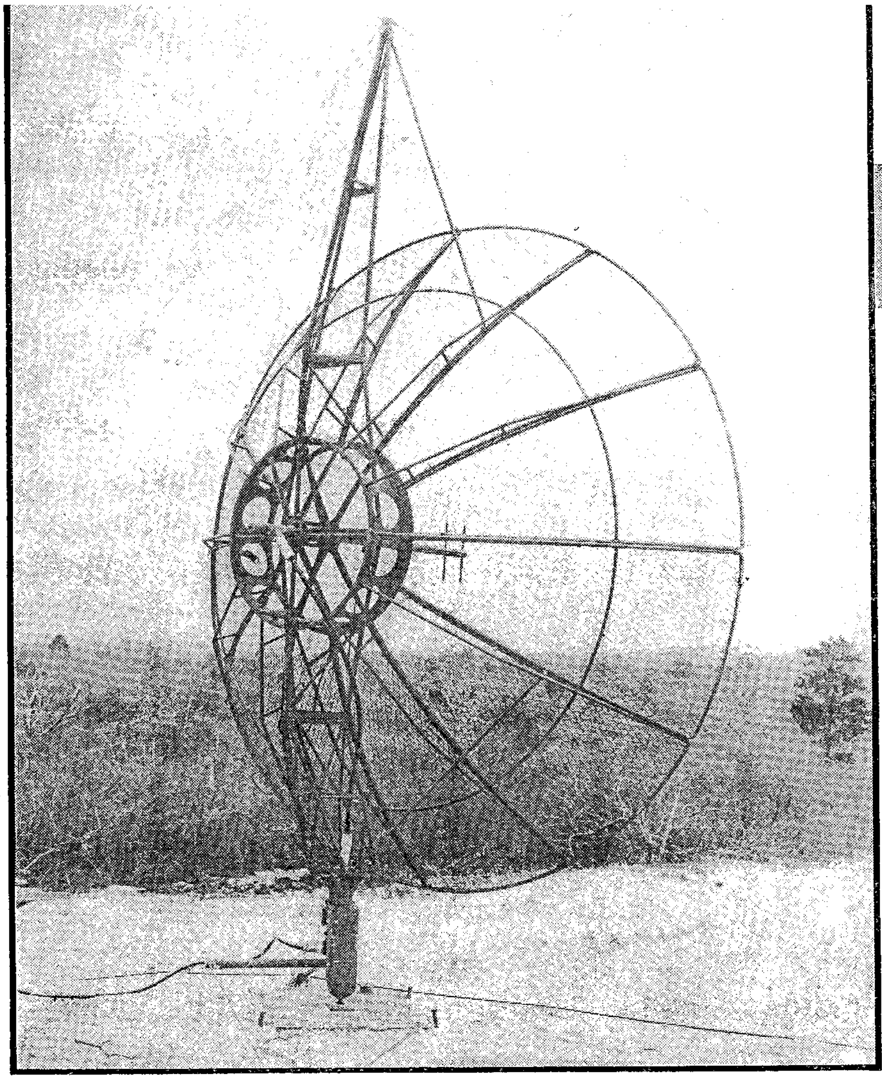

RADAR

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Close-up of antenna, showing remote indicating gear at base, permitting antenna to be separated 100 feet from operating position. Since the antenna was a favorite target, separation protected crew

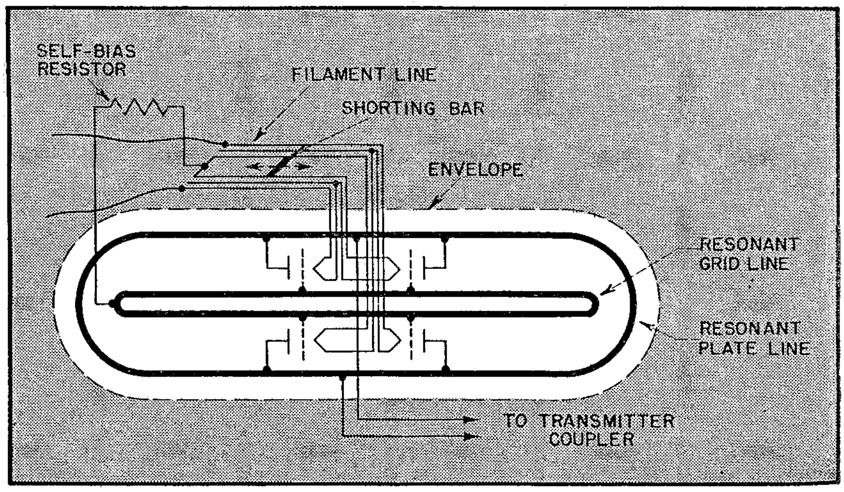

FIG. 1—Schematic of the internal-circuit triode oscillator. Four triodes are connected directly to resonant grid and plate lines within the tube

THE TRANSMITTER of the AN/TPS-3 radar is a single-tube oscillator employing a tube specially developed for this frequency by the first named author. It consists of four triode sections connected in push-pull-parallel as shown in Fig. 1. These sections are connected together by means of tuned grid and plate lines entirely contained within the glass envelope. The r-f output is brought from the tube by two leads connected to each side of the plate line at its maximum voltage point.

The grid line is situated directly below the plate line and is therefore coupled to it. A lead from each end of this line, at its zero voltage points, is brought out of the tube. Grid bias is applied to either one of these leads.

Each of the four thoriated tungsten filaments is brought out independently and they are tied together externally by another section of transmission line. By properly adjusting the length of this filament line the tube may be made to operate over a frequency band of 590 to 610 mc. Grid bias is developed by connecting a resistance of the proper value between one of the grid leads and the zero voltage point of the filament line.

The tube operates as a push-pull triode oscillator in a tuned-grid tuned-plate circuit. The most efficient means of coupling to the tube is to connect the transmission line directly to the plate leads. For safety reasons, the transmission line must be held at d-c ground potential. This requires the plates to be held at d-c ground and the keying voltage must be applied negatively to the filaments.

Although the tube has operated satisfactorily at 30 kv, the normal operating voltage in the AN/TPS-3 is 24 kv. This voltage is applied to the filaments in negative pulses of

ON 50 CENTIMETERS

Details of transmitter, receiver and indicator systems of the TPS-3 600-mc early-warning radar are presented in this concluding installment. The transmitting tube contains tuned circuits within the envelope, and is modulated by a rotary spark gap

1.5 microseconds duration, occurring at the rate of 200 per second. This means that the transmitter is operating only 0.03 percent of the time. During this operating time it produces r-f power at a rate of 200 kw, but the average power produced is only 60 watts. The high peak power requirement puts a stringent demand on filament design, since the filament must be large enough to provide sufficient emission to allow the production of 200 kw. The filaments consume 400 watts of heating power.

Another unusual feature is the large interelectrode spacing. If it were not for the high voltage employed, this would mean a prohibitively long transit time at 600 mc and the tube would operate very inefficiently. As a matter of fact, the tube will not oscillate until the voltage exceeds about 5000 volts. This means that the tube cannot be used as a cw oscillator since the plate dissipation would be far too high. Under the pulsed conditions the tube operates at 25 to 30 percent plate efficiency.

The modulating system consists of a modulator unit, a pulse transformer, and a rotary spark gap mounted on the shaft of the power unit. A functional schematic of these units is shown in Fig. 2. The modulator and power unit are placed 50 feet from the console of the radar and connected to it by cables. The pulse transformer is in the console, situated next to the transmitter, and is connected to the modulator by 50-ohm flexible coaxial cable.

The Modulating System

The modulator proper consists of a conventional voltage doubler, a charging choke and a pulse-forming artificial transmission line. The voltage doubler produces 8000 volts, negative d-c, across the terminals of its filter capacitors and applies it through the charging choke to the five parallel capacitors of the pulse line. These form a series-resonant circuit with a half period of 5000 microseconds. When the 8000 volts is applied to this combination the voltage on the capacitors builds up slowly. In 5000 microseconds it reaches twice the applied voltage, or 16,000 volts negative. When the pulse line is shorted to ground, it discharges through the primary of the pulse transformer in a period of 1½ microseconds. The time of discharge is determined by the constants of the line, i.e., the values of the capacitances and inductances. These constants are adjusted so that the characteristic impedance of the line at the pulse frequency is 50 ohms. Since the pulse line is connected to a 50-ohm load, half of the total voltage will appear across the load and half across the pulse line.

The pulse transformer has applied to its primary a rectangular pulse

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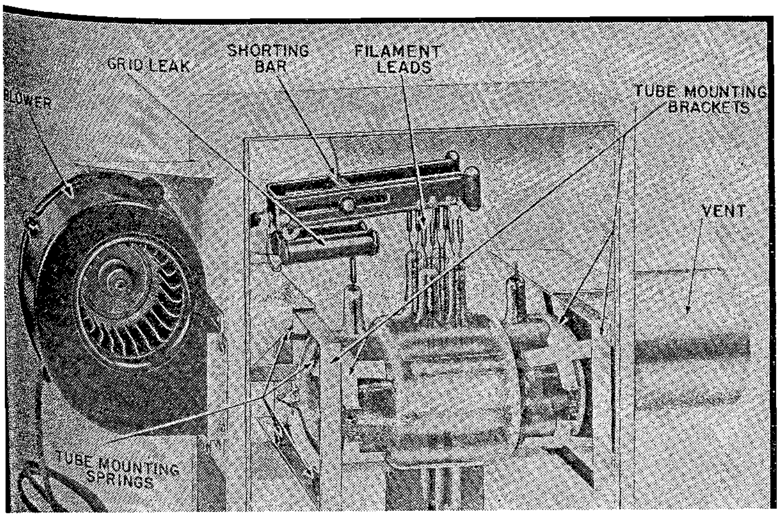
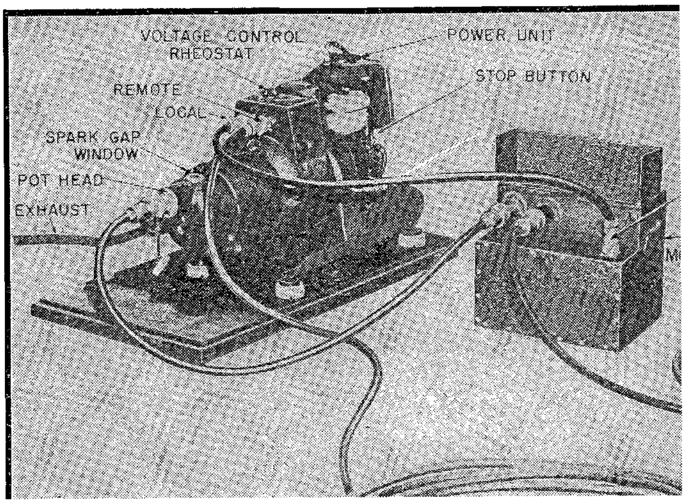
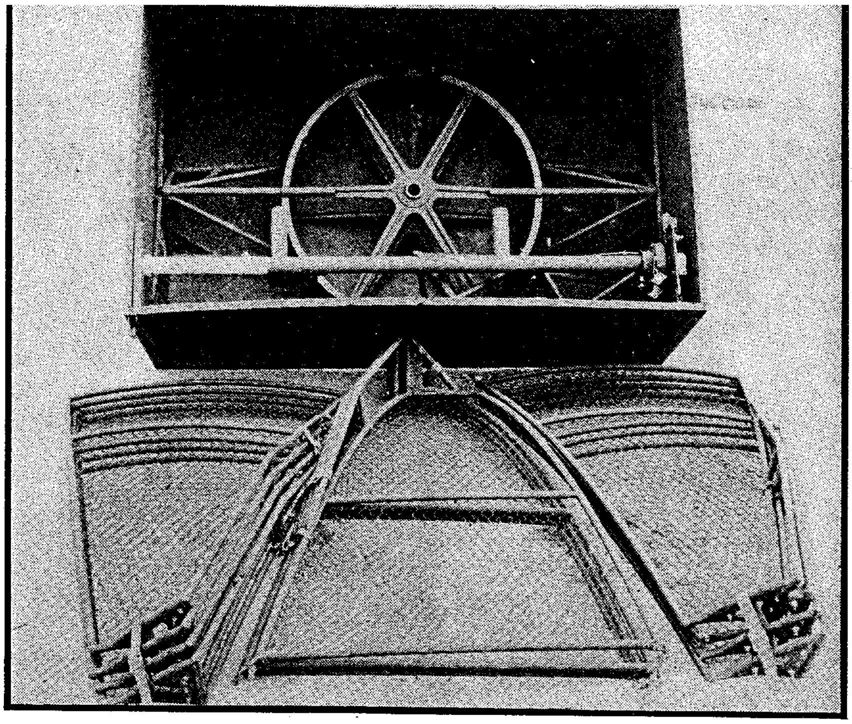


Interior view of transmitter, showing VT-158 internal-circuit tube. The corresponding schematic circuit is shown in Fig. 1. The output is taken directly from the plates, at d-c ground potential. Negative modulating pulses are applied to the filament



Power unit and modulator. A three-pole rotary spark gap, mounted on the shaft of the 400-cps primary power alternator, discharges the pulse-forming circuit at 200 pulses per second

of 8000 volts amplitude, 1.5 microseconds long. This transformer is designed with a very low leakage inductance and low losses so it will pass high frequencies efficiently. The ratio of primary to secondary is 1:3 so that the secondary voltage will be −24,000 volts. Figure 2 shows two windings on the secondary of the pulse transformer. These are actually two parallel windings insulated from each other, and carry the filament current for the transmitter tube. This allows the use of a filament transformer without high-voltage insulation. A separate winding of very few turns on the pulse transformer produces a 400-volt negative pulse which is used as a trigger to control the circuits in the indicator.



Antenna disassembled and packed for transport. All major components can be broken down into small packages, each capable of being carried by a man

The switch that short-circuits the pulse line is a rotary spark gap mounted on the shaft of the power unit. The power unit is a 12-pole 400-cycle alternator operating at 4000 rpm. Since the spark gap has three segments, the pulse line will be short-circuited three times per revolution, or 200 times per second. The high voltage point of the pulse line is connected to a single stationary tungsten pin in the housing of the spark gap. A metal disc fixed to the shaft of the alternator carries three tungsten pins, spaced 120 deg. apart, past the stationary pin. A carbon brush riding on the metal disc provides a low resistance path to ground. When one of the rotating pins approaches the stationary pin, the 16,000 volts on the stationary pin breaks down the air between them and provides an ionized path through which the pulse line discharges. Between pulses the voltage doubler and charging choke again charge up the pulse line to −16,000 volts. The wave shape of the voltage on the pulse line and the wave shape of the voltage on the primary of the pulse transformer are shown in Figure 3.

It is interesting to note the magnitude of the instantaneous currents and powers flowing in some of these circuits. For instance, the transmitter tube is known to have an impedance of 450 ohms to direct current. Since the applied voltage is 24,000, the direct current flowing through the transmitter tube during the pulse is approximately 50 amperes and the plate power is approximately 1.2 megawatts. The current in the primary of the pulse transformer and the rotary spark gap is 150 amperes.

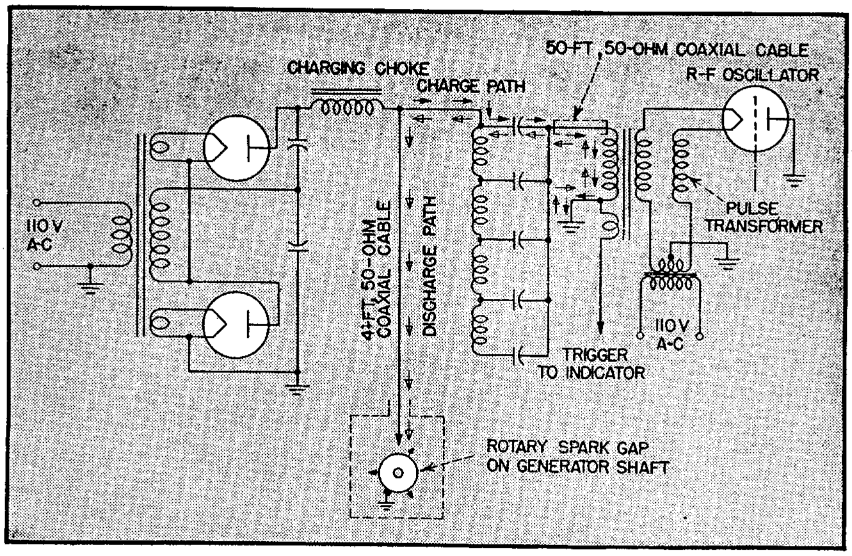


FIG. 2—The modulator circuit. The voltage doubler charges the *LC* network (pulse-forming artificial transmission line), which is discharged through the r-f oscillator by the rotary spark gap

Receiving and Indicating System

The receiver is conventional, operating on the superheterodyne principle. It differs from an ordinary receiver only in the wide bandpass and in the low noise figure. The optimum bandwidth for a receiver to be used with a 1.5 microsecond pulse is the reciprocal of the pulse width, or 0.66 mc; however this optimum is not very critical and the actual bandpass of the receiver is approximately 1.25 mc.

The noise figure of a receiver can be considered as a comparison of the actual receiver with a perfect receiver. Since the radar must operate on extremely small signals, the gain of the receiving system is usually high, so that noise is always present in the output circuit. The amplitude of this noise is the limiting factor in the size of the signal that is discernible. The output circuit of a perfect receiver will have present in it only the amplified thermal noise in its input circuit. An actual receiver has, in addition other noise, such as shot noise, generated within the receiver itself. The noise figure is a method of comparing the actual noise present to the noise that would be present if the only source were the passive resistance of the input circuit. The noise figure is expressed in db and is independent of the impedance of the input circuit or bandwidth and is therefore a figure of merit of all radar receivers. The receiver of the AN/TPS-3 has a noise figure of approximately 10 db.

Figure 4 is a block diagram of the receiver. The first two stages are

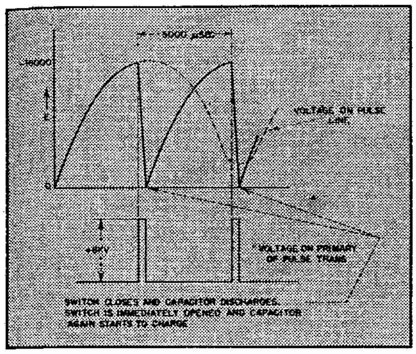


FIG. 3—Waveforms in the modulator circuit. Resonance charging is employed to reach 16,000 volts across pulse line, which is discharged at peak of cycle

radio-frequency amplifiers tuned to 600 mc, employing grounded grid triodes. The local oscillator is injected into the cathode circuit of the second r-f amplifier and the converter is a silicon crystal in the plate circuit of this stage. The converter output feeds into an i-f amplifier consisting of six stages, followed by a diode detector and a video amplifier whose output is then fed into the indicator. There are also several special circuits built into the receiver to eliminate interference caused by the enemy as countermeasures. These are known as antijamming circuits.

The indicator circuits divide themselves into four sections. These are the video circuits, the type-A indicator sweep circuits, the plan position indicator (ppi) sweep circuits and the marker circuits. The type-A presentation sweep circuit shown in Fig. 5 begins with a one-shot multivibrator that produces negative square waves. By means of a switch, the length of the square wave can be set to 200, 600, and 1200 microseconds. The square wave is applied to a sweep generator which produces a linear sawtooth wave of the same period as the square wave. The sawtooth is amplified by a pair of cascade amplifiers and applied to the horizontal plates of the A-scope.

The ppi presentation, (Fig. 6), starts with its own independent multivibrator, also adjustable over the same three ranges as the A-scope. This allows the range presentation of the A and the ppi-scope to be set independently. The ppi multivibrator is fed into another sawtooth generator and a single stage preamplifier. The preamplifier drives the primary of a rotary transformer, each of whose two secondaries are connected through amplifiers to one pair of magnetic deflection coils on the ppi tube. The rotary transformer is essentially a two-phase motor with a single-phase rotor which is rigidly connected to the antenna.

As the antenna rotates the rotor must follow. This induces sawtooth voltages of varying magnitude in each of the two secondaries on the stator. The voltages in each of the two stator windings are in time phase, but are 90 deg apart in space phase; i.e. when the voltage in one winding is a maximum, the other is a minimum. These voltages are amplified and applied to the deflection yokes of the ppi tube. The result is a radial sweep which rotates about the center of the tube in synchronism with the rotation of the antenna. By pointing the antenna toward true north and then adjusting the position of the stator until the sweep line points to 0 deg on a graduated scale around the face of the tube, the sweep line is made to indicate true antenna position.

Both the A-scope multivibrator and ppi-scope multivibrator are triggered by the pulse generated in the third winding of the pulse transformer, so that the sweep line in both tubes always begins the instant voltage is applied to the transmitter. Although the voltage on the transmitter only lasts for 1.5 microseconds, the sweep line in each tube continues for the length of time determined by the setting of the controlling resistor in its multivibrator.

Of special interest in the ppi sweep circuit are the precautions taken to have the sweep line begin every sweep exactly at the center of the tube. This is accomplished by a clamping circuit. Each of the magnetic deflection yokes of the ppi tube are driven by a pair of amplifiers in push-pull. The grid of each push-

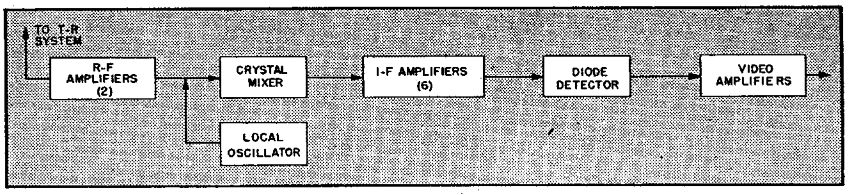


FIG. 4—Block diagram of receiver. At 600 mc, useful gain can be obtained by preamplification before the mixer. The nominal bandwidth of the i-f amplifier is 1.25 mc

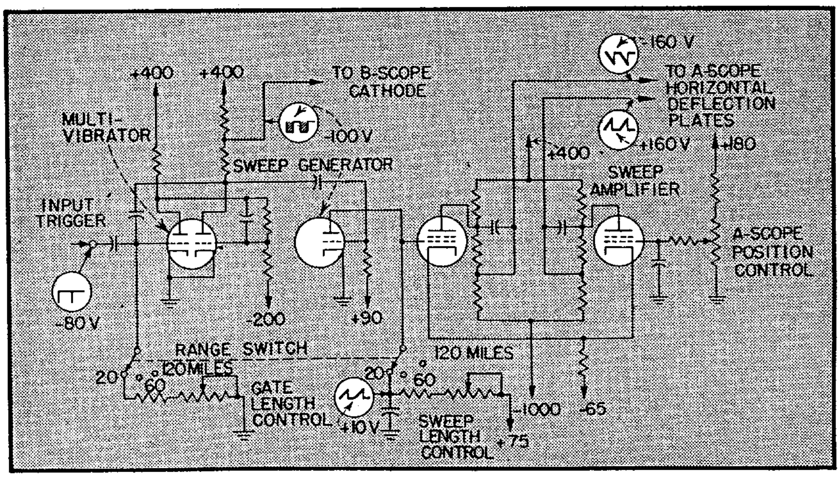


FIG. 5—Simplified schematic of sweep circuit for type-A indicator

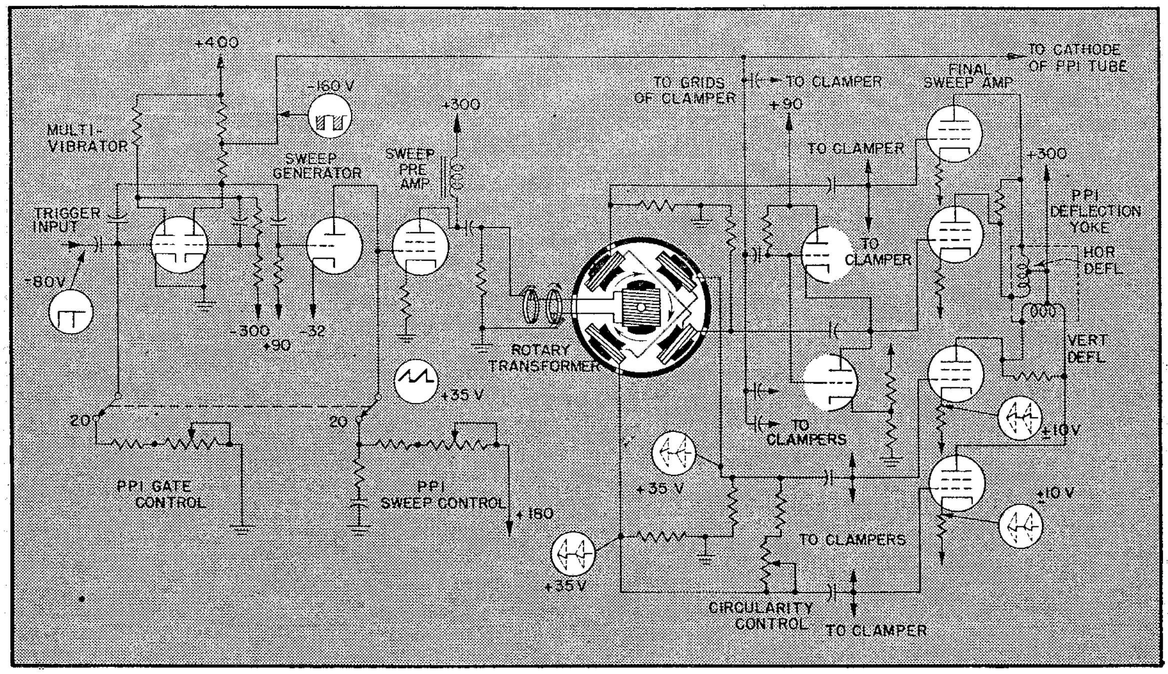


FIG. 6—Simplified schematic of sweep circuit for plan position indicator. Rotor of rotary transformer is connected to antenna drive, so direction of deflection corresponds to antenna position

pull amplifier is connected to a pair of clamping tubes as shown in the functional schematic. The grids of the clamping tubes are tied to a high positive voltage so that the clampers are normally practically short-circuited. This keeps the grid of each of the push-pull amplifiers at a fixed potential determined by the voltage drop through the clampers and the resistance from the cathode circuit of the lower clamper to ground. When the sweep voltage is applied to the grid of the amplifier a portion of the square wave from the multivibrator is also applied to the grids of the clampers. This being negative, the clampers are cut off and the grid of the amplifier is allowed to rise linearly with the sawtooth. At the end of the sawtooth the square wave also is ended and the clampers are once more short-circuited, bringing the amplifier grids back to the same fixed potential.

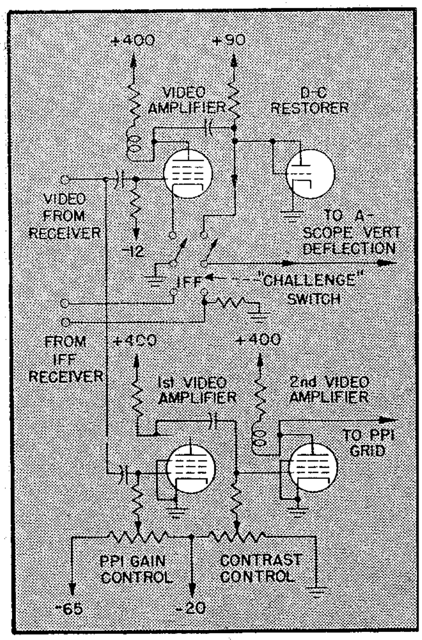


FIG. 7—Video amplifiers for A-scope and ppi. The ppi stages limit the pulses to avoid blooming and loss of contrast

Separate video channels, Fig. 7, are provided for the A-scope and ppi-scope. The A-scope video is a single stage amplifier whose output is connected to one vertical plate of the A-scope. The ppi video channel is somewhat more complicated, since the signals are applied to the ppi tube as intensity modulation and their levels must be accurately controlled. The amplifier consists of two stages in cascade which act as amplifiers and clippers. By controlling the bias on these two stages the maximum and minimum signal level can be controlled, giving control of gain and contrast. The output of this two-stage amplifier is connected to the control grid of the ppi tube.

The unoccupied deflection plate of the A-scope tube is connected to the output of the marker circuits. These circuits produce marker pulses which resemble echoes, spaced at even intervals along the A-scope and ppi-scope sweep line. The markers are spaced 107 microseconds apart, representing 10 miles. Every fifty-mile marker is somewhat longer than the others. The marker circuits begin with a multivibrator which is triggered from the same source as the sweep multivibrators and produces a square wave of fixed length equal to the maximum range of the presentations. This square wave is applied to a normally quiescent oscillator whose tank circuit is adjusted to 93 kc. The resultant oscillations have a period of 107 microseconds. These are then amplified, squared, and clipped as shown in Fig. 8. The resulting markers are then fed into one half of a mixer tube, the other half of which is fed by one-shot multivibrator flip flop circuit whose constants are adjusted to ⅕ the frequency of the 10-mile markers. This circuit is driven from a point in the 10-mile marker circuit and produces a longer marker at every fifth 10-mile marker. The output of the mixer tube is fed directly to the A-scope and through a buffer amplifier to the control grid of the ppi scope. On the A-scope the markers appear as downward deflections along the sweep line, giving the impression of a marked scale. On the ppi scope they appear as bright spots along the sweep line, giving concentric circles as the sweep line rotates. The range of any target may be measured at once on either the A-scope or the ppi-scope by noting its position with respect to the markers.

Since the maximum sweep length of both tubes is only 1200 microseconds and the total time between successive r-f pulses is 5000 microseconds, some means must be provided to extinguish both tubes during the period when no sweep is present. This is accomplished by applying the square wave in each multivibrator to the cathode of its scope. The square wave turns on the c-r beam only during the time of each sweep.

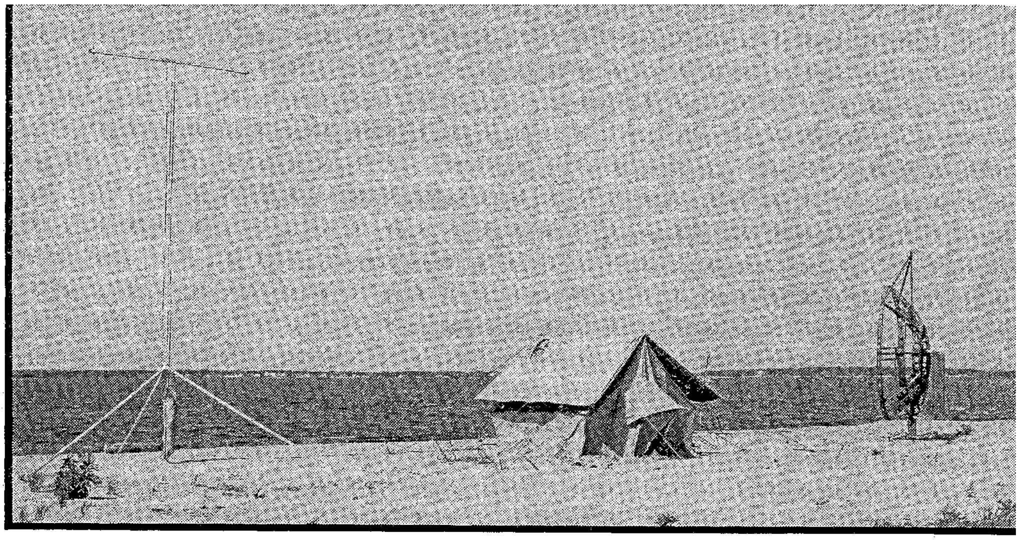


FIG. 9—TPS-3 with separation kit in place. The antenna at left is the iff radiator, used to identify friendly planes

Recent Modifications

After the AN/TPS-3 had been in production for some time, field reports indicated that certain changes would be desirable. The most important of these was some means of protecting the operator, since it developed that radar antennas were a favorite target for strafing enemy planes. Accordingly, Evans Signal Laboratory designed and produced a pedestal upon which the antenna could be mounted 100 feet from the set. This pedestal contained only the antenna drive motor, the rotary transformer and a means of connecting r-f power to the antenna. It was connected to the radar set by a control cable and flexible 50-ohm cable of large enough diameter to carry the peak r-f power. This allowed the set itself and the operators to be dug into a fox hole or any other available shelter leaving the antenna unrestricted. Fig. 9 is a photograph of a test setup showing the separation kit.

Acknowledgment

The authors wish to acknowledge the cooperation of many individuals in commercial concerns who assisted in the realization of this equipment. In particular, it is desired to acknowledge Dr. Irving Wolff and Martin Richmann of RCA for their contributions on the receiver, W. Eitel and J. McCullough of Eitel-McCullough for their assistance on the VT-158 internal-circuit transmitting tube, W. Schwam and N. Aram of Zenith Radio Corporation, J. Knezo and H. Bolton of Breeze Corporation, Dr. S. Mauntner of Skydyne Corporation and A. Newman of Homelite Corporation.

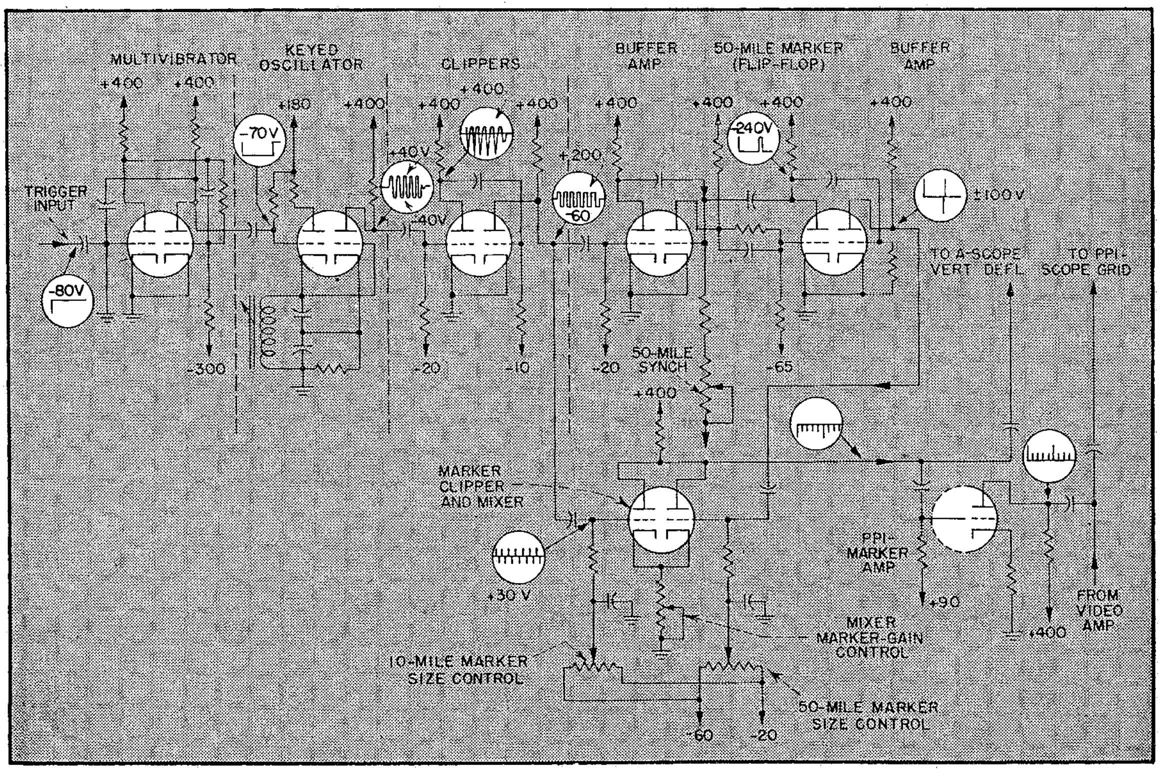


FIG. 8—Simplified schematic of marker circuits, which produce vertical calibration marks on A-scope, concentric range circles on ppi