are generated in the timing unit to initiate the transmitter pulses and to synchronize the receiving and indicating systems with them. Narrow trigger pulses are fed to the transmitting system which comprises a driver, modulator, and r-f generator (cavity magnetron). R-f pulses of 0.8 μsec width, 3,000-mc frequency, and 300 kw peak power are generated every 586 microseconds in the transmitting system and applied through the co-axial transmission line to the antenna. On their way to the radiator, the pulses pass an enclosed low-pressure spark gap known as the transmit-receive switch (T/R box). This gap breaks down during each pulse and short-circuits the transmission line to the receiver, thus preventing the transmitter pulses from burning out the crystal mixer of the receiver.

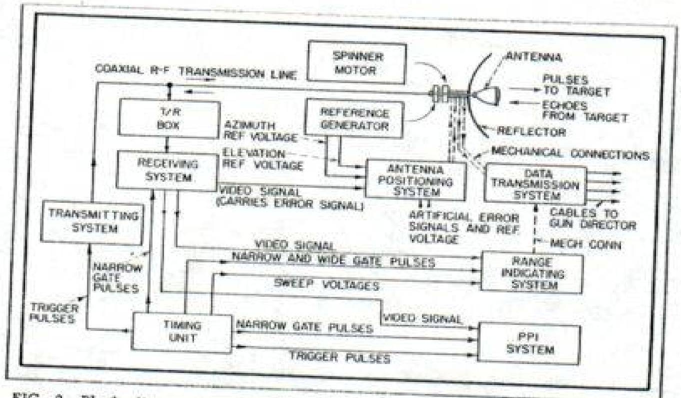
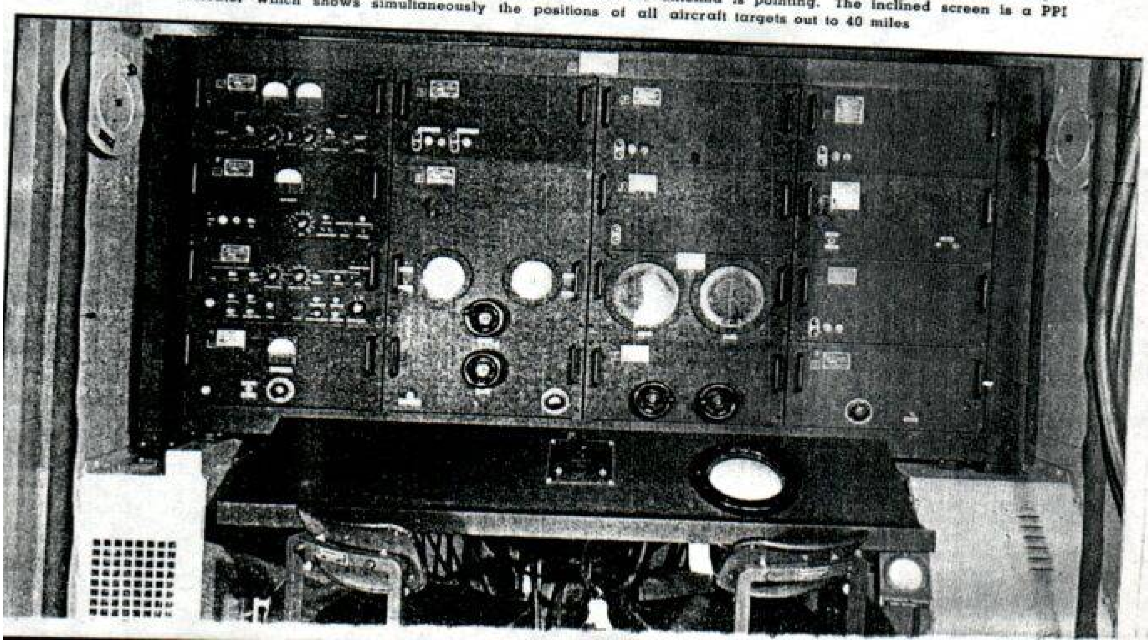


FIG. 2—Block diagram of the SCR-584. Details of the transmitting system are included in this article; other elements are in articles to follow

The pulses continue to the radiator, passing concentrically through the shaft of the spinner motor which rotates the antenna to produce the conical scan. After reflection from the target the pulses are received by the same antenna and return along the same transmission line. The transmitter is then inactive and its impedance is different from that of the transmission line. Consequently, little of the received signal is absorbed by the transmitter. The T/R spark gap has by then ceased conduction, so the transmission line conducts the signal to the receiver. Here it is converted in a silicon-crystal mixer to an intermediate frequency of 30 mc, amplified, detected, and amplified again as a video control signal. Pulses are fed to the receiver from the timing unit to bias the i-f amplifier during the transmission of the pulse, as additional protection against overload.

The video output of the receiver is fed to three units. The first is the antenna positioning system which compares the error signal (the amplitude modulation envelope of the received pulses) in phase and amplitude with reference voltages derived from a reference generator mounted on the spinner shaft. This comparison develops two control voltages, one proportional to the azimuth component of the error

The SCR-584 units. The two oscilloscopes at left of center are the type J indicators used in measuring the distance to the target. The dials at the right indicate the azimuth and elevation angles at which the antenna is pointing. The inclined screen is a PPI indicator which shows simultaneously the positions of all aircraft targets out to 40 miles



signal, the other proportional to the elevation component. These control voltages operate an amplidyne control system which orients the antenna so that the error signal is a minimum. Manual positioning is also possible through the use of an artificial error signal, produced within the equipment and controlled by knobs set by the operator to the desired values of azimuth and elevation.

Another output from the receiver is fed to the range indicating system. This system contains two 3-inch oscilloscopes used as type J indicators. The sweep pattern is circular. The echo signal is displayed as a radial pulse on the trace. One scope covers a range of 2000 yards for fine indication of the range, and the other covers 32,000 yards for coarse indication. The circular sweep is provided by sweep voltages derived from the timing unit.

The range indicating system is used primarily as an adjunct to automatic operation. The operator adjusts the tracking handwheel so as to keep the echo pulse on the calibration hairline. The range unit includes a mechanical aided-tracking device which maintains a given rate of change of range to keep up with the target, while the operator feeds in occasional corrections to the rate. A mechanical connection from the range handwheel to the data transmission system introduces the range coordinate, and similar connections from the antenna introduce the azimuth and elevation coordinates. The data transmission system computes the height of the target, and passes all the information to the gun computer.

The remaining component shown is the plan position indicator (PPI) system. This is an indicator used primarily during the search phase of the radar operation. The cathode-ray beam in the PPI is deflected radially, starting from the center of the screen at the instant the transmitted pulse leaves the radar and continuing outward at a constant rate. The sweep rotates synchronously with the antenna as it scans in azimuth. When an echo is received from a target, the c-r beam is brightened and a spot appears on the trace representing the target. The distance of the spot from the center of the tube indicates the slant range of the target and the direction of the trace indicates the azimuth angle to the target. The PPI thus presents a map of the area surrounding the radar, with all targets within range shown in their relative positions, in plan view. The deflection currents are generated within the PPI system, and are synchronized by trigger pulses from the timer unit.

The Transmitting System

The transmitting system block diagram is shown in Fig. 3, and simplified schematics of the driver and modulator are shown in Fig. 4 and 5. The driver unit is controlled by a short, sharp trigger pulse of 15 volts amplitude derived from the timer unit (as indicated later in this series of articles). These pulses drive a one-shot (biased) multivibrator (6SN7GT tube) which generates a negative rectangular pulse of two microseconds duration. This is fed to a 6L6G inverter stage which reverses the polarity and applies the pulse, in positive polarity, to the first driver stage (type 3E29).

The first driver is coupled by a pulse transformer (capable of passing short pulses) which reverses the polarity, feeding positive pulses to the second driver stage. The negative pulse appearing in the output of the second driver stage (two type 3E29) is fed back to the grid of the first driver through a low-pass filter network which serves as an artificial transmission line. The constants of this line are so chosen that the pulse requires exactly 0.8 microsecond to pass through the line. Consequently 0.8 microsecond after the pulse is applied in positive polarity to the first driver, a large negative pulse is fed

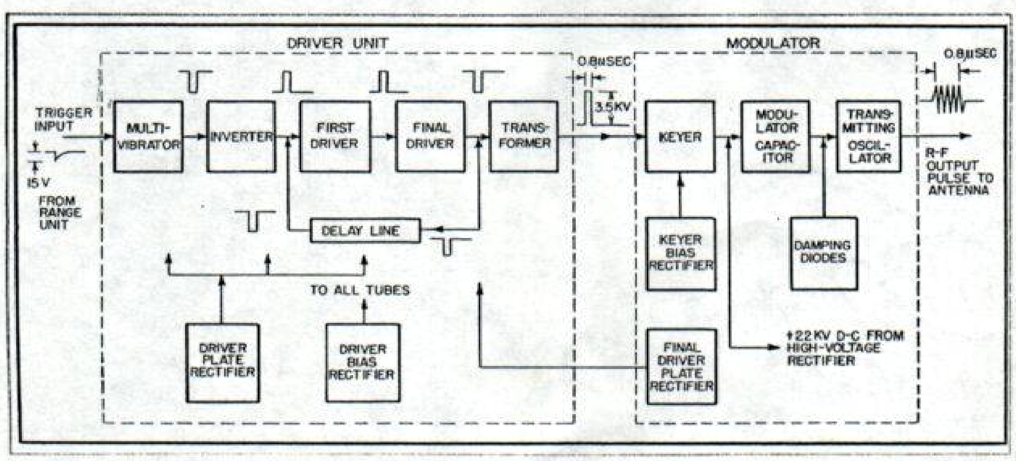


FIG. 3—Block diagram of the transmitting system. Acting under the control of the timing unit, these circuits create r-f pulses of the required length, power and rate

back to it, thus cutting off the first driver and forming the trailing edge of the pulse. The resulting pulse appears across the output pulse transformer, with an amplitude of 3,500 volts, positive against ground.

The output of the driver is fed to the grids of the modulator or keyer tubes, two type 6C21 tubes in parallel, shown in Fig. 5. The grids are biased to −1400 volts and thus remain cut off between pulses.

When the driver pulse appears, it drives the grids of the modulator tubes into the positive region, and the modulator tubes pass a current of about 20 amperes, discharging the modulator capacitor (previously charged to 22 kilovolts) through the magnetron. This sudden passage of current excites the magnetron into oscillation at the desired frequency (in the band from 2,700 to 2,900 mc).

At the conclusion of the driver pulse, the modulator tubes suddenly become nonconducting and the discharge through the magnetron is stopped. There is a tendency for the circuit to continue to oscillate, due to resonance between the stray capacitance of the magnetron and wiring with the inductance which completes the capacitor charging circuit to ground. To damp this resonant circuit, three diodes (type 8020) are provided which conduct

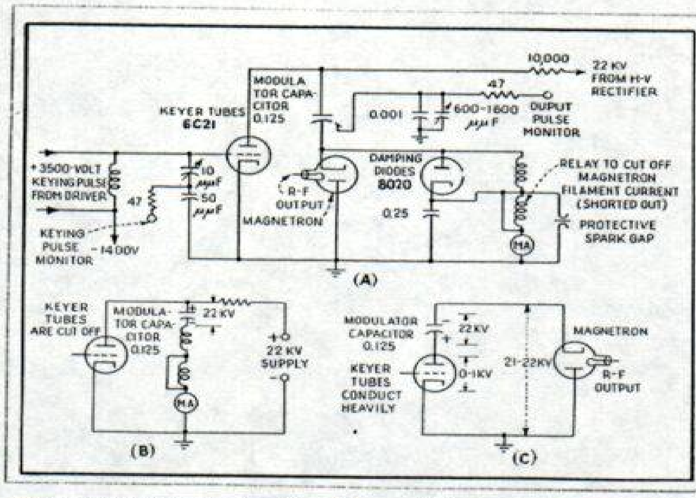


FIG. 5—(A)—Simplified schematic of the modulator and r-f generator. (B)—Equivalent circuit between pulses, while modulator capacitor is charging. (C)—Equivalent circuit during discharge through magnetron

the positive halves of the oscillations and thus rapidly absorb the stored energy.

Figure 5 shows the two equivalent circuits of the modulator. At the lower left is the condition between pulses, with the modulator tubes cut off, and the modulator capacitor charging from the power supply at a slow rate through the inductance. At the lower right is the condition during each pulse, in which the capacitor is discharged through the magnetron. The inductance, which cannot pass a sudden change in current, prevents the power supply from being short-circuited during the pulse, while allowing the capacitor to be charged at a slow rate between pulses.

The r-f transmission system, radiator, spinner mechanisms, and receiver will be described in the second article of this series.—D.G.F.

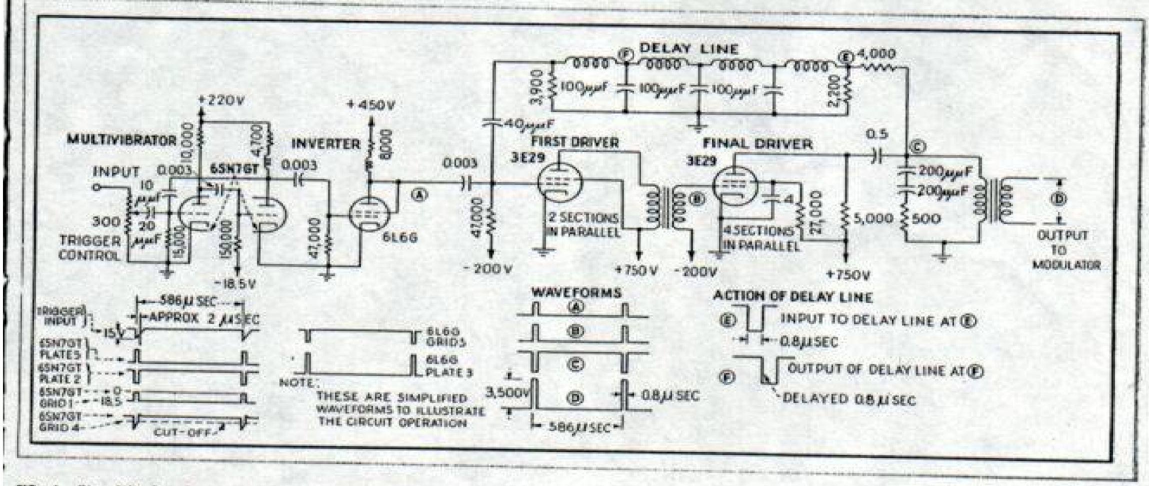


FIG. 4—Simplified schematic of the driver unit, which creates 0.8-microsecond pulses of 3500-volt amplitude for driving the modulator tubes

echo. The time between the two is a measure of the range. Type J is similar, except that the trace is circular, about the periphery of the tube, rather than linear. Type PPI has been described elsewhere in this and previous issues; it produces a map-like indication by radial deflection from the center of the tube, the deflection keeping step with the azimuth rotation of the radiated beam. Type B presents range information vertically and azimuth information horizontally, in rectangular coordinates, and is thus a distorted portion of a PPI picture. Tube sizes vary from 3-inch (SCR-584 J-scopes) to 12-inch (SCR-270 PPI). Most A-scopes are five-inch tubes and PPI's are typically about seven inches in diameter.

The sets described here cover the gamut of radio frequency from 110 mc to 10,000 mc (270 centimeters to 3 centimeters wavelength). The peak power employed varies from 50 to 350 kw. These are typical figures, although higher powers have been used in early-warning sets employed by the Air Forces and the Navy. In general, the beam widths, pulse rates and scanning rates will be found consistent with the requirements previously stated. Moreover, the maximum ranges quoted are generally consistent with the radar equation, when the indicated constants are substituted. One major difference should be stated, however. Some of the maximum ranges given are those which occur when the radar beam is partly reflected from the surface (sea or ground) and partly transmitted directly to the target. Constructive interference of the two waves may, in ideal circumstances, double the maximum range predicted by the radar equation. Destructive interference, under the same circumstances, may similarly reduce the maximum range to zero miles. Hence a wide variety of possible maximum ranges exists, depending on the conditions of measurement. The radar equation gives an index to average performance.—D.G.F.

REFERENCE

(1) Fink, D. G., The Radar Equation, ELECTRONICS, p 92, Apr. 1945.

U.S. SIGNAL CORPS RADARS

SCR-547	SCR-582/682	SCR-584/784	AN/TPL-1	AN/MPG-1	Type Number
Range finder for AA fire-control (mobile)	Coastal search for ships and planes (fixed)	Search (s) and automatic track (t) for AA fire-control (mobile)	Light weight searchlight control (mobile)	Seacoast fire-control against marine targets (mobile)	Primary Function
2 trucks and trailer; 49,487 lb	3359 lb (582); 13,640 lb (682)	Trailer, 20,000 lb (584); 12,000 lb (784)	Trailer; 4205 lb	Trailer; 28,000 lb	Size, Weight
2720-2890	2800	2700-2900	2700-2900	10,000	Carrier Frequency (mc)
10	10.7	10-11	10-11	3	Wavelength (λ) (cm)
80	30 (582) 225 (682)	300	200	60	Peak Power (P_t) (kw)
0.5	1	0.8	1	1 (s) 0.25 (t)	Pulse Width (d) (microseconds)
4098	500 (582) 420 (682)	1707	400	1024 (s) 4098 (t)	Pulse Rate (f_r) (pps)
2 57-inch parab.; 5000	4-ft paraboloid; 800-900	6-ft paraboloid; offset dipole; 1200	4-ft paraboloid; 860	Schwarzchild rapid-scanner; 12,000	Radiator Type, Size, Gain (G_o)
Range only, optical tracking	Circular search	Helical search, conical track	Helical search, conical track	Circular search; also 10° sector; track	Types of Scan
3.8	6	4 (7 when spinning)	10	0.6 az., 3 el.	Beam Width (b) (degrees)
Manual	10-20	6	7.25	160°/sec	Horizontal Scanning Rate (rpm)
—	18 (582), 14 (682)	15	18.5	17	Receiver Noise (n) (db above $kt\Delta f$)
6	1.5 (582), 2 (682)	1.7	1.8	10	Receiver Bandwidth (Δf) (mc)
1 type-A	1 type-A, 1 type-PPI	2 type-J, 1 type-PPI	3 type-A, 1 type-PPI	2 type-B, 1 type-PPI	Indicators
12	45 (582), 140 (682)	34 (s), 18 (t)	34	28 (battleship)	Maximum Range (r_{max}) on Bombers at 10,000 Feet (miles)
300	1000 (582), 500 (682)	500	500	—	Minimum Range (yd)
25	2 per cent	15	200	—	Range Accuracy (yd)
—	2	1 (s), 0.06 (t)	1 (s), 0.5 (t)	—	Angular Accuracy (degrees)

The SCR-584 Radar

Details of the r-f system and receiver of the outstanding anti-aircraft gunfire-control radar, including hitherto unpublished information on microwave plumbing, rotating joints, crystal mixers, t/r tubes, and gated i-f amplifiers. Operating principles and specifications were given last month

The radio-frequency pulses generated in the cavity magnetron of the SCR-584, as described in the first installment (ELECTRONICS, November, 1945, page 104), are conveyed to the radiator by a system of microwave plumbing and components known as the r-f system. The echo pulses received from the target are conveyed from the radiator to the receiver through the same system. In this article,

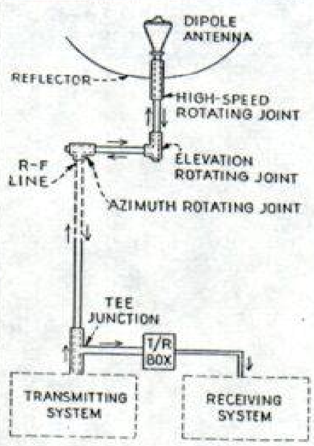


FIG. 1—Block diagram of the r-f system, by which the transmitted pulses and echoes are conveyed to and from the radiator

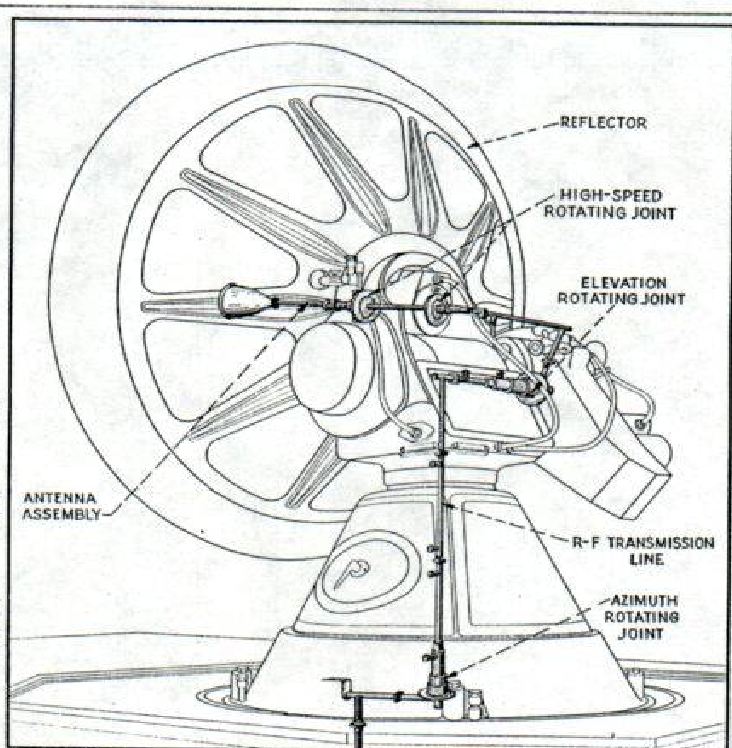
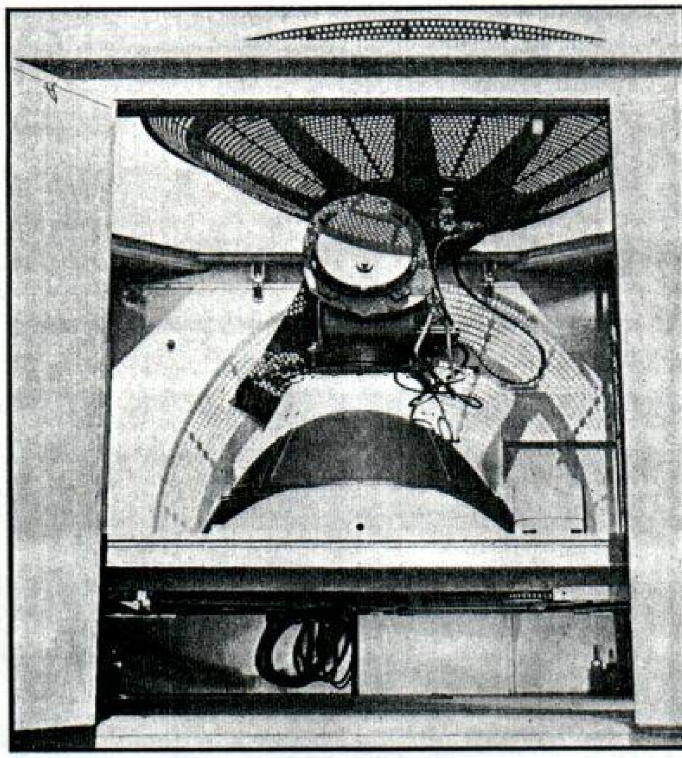


FIG. 2—Perspective view of the r-f transmission line and rotating joints, from magnetron output to dipole radiator



Closeup of antenna and platform of radar set SCR-584, partly raised out of the trailer. When in operation, the platform is up flush with the roof of the trailer

the details of the r-f system and receiver are described.

Basic Functions of the R-F System

The essential components of the r-f system are shown in the block diagram in Fig. 1 and in perspective in Fig. 2. As the r-f pulse leaves the transmission system it encounters a T-junction, which joins three coaxial lines. One branch leads to the radiator. En route the signal passes through three rotating joints. These joints permit the radiator to move in azimuth and elevation for helical scanning, and permit the dipole radiator to be spun about the axis of the paraboloid, for conical scanning.

The remaining branch of the T-junction leads to the receiver. In this branch the transmitted signal encounters the t/r (transmit/receive) box, a low-pressure gas discharge tube which breaks down and prevents passage of the strong transmitted signal to the receiver. At the conclusion of the transmitted pulse, the t/r gap deionizes, and the echo signals thereafter received are passed to the receiver. Coincidentally, the impedance of the cavity magnetron changes, so that the echoes are reflected from the transmission system with but minor loss due to absorption.

The transmission lines themselves are of the coaxial variety, with the inner conductor supported at intervals by quarter-wave stubs. The diameter of the inner conductor is increased at the stub, and for one quarter wave on either side, to increase the frequency band over which the stub support introduces negligible loss. A typical stub support and a joint in the line are shown in Fig. 3. The rotating joints are shown schematically in Fig. 4. Each joint consists of quarter-wave overlaps between outer and inner conductors, within each of which is a small gap. The gap permits passage of the r-f energy, by capacitive action, while allowing free rotation of the joint about the axis of the line. Each joint is covered with a gas-tight seal which permits the lines to be filled with dry air under five pounds pressure.

Dipole Radiator

The dipole radiator is shown in Fig. 5. A plastic housing surrounds the assembly to contain the air under pressure. The coaxial line is surrounded, at the left, by a quarter-wave collar which converts the single-ended feed of the line to the push-pull feed required to excite the dipole. The inner conductor is built up to large diameter, as shown, thereby changing the impedance of the line so that it matches the impedance of the dipole. The dipole itself consists of two rounded projections, one soldered directly to the outer conductor, the other connected to the inner conductor and projecting through a hole in the outer conductor. The two segments of the dipole are of different lengths so the radiation from it is slightly assymetrical with respect to the axis line. As a result the axis of the beam is displaced from the axis of the paraboloid and as the dipole spins the beam traces out a cone (conical scanning, see part I).

At the right of the assembly is a metal disk which reflects the forward radiation from the dipole, returning it to the reflector. This forward radiation would otherwise be largely wasted since it would spread outside the limits of the beam. The coaxial line is shorted at the righthand end, at such a distance from the dipole that the signal reflected from the short appears in proper phase at the dipole to reinforce the radiated signal.

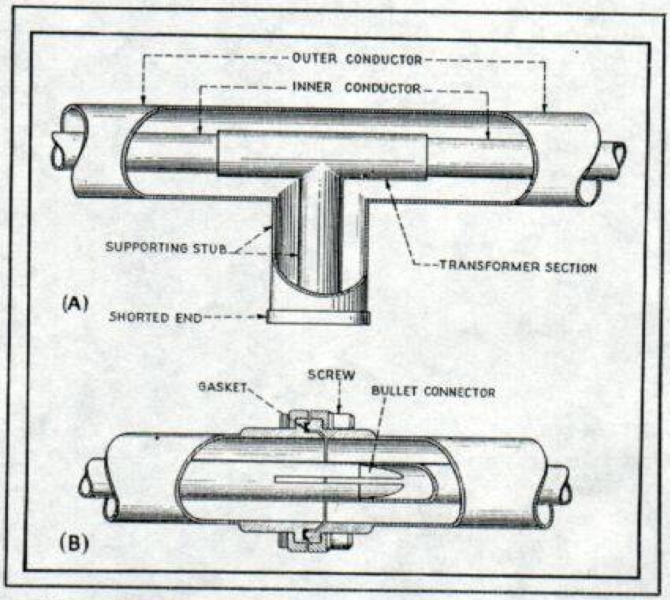


FIG. 3—Coaxial transmission line fittings: (A) broadband quarter-wave stub support; (B) in-line joint

Transmit-Receive Switch

The t/r box (Fig. 1) is a device which permits the use of the same radiator for transmission and reception. Its essential element is the t/r tube (type 713A) shown in Fig. 6. This tube comprises two conical electrodes supported on metal flanges which extend through the glass envelope and become part of a resonant cavity (Fig. 6A). The cavity is tuned by tuning plugs to resonate at the carrier frequency. Consequently when the transmitted signal appears at the cavity input (through a coupling loop), the cavity is excited, and a high potential appears across the conical electrodes. Sufficient free ions are present in the tube (supplied by an auxiliary keep-alive electrode within the tube) to permit almost immediate ionization of the gap. The breakdown short-circuits the cavity and detunes it so that the magnetic field within it collapses at once, and the signal is prevented from leaving the cavity via the output coupling loop. The tube is filled to a pressure of about 1 mm of mercury of water vapor, which ionizes in a few hundredths of a microsecond.

At the conclusion of the transmitted pulse, the gap deionizes (the recovery time is about 1 microsecond), and the cavity regains its tuned condition. Thereafter, when echo signals are received, they excite the cavity (but to such a low power level that the gap does not break down) and they are coupled through the cavity directly to the receiver input circuit of receiver.

In the discharge condition, the t/r box introduces an attenuation to the transmitted signal of over 60 decibels, which reduces the power from 300 kw to well under 100 milliwatts. This level is small enough to be harmless to the receiver but sufficient to excite the receiver so the transmitted pulse is visible on the type J range scope. The power consumed in maintaining the gas discharge is negligible compared to the 300-kw level of the transmitted pulse.

The Receiving System

A block diagram of the receiving system is shown in Fig. 7. The echo signal is passed by the t/r box directly to the crystal mixer, where it is combined with a local-oscillator signal 30 mc higher in frequency. The 30-mc intermediate frequency is then amplified in two i-f stages (preamplifier) which are mounted directly adjacent to the crystal mixer. The remaining i-f stages are located (for convenience) at some distance, in the receiver proper. After the fifth i-f stage, the i-f channel breaks up into two branches, one (the range channel) feeding the indicators, the other (servo channel) feeding the auto-tracking circuits.

The circuits of particular interest in the receiving system are those which convert the carrier frequency to the intermediate frequency. Care must be taken in these circuits to maintain the noise level as close as possible to the inescapable noise level introduced at the antenna itself.

Crystal Mixer

The three most serious sources of additional noise, in order of importance, are the crystal mixer, the i-f amplifier and the local oscillator. The first two i-f stages are located as close as possible to the mixer stage to avoid losses at low level in the connecting cable. By attention to such details it has been possible to keep the noise in the receiver output to within 15 db of the theoretical level present in the antenna circuit.

The multi-grid converter tubes

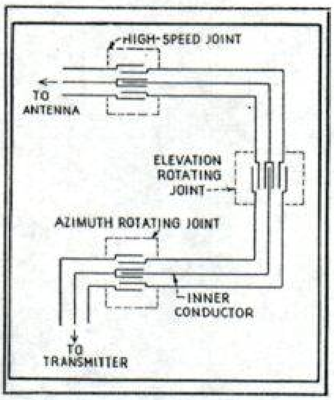


FIG. 4—Rotating joints. The r-f signal is transmitted past the air gaps by capacitive action

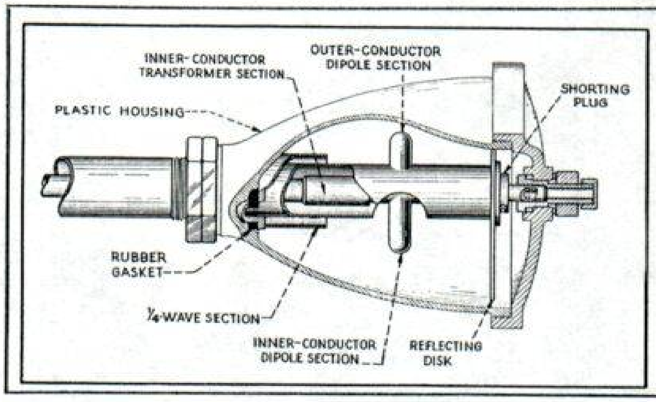


FIG. 5—Dipole radiator, transformer sections and reflector plate. A slight difference in the length of the dipole elements produces off-axis radiation for conical scanning

used in superheterodynes at lower frequencies are not suitable at microwave frequencies because of the noise introduced by random interception effects at the grid wires. The diode is accordingly chosen for microwave applications. The most efficient form of diode detector thus far uncovered is the silicon crystal. A slab of silicon, specially heat treated and etched, with a tungsten catwhisker bearing upon it, is mounted in a small cartridge and the whole assembly filled with a plastic compound.

The cartridge is mounted in a housing, known as the mixer, shown in Fig. 8. The coupling loop at the lower left abstracts the received signal from the t/r box and passes it to the crystal. The local oscillator input, at a level of 25 to 50 milliwatts, is fed through the arm at the upper right, through a right-angle bend to a coaxial member whose inner conductor terminates near the crystal in a flat coupling plate. The level of the local oscillator signal is controlled by the screw adjustment until the rectified direct current passing through the crystal is about 0.6 ma.

The i-f output is developed between the base of the crystal cartridge and ground, and is fed out through the arm at the lower right to a flexible coaxial cable which connects with the i-f preamplifier. In the output line is placed a small metal cup, insulated from the outer conductor by a thin section of mica insulation. The capacitance thus formed acts as a short-circuit at carrier frequencies and thus prevents absorption of the r-f signal in the i-f amplifier. The capacitive reactance is, however, 100 times as great at 30 mc as at 3,000 mc, so the bypass has relatively little effect on the i-f components. The mixer has no tuned elements and is constructed to operate without adjustment over the range from 2,700 to 2,900 mc.

Local Oscillator

The generation of c-w power at 3,000 mc, even in the small amount

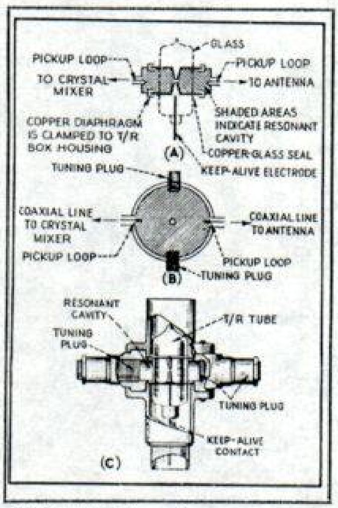


FIG. 6—T/r tube and resonant cavity. (A) Schematic view, side; (B) schematic view, top; (C) cut-away view

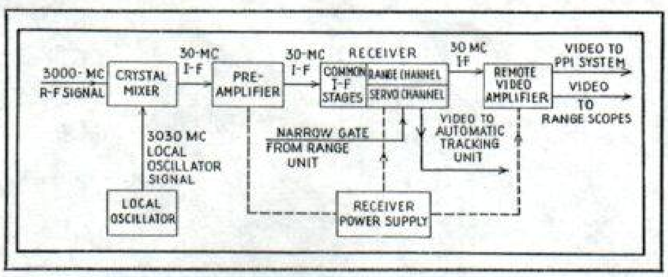


FIG. 7—Block diagram of receiving system. This system converts the r-f echo pulses at 3,000 mc to video pulses which actuate the c-r indicators and auto-tracking circuits

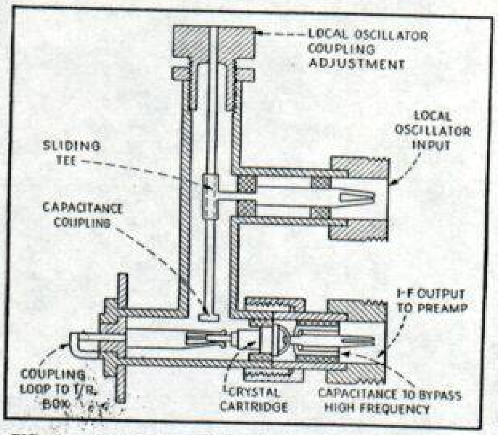


FIG. 8—Vertical cross-section of the r-f mixer. The local oscillator is loosely coupled to the silicon cartridge

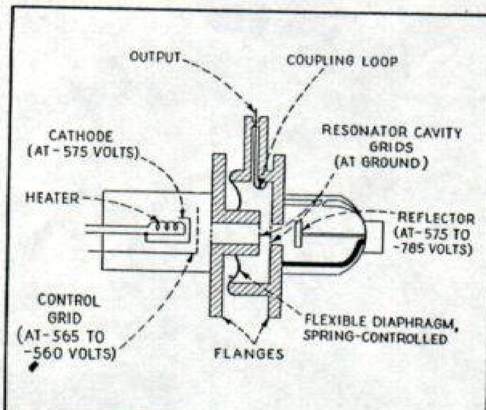


FIG. 9—Cross-section of the reflex klystron, used as a local oscillator in the receiver

required for local oscillator service, is a difficult task because of transit time limitations. To avoid these difficulties, the local oscillator tube employs the klystron principle to separate the effects of transit time from the oscillating circuit. The particular form of klystron used is a single-cavity type known as the reflex klystron, illustrated in Fig. 9. It operates as follows: Electrons from the cathode are formed in a beam and accelerated at about 575 volts. The beam passes within the center post of a cavity resonator and thence through two grids which are part of the cavity walls. The initial passage of the electrons causes a weak oscillation to be set up within the cavity, by shock excitation, and as a result the potential between the two resonator grids varies at the carrier frequency.

Electrons passing the gap thereafter find themselves alternately accelerated and decelerated by this variation in potential. On leaving the gap, the variations in electron velocity persist, with the result that the faster electrons catch up with those which pass unaccelerated, while the slower electrons fall back on the unaccelerated ones. In consequence, the electron stream becomes bunched, that is, more dense in spots and less dense in others.

Meanwhile the electron stream encounters a decelerating d-c field applied by the reflector electrode (about −700 volts). This causes the electron stream to reverse its path, while the bunching process proceeds, and to re-enter the resonator gap. If the velocity of the electrons and the reflector potential are properly chosen with respect to the wavelength and the dimensions of the tube, the bunched electrons arrive back at the resonator gap just as the potential across the gap is such as to cause maximum retardation of the electron bunch. The electron bunch thereupon gives up a portion of its kinetic energy to the resonator.

As the succession of electron bunches re-enters the gap, the oscillations are successively reinforced until equilibrium is reached between the energy abstracted from the cavity (via the coupling loop shown) and the energy input to the beam less losses within the tube. Power levels in the hundreds of milliwatts are readily produced.

The frequency of oscillation depends not only on the natural period of the resonator, but also on the phase with which the returning bunches enter the gap, and this phase may be changed by adjusting the voltage on the reflector electrode. This electrical method of tuning is employed to tune the receiver precisely to the transmitter frequency. The tube will oscillate at several values of reflector voltage; the most negative value is generally chosen. Care is taken to stabilize the accelerating and decelerating potentials applied to the klystron, to avoid electrical detuning. Care must also be taken to avoid feeding too great an output from the local oscillator to the crystal detector, since excessive power absorption by the crystal will injure the rectifying interface. The local oscillator is coupled very loosely to the crystal by the flat probe electrode shown in Fig. 8, not only to minimize this danger, but also to prevent absorption of the echo pulses in the local oscillator itself, which is tuned within 1 percent (30 mc at 3,000 mc) of the carrier frequency.

The I-F Amplifier

The i-f preamplifier is coupled to the mixer through a transformer, but thereafter the i-f stages are coupled by single tuned circuits, inductively tuned. The inductive element is placed in the grid of the following tube, rather than in the plate of the preceding tube, to minimize the resistance in the grid return, which would prolong recovery after overload. Type 6AC7 high-g_m pentodes are used. The avc voltage is applied to the grid of the second stage.

The output of the preamplifier is conducted through flexible coaxial cable to the remaining i-f stages in the receiver proper. A simplified schematic of the i-f, detector, and video circuits is shown in Fig. 10. The 3rd, 4th, and 5th i-f stages are substantially identical to the second stage, employing 6AC7 tubes with single-circuit inductively-tuned coupling. The interstage coupling is loaded with the plate resistance of about 850 ohms, producing a gain of about 7 per stage across an overall band of 1.7 mc. The 3rd stage has avc.

The sixth i-f stage is a dual unit, one tube feeding the remote video amplifier outside the receiver chassis, the other leading to a 7th i-f stage. This latter (servo) channel operates under gate control, that is, the 6th servo i-f stage passes signal only during a brief period corresponding to the time the desired echo is received.

The function of gating in the automatic tracking circuits will be evident from the following. When the radar views more than one target simultaneously, as may readily happen in antiaircraft activity, a separate sequence of echo pulses is received from each target. The automatic tracking circuits have no way of distinguishing between these sequences of pulses and they tend to move from one target to another, or to seek a position midway between targets.

To avoid this confusion, the radar operator must select a target and see to it that the radar follows that target to the exclusion of all others. The target is selected initially on the PPI indicator and then identified as a particular echo pulse on the type J range scopes. Thereafter the operator adjusts a control which keeps a hairline centered on the echo selected. The control is connected to a pulse-forming circuit which develops a narrow rectangular pulse (narrow gate pulse) which occurs just prior to reception of the desired echo.

The narrow gate pulse is applied, in positive polarity, to the screen grid of the sixth i-f stage in the servo channel. In the absence of the narrow gate pulse, the screen grid is grounded and this stage remains inactive. During the narrow gate pulse, however, the stage is suddenly activated and passes the signal to the succeeding i-f stage and thence to the detector, video and servo-control circuits. The width of the narrow gate is normally about 3 microseconds, and is thus capable of cutting off all echoes outside a segment of about 3,000 feet in the range coordinate. A recent modification of the equipment consists of the so-called N^2 gate (N^2 for narrow-narrow), in which the control gate is only 0.5 microsecond long, corresponding to a segment in range of about 500 feet.

One other precaution must be taken in the automatic tracking system. If the amplitude modulation on the pulse sequence (which arises from off-axis targets as a result on the conical scanning, see part I) is not of constant amplitude, the comparison between reference voltage and error signal cannot be carried out successfully. Consequently it is necessary to apply an amplified automatic gain control voltage to the 2nd and 3rd i-f stages. This voltage is obtained by passing the pulse sequence from the servo channel output to a diode detector which develops the peak value of the amplitude-modulated pulse sequence. This peak value is amplified through a cathode-follower stage and applied to the i-f stages.

The timing and indicating systems will be described in the concluding installment of this series.—D.G.F.

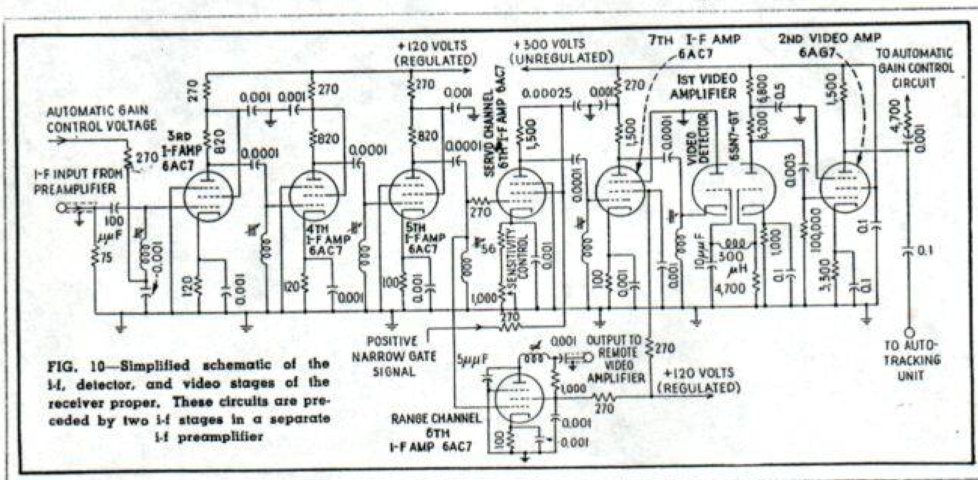


FIG. 10—Simplified schematic of the i-f, detector, and video stages of the receiver proper. These circuits are preceded by two i-f stages in a separate i-f preamplifier