The SCR-268 RADAR

Developed before the war by the Signal Corps, the SCR-268 has seen service on all fronts detecting enemy aircraft, directing searchlights and guns toward them. Surpassed in performance, and captured by the Germans and Japanese, it may now be described

On the evening of May 26, 1937, Mr. Harry Woodring, the Secretary of War, stood with a group of officers and civilian scientists on a field of the Signal Corps Laboratories at Fort Monmouth, New Jersey. Before them, spread over the field, were the transmitter and receivers of a radio detector, the SCR-268 prototype. Connected with the radar were the controls of a standard anti-aircraft searchlight.

As prearranged, an Army aircraft flew over the field in the darkness. Three enlisted men, viewing oscilloscopes, put the radar "on target" and tracked it across the sky. When tracking was established, the command was given to light the searchlight. As the light pierced the darkness, the aircraft, caught in the beam, became visible to those on the ground.

The next day, orders were given to move the equipment to a remote corner of Fort Hancock, where secrecy could be better preserved. In the eight years that have intervened, secrecy has been the watchword of radar development. But in November 1944, the SCR-268 was reduced in classification from "confidential" to "restricted". By that time, the equipment had been captured, with crews and instruction books, by the Germans and the Japanese. Moreover it had been far surpassed by later radar equipments. While still in use, the 268 was obsolescent, almost antique.

When the editors of ELECTRONICS first approached Signal Corps authorities for permission to describe the SCR-268, they were asked "Why do you want to describe that set?" The answer, not obvious to those working in the radar field, is that the greater part of the electronics industry has never seen a radar set, or a technical description of one, in any form. The SCR-268, by virtue of its early development and wide employment in the war, is not only a significant milepost in radar development, but the first radar to reach such a venerable position that describing it would offer no aid or comfort to the enemy.

Basic Elements

A radar detects the presence and position of objects by means of reflected radio waves. In the case of the SCR-268, the "object" is ordinarily an aircraft, and the radio waves are projected in sharp bursts or "pulses" at a rate of 4098 per second. A pulse is transmitted every 244 microseconds. Each pulse is of extremely short duration, approximately six microseconds. Between pulses, there is a period of about 240 microseconds during which the radar receivers may detect the echoes reflected from the target aircraft.

When the radar detects a target, the position of the aircraft is indicated in three coordinates, known as the slant range, the elevation (or angular height), and the azimuth. The slant range is the distance from the radar to the target. The elevation is the vertical angle subtended at the radar by the target and the ground plane. The azimuth is the horizontal angle subtended at the radar by the target and true north. The target coordinates are illustrated in Fig. 1.

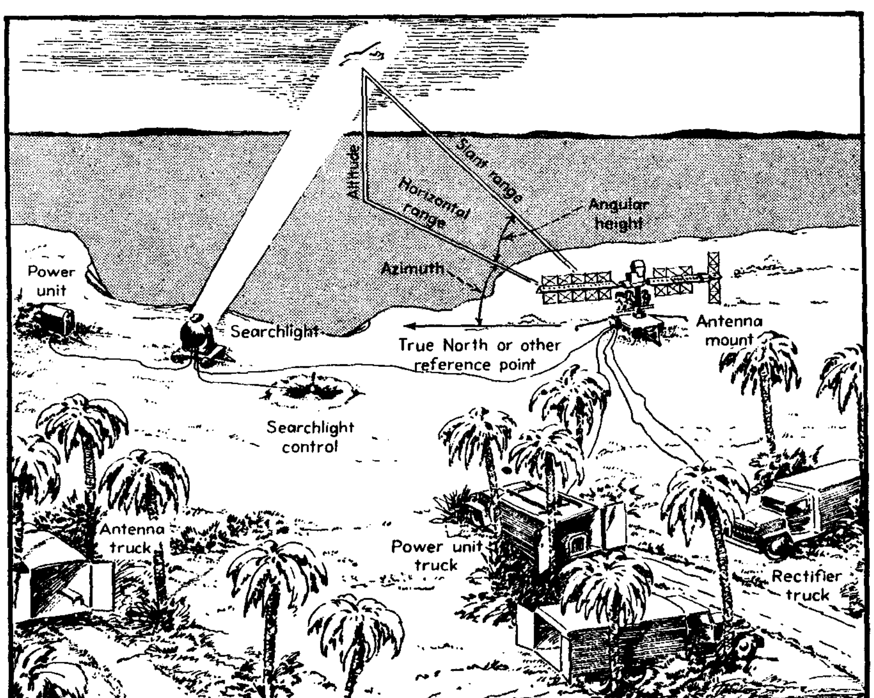

FIG. 1—Artist's sketch illustrating a typical setup, including power supply and transporting trucks

The radar measures the range of the target by timing the interval between transmission of a pulse and reception of the echo. Since radio waves travel at a velocity of 0.186 miles per microsecond, for each microsecond in the interval the wave travels 0.186 miles round trip from radar to target and back. Accordingly, the distance to the target is 0.093 miles for each microsecond

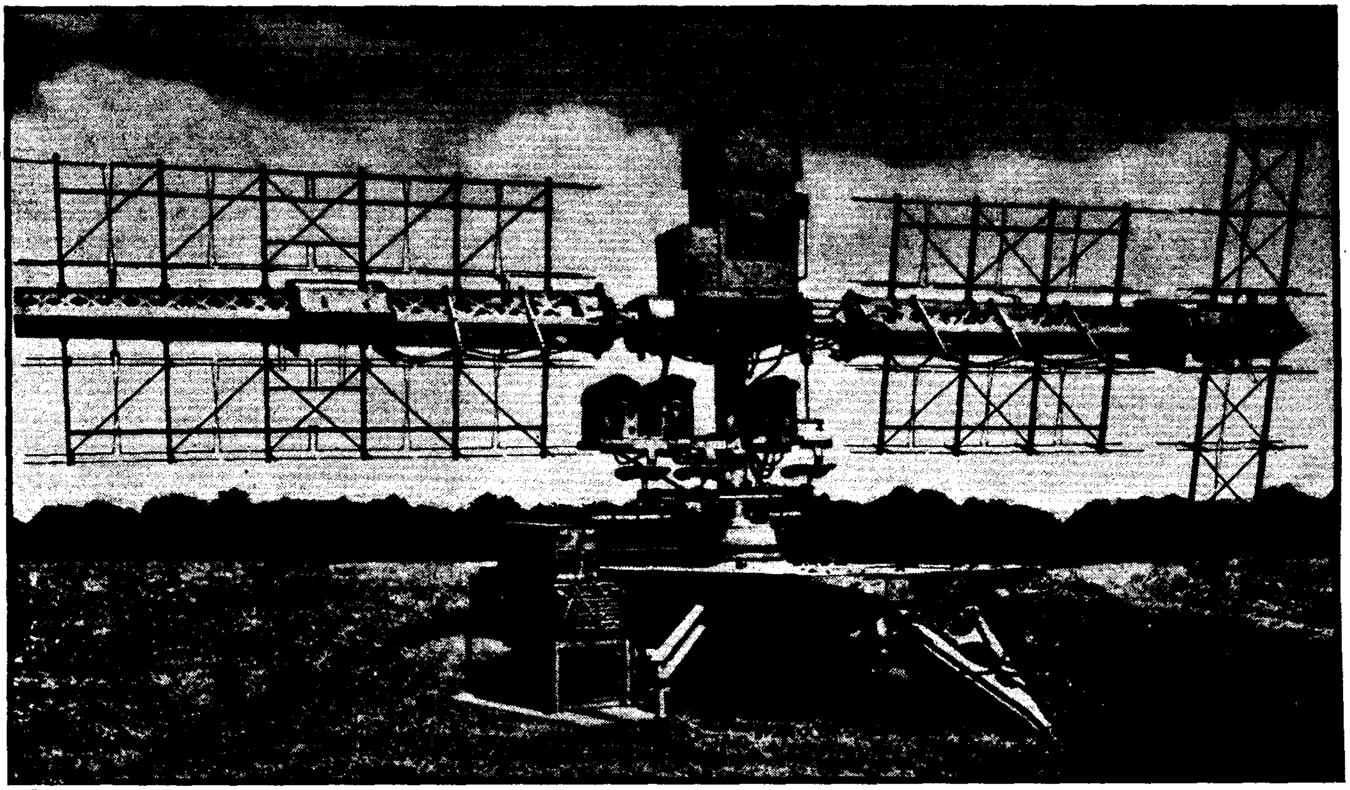

FIG. 2—The SCR-268 radar, seen from the back or control position, showing the azimuth receiving array at the left, the elevation receiving array at the right and the transmitting array in the center

in the interval. If the measured interval between transmission and reception is 100 microseconds, the range of the target is 9.3 miles. The maximum interval which can be accommodated is the interval between pulses, or about 240 microseconds. Consequently, the maximum detection distance, as determined by the pulse interval, is 0.093 x 240 = 22 miles. Sufficient power in the transmitter and sensitivity in the receivers are provided to produce a discernible echo from an aircraft at this distance.

The azimuth and elevation angles are measured by noting the angles at which the receiving arrays are pointed with respect to true north and the ground plane as the target is observed. In the SCR-268 two directive receiving aerials are provided, the azimuth and elevation arrays. The reception pattern of the azimuth array is a fan-shaped figure with a long vertical axis. The pattern of the elevation array is similar, but rotated through 90 degrees, that is, the long axis is horizontal.

The target information gathered

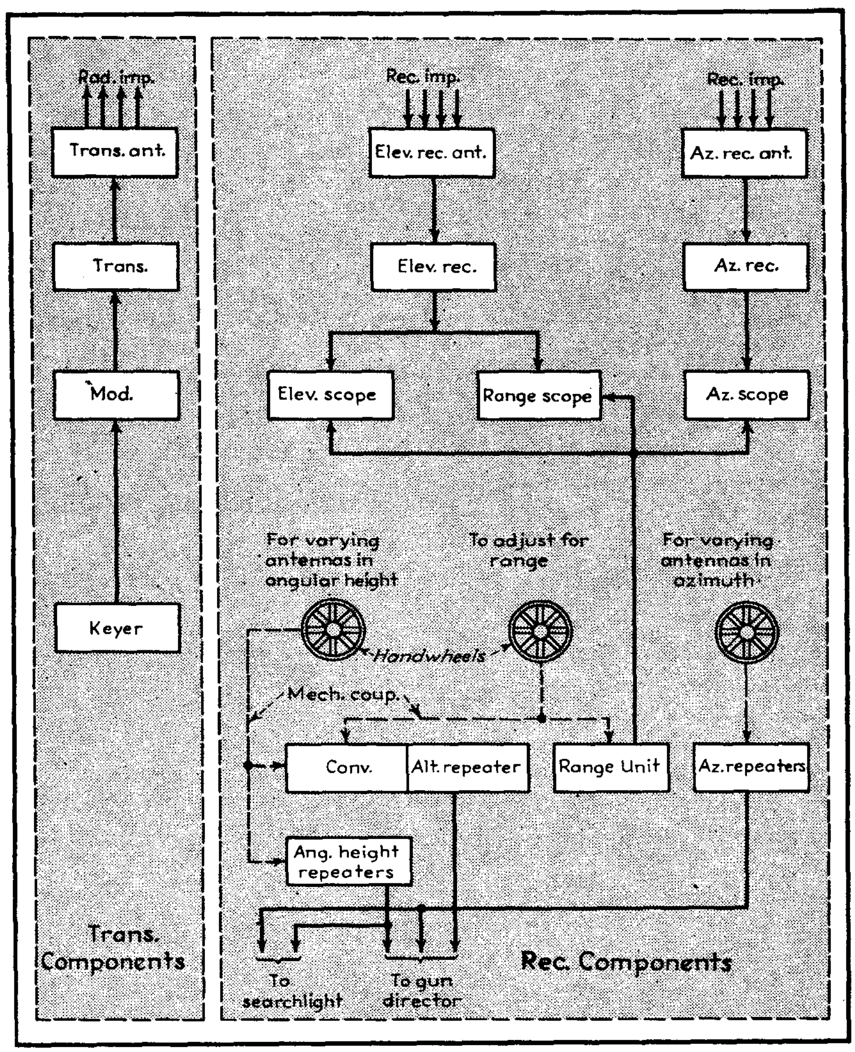

FIG. 3—Simplified block diagram showing basic components of the equipment

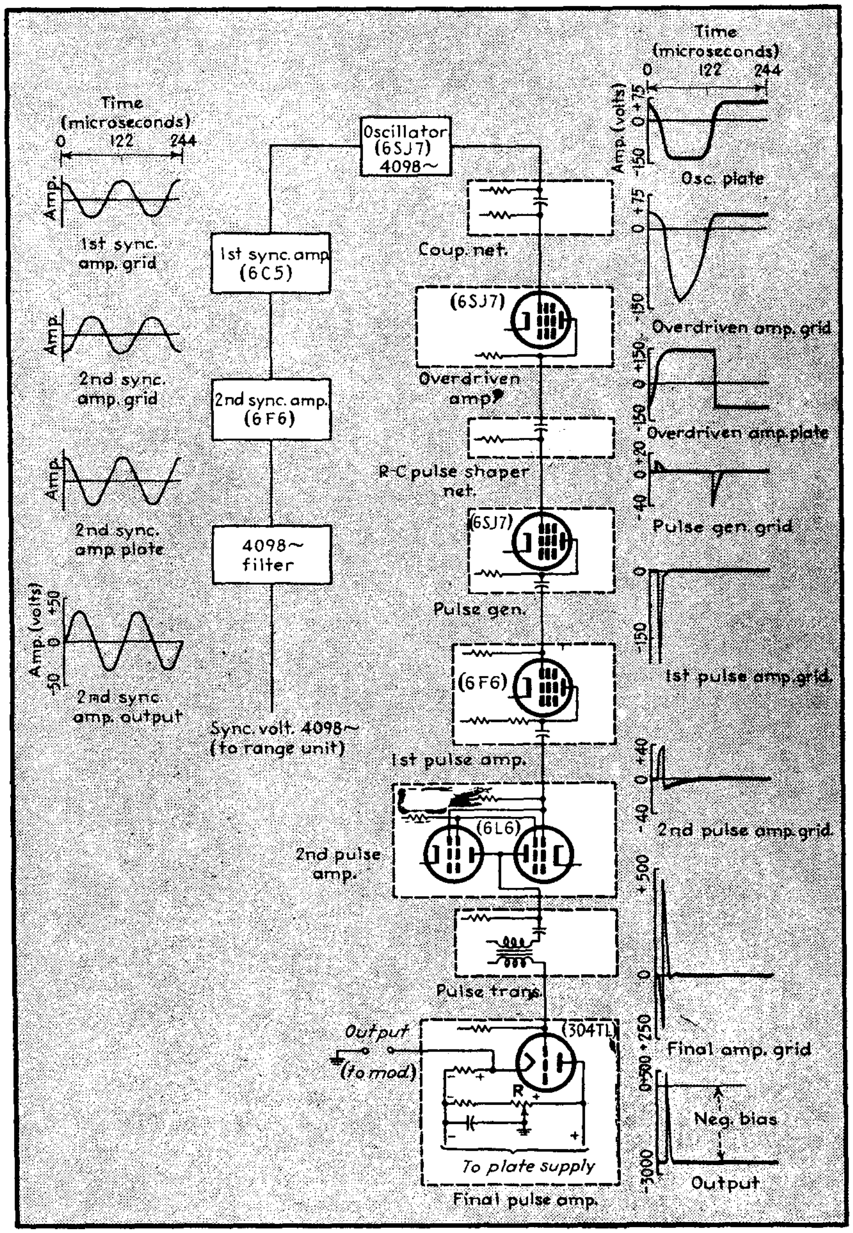

FIG. 4—Functional block diagram of the SCR-268 radar keying unit

by the radar is transmitted automatically to control circuits which keep the searchlight or anti-aircraft gun trained in the direction (azimuth and elevation) indicated by the radar. Thus when the radar is on the target the searchlight or gun is also on the target and can illuminate or fire at the will of the artillery officer.

The reflection of radar signals is a highly inefficient process.[1] The power radiated in the pulse disperses with the square of the distance as it travels to the target, and the power in the echo disperses at the same rate as it returns to the radar. It follows that the power available to actuate the receivers falls off as the fourth power of the distance to the target. This means that an increase of 16 times in power (12 db) is required to double the maximum range of a radar viewing a given target in empty space. Thus an aircraft which is easily visible at 5 miles, using moderate power and receiver sensitivity, may be completely invisible at 20 miles.

This reasoning points to the necessity of employing the highest possible power in the transmitter and the greatest possible sensitivity in the receiver. In the SCR-268, the peak power of the pulses is 75 kilowatts, and the receivers are sensitive to a signal power of 0.1 of a micromicrowatt (10^{-13} watt). Judged by pre-war standards, these are remarkable achievements at the frequency (205 mc) at which the radar operates. But by present standards the transmitter power is not outstanding, and the receiver performance is poor. Nevertheless, the power and sensitivity are adequate to detect aircraft at distances up to 22 miles, provided the aircraft is not too close to the horizon.

General Description

The SCR-268 is pictured in Fig. 2. The radar components are mounted on a trailer. In addition, four large trucks are required, one supplying primary power, another supplying high voltage for the transmitter, and two for the transportation of the radar components.

The trailer consists of a rotatable pedestal which carries three antenna arrays. From left to right as seen from the back of the equipment, these are the azimuth receiving array, the transmitter array, and the elevation receiving array. Behind each receiving array is the corresponding receiver. Atop the pedestal is the transmitter. Directly below the transmitter are three oscilloscopes, with bucket seats in front of them. Here the three operators observe the azimuth, elevation and range, turning handwheels which keep the radar pointed at the target. The handwheels are con-

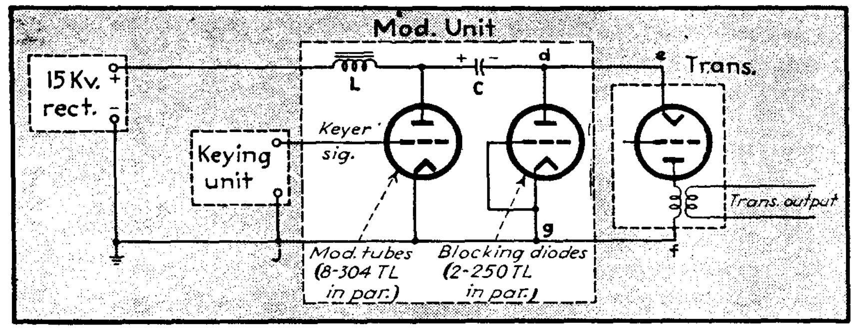

FIG. 5—Simplified schematic of the modulator, which produces wave forms shown in Fig. 6

nected also to the converter which transmits the target coordinates to the associated searchlight control or gun director. On the ground beside the trailer are the keyer and modulator units which drive the transmitter.

The SCR-268 weighs 82,315 pounds, complete with all auxiliaries and trucks. It consumes 15 kva of power. Despite these large figures it can be (and has been) set up and ready for operation within a few hours of being put ashore at a beachhead.

The block diagram, Fig. 3, shows the flow of the signal through the equipment. At the left are the transmitter components, which comprise a separate group. The keyer establishes the basic timing of the transmitted pulses at 4098 per second and produces the short (3 to 9 microsecond) pulses which drive the modulator. The modulator raises the power level of the keyer output and applies modulating pulses to the transmitter. The transmitter is a self-excited tuned-plate tuned-grid oscillator consisting of 16 tubes in a ring circuit. The transmitter output is applied to the transmitting array, which radiates a beam of circular cross section approximately 10 degrees wide.

When the transmitted beam encounters a target, the echo is returned to the two receiving arrays. The directivity of these arrays is about 12 degrees in the azimuth array and 9 degrees in the elevation array. By means of receiving antenna "lobe switching", to be described later, the directivity in azimuth and elevation is refined to about ±1 degree in each coordinate.

The signal received by the elevation array is passed to the elevation receiver and thence to two cathode-ray indicators. One indicator displays the range of the target, the other the elevation. Both are "type A" indicators, that is, they are essentially similar to a conventional test oscilloscope. The cathode-ray beam is driven by a sweep circuit at constant speed from left to right. The echo signal from the associated receiver is applied to the vertical deflection plates so that the beam is deflected upward whenever an echo is received. At the left end of the oscilloscope trace the transmitted pulse appears. This establishes the "zero" of the time scale. The distance from the transmitted pulse to the echo, measured on the range indicator, gives the distance to the target, or range.

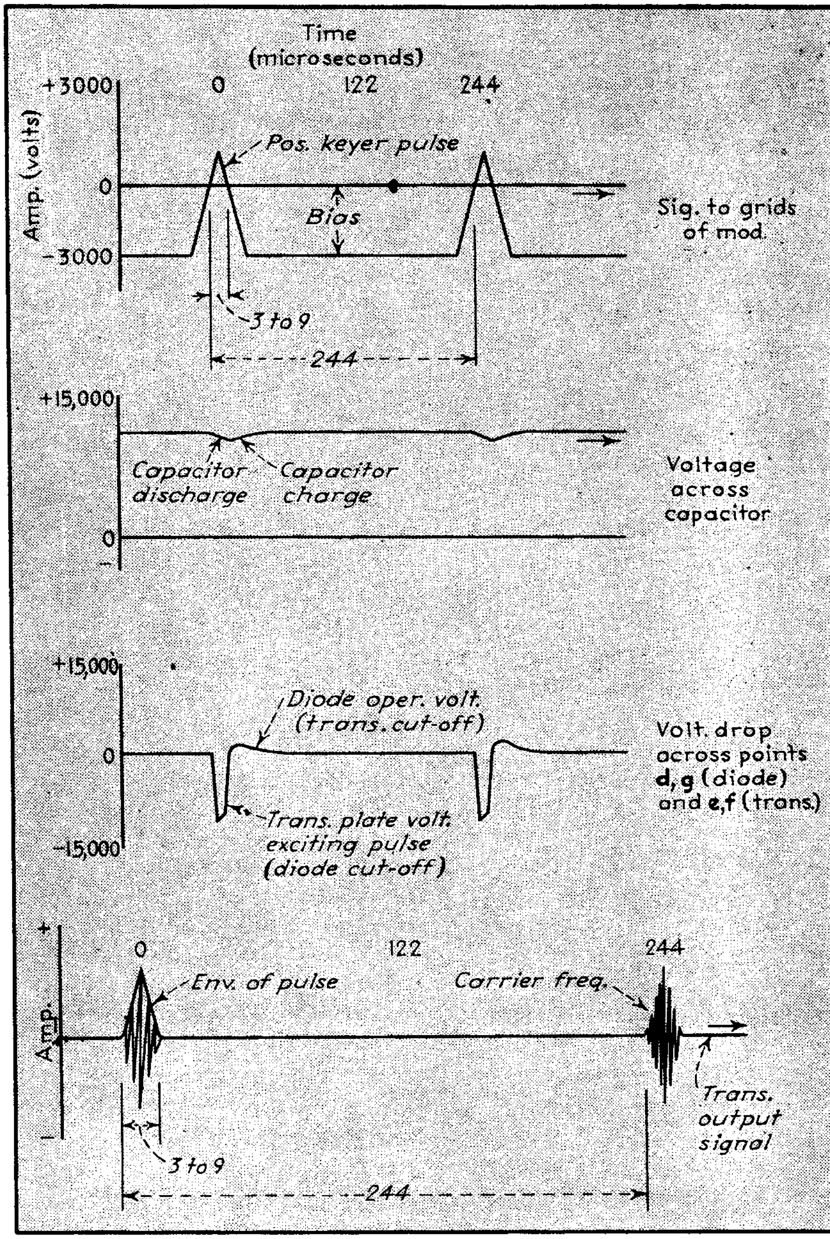

FIG. 6—Modulator wave forms, obtained by means of the circuit shown in Fig. 5

The elevation indicator is similar, except that two echoes are displayed, slightly displaced from one another. The two echoes, known as the "split image", are produced by shifting the directivity pattern of the elevation array slightly, at a rapid rate, by the receiving antenna lobe-switching method. The operator adjusts the elevation array until the two echoes in the split image have the same height. The array is then pointed directly at the target within the one-degree error previously mentioned.

The azimuth receiver is connected to a similar oscilloscope which displays a split image produced by shifting the pattern of the azimuth array. The operator at this indicator adjusts the orientation of the azimuth array until the two pulses in the split image are of equal height. The azimuth array is then pointed at the target within 1 degree accuracy.

The remaining items shown in Fig. 3 are the repeaters and converters which transmit the target information in suitable form to the searchlight or gun director. The principal electronic component here is the range unit, which introduces a time shift in the deflection circuits of the range indicator. When the operator turns the range handwheel, the radar echo is moved horizontally on the indicator screen. This permits the echo to be placed over a specific reference point, from which the range may be read accurately. The range accuracy of the SCR-268 is plus or minus 200 yards.

The high voltage power rectifier supply for the transmitter is mounted in a separate truck as previously mentioned. This latter rectifier has a capacity of 500 milliamperes at 15,000 volts. Since the output drain on this power supply is confined to periods less than nine microseconds long, with 240 microsecond intervals between them, the filter required is not large.

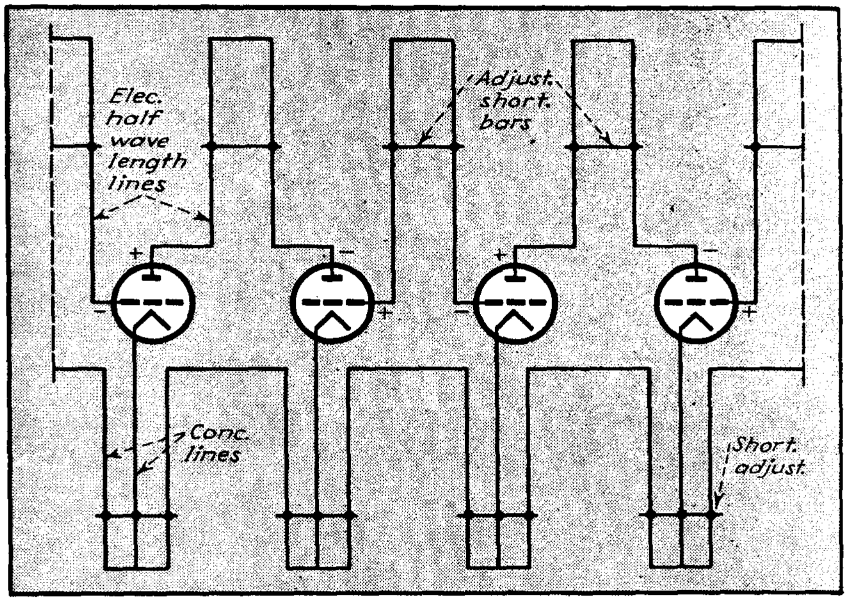

FIG. 7—Simplified schematic of the SCR-268 radar transmitter, showing just four of the sixteen type 100TS tubes used in a ring circuit

The Keying Unit

The heart of the radar is the keying unit, which establishes the basic timing of the system. The keyer must first establish the rate at which the pulses are sent out, 4098 per second. Secondly, it must produce individual pulses of the requisite short duration, and it must prevent any undue variation in the length of successive pulses.

The output of the keyer is used to drive the modulator tubes, which are cut off between pulses by a heavy negative bias. The keyer output is, therefore, a positive pulse capable of overcoming this negative bias and driving the modulator grids well into the positive region. These requirements add up to a formidable total. The keyer must provide an accurately timed pulse of from three to nine microseconds length, and of some 3500-volts peak amplitude. This requirement is met by the use of eleven tubes in the keyer unit, two of which are power supply rectifiers.

Figure 4 is a simplified schematic of the keyer unit. The basic timing element is the 4098-cps oscillator (6SJ7 at the top of the diagram). This is an electron-coupled oscillator of the Hartley type. Two outputs are taken from the oscillator, one intended for the range unit and the other for the keyer proper. The former path consists of two amplifiers and a 4098-cps filter, the output of which is a 4098-cps sinewave of 50 volts peak amplitude. The latter, or keyer, path starts at the oscillator plate, which provides a flattened (non-sinusoidal) wave. This voltage is passed through a coupling circuit (0.01 μf series capacitances, with 100,000-ohm and 50,000-ohm shunt resistance) which sharpens the oscillator output. The sharpened wave is then applied to an over-driven (grid-current limiting) amplifier which flattens the wave again, but by this time the pulse possesses a much sharper leading edge. Following is a peaking circuit of very short time constant (0.00005 μf and 50,000 ohms) which responds only to the leading and trailing edges of the applied wave. The output consists of a small short positive pulse, and a somewhat larger negative pulse which is not thereafter used. These pulses are applied to the pulse generator which is biased to cut-off. It responds to the small pulse, but not to the negative pulse. The output of this stage is a sharp pulse of about -170 volts amplitude.

The remaining portion of the keyer is occupied with increasing the peak voltage of this pulse and reversing its polarity. The first pulse amplifier (a 6F6 beam-power tube) is intended to produce a higher current pulse, without a high voltage output. This current pulse drives two 6L6 beam power tubes in parallel, the output of which is conducted to a pulse transformer, capable of passing very short pulses. The output of the transformer is a double-peaked wave of about 750-volts peak-to-peak amplitude, centered about a point two-thirds up from the negative peak. This wave is applied to the grid of the final amplifier, a 304TL triode. This tube is a high-current thoriated-tungsten triode, consisting of four triode units in a single envelope.

When the pulse arrives at the 304TL grid the tube passes a current of approximately 1 ampere through a cathode coupling resistance, thus producing a pulse of 3500 volts peak amplitude across the output terminals. Since the tube is biased to cut-off, there is no response to the negative peak. Between pulses, when the 304TL is not conducting, its output terminals are connected across the B-supply voltage. One output terminal is some 2500 volts negative (adjustable by resistor R) with respect to ground. This is the bias voltage for the succeeding modulator tubes. The use of the cathode-follower circuit in the final keyer amplifier provides a low impedance output, which permits conducting the short-length pulses over coaxial cables to the modulator unit.

The Modulator Unit

The function of the modulator unit is to amplify the keyer output to a high power level, suitable for plate-modulating the transmitter (r-f oscillator) proper. Figure 5 shows the simplified schematic.

The modulator tubes (8 type 304TL tubes in parallel) act as an electronic switch, under the control of the keyer. The electronic switch is in series with the storage capacitor *C*. This capacitor is charged continuously from the high voltage power supply (15,000 volts) through the choke *L* and the blocking diodes (2 type 250TL tubes in parallel). When a positive pulse is delivered by the keyer to the modulator grids, the modulator plates suddenly conduct. The inductor *L* impedes any flow from the power supply through the modulators for the duration of the pulse. Therefore, the only source of plate current is the storage capacitor *C*. This capacitor discharges, during the pulse, through the series circuit composed of the modulator tubes and the transmitter (oscillator) tubes. The resultant sudden pulse of current causes the transmitter to oscillate and it continues to do so while the pulse is applied.

The current passing through the modulator tubes is about 10 amperes, and the voltage drop across them is about 3000 volts. Hence 12,000 volts at 10 amperes passes through the plate circuit of the transmitter. This is a peak input of about 120 kilowatts, of which about 75 kw appears as useful r-f output power.

When the modulators conduct, they form a closed circuit of which the storage capacitance and the series inductance (leads and transmitter tank circuit) are a part.

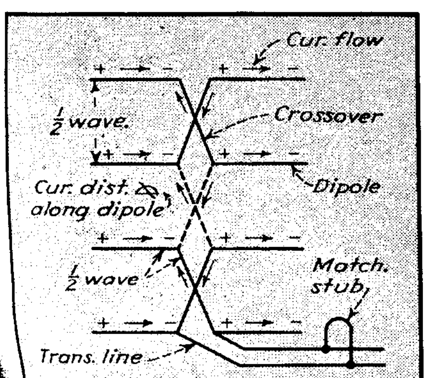

FIG. 8—Basic directive array scheme, showing eight of the sixteen transmitting dipole elements. The associated reflectors are omitted in this drawing

There is, therefore, a tendency of the current in this circuit to oscillate and over-shoot in the negative direction. This causes the transmitter to be cut-off sharply at the conclusion of the pulse. Any further oscillation in the modulator circuit is suppressed by the blocking diodes.

Modulator wave forms are shown in Fig. 6. It is to be noted that the pulse lasts only about 2.5 percent of the total time, so that only a small portion of the charge stored in capacitor *C* is withdrawn during each pulse. The diodes permit this charge to be replaced, at a slow rate, between pulses. But the diodes, being one-way conductors, have no effect during the pulse discharge.

The Transmitter Proper

The function of the transmitter is to develop r-f pulses of 75 kw peak power. The average power is not nearly so great, however, since the transmitter is turned on only 2.5 percent of the time (4098 pulses, each about 6 microseconds long, per second). The essential problem of the transmitter design, then, is providing sufficient emission in the transmitter tubes to meet the momentary high power requirements. The required peak emission, as indicated from the discussion of the modulator circuit, is of the order of 10 amperes. No suitable tube was available with such emission, so it was necessary to employ a large number of tubes. The tubes are type 100TS.

It was not feasible to connect the transmitting tubes in parallel or in push-pull-parallel because the addition of the tube capacitances would prohibit operation at the high frequency desired. To avoid this difficulty, the ring circuit was adopted. Essentially, this is a multiple push-pull tuned-grid tuned-plate arrangement. In this circuit, an elementary form of which is shown in Fig. 7, the tubes are separated by tuned circuits and arranged in a closed ring. As shown, grids of adjacent tubes assume opposite polarity, and to sustain oscillations the plate of each tube has the opposite polarity from its grid. When an even number of tubes is employed in the ring, the necessary alternation of grid and plate polarities between adjacent tubes is maintained throughout the ring. Since the tube capacitances are essentially in series, any required number of tubes may be employed. Sixteen tubes are required to provide the necessary emission.

The tuned circuits are segments of parallel transmission lines, approximately half-wavelength long, with adjustable shorting bars. The r-f current in all the shorting bars, at any instant of time, is in the same direction, so the shorting bars form a virtual closed circuit from which energy may be picked up by a pick-up coil. A single-turn pick-up coil is used to connect the transmitter to the output transmission line.

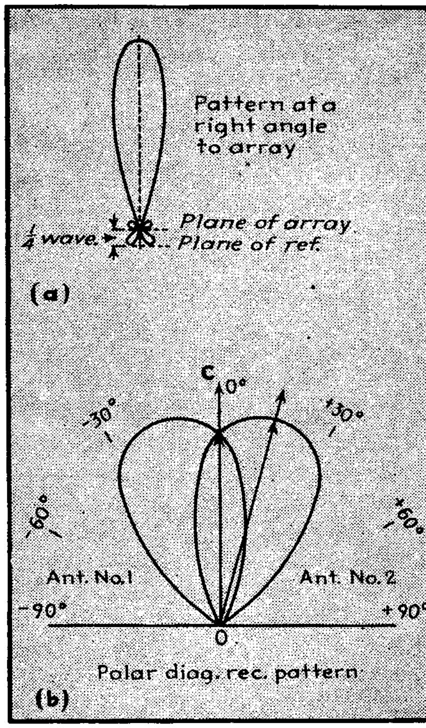

FIG. 9—(a) Directive pattern of receiving array with reflectors spaced ¼-wavelength apart. (b) Double receiving antenna pattern, obtained by lobe switching described in the text

The filament power for the transmitter tubes is conducted through quarter-wave concentric transmission lines, shorted at the input end. These segments prevent absorption of r-f power by the filament circuit.

The modulator is connected to the transmitter through a high-voltage slip ring which permits the pedestal to turn when following targets without breaking the connection. The transmitter plate circuits are joined at points below the shorting bars and connected to ground. The modulator output, in the form of a high-voltage negative pulse, is applied to the transmitter filaments. The transmitter grids are joined at points beyond the shorting bars and returned to the filaments through a resistance.

Transmission Line and Radiator

From the pick-up coil, the transmitter output is conducted over an open-wire transmission line to the transmitting radiator. The radiator consists of 16 half-wave dipole radiating elements and 16 similar reflector elements spaced one-quarter wave behind the radiators. The elements are arranged parallel to each other, four dipoles wide and four high, and spaced one-half wavelength in the plane of the array. Horizontal polarization is used.

The dipole radiator elements are interconnected cross-wise at their ends as shown in Fig. 8. Thus the current in each half-wave segment in the array flows in the same direction, at any instant of time, and there is complete cancellation of the r-f field in the plane of the array. The field is a maximum along an axis at right angles to the plane of the array, thus providing the necessary directivity of transmission. The transmitting antenna beam width is about 10 degrees wide between the 3-db points, that is, the field radiated five degrees off the axis is 3 db less than the field along the axis. The gain of this radiator, relative to an isotropic (point-source) radiator, is about 400 times. Thus the effective power radiated to the target is about 400 x 75 kw = 30,000 kw. A matching stub is used on the transmission line to match the impedance at the ends of the dipoles.

Receiving Arrays and Lobe Switching

The receiving arrays are very similar to the transmitting radiator, differing only in shape and in the provision of lobe switching. The azimuth array is six dipoles wide and four dipoles high, with a similar number of reflectors. The radiation pattern formed by this arrangement is a fan-shaped figure with its long dimension in the vertical plane, which permits discrimination in the azimuth (left-right) coordinate. The elevation array is arranged two dipoles wide and six dipoles high with corresponding reflectors. The radiation fan in this case has its long dimension in the horizontal direction, an arrangement suitable for discriminating in the elevation (up-down) coordinate.

Both receiving arrays are arranged for lobe switching to refine the accuracy of the angular indications. The technique is as follows: The directivity pattern of an array is a lobe-shaped figure like that shown in Fig. 9(a). Suppose, first, that two arrays are used side by side at a slight angle to one another. Then two overlapping lobes are provided. The signals received from the two arrays are of equal amplitude when the signal arrives from a direction midway between the two lobes as along line OC in Fig. 9(b). If the signal arrives from the left the signal from the left-hand lobe predominates, whereas a signal from the right causes maximum amplitude in the right-hand lobe. The sharp slope of the lobe patterns at their intersection makes the direction of equal amplitude correspondingly precise.

The technique of lobe-switching provides a double-lobe pattern from a single array. The array is divided into two halves (left and right halves in the azimuth array) which are connected not by cross-wires as in the transmitting arrangement but by phasing stubs, that is, adjustable segments of transmission line somewhat less than a half wavelength long. Two terminations are taken from the array, one at the left end, the other at the right end as shown in Fig. 10. The directivity of such an array, with phasing stubs inserted, is found to be slightly different, depending on which termination is used.

To illustrate this effect, consider

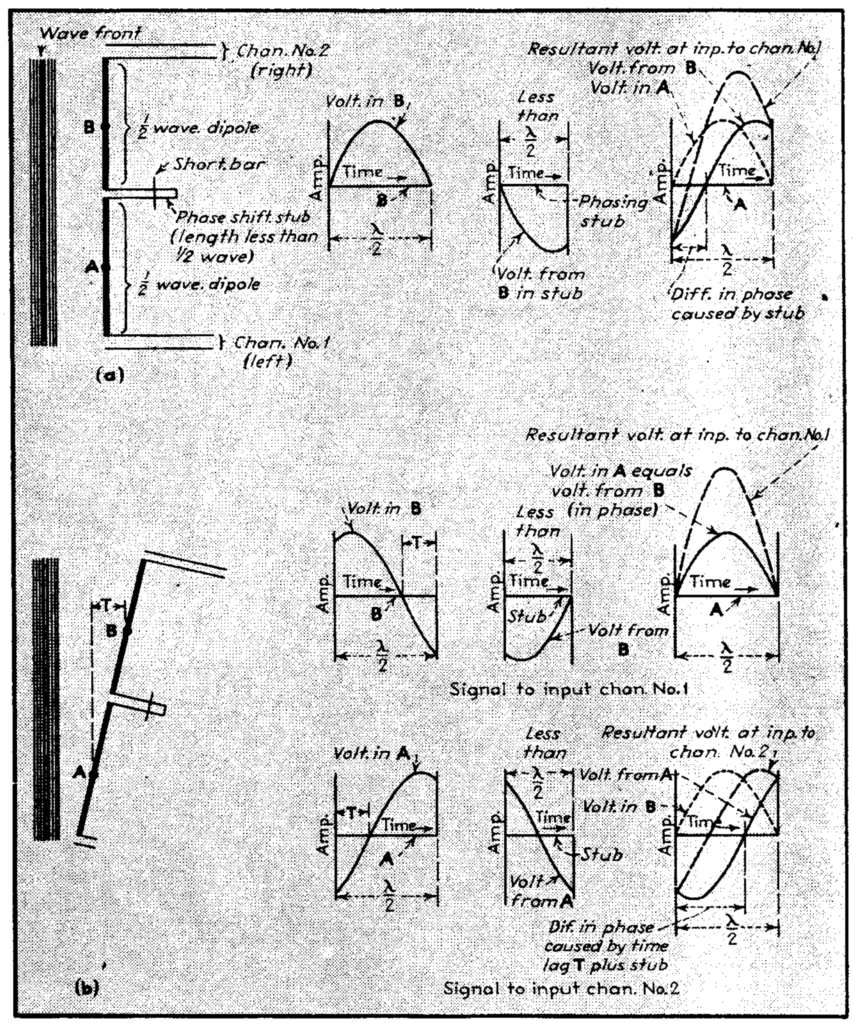

FIG. 10—SCR-268 radar receiving antenna lobe-switching results showing (a) voltage when the plane of the array is parallel to the wave front and (b) voltage when the plane of the array is at an angle to the wave front

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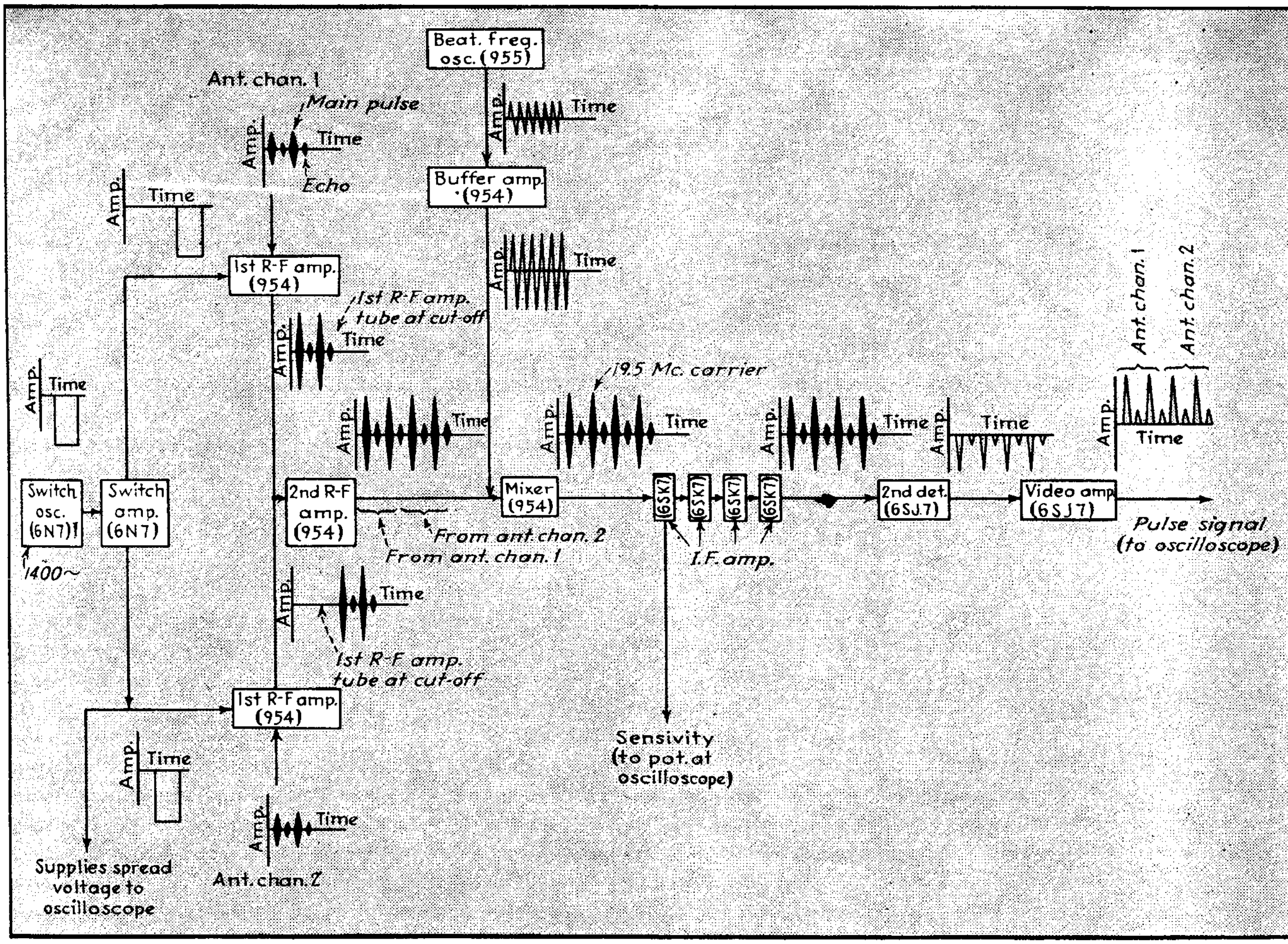

FIG. 11—Functional block diagram of one of the two receivers

a signal wave front arriving parallel to the array. The wavefront induces voltage in the two halves of the array at the same instant. Consider the array from the back and assume that the left-hand termination is in use. The signal induced in the left half of the array arrives at once at the termination, but the signal from the right half of the array arrives at the left-hand termination only after a delay caused by its passage through the phasing stub. Hence the net voltage arriving at the left-hand termination is a vector sum, and this vector sum is the same as though the wave had arrived from an angle to the left and as if no phasing stubs were present. The phasing stubs thus cause the antenna pattern to shift to the left when the left-hand termination is in use.

By the same process, the stubs cause the directivity of the array to shift to the right when the right hand termination is in use. By shifting alternately from left-hand to right-hand termination, the effect of two lobes is produced. Accurate direction finding is obtained when the signals from the two terminations have the same amplitude. In the elevation array, the array is divided into top and bottom halves and the same effect is produced in the elevation coordinate.

In practice, the phasing stubs are adjusted when receiving a wavefront of known orientation until the peaks of the lobes are spaced approximately 10 degrees and a symmetrical variation in signal is obtained on either side of the center direction. Thereafter this adjustment is preserved until the radar moves to a new location. A signal generator ("tweeter") produces the required wavefront and a technique has been developed to avoid the effects of external reflections. As in the case of the transmitting array, matching stubs are employed on the transmission lines to match the receiving array impedance to the line.

One possible source of trouble in the operation of the radar is the existence of side lobes, that is, minor directivity patterns offset from the main pattern by some 25 degrees. Proper adjustment of the array will keep the sensitivity of the array in these side directions about 30 db below that of the main lobe, but the effect cannot be eliminated entirely. Thus a nearby target centered in a side lobe may produce a stronger signal than a distant target centered in the main lobe. Moreover, at the intersection between the left-hand main lobe and a right-hand minor lobe signals of equal amplitude will appear. The array will then be pointed, not at the target, but some 25 degrees away from the target. The true lobe intersection can, however, always be determined by noting the symmetry of the signal variation as the array is moved either side of the equal-amplitude direction. The false balance is not symmetrical.

The Receiver

Two identical receivers are employed in the SCR-268, connected to the elevation and azimuth arrays. A block diagram of the receiver is

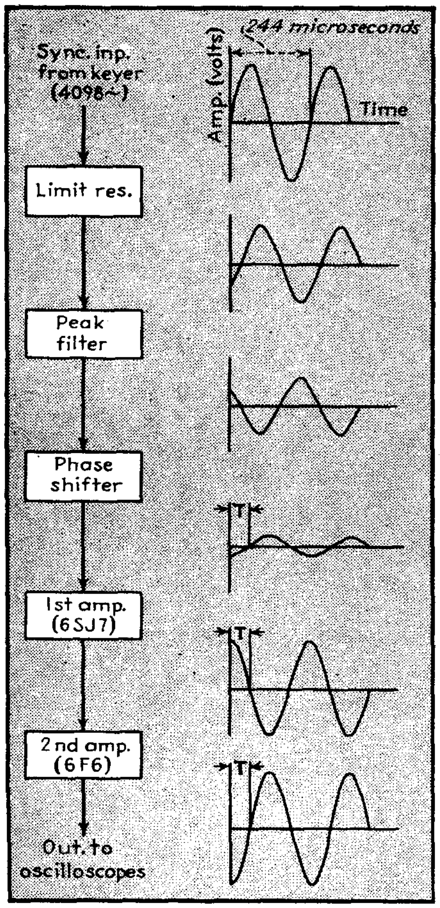

FIG. 12—Diagram showing how the SCR-268 radar range unit functions

shown in Fig. 11. Two antenna inputs are provided, for each of the two terminations of the array. These are connected to separate r-f amplifiers (type 954 acorn pentodes) which are switched alternately on and off to provide reception alternately on the respective lobes of the array.

The switching is accomplished by applying a rectangular wave of voltage to the grids of the r-f stages, the wave being obtained from a multivibrator (switch oscillator, 6N7 double triode) and a subsequent amplifier (6N7). The multivibrator produces a rectangular wave at a frequency of approximately 1400 cps. Approximately three pulses and echoes are passed through one r-f stage while the other is blocked. Thereafter, the first r-f amplifier is blocked and the second passes three pulses. In this manner reception is switched rapidly from one lobe to the other.

The two r-f stages are joined together at their plates. Hence at this point the successive lobe signals are interspersed in time sequence. Thereafter, the joint signal is amplified by a second r-f stage (954).

The tuned circuits associated with the r-f stages consist of a single inductance, permeability tuned and loaded with resistance to present a bandwidth of about one megacycle. This bandwidth is somewhat greater than the spectrum occupied by the incoming pulses, the extra space being provided to cover possible shifts in transmitter frequency.

At the output of the second r-f stage, the signal is mixed with a local oscillator signal. This signal is derived from a type-955 acorn triode oscillator in a Hartley circuit, followed by a 954 buffer stage. The mixer tube is a 954, with the pulse signal and local oscillator output applied jointly to its control grid. At the output of the mixer the difference frequency of 19.5 Mc appears.

The 19.5 Mc intermediate frequency is amplified in four i-f stages (6SK7), coupled with single tuned circuits which are permeability tuned and loaded to achieve 1-Mc bandwidth. The voltage gain of each stage is about 12, or $12^4 =$ 21,000 overall for the four stages.

The second detector is a triode (6SJ7) operated at cut-off bias. The detector feeds a video amplifier (6SJ7) having a gain of about 2.5. The output (taken from the plate of the video amplifier) is about 10 volts peak-to-peak maximum into a 500-ohm output circuit. Any signal higher than this saturates the video amplifier.

The sensitivity of the receiver is such that, at maximum gain, the noise developed at the receiver input will saturate the video amplifier. Sensitivity is controlled remotely, from a control associated with the cathode-ray indicator. The sensitivity control voltage is applied to the cathode of the first i-f stage.

In addition to the video output, the receiver provides a "spread voltage" for separating the indications of the two lobes on the cathode-ray indicator screen. The spread voltage is derived from the output of the switching amplifier. To assure that the gain in the two lobe channels is equal, a balance control is provided in one of the first r-f stages. This balance control is set during the calibration procedure, using a standard signal generator.

The Range Unit

The range unit is a device which controls the timing of the indicator traces relative to the production of the transmitted pulses. The range unit shown in the block diagram of Fig. 12 is essentially a phase shifter, capable of shifting the phase of the 4098-cps sine wave by any amount, continuously and smoothly.

The input 4098-cps wave is derived from the keyer (shown in Fig. 4). After passage through a limiting resistor, and through a filter to remove harmonics, the sine-wave is passed through a Helmholtz coil. This device consists of two sets of stator coils, arranged at right angles. The current fed one set of coils is advanced 90 electrical degrees by passage through a capacitor-resistor network. The result is a rotating magnetic field at the center of the coil system. This field induces a sine-wave voltage in a small pickup coil at the center of the system. The phase of the induced voltage is fixed so long as the pick-up coil is stationary. When the coil is rotated, the phase shifts in direct proportion to the angular motion of the coil. The induced voltage is amplified in two stages and the output is fed to the indicators as subsequently described.

The Indicator Units

Three identical units are used as indicators by the range, elevation and azimuth receiving antenna array operators. These indicators are very similar in appearance and function to a conventional cathode-ray oscilloscope. Besides the basic power supply, the indicator units derive three voltages from the other units of the radar: (1) the pulse signal from the video amplifier of the associated receiver, (2) the spread voltage from the switch amplifier of the receiver, and (3) the phase-shifted 4098-cps sinewave from the range unit.

A block diagram of one indicator, showing its waveforms, is given in Fig. 13. The basic synchronizing input comes from the range unit. This sinewave voltage is first amplified in an over-driven sync amplier (6AC7). The negative grid voltage cutoff and positive grid current saturation convert the sinewave input into a more nearly rectangular wave which is fed to a pulse generator (6L6), also overdriven. In the plate of this high-current tube is an inductance. The sudden current changes at the sides of the rectangular wave, passing through this inductance, induce high peaks of voltage which are used to control the following sweep-voltage generator after passing through a peak filter.

The sweep generator consists of a capacitor, charged through the 6L6 sweep generator tube. The approximately constant current characteristic of the 6L6 results in a closely linear increase in voltage across the sweep capacitor until the sudden positive peak arrives from the preceding peak filter. Then the capacitor is suddenly discharged by the heavy reverse current passed by the sweep generator tube. The result is that the voltage across the sweep capacitor has the saw-tooth form required for deflecting the electrostatic cathode-ray tube.

Before application to the c-r tube, the sweep voltage is amplified (6SJ7) and mixed with the spread voltage. The spread voltage, which we recall is synchronous with the lobe-switching, is amplified (6SJ7) and causes the saw-tooth sweep wave to be displaced bodily upward and downward, as shown in the figure. Thus the sweep associated with the one lobe-channel is displaced horizontally on the c-r tube with respect to the sweep associated with the other lobe-channel. This causes the image to appear "split" as shown at the bottom right in the diagram.

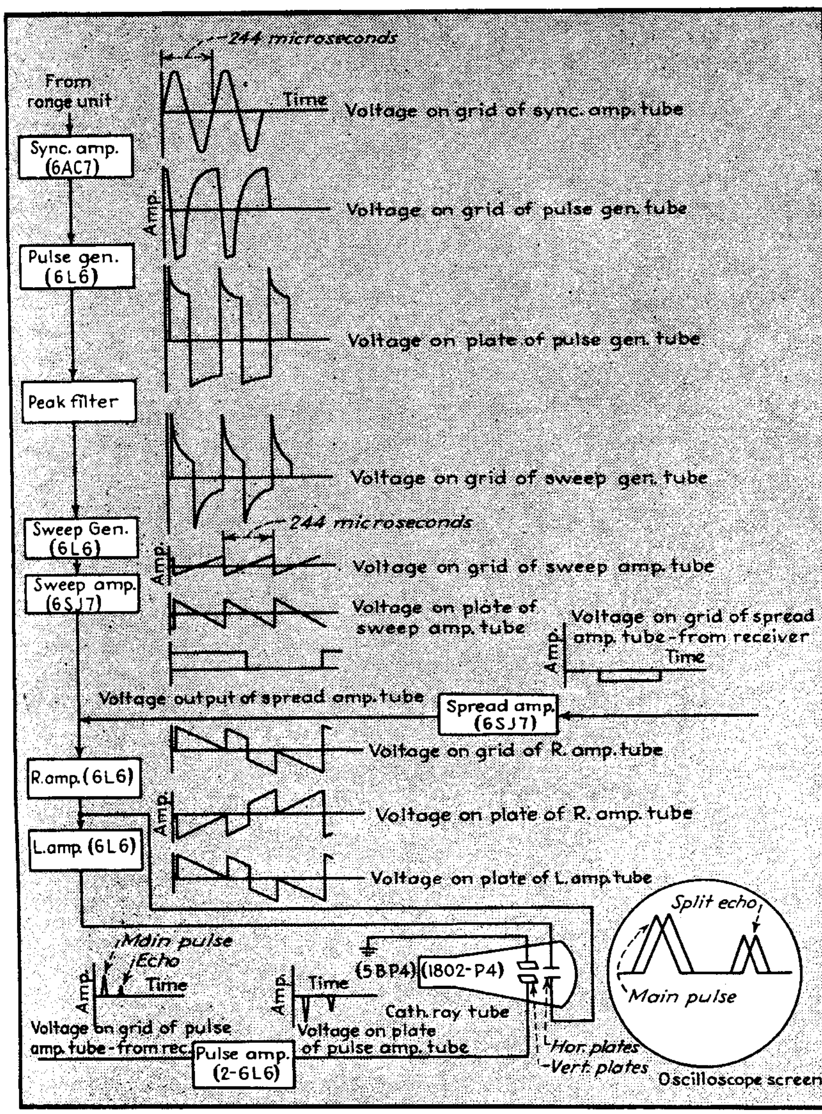

FIG. 13—Functional block diagram of one of the three oscilloscope indicating units

The displaced sawtooth wave is applied to two amplifiers (6L6's) which produce symmetrical waves of opposite polarity for application to the horizontal deflection plates of the c-r tube. The symmetry is essential to produce a linear sweep.

The receiver output is amplified in a pulse amplifier (2-6L6's) and then applied to the vertical deflection plates. The resulting screen pattern is a series of pulses in pairs. The first pair is a split image of the transmitted pulse, which is transmitted directly from the transmitting array to the receiving array. The receiver is considerably overloaded at this instant, and the pulse saturates the amplifiers and hence is flattened at the top. No special device is provided to protect the receiver during the transmitted pulse. The next pair of pulses to the right is a split image of the pulse echo from a target.

In operation, the azimuth and elevation operators adjust the spread voltage and the amplitude of the pulses until the split image is displayed conveniently for comparison of the amplitudes of the two components of the split image. Thereupon the angular orientation of the corresponding array is adjusted until both components are of equal height. The array is then pointed directly at the target.

Range Indicator

The range indicator does not make use of the spread voltage so only a single image appears for each echo. The range operator adjusts the phase shift of the range unit until the target echo appears under a cross-hair on the associated scope screen. The range to the target is then read off the phase-shift dial, which is calibrated in thousands of yards.

The SCR-268 employs 110 vacuum tubes, which are divided among the several units as follows: high voltage rectifier 4, keyer 11, range unit 3, modulator 10, transmitter 16, two receivers 15 each, three indicators 12 each. Despite this fact, and the evident complexity of the circuits, the 268 has proved to have outstanding serviceability in the field. —D.G.F.

REFERENCES

(1) Fink, D. G., The Radar Equation, *Electronics*, p. 92, April 1945.