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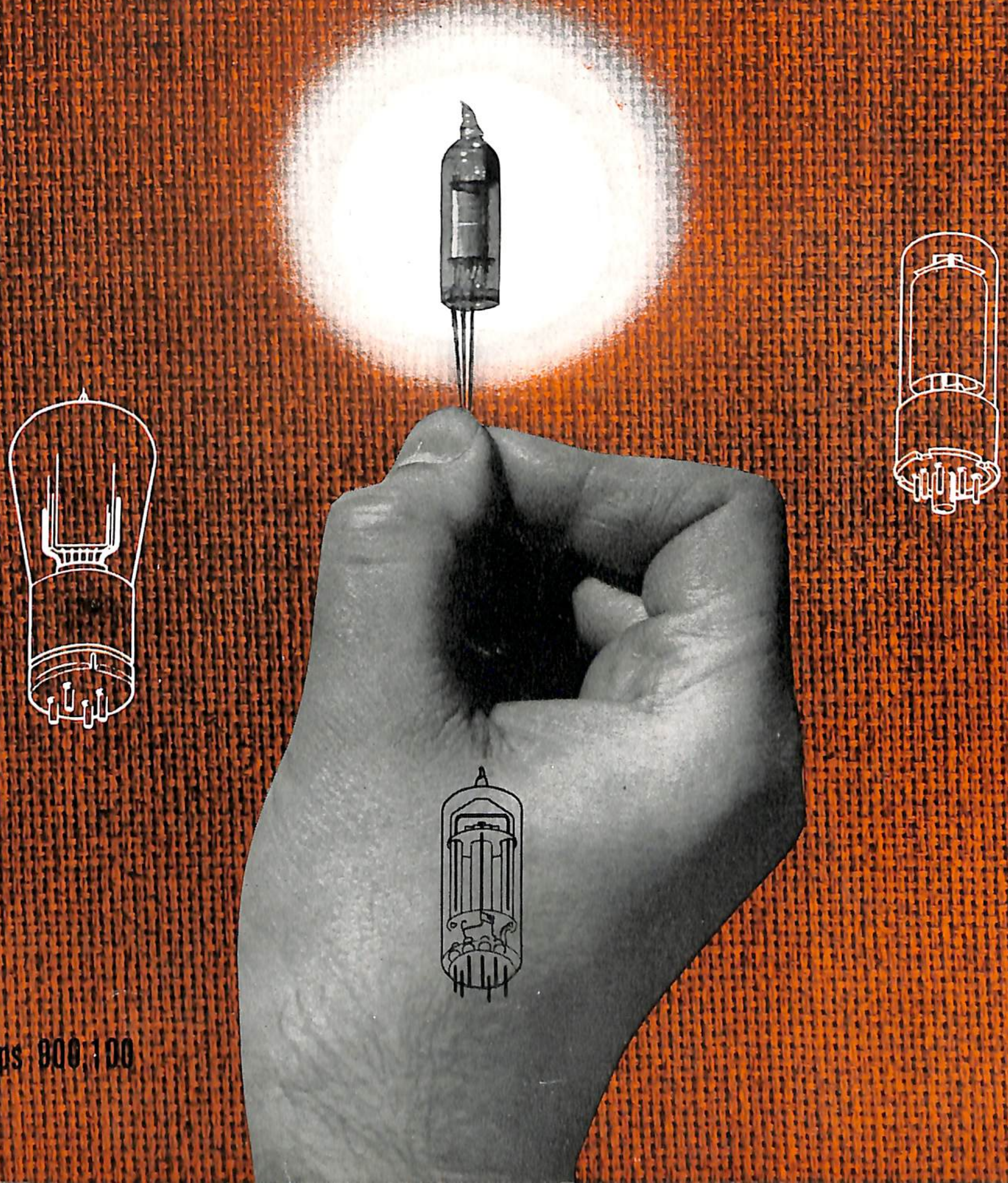
APRIL 1947

BUSHIPS Electron



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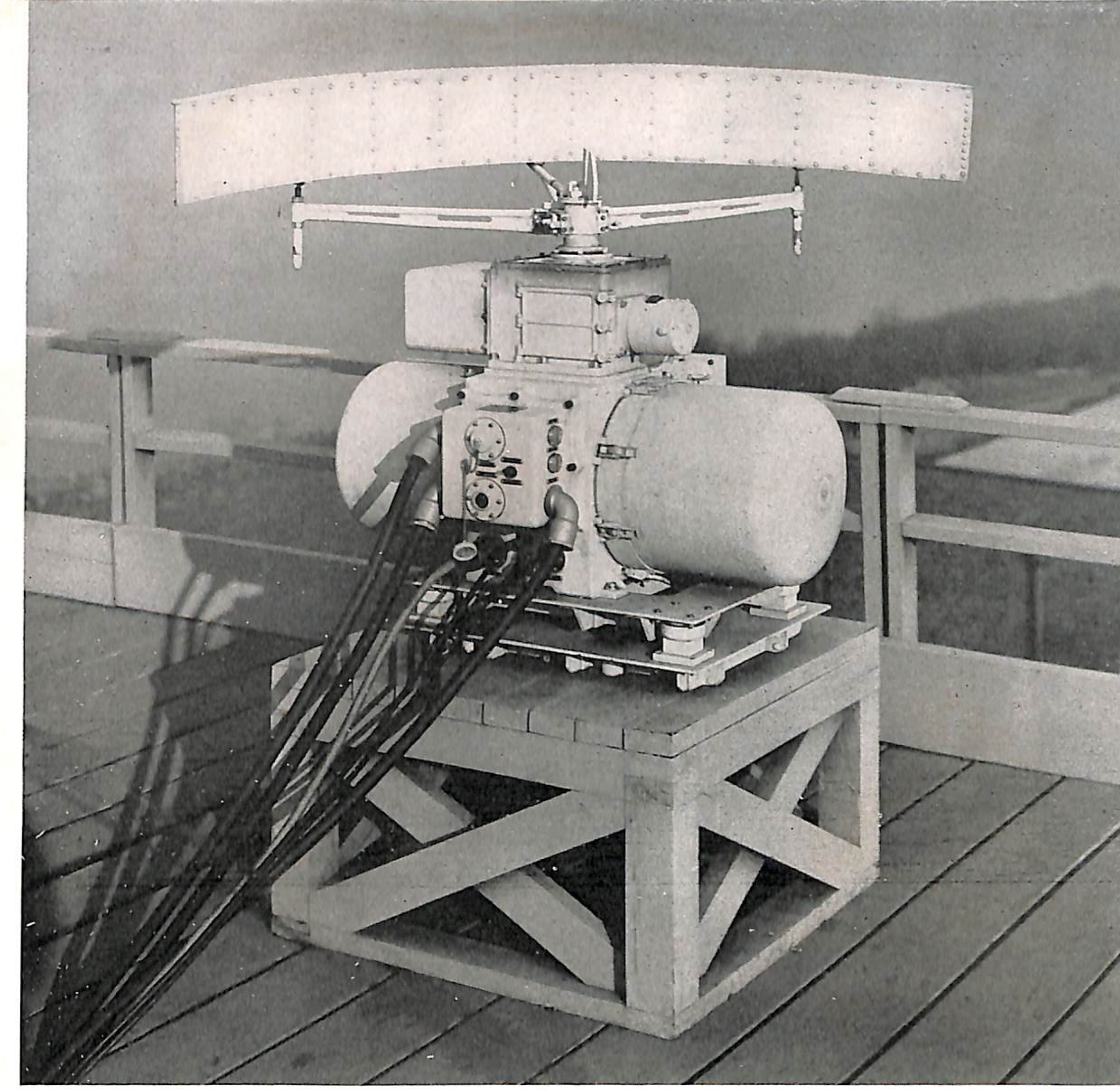
BUREAU OF SHIPS — NAVY DEPARTMENT

CXJG

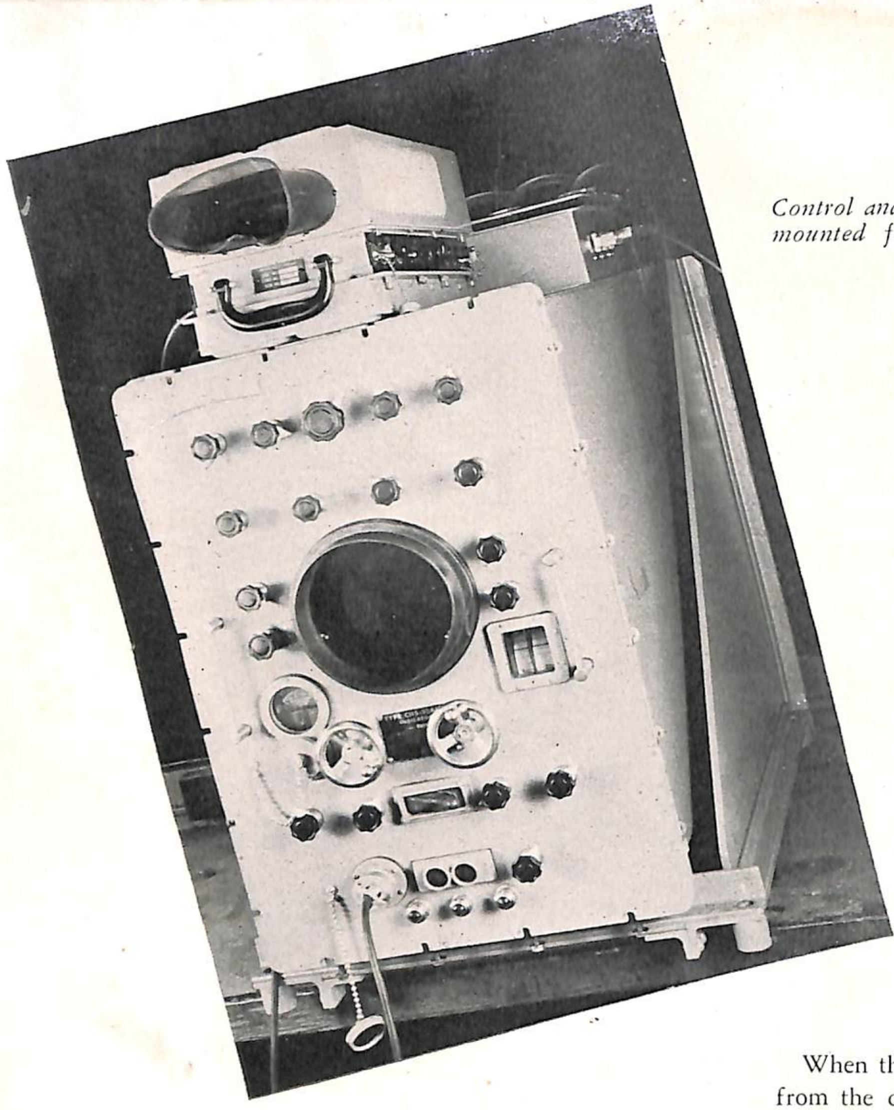


Transmitter-Receiver-Antenna Assembly of the CXJG 1-centimeter surface-search radar mounted for testing purposes at the Naval Research Laboratory.

1-Centimeter Search Radar

There has long been recognized a need for a surface-search radar operating in the one-centimeter region in order to gain the advantages of a very narrow beam and extreme definition on short-range targets. Early in the summer of 1945 the Bureau of Ships released a Radiation Laboratory developmental model of such a radar to Sylvania to be used as a basis for a pre-production contract of 15 equipments. In order that an early evaluation of radar performance in this frequency range could be made, only minor changes were authorized on the original developmental equipment. This procedure made possible delivery of the first pre-production model of the CXJG during the summer of 1946.

Preliminary tests and inspections by both Naval and civilian personnel disclosed that technical operation was in general satisfactory but some defects in mechanical design and layout of component parts were apparent. Since it is the policy of the Bureau to give the utmost consideration to future servicing of equipment as well as the best in technical design and efficiency commensurate with space and weight limitations, several changes in mechanical design and electrical characteristics will be incorporated into any future production. The preproduction models consist of 4 units, Transmitter-Receiver-Antenna Assembly, Control and Plan Position Indicator, Gyro-Compass Synchro Amplifier, and the Rectifier



Control and Plan Position Indicator of the CXJG bench mounted for testing. Test scope type TS-34A-AP is mounted on top of indicator.

Power Unit, with weights of 260, 265, 80, and 225 pounds respectively. Test equipment supplied consists of a test scope (TS-34A/AP), crystal checker (TS-268/U), and FM test set (TS-223A/AP).

TRANSMITTER-RECEIVER UNIT

The transmitter-receiver unit contains circuits for the generation, transmission, and reception of super-high-frequency pulses. The transmitter section of the unit consists of a trigger generator, modulator, magnetron oscillator, and associated r-f waveguide assembly.

The trigger generator, which is the timing device for the entire system, is a free-running multivibrator utilizing a type 6SN7GT tube and components chosen to produce trigger pulses at a repetition rate of 750 per second. These trigger pulses are passed through a cathode follower (6SN7GT) and then applied to the modulator as positive pulses of 150 volts. The modulator circuit consists of a hydrogen thyratron (4C35), a charging choke, pulse-forming network, and the primary of the high-voltage pulse transformer.

When the modulator circuit is triggered by the pulse from the cathode follower, the pulse-forming network generates a 4000-volt pulse 0.17 microseconds in duration. This pulse is applied to the primary of the high-voltage pulse transformer which steps it up to 15,000 volts before application to the magnetron. When this high-voltage pulse is applied to the magnetron, oscillations occur resulting in a high-intensity r-f pulse which is carried to the antenna by means of a waveguide. Conventional TR and anti-TR circuits are utilized to protect the receiver during pulse transmission and to prevent attenuation of the returning signal during reception.

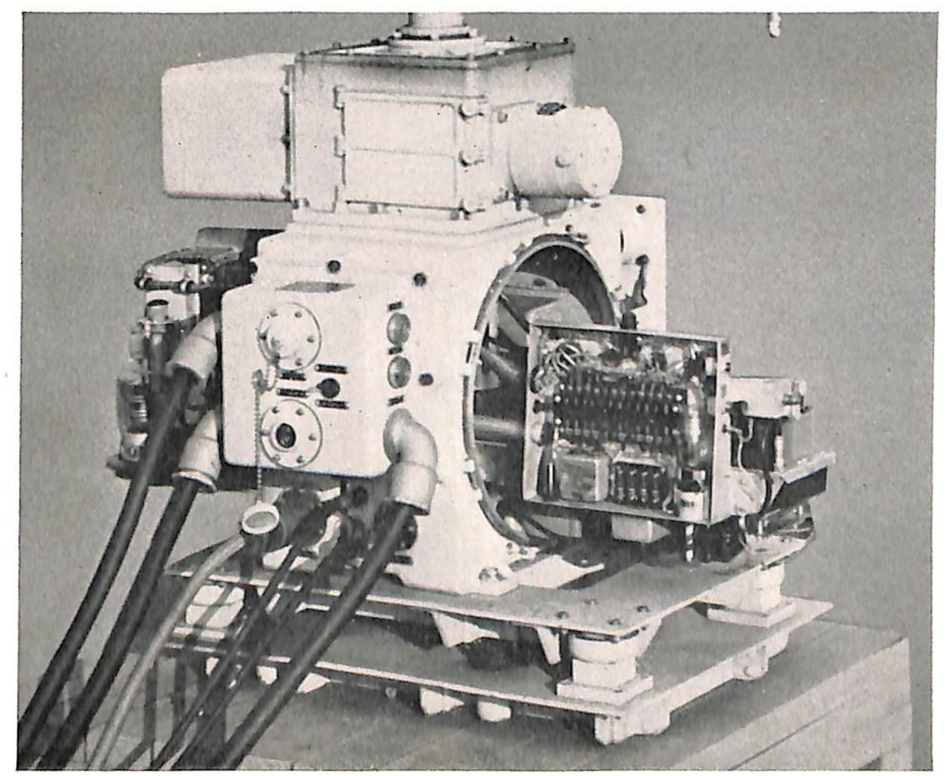
In order to synchronize the outgoing r-f pulse with the other components of the system, a synchronizing pulse is taken off the cathode of the modulator which will occur simultaneously in time with the r-f pulse generated in the magnetron. This synchronizing pulse is used to trigger the sweep and marker circuits in the indicator and to gate the receiver for suppression of clutter at close-in ranges.

The receiver section of the transmitter-receiver unit is of the superheterodyne type employing a crystal mixer, eleven stages of stagger-tuned intermediate frequency amplification, and a few other refinements such as AFC *(Automatic Frequency Control)*, a stabilized oscillator circuit, STC *(Sensitivity Time Control)*, and a ship's-head marker circuit. The 30 Mc output of the crystal mixer is passed through one stage of amplification (a 6AK5 connected as a triode to keep the noise level at a minimum) to the grounded-grid triode (6J6) which results in a very good signal-to-noise ratio. The output of the grounded-grid triode is then applied to the i-f amplifier strip (11 type 6AK5 tubes) with the tuning staggered from 25 to 36 Mc. Staggered tuning, in combination with components of the i-f strip, provides a bandwidth of 9 Mc. The gain of the receiver is controlled by variation of the grid bias on the first six stages of the i-f amplifier.

A type 6AL5 is used as the second detector, with maximum video frequency response of 7 Mc obtained by the use of series peaking in the plate circuit. The reason for extending the video response to 7 Mc is to preserve the pulse shape which, due to its 0.17-microsecond duration, requires a large bandwidth for faithful reproduction. The output from the detector is coupled to a cathode follower (6J6) which is connected as a single triode having a negative output voltage limited to a maximum of 0.9 volts. This output is carried via coaxial cable to the video amplifier strip located in the control and plan position indicator unit.

The AFC crystal mixer operates in the same manner as the receiver crystal mixer. Its purpose is to provide a 30-Mc intermediate-frequency voltage for the AFC channel. This intermediate-frequency voltage is obtained by piping the incoming r-f signal into the AFC crystal mixer along with the r.f. from the local oscillator, the resultant output being a 30-Mc i.f. The output of the AFC crystal mixer is fed to an r-f transformer having secondaries wound in opposite directions. The noise voltages induced in the secondaries of this transformer are of opposite phase so that, at the center tap where the output is taken off, these voltages will cancel, while the i-f signal will be permitted to pass to the following two i-f amplifier stages. This is to eliminate as much as possible of the extraneous oscillator noise. The output from the first stage is taken off the cathode, and that from the second stage is taken off the plate.

The output from the second of these i-f stages is applied to the grid of a 6AK5 operated as a phase splitter with outputs of equal amplitude but opposite polarity taken from the plate and cathode. If the frequency rises above or falls below the desired 30-Mc i.f. the voltage applied to the grid of the phase splitter will either swing negative or positive, respectively. This is due to the action of a tuned circuit in the plate of the first i-f amplifier stage mentioned above, and the conventional polarity reversal through the second i-f stage. The two outputs from the phase splitter are coupled to the cathodes of a dual diode (6AL5) the outputs of which operate an Eccles-Jordan (*flip-flop*) multivibrator. One output is applied to each section of the flip-flop



Antenna assembly of the CXJG with protective covers removed exposing the transmitter-receiver unit on the left and the modulator unit on the right.

circuit. The output voltage wave of the flip-flop circuit, taken from the plate of the second section, is coupled to the tuner grid of the local oscillator and acts as an automatic variable adjustment to the oscillator which has a coarse adjustment set by the manual tuning control. The voltage applied to the tuner grid of the oscillator by the AFC circuit will always be negative in respect to ground, but may be made more or less negative as the occasion demands, with the maximum change in the vicinity of 5 volts.

In order to minimize the effect of variation of the ship's power supply on the frequency of the receiver local oscillator, the filament voltage and plate voltage are stabilized. The filament voltage of 6.3 volts at 950 cycles is provided by a 6J6 in a carefully stabilized Hartley oscillator circuit.

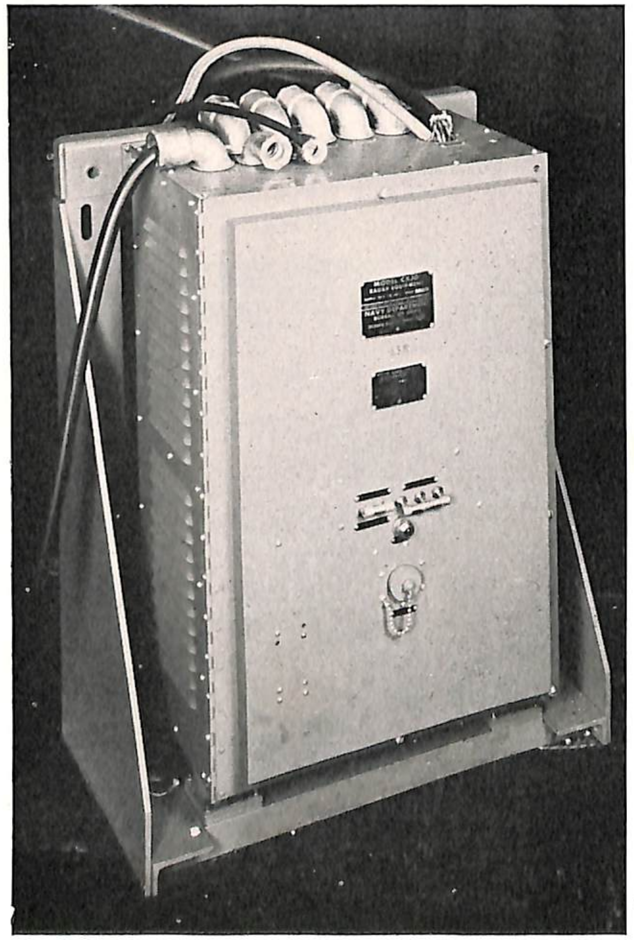
The sensitivity time control circuit employs a 6J6 connected as a single triode. In the plate circuit of this stage are the necessary resistive and capacitive components to produce the desired STC waveforms. When the positive trigger pulse from the modulator circuit is applied to the grid of the STC tube the circuit will conduct heavily but, since the pulse is very short in duration, this negative swing will be almost instantaneous, the depth of drive being controlled by the STC amplitude control located on the indicator front panel. This control effectively sets the plate voltage of the STC tube. The recovery time or length of sweep of this circuit is adjustable, being controlled by two variable resistors which make up part of the R-C time constant in the plate circuit of the tube.

The ship's-head marker circuit is used to intensify the sweep line to show the dead-ahead direction of travel of the ship, which permits the navigation of the ship through narrow lanes or alongside a dock. A synchro generator, located on the antenna drive unit housing, is mechanically coupled to the antenna shaft. At the base of the synchro generator are two microswitches and a cam. The first microswitch utilizes two contacts and the second switch only one. As the antenna rotates, the ship's-head marker cam revolves correspondingly so that, as the antenna approaches a dead-ahead position, the rise on the cam approaches one of the microswitch actuating rollers. The rise causes the arm of the microswitch (which we will designate S-1) to operate, leaving the circuit closed through S-2. The cam revolves further, causing S-2 to open since there is only one contact on this switch. At the moment the antenna faces dead ahead S-1 drops back to its first position but S-2 remains open. The shift from one contact to the other by S-1 causes a momentary open circuit in the receiver gain control line. The result of this momentary open circuit is that the receiver noise, at full gain, appears as a bright line on the scope face because the open circuit is of sufficient duration to allow two or three sweeps to be generated.

CONTROL AND PLAN POSITION INDICATOR

The control and plan position indicator consists of a sweep multivibrator, sweep generator, video amplifier, range-marks circuit, range-marker circuit, and associated servo-amplifier and power-supply circuits. The information obtained by the equipment is presented on a circular type of indicator (PPI), with the set being at the center of the indicator. Four range markers are provided for rough estimation of target range. Five range sweeps of 1, 2, 4, 10, and 20 miles are provided. The four range markers represent 1/4, 1/2, 1, 2 1/2, and 5 miles respectively on the five sweeps. A movable range marker, commonly referred to as the range ring, is also provided to obtain fine range measurements. When this movable marker is adjusted to coincide with the target, the range of the target is indicated accurately by a dial.

The sweep multivibrator is a one-kick multivibrator which is triggered by the positive synchronizing pulse from the modulator cathode circuit. The output of the sweep multivibrator is coupled to the sweep generator, which employs a type 6SN7GT tube with associated circuit components. The constants of this sweep circuit are chosen by the SWEEP MILES switch on the indicator in such a manner that any one of five lengths of sweep time may be utilized by the operator. The output of the sweep generator is passed through two stages of amplification and coupled to the grid of a cathode follower. The output of the cathode follower, a positive voltage, is impressed on the grid of an 807 tube which acts as a current amplifier and inverter. The resultant output from this 807 is then passed through the deflection coils, thereby generating magnetic fields which deflect the electron beam in the cathode ray tube from the center toward the outer edge of the screen. These deflections of the beam effectively form the sweeps which are seen on the scope face.



Front view of the rectifier power unit of the CXJG equipment.

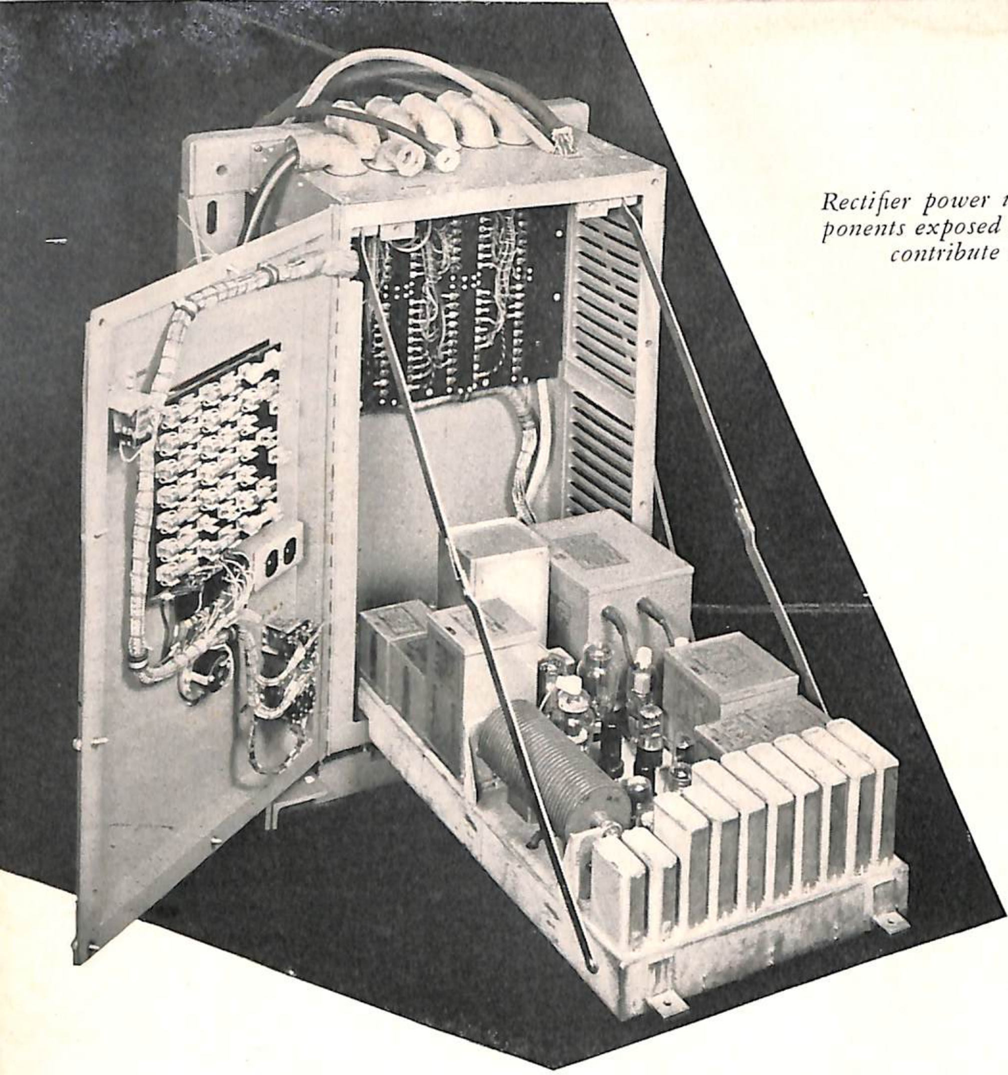
The video-amplifier section of the indicator supplies the PPI with the target information, fixed and movable range markers, and the IFF signal, all of which may be presented on the screen. The video amplifier section contains three 6AC7's, two 6AG7's and one 6H6. The video from the receiver unit is brought into the indicator by coaxial cable and applied to the grid of a 6AC7 which acts as a mixer amplifier. The IFF video is also brought into the indicator by coaxial cable, passed through one stage of amplification (a 6AC7) and applied to the mixer-amplifier. In addition to these two voltages, the range markers and the movable range marker are likewise applied to the mixer amplifier, thus making a total of four signal voltages which are mixed and amplified in this stage. The output of the mixer-amplifier is coupled to a second amplifier stage (a 6AG7) which has a combination of series and shunt peaking in its plate circuit for high-frequency compensation. The output of this stage is coupled to the cathode of the PPI through a clamping circuit utilizing a 6H6 diode to obtain the clamping action.

The remaining 6AC7 and 6AG7 are utilized to furnish an output from the indicator to repeater units. To accomplish this, the video line is tapped inside the indicator and coupled to the grid of the 6AC7 whose plate circuit contains both series and shunt peaking for high-frequency compensation. This stage acts as a conventional amplifier and inverter, its output being delivered to the 6AG7 which is operated as a cathode follower. The reason for this cathode follower is to facilitate impedance matching to the coaxial cable carrying the video to the repeaters.

The range-markers circuit is designed to generate the fixed range markers. It consists of an oscillator, a cathode follower, a clipper stage, two amplifiers, and a blocking oscillator. The frequency of the basic oscillator is determined by the L-C combination in the cathode circuit, there being five possible combinations. They provide oscillations at frequencies which are equivalent to 500, 1000, 2000, 5000, and 10,000 yards respectively, depending upon which sweep is in use on the indicator. The output of the oscillator, a quasi-sinewave, is clipped, amplified, and sharpened in the stages following the oscillator. The single-swing blocking oscillator output is in the form of sharp pips which are the final range markers. These pips are connected to the mixer-amplifer through the markers potentiometer which controls the brightness of the markers on the indicator screen.

The movable range marker, or range ring, is generated in the range-ring circuit and is used to accurately determine and indicate the range of a target having a range of 10 miles or less. This circuit consists of five tubes with associated components necessary to generate the marker and provide variable adjustment of its position coincident with actual range of the target. The input trigger from the modulator circuit in the transmitter-receiver unit is passed through one stage of amplification and inverted with the resultant output being a negative voltage pulse. This negative pulse is applied to the second section of the first tube in the range-ring circuit, a 6SN7GT, which is normally conducting heavily since its grid is tied to 250 volts through one half of a 6H6. The other half of the 6SN7GT is normally cut off with a high grid bias, and its plate is coupled to the grid of the second section. When the negative trigger pulse is applied to the second half of the 6SN7-GT it is driven beyond cutoff almost instantaneously, but the voltage rise in the plate circuit is made very linear due to current-regulating features in the circuit. The rate of rise, and consequently the slope of the voltage wave, is determined by the R-C constants in the circuit. There are two R-C combinations available to the operator through the use of the range switch, the first generating a 2-mile range sweep and the second a 10-mile range sweep.

This exponential voltage wave is impressed on the plate of the second half of the 6H6 mentioned above. In the cathode circuit of this tube is a precision wire-wound linear potentiometer which is mechanically coupled to the range crank. This potentiometer sets the cathode voltage in such a manner that, when the exponential voltage applied to the plate reaches and slightly exceeds the cathode voltage, the tube will conduct. This point of conduction is determined by the setting of the range crank, the actual range being read on a dial mechanically coupled to the range crank. When the diode conducts there will be an instantaneous heavy current flow through the tube, forming a pulse across the load resistor located in the cathode circuit. The output from the cathode resistor is passed through



Rectifier power unit with front panel opened and components exposed by lowering inner panel. These features contribute to ease of servicing of this unit.

a differentiating circuit and applied to the grid of a 6AC7 which is biased beyond cutoff. This stage, acting as a clipper-amplifier, clips all but the very peak of the positive pulse of the input waveform, amplifies and inverts it, with a resulting negative pulse in the output. This negative pulse is passed through a pulse transformer and one more stage of amplification before being applied to the plate of a single-swing oscillator. Due to transformer coupling between plate and grid of this circuit, a positive pulse will be applied to the grid of the stage, which is normally at cutoff. This will cause the circuit to oscillate, developing a very sharp, well-defined positive pulse in its cathode circuit. This pulse, which is the range marker or range ring, is coupled to the mixer-amplifier in the video section discussed previously.

The control and indicator unit has a self-contained power supply which supplies power to all the various circuits in the unit proper. This power supply obtains 115-volt 60-cycle input from the rectifier power unit. The outputs furnished by this self-contained power unit are +4500, +310, +250, +185, and —100 volts.

RECTIFIER POWER UNIT

The rectifier power unit supplies all the voltages (except the keep-alive) necessary for the proper operation of the transmitter-receiver. In addition this unit acts as a junction box and provides a switching arrangement for the presentation of either relative or true bearing on the indicator screen.

The major outputs furnished by the unit are a +4000-volt high-voltage supply, a +300-volt regulated power supply, a —175-volt regulated supply, and various filament voltages. The high-voltage power supply is a conventional full-wave rectifier system utilizing two type 3B24 tubes and associated circuit components to obtain the necessary 4000 volts in the output. This output is supplied to the modulator section of the transmitter-receiver through a high-voltage coaxial cable. The regulated 300-volt supply employs a 5U4G full-wave rectifier coupled to a vacuum-tube regulating section to provide independence from a-c supply and load variations over a wide range. The negative 175-volt regulated supply is obtained from a type 6X5GT full-wave rectifier having an output filtered to allow only a 0.13-volt peak-to-peak ripple voltage. This filtered voltage is then coupled to a vacuum-tube regulating section, the output of which is used to provide the reflector and tuning voltages for the local oscillator.

Fifteen CXJG equipments have been delivered by the Sylvania Company. Assignment of these equipments has been made to N.R.L., OpDevFor, USCG, USMC, U. S. Army, and to selected Navy vessels. It is expected that much valuable information will be gained under the varied operating conditions of the above services. One of these equipments is being used by the Naval Antarctic Expedition on the USS *Northwind* for navigation purposes. Due to the very short pulse length a minimum range of about 75 yards is expected. This feature together with the 0.8° beam width and super-high frequency should make the system invaluable in navigating through channels which are buoy marked, or in close waters, during periods of low visibility due to darkness, fog, or other causes. The Bureau has not yet received any actual reports of operation of this equipment from the Antarctic Expedition.

The over-all design characteristics of the CXJG are as follows:

Primary input supply	115-volts, 60-cycles, single phase
R-f power output (peak)	23-kw
Frequency	23744-24244 megacycles
Pulse length	0.17 microseconds
Pulse repetition rate	750 pps
Antenna beam width (half-power points)	0.8° horizontal 10° vertical
Antenna scanning rate	1 or 6 rpm
Antenna gain (absolute)	34 db
I-f bandwidth (half-power points)	9 Mc
Video bandwidth (half-power points)	7 Mc
Receiver noise factor	16 db
Receiver features	AFC, STC
Repeater output provisions	Standard trigger, video and 1-speed bearing for one repeater. Variable range-ring feed from radar. Additional repeaters can be added if a standard PPI adaptor is used.
Range accuracy	±40 yds (75-4000 yards) ±200 yds (75-20,000 yards)
Bearing accuracy	±1°
Range resolution	55 yds on 1-, 2-, and 4-mile sweeps. 120 yds on 10-mile sweep. 240 yds on 20-mile sweep.
Bearing resolution	0.5°
Total weight	830 pounds.

PUBLICATIONS

The East Coast Publications Distribution Center has been moved from Williamsburg to Norfolk, Va. The correct mailing address is Officer in Charge, Publications Distribution Center, Bldg. No. 101, NSD, Norfolk, Va.

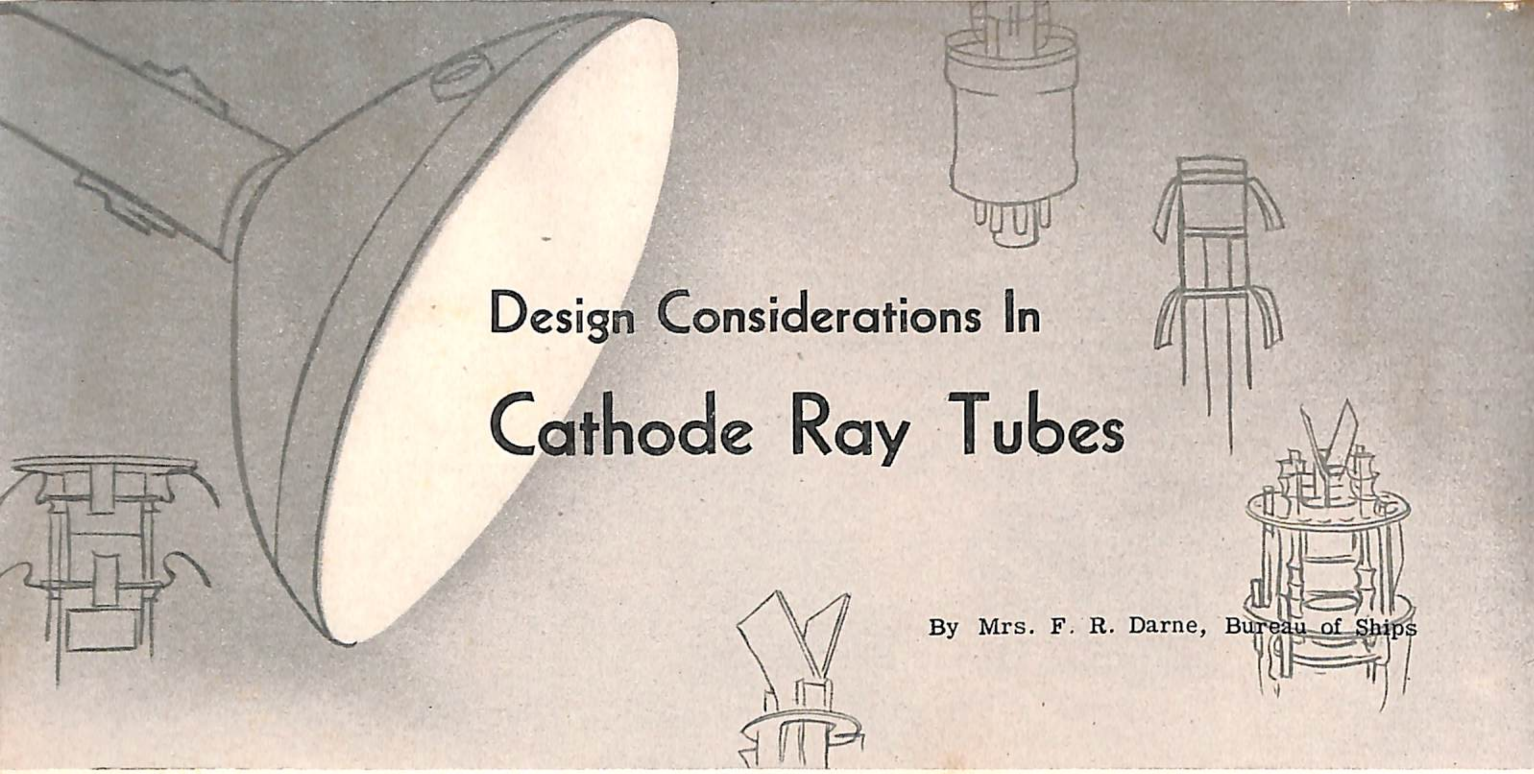
RECONDITIONING SA/SA-2 ANTENNAS

The high failure rate of antenna arrays for SA, SC and SK radar equipments caused special maintenance procedures to be inaugurated. It was requested that all antenna array frameworks and dipoles on these equipments be inspected quarterly, and those installed directly aft of the stack be inspected monthly. One of the constituents of stack gas is sulphur which, when mixed with salt water spray, forms sulphuric acid. Since stack gas reaches temperatures of 500 to 600° F, it tends to dry out the paint on frameworks and dipoles, causing it to crack easily from vibration and the shock of gunfire. This allows the sulphuric acid accompanying the fumes to etch into the metal under the paint, and thus starts the material rusting.

When the paint on the frameworks or dipoles has started to crack, and rust has begun to form, immediate action should be taken to clean the surrounding surfaces of old paint, soot, rust, etc., using a good strong wire brush. The clean surface should then be repainted, using a hand brush, with two coats of 52P18 zinc chromate primer and two to four coats of exterior battleship gray paint. In this connection it should be noted that brass dipoles need not be coated with the 52P18 zinc chromate primer. Also, a coat of tallow and white lead should be caulked between the dipole support and the mattress junction, at the time of installing or reworking the dipole and dipole support on the mattress framework, in order to provide a weather seal to the frame interior.

In order to provide replacement material for reconditioning the antenna assemblies of the Models SA and SA-2 radar equipments, the Bureau of Ships has issued "Field Change No. 37—SA". This field-change kit provides for reconditioning the antenna radiator assemblies, "bazooka" assemblies, lobing motor cable end-seal insulators, rings and gaskets. All necessary materials (except 5/64- or 3/32-inch diameter welding rods) are included in the kit. Ships in need of replacement parts for their SA radar antennas should contact one of the following activities for this field change kit:

- Puget Sound Naval Shipyard, Bremerton, Washington
- Norfolk Naval Shipyard, Portsmouth, Virginia
- Charleston Naval Shipyard, Naval Base, South Carolina
- Boston Naval Shipyard, Boston, Mass.
- Terminal Island Naval Shipyard, San Pedro, Calif.
- Philadelphia Naval Shipyard, Philadelphia, Penn.
- Naval Repair Base, New Orleans, La.
- Naval Supply Depot, Clearfield, Utah
- Naval Supply Depot, Bayonne, New Jersey
- Naval Supply Depot, San Diego, Calif.
- Naval Supply Depot, Mechanicsburg, Penn.



Design Considerations In Cathode Ray Tubes

By Mrs. F. R. Darne, Bureau of Ships

■ Prior to the war and the development and production of radar on a large scale, usage of cathode ray tubes was limited to oscilloscopes and television. Oscilloscopes, being test and laboratory instruments, are not inherently critical in requirements for interchangeability and high-quality. Television was still in its early stages and had not been standardized. Radar brought requirements for reproducible, interchangeable, rugged cathode ray tubes with improved performance in spot size, sensitivity, focusing, and screens, and better insulation at the base, particularly for aircraft use. This entailed the development of testing methods, standardized among tube manufacturers and government laboratories, in addition to research on improvement of the tubes themselves. A knowledge of this material should lead to more effective and intelligent use of cathode ray tubes.

Cathode ray tubes fall into a variety of general classifications, depending on size of screen, type of luminescent material used, and methods of focusing and deflecting the beam.

NOMENCLATURE

Designation of each cathode ray tube type is assigned by the Radio Manufacturers Association Data Bureau according to a system consisting of three groups of symbols: (1) a number to correspond to the nominal maximum bulb diameter in inches, (2) a letter to distinguish between tubes of the same diameter, and (3) the letter "P" and a number to indicate the type of phosphor. For example "2AP1" signified "two-inch bulb", "first two-inch type registered", and type "P1" phosphor. Addition of an "A" to this nomenclature "2AP1A" signifies that an improvement was made subsequent to the original registration of the 2AP1.

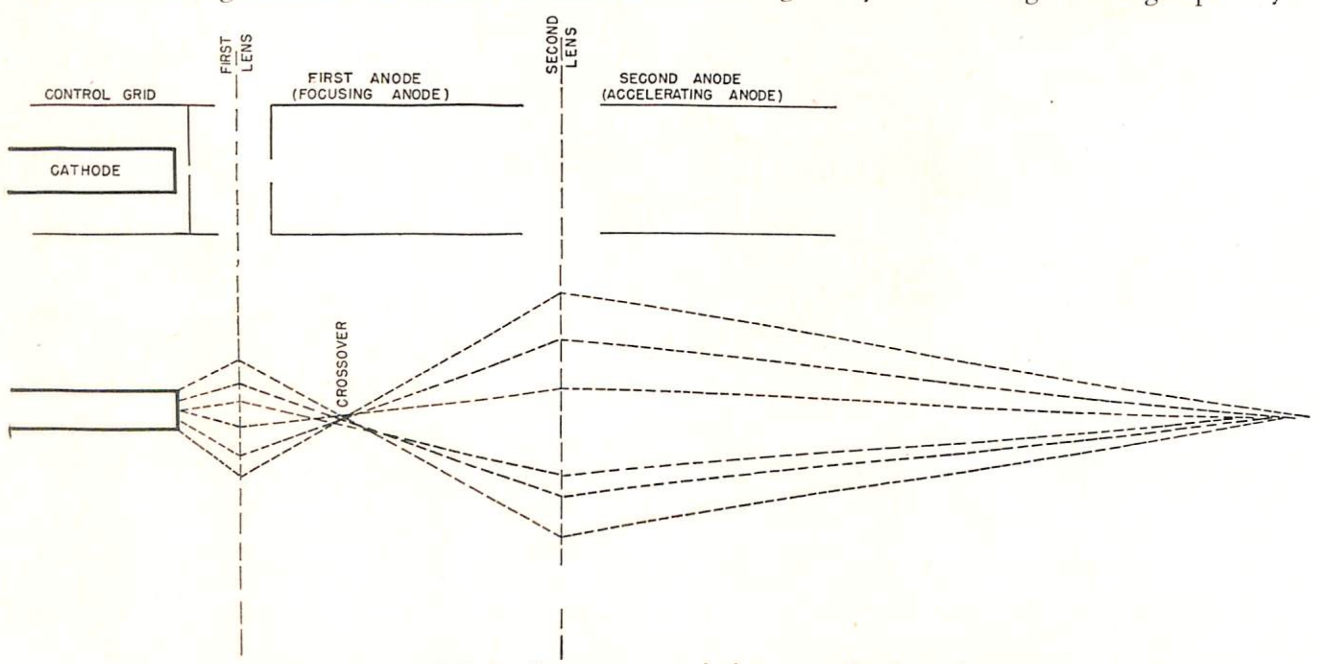


FIGURE 1—*Triode electron gun and electron paths through gun.*

THE ELECTRON GUN

The concentration of electrons into a beam is accomplished by electron optical methods of focusing, which are analogous to the focusing of light beams by a glass lens. Electron lenses are formed by electrostatic or magnetic fields which exert a bending action upon an electron trajectory, the amount and direction of bending depending upon the strength of the field and the electrode configuration.

Electron guns used in cathode ray tubes are based on a two-lens principle. The simplest form of gun structure and its effect upon an electron stream are illustrated in figure 1.

The first lens comprises a *cathode*, a *control grid*, and the first (or *focusing*) anode. Oxide-coated cathodes are used because of their high emissivity and low operating temperature. The latter feature is desired since aberrations in the lens, and consequently spot size, increase with the initial velocity of the electrons. For maximum efficiency, practically all the current emitted by the cathode should be concentrated in the spot. Since the radius of the beam going through the lens varies with the radius of the emitting areas, a limiting aperture is used to mask off part of the cathode area. The aperture is placed near the end of the control electrode, the voltage of which determines the amount of current in the beam, thereby controlling the brightness of the spot at the screen. The effect of control voltage on spot size is kept to a minimum. The second (or *accelerating*) anode accelerates the electrons toward and through the lens to converge at a focal point, termed the "cross-over", where the rays cross the axis of the gun.

The first lens should be shaped to permit high current without too large a cross-over beam diameter. Misalignment of gun parts or apertures, or cylinders not quite round, will form an elliptical or poorly defined spot. As in light lenses, electron lenses are subject to aberrations of the chromatic and spherical forms, as well as aberrations caused by space-charge effects. These aberrations affect size and definition of the spot, but cannot be entirely eliminated. The first lens voltage should be high enough to saturate the emission from the cathode when maximum beam current is needed. High voltage also minimizes any de-focusing action of the space charge near the cathode, but too high a voltage makes the control of the electrons more difficult. The voltage of the first lens has little effect on the diameter of the beam at the second lens.

The second lens images the crossover into a spot at the viewing screen, and is relatively simple. The major problems involved are ease and accuracy of construction and reduction of spherical aberration. Spherical aberration may be minimized by increasing the size of the lens, but the size is limited by the gun diameter in electrostatic types.

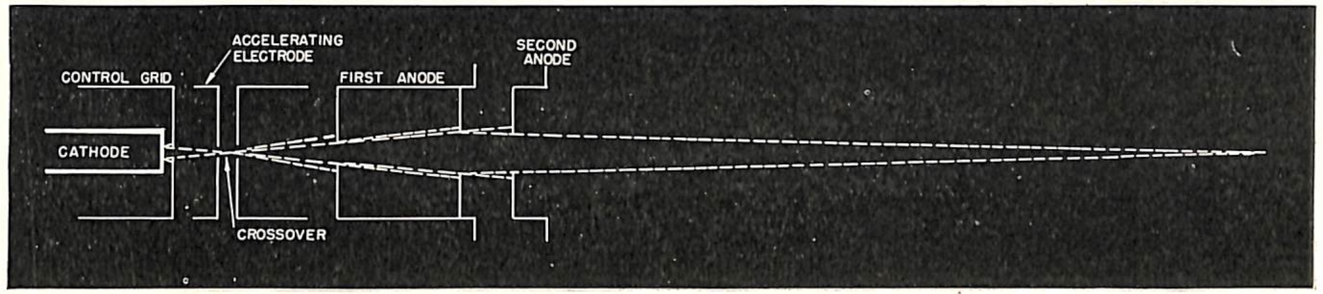


FIGURE 2—*Tetrode electron gun. Accelerating electrode connected to second anode placed adjacent to grid.*

The gun illustrated in figure 1 is of the so-called "triode" construction, and has the advantage of simplicity. The disadvantages are that the electrons are first accelerated by the low voltage of the focusing anode and there is interaction between focus and brightness controls, and also that close spacing and critical alignment are involved.

Modern cathode ray tubes usually contain the "tetrode" form of gun, two versions of which are shown in figures 2 and 3.

In the tetrode construction an accelerating anode, connected to the second anode, is placed between the grid and the focusing anode. This arrangement overcomes the interaction between focus and brightness controls

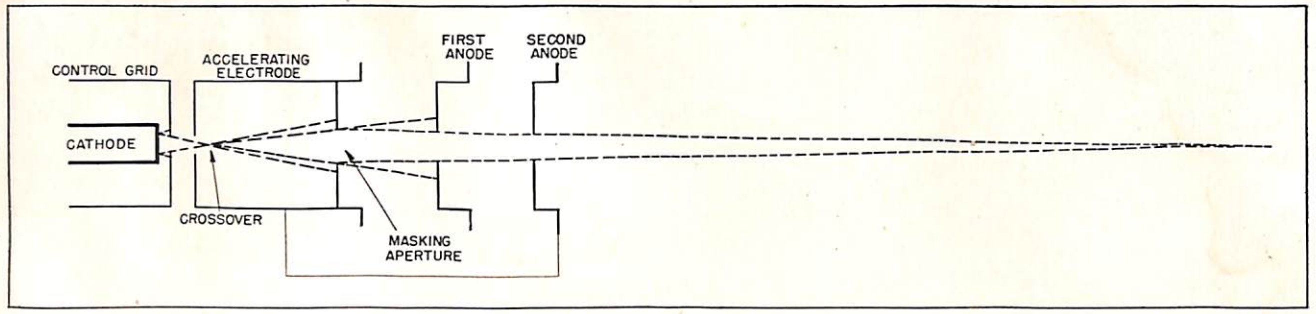


FIGURE 3—*Tetrode electron gun with "zero-first-anode-current" construction, long accelerating electrode with masking aperture, and focusing anode.*

in electrostatic types, and allows the cross-over point to be formed at a higher voltage with resultant smaller focused spot. The earlier versions used a disk, as shown in figure 2. An improvement recently introduced and now included in nearly all the newer service-approved electrostatic cathode ray tubes, is the "zero-Ib1" (*zero-first-anode-current*) gun, wherein the accelerating electrode is lengthened, and carries a masking aperture which limits the beam diameter, the first anode being shortened to a disk which is used for focusing only. By this arrangement the focusing anode draws no current, so that its voltage may be tapped from the power supply bleeder without necessitating readjustment of focusing control with variation of beam current (modulation). The beam is thereby reduced to a small width before entering the focusing field, and badly aberrated rays are prevented from entering the second anode aperture.

DESIGN DETAILS AFFECTING OPERATING OF CATHODE RAY TUBE GUNS

The most wanted characteristics of a cathode ray tube are: (1) a small round spot at the screen, (2) high brilliance of the spot, (3) little effect on size or shape of spot with deflection, (4) ability to operate at low voltages, (5) high deflection sensitivity, (6) short over-all length, (7) sensitive control of spot brightness (low grid-drive requirements). Some of the factors governing these points conflict with each other, so the design chosen for each type must be a compromise in which maximum performance in one respect is sacrificed to obtain improvements in some other characteristic. Examples of such considerations are listed below.

Spot size is decreased by high focusing and accelerating voltages, a long gun, a short gun-to-screen distance and low beam current. Since the beam is densest at its core, it is better to reduce the diameter by masking off the edges than to generate a narrow beam current with less total current in it.

A brilliant spot is attained by high beam current, i.e., high emission and high accelerating voltages. Enlarging the grid aperture increases current density at the beam center, but it also increases spot size. However, spot size may be reduced by an increase in grid bias, hence the use of a larger grid aperture makes possible a choice by the operator of either a small spot for fine detail or a bright spot for high-speed traces.

Increase in spot size with deflection (deflection defocusing) which occurs in electrostatic types is due to the fact that the electric field which deflects the beam accelerates the side nearest the negative electrode more than the side nearest the positive electrode, resulting in an elongated spot. To reduce this distortion, the beam divergency angle should be small and the deflection take place within a small angle. This means a long gun-to-screen distance.

Operation at low second-anode voltage improves deflection sensitivity and permits the use of a compact, low-cost power supply. Alternatively, high voltage is advantageous because the beam current increases as the 3/2 power of the voltage. The spot size decreases due to less space charge effect (space charge increases spot size due to mutual repulsion of the electrons in the beam), and the fluorescent screen becomes more efficient at high voltages.

Deflection sensitivity is increased by long gun-to-screen distance, but brilliancy of spot is reduced.

Short overall length permits design for small spot size at the expense of deflection sensitivity and increased distortion due to a wider deflection angle.

The maximum permissible spot size at the end of the beam is determined by the maximum deflection angle, length of deflection electrodes, and amount of permissible deflection distortion.

One method of increasing sensitivity without sacrificing intensity or increasing tube length is the addition of a third anode, termed the *intensifier*, which accelerates the beam toward the screen after it has been deflected. This anode is formed by a separate conducting ring on the inner surface of the bulb and is usually operated at double the second-anode voltage.

FOCUSING

Electrostatic and magnetic methods of focusing each have advantages and disadvantages. Electrostatic systems are subject to "modulation defocusing", i.e., reduction of the grid bias requires lowering of focus voltage to keep the spot in focus. Magnetic focusing is not subject to this effect, and also introduces less aberration as the second lens is not limited in physical size by gun diameter. The gun is simplified by the omission of a focusing anode. On the other hand, the need for focusing coils and yokes to form the magnetic fields is an offsetting factor in the choice of focusing methods.

Electrostatic focusing has been improved by the zero-Ib1 gun described above. The most recent types of magnetic guns have also been improved by the inclusion of a limiting aperture in the grid cylinder. This masks off the edges of the beam and reduces spot size without much sacrifice in brightness because of the concentration of the beam at the core. Both positioning and alignment of this masking aperture are critical. If maximum results are to be achieved, the aperture must be placed at the point where the beam is focused to its smallest and sharpest spot and must be aligned so as not to mask off any of the center portion of the beam. An electron gun of this type is illustrated in figure 4.

Advantages of electrostatic deflection are (1) elimination of coils and/or magnets, (2) low power requirements and simpler deflection circuits, (3) freedom from ion spot, and (4) possibilities of higher deflection speeds.

Deflection may take place after acceleration, or part of the acceleration can take place after deflection. In the former method there is an increased amount of beam current, and greater light output. In the latter method there is greater sensitivity, since the deflection is applied to a lower-voltage beam.

Deflection sensitivity increases with the width of the deflection plates and the length between deflection plates and screen, and is inversely proportional to the distance between the deflection plates and the accelerating voltage. Deflection sensitivity is expressed in millimeters or inches of spot deflection per volt applied to the deflection plates. The "Deflection Factor" expression used in Service specifications is the reciprocal of deflection sensitivity, and is expressed in volts required for an inch of deflection.

MODULATION

Modulation may be applied to the beam by changing the bias voltage applied to the control grid to vary its

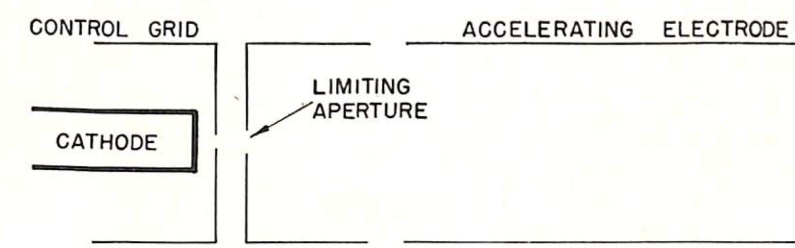


FIGURE 4—*Electron gun for magnetic types with limiting aperture.*

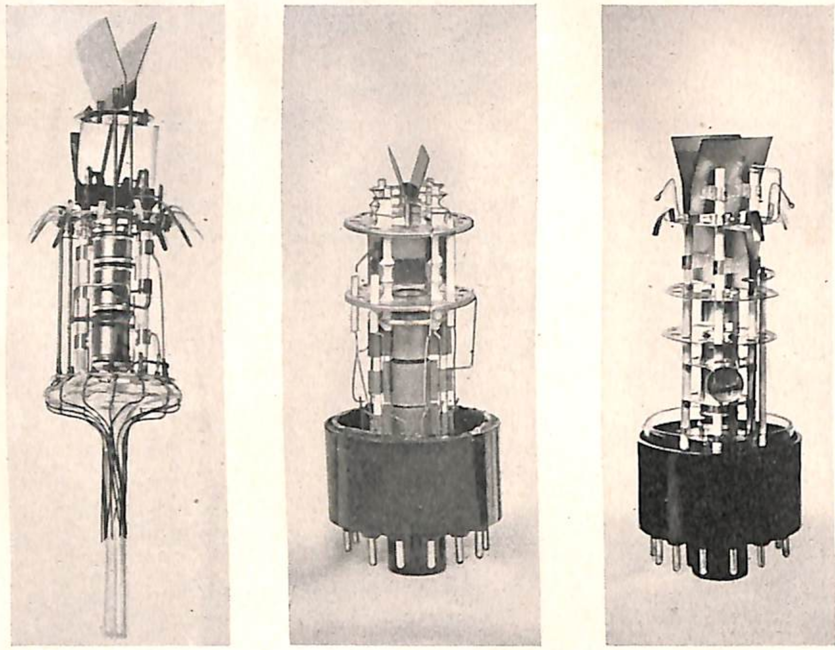
DEFLECTION

Magnetic and electrostatic deflection methods are both used. In magnetic deflection the field is inversely proportional to the square root of the second anode voltage, while in electrostatic deflection the field is inversely proportional to the voltage, which means higher voltages are needed with consequent difficulties in applying them to the deflection plates.

Advantages of magnetic deflection are: (1) greater structural simplicity and ruggedness since there are no deflecting plates and focusing anodes to be aligned and supported, (2) a shorter focal length, permitting a shorter tube, and (3) the feasibility of applying a rotating radial sweep which gives the polar indications needed for PPI radar displays.

intensity as used in television or PPI displays, or by maintaining the intensity constant and placing the modulation on one or both sets of deflection electrodes, as is done in oscilloscopes.

The amount of grid driving voltage needed to modulate the beam over its full range from zero to maximum available beam current depends upon the cutoff characteristics of the control electrode. There is considerable variation in cutoff ranges from tube to tube. This is chiefly due to the very close spacing between cathode and grid (of the order of 0.01 inch) and the fact that variation in the temperature of the cathode changes this spacing by a very appreciable percentage. The length of the "skirt" between the grid aperture disk and the end of the grid cylinder also affects the cutoff value. All



Typical electron-gun assemblies for tubes employing electrostatic deflection.

present-day types require a considerable amount of grid drive. Attempts are being made to improve this characteristic by placing a mesh grid over the grid aperture, but to date this has not been very successful.

LUMINESCENT SCREENS

Screen types differ in initial fluorescent color, phosphorescence or after-glow color, and persistence. Each type of screen used is identified by the letter P followed by a number. Some characteristics and common uses of the screens used in Service equipments and laboratory test instruments follow:

P1—Green, single layer, synthetic willemite (zinc silicate) (Zn_2SiO_4:Mn) with medium persistence. General purpose oscilloscope screen with high visual efficiency.

P2—Bluish-green, single layer zinc-sulphide (ZnSCdS:Mn:Cu) with long persistence. Used in low-frequency oscilloscopic work.

P3—Yellow, zinc-berryllium silicate with medium persistence. (*Obsolete.*)

P4—White, zinc-berryllium silicate mixed with zinc sulphide, medium persistence. Used in television.

P5—Blue, single layer, calcium tungstate ($CaWO_4$) with very short persistence. Has high photographic efficiency and medium visual efficiency. Most rapid decay of any production phosphor. Used for photographic recording on moving films for frequencies up to 60 kc. (Note: Some past tubes labelled P5 have contained the sulphide phosphor now designated P11).

P6—White, zinc sulphide mixed with zinc-cadmium sulphide, short persistence. Principal application is for color television.

P7—Cascade (two-layer) with yellow (ZnSCdS:Cu) and blue (ZnS:Ag), long persistence. Short blue flash and long yellow afterglow. Used for PPI radar presentations.

P10—Single layer, dark-trace potassium chloride (KCl) (Not a phosphor, but a scotophor) with magenta darkening. Used in applications requiring projection of a persistent image. Not active at present.

P11—Blue, single layer, zinc sulphide (ZnS:Ag) with short persistence. Has very high photographic efficiency and high visual efficiency. Rapid initial decay, but not quite as fast as P5. Can be used for photographic recording on moving films for frequencies up to 9 kc.

P12—Yellow, single layer (ZnF_2MgF_2:Mn) with medium persistence. Used in radar applications where P1 screens produce objectionable flicker, i.e., for scans equal to or somewhat slower than visual persistence.

P14—Orange, cascade [ZnS(75%)CdS(25%): Cu and blue] with intermediate persistence. Noticeable flicker at 12 scans/min; best performance near 60 scans/min. Chosen by AAF as optimum decay for AN/APQ-7. Similar to P7 in operating requirements.

MECHANICAL DESIGN

Alignment of electrodes and apertures has a critical effect upon the performance and ruggedness of these tubes, and a great deal of work has been carried out toward improvement of the mechanical strength of the gun and deflection assemblies. Illustrations of various types of cathode ray "mounts" for electrostatic and magnetic types are shown in figure 5.

In addition to faulty mount construction, usability of the tube may be adversely affected by defects in the glass bulb or face, and in the luminescent screen. Glass defects which may occur are referred to as blisters, bruises, scratches, cracks, stones, scale particles, knots, cords, mold marks and chill or wrinkle. Screen blemishes are identified as bright spots, dead spots, shaded and mottled areas, water marks, siphon marks, etc. The size, number, and location of such defects are limited by inspection methods to assure that the pattern on the screen will not be marred to an extent which may interfere with satisfactory operation of the tube. Other mechanical checks must be made for bulb roundness, wall thickness, dimensional tolerances, neck straightness, face contour and neck and bulb alignments. The use of materials which are affected by magnetic fields may have an adverse effect on the behavior of the electron beam. There are also requirements for mechanical strength, electrical breakdown resistance, and wearability of the bases, snap, and cap connectors.

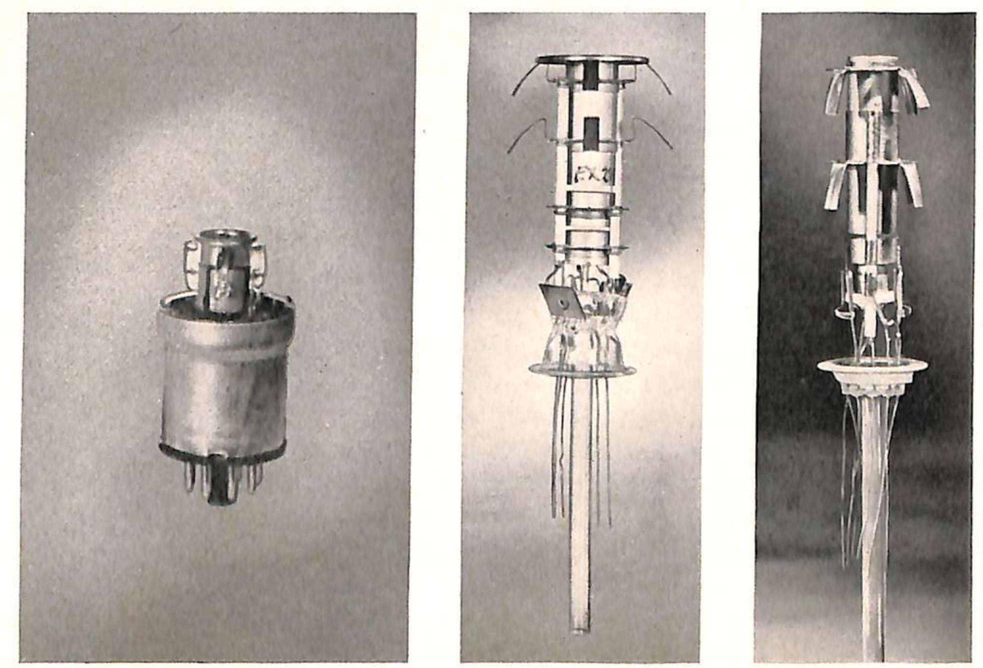
DEVELOPMENT OF JAN SPECIFICATIONS

Methods for checking each electrical and mechanical characteristic of cathode ray tubes to assure that each tube accepted for Service use falls within predetermined tolerance limits, and the determination of acceptable limits, have been worked out among representatives of tube manufacturers, equipment manufacturers, and Army and Navy engineers. The results are incorporated into the tube specification sheets for each type included in the Joint Army-Navy Specification JAN-1A for Electron Tubes. All types which have found their way into Service equipments in the past, or have been purchased as components of a commercial equipment and which require replacements, are covered by a JAN-1A specification sheet so that satisfactory replacements may be procured for proper operation of these equipments.

In equipments of new design, only tubes on the current preferred lists are to be used. The Army-Navy Preferred List indicates one preferred tube for each anticipated application so that the multiplicity of similar types (except for certain highly specialized laboratory use) may be reduced to one standardized line of high-quality, carefully-designed, rugged cathode ray tubes. The 1947 issue of the Army-Navy Preferred List contains the following cathode ray tubes: 2AP1A, 3DP1A, 3JP1, 3JP7, 3JP12, 5CP1A, 5CP7A, 5CP12, 5FP7A, 5FP14, 5JP1, 7BP7A, and 12DP7A.

When new tubes are developed which prove superior for any particular application, they will be added or substituted into the next revision of Preferred List.

Electron-gun assemblies for cathode ray tubes employing electromagnetic deflection.



High Speed Transmissions on the very-low Frequencies

In the past twenty years tremendous strides have been made in the methods of communicating at the higher frequencies. New equipments have been developed and new methods devised which increased the speed of communications to such an extent that we now have systems such as the four-channel *multiplex* teletype handling 240 words per minute, and the single-sideband *multitone* system with a possibility of twelve teletype channels to handle 720 words per minute in a required band width of only 10 kc.

This progress in the high frequencies is indeed gratifying but it appears we have neglected the very-low frequencies, as traffic in the band from 5 to 35 kc is still moved at a speed in the vicinity of twenty words per minute. This snail's pace is shocking in view of the fact that these very-low frequencies have certain undeniable propagation advantages over all other frequencies, and are necessary for the fulfillment of Navy communication requirements that cannot be met except with low frequency and high power. An increase in traffic speed on this band is very desirable, but there are many problems to be solved before this is possible. A discussion of these problems is the purpose of this article.

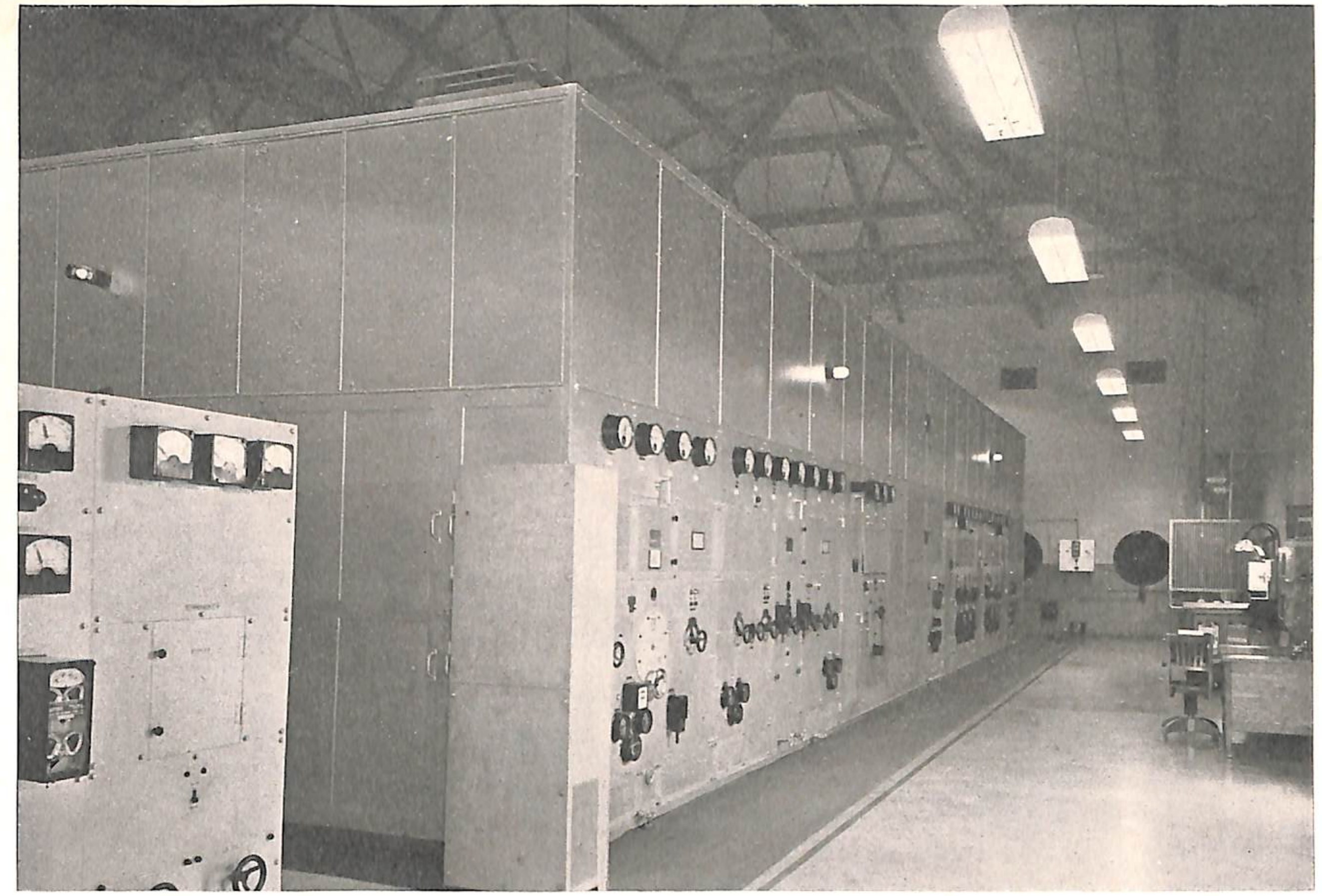
It has been accepted that the 500-kilowatt TBJ and TAW transmitters could not be successfully keyed at speeds in excess of 25 w.p.m. by ordinary on-off keying. This was at first attributed to the long charge-discharge time required by the antenna, due to the use of a high-Q antenna system. However, there is no data at hand to prove conclusively that all the limitations are confined to the antenna, and it is suspected that the power supply may also be limiting the speed due to charge-discharge time of the rectifier tubes and associated filters.

Frequency-shift keying on the very low frequencies was investigated, as the carrier in this system would be on continuously thereby overcoming any limitations which may be presented by the power supply. Tests were made to collect data regarding the Q of the antenna used on the TBJ at Annapolis. The transmitter and antenna were both tuned to 18 kc and the power output noted. When the transmitter frequency was changed without retuning the antenna it was found that a 20-cycle shift caused the output to be reduced to 50%. This means that if frequency-shift keying were employed so that the carrier was shifted 20 cycles from the resonant frequency of the antenna, the radiated power would only be 50% of that possible at the resonant frequency. This would cause tremendous power dissipation in the final amplifier and would therefore be a very inefficient system.

The dotting speed of the 60 w.p.m. teletype is approximately 23 cycles per second. However, the teletype signal is a square wave which contains not only the fundamental but also harmonics. Consequently, the resulting complex wave must contain at least the third harmonic or its departure from the square wave prohibits its use in systems such as the teletype. This means that, in order to keep the distortion within practical limits, the third harmonic of the fundamental keying speed must be transmitted.

In order to pass 23 cycles through a medium, that medium must therefore have a minimum band width of 3 x 23 or 69 cycles. The medium in this case is the TBJ antenna system which, as explained above, has a very narrow band, and therefore must be radically changed before it can be expected to pass a band of 69 cycles.

The most desirable arrangement to facilitate coverage of this band would be a system in which the antenna was tuned from mark to space frequencies in synchronism with the transmitter frequency shifts. Another acceptable arrangement would be the introduction of resistance into the antenna system so as to lower the Q and broaden the resonance curve and thereby enable it to pass the desired frequency band. However, due to the high power involved, either of these arrangements present tremendous physical problems which are not materially reduced by the use of the multiple antenna tuning employed with these large transmitters.



The high-power low-frequency transmitter at Lualualei.

It has been suggested that *cable code* may be adaptable, as twice the intelligence could be transmitted in the same bandwidth as that required for International Morse. However, cable code is a three-element or three-condition code, composed of *marking, spacing,* and *zero* (or neutral) conditions, and it would be necessary to use special frequency-shift keyers and receiver adaptors to generate and convert the three radio frequencies for these conditions. Nevertheless, such equipment is not impractical and, moreover, there are two types of cable code available, Cable *Morse* and Cable *Printing*. The Cable Morse is only usable with a type-recording equipment and is not adaptable to aural or printing reception, but the code is the same as International Morse and Navy operators should be able to read the tape with very little additional training. The Cable Printing code cannot be used for aural or tape-recorder reception but may be used with teletype when translator equipment is used to convert the 7.42-unit teletype code to the cable code and vice versa. With either of these cable codes, keying of the TBJ or TAW at 25 words per minute dotting frequency would be approximately equal to that for 15 word-per-minute International Morse keying.

By way of summary it may be said that this is a very interesting but complex problem for which the Bureau of Ships does not yet have a satisfactory answer. However, in a recent demonstration of FSK applied to VLF circuits, by shifting the frequency of a 20-kc tank circuit in synchronism with the square wave keying, a dotting speed equivalent to 500 w.p.m. was successfully transmitted. No official development proposals have been made as yet, but the problem is under active discussion. It appears possible to apply the principle to existing VLF equipments, as well as those to be procured. These investigations are being continued and it is hoped that a workable system will be developed in the near future.

■ With the advent of the first general-service radars (CXAM, SC-Series, etc.), technicians were confronted with strange phenomena not previously encountered in communication systems, such as higher frequencies, pulsed r-f energy, microsecond timing, scope presentation of returning signals, and rapid pulsing of the transmitter, to name only a few. One of the problems which presented itself, not only to the technicians but to the design engineers as well, was the problem of protecting the radar receiver during the time that the high-voltage r-f pulse was being transmitted by the transmitter section of the equipment. Since the repetition rate of all general-service radars is at least sixty pulses per second and usually many times more, it was evident from the first that a mechanical switching device to

The "Magic Tee"

close and open the receiver r-f input section in synchronism with each transmitted pulse was out of the question. This inescapable fact led to the development of the electronic switching method commonly referred to as *duplexing*, which in its earliest stage consisted of a spark gap placed at a critical distance from a junction point so that when it was broken down due to a high voltage pulse from the transmitter it would present a high impedance at a pre-determined point, thereby preventing the high-voltage pulse from entering the receiver section. This spark gap was replaced in most cases by gas-filled tubes very early in the program, but the principle of operation remains the same.

In the late spring of 1944 the very popular SG (surface-search) radar was modified in many ways, one of which was the introduction of a second gas-filled tube in the r-f section. This tube was called the *anti-duplexing* tube, and its purpose was to prevent returning echoes, which were relatively weak in comparison to the outgoing pulses, from being attenuated by leaking back into the r-f section of the transmitter. There were other reasons for incorporating this anti-duplexing tube into the system which were discussed in detail in ELECTRON for May 1946, page 1. These duplexing and anti-duplexing tubes later became known as the *TR* and *anti-TR* boxes or cavities. With the passage of time, the TR and anti-TR boxes with associated waveguide fittings were improved in efficiency by various methods such as more efficient tubes, keep-alive voltages, etc.

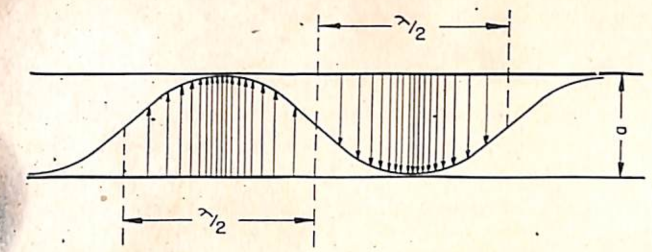


FIGURE 1—*E-line distribution in a rectangular waveguide, showing the reversal of polarity coincident with phase changes. View is from the narrow side of the guide as indicated by the dimension "a".*

However, a very late development in the waveguide duplexing field was the introduction of the *magic tee.*

Basically, the operation of the magic tee depends upon the difference between the coupling of waveguide tees in the *E* and *H* planes. From waveguide theory we know that the energy in a waveguide is contained in two fields, an electric or *E*-line field, and a magnetic or *H*-line field. The *E* lines in a waveguide can be represented as straight lines existing in a plane perpendicular to the widest dimension of the guide, while the *H* lines are in the form of loops formed in a plane parallel to the widest dimension of the guide. By this geometrical arrangement the *E* and *H* lines, and consequently the electric and magnetic fields, will be at right angles to each other.

To visualize the electric field in a waveguide let us assume a sine wave traveling along the waveguide with the peaks (both positive and negative) bounded by the walls of the wide dimension of the guide. In other words, if we look at the narrow dimension of this guide we will see the rise and fall of the sine curve as a single line with the electric field intensity at its maximum at the peaks of the curve as shown in figure 1. Obviously this field would reverse in polarity with each reversal in phase of the sine curve. If this field were plotted by arrows representing the *E* lines at right angles to the side walls of the guide there would be few at the null point of the sine curve and a gradually increasing number as the field approached a maximum, with the polarity (indicated by arrow heads) changing direction in the guide as the curve swings through its complete cycle. This action is repeated rapidly thus developing the electric field in the guide.

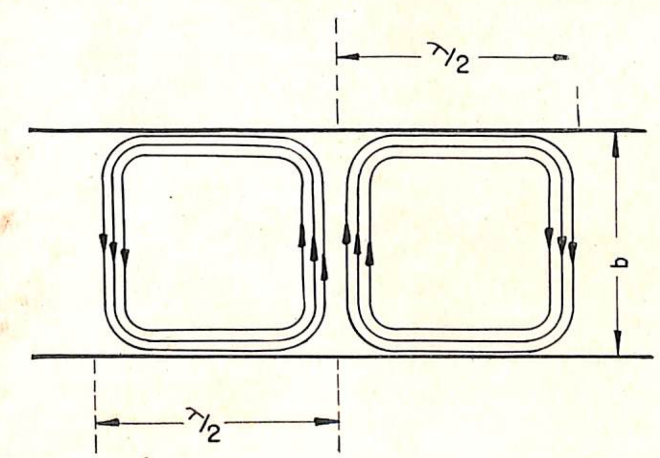


FIGURE 2—*Electromagnetic or H lines in a rectangular waveguide as viewed from the wide dimension indicated by "b". Note that maximum H field occurs simultaneously with minimum E field as shown in figure 1.*

An *H* field may be visualized as a series of closed loops formed in a plane parallel to the wide dimension or side walls of the waveguide, as shown in figure 2. From fundamental theory we know that in transmission of r-f energy through a transmission line the electric and magnetic fields are inseparable but will be displaced from each other by ninety degrees in both space and time. Therefore, if we combined figures 1 and 2, it will be shown that the maximum electric field occurs

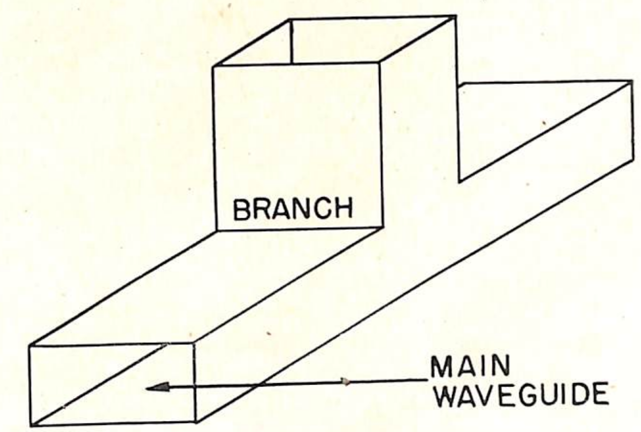


FIGURE 3—*Waveguides connected to form an E-plane T junction.*

during the minimum magnetic field and vice versa. When two pieces of waveguide are joined as shown in figure 3 they are said to form an *E*-plane T junction. If they are joined as shown in figure 4 they form an *H*-plane T junction. It is an established fact that when energy is fed into a T junction with matched loads on the branch arms, the energy will divide between the two branches. However, a fact which is often overlooked is the phase relationship between the electric fields in the two branches in reference to the junction point. This depends upon whether an *E*- or *H*-plane junction is employed.

Referring to figures 1 and 3 let us explore the transfer of energy from the branch arm into the two sections of the main waveguide. As can be seen from figure 1, the *E* lines are following a sinusoidal pattern as the wave approaches the end of the branch arm. As has been explained in preceding paragraphs, the polarity of the *E* lines will be changing as the wave progresses down the guide, with the result that the heads of the arrows will be reversing direction in the guide simul-

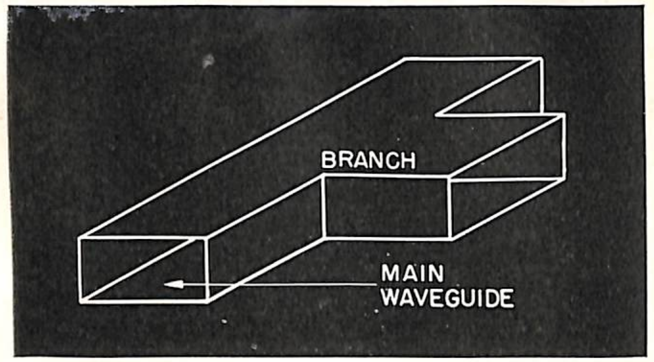


Figure 4—*Waveguides connected to form an H-plane T junction. Compare this type of junction with that shown in figure 3.*

taneously with the changes in polarity. Figure 5 is a cut-away view of the *E*-plane junction looking at the narrow dimension of the guide. It can be seen from this figure that as the *E* lines reach the end of the branch arm they tend to bend outward, forming curved lines which eventually will join the opposite wall of the main guide. However, in so bending and progressing out the two arms of the main guide, their phases will be reversed making them 180° out of phase but identical in amplitude at any point equidistant from the junction.

On the other hand, if we consider figures 2 and 4 the transfer of energy is of a different nature. In figure 2, which is a side view of the waveguide, we see the *H* lines formed in loops in the waveguide, parallel to the sides of the guide. As stated previously, for each series of *H*-line loops there will be a series of *E* lines, combined as shown in figure 6, which is a side view of the guide. To better illustrate the division of *E*-line energy and the resultant identity of polarity in the branches, only four *E* lines are shown in this figure. As the *H* loop approaches the junction, it will start to divide into two *H* loops with accompanying *E* lines. Since our reference in this explanation is the *E* lines or field, we

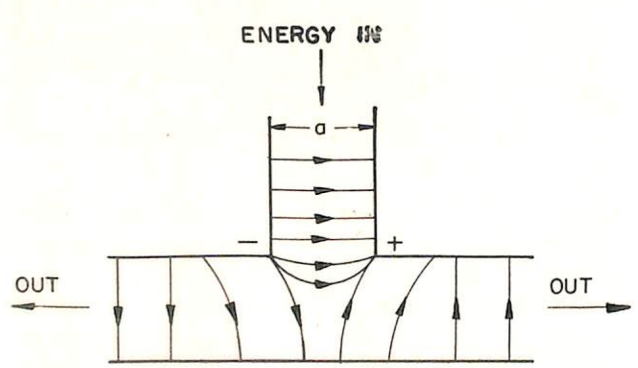


Figure 5—*Transfer of energy from a branch to adjacent arms through an E-plane junction resulting in out-of-phase electric field conditions in the adjacent arms. Dimension "a" is the narrow side of the guide.*

can therefore state that the division of energy will result in no change in polarity of the *E* lines in the loops of *H* lines proceeding out the two branches. Therefore, we have established that *E*-plane junctions will result in electrical energy proceeding out the branch arms 180 degrees out of phase, while *H*-plane junctions will result in electrical energy proceeding out the branch arms in phase.

A simple rectangular magic tee is a four-branch network consisting of the main waveguide, an *E*-plane junction and an *H*-plane junction, as shown in figure 7. In this type of tee, if power is sent into any arm or branch with matched loads on the other three, the power will divide between the two adjacent arms and no power will go into the opposite arm, as illustrated in figure 8. We see then that energy transmitted into the *H*-plane branch (magnetron input) will go out the two branches comprising the main waveguide (toward the two TR's) but no power will go out the *E*-plane branch (antenna) since the *H*-plane energy excites only an even-function

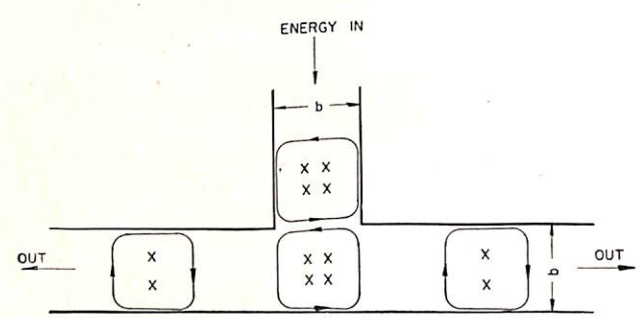


Figure 6—*Transfer of energy from a branch arm into adjacent arms through an H-plane junction resulting in an in-phase electric field condition in adjacent arms. Dimension "b" is the wide side of the guide.*

wave about the plane of symmetry, whereas it takes an odd symmetry to excite the *E*-plane branch. Conversely energy sent into the *E*-plane branch will not couple to the *H*-plane branch for *E*-plane energy excites only an odd-function wave about the plane of symmetry, and it takes an even symmetry to excite the *H*-plane. Of course if there are reflections in either or both of the branches adjacent to the *E* or *H* planes which will alter the phase of the outgoing wave, the opposing side arm (either *E* or *H* junction) will be excited by these reflected waves. On the other hand, reflected waves from equal mismatches in the adjacent branches at points equidistant from the junction result in a wave converging on the junction with the same symmetry as the diverging wave, so that the reflected waves can only excite the side arm from which they were originally fed.

By the reciprocity theorem it is established that energy coming in from the two adjacent branches will only go into one of the junctions, either the *E*-plane or the *H*-

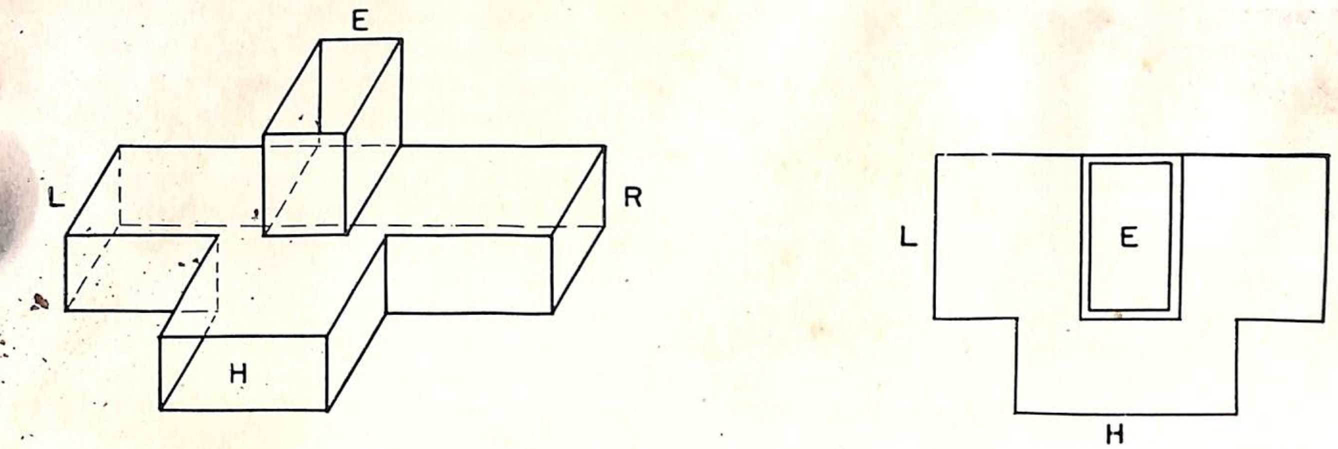


Figure 7—*Two views of a conventional rectangular magic tee showing both an E- and H-plane junction with the main waveguide extremities indicated by L and R.*

plane, depending on the phase of the two when they arrive at the plane of symmetry. For example, if energy is originally transmitted through the *E* branch it will proceed out the adjacent arms out of phase. Upon returning to the junction this energy will proceed out the *E* branch, provided the phase relationship has not been changed due to a mismatch some place in the system, thus tending to bring the two waves into phase. If this mismatch should be placed in the system to bring these waves in phase, they would proceed out the *H* plane since the in-phase condition would excite the *H* plane but would not excite the *E* plane.

For most applications of the magic tee it is desirable to have some matching transformers added to the tee. The only restriction on these matching devices is that they do not upset the symmetry of the waves at the junction. If the two ends of the main waveguide are terminated in matched loads and energy is sent into the *E*-plane branch a mismatch will be found which may be cancelled out by the addition of a suitable iris or other device in this branch. Similarly, one may produce a match for energy fed into the *H*-plane branch.

A magic-tee duplexing system is shown in figure 8, in which the orientation of the *H, E, L,* and *R* arms of the two magic tees corresponds with those in figure 7. The distances from the junctions to the two TR boxes differ by a quarter wavelength, but the total distance from the lower magic tee to the upper magic tee is the same through both paths.

Magnetron power goes out the arms in which the TR tubes are located, the two waves being in phase since they are fed in on an *H*-plane junction. These waves are reflected from the fired TR tubes and come back to the magic tee out of phase since one wave has had to travel a half wavelength farther than the other. They then will go out the antenna arm since it is an *E*-plane junction and will be excited by the out-of-phase components arriving at the junction. The leakage powers of the fired TR tubes arrive at the upper magic tee junction in phase and thus go out into the dummy load if the TR boxes are identical. When the system is receiving a signal, the received power comes in the antenna arm, divides and goes out through the arms with the TR boxes in them, passes through the TR tubes and arrives at the upper magic tee junction out of phase. Upon arrival at the upper magic tee out of phase they will excite the *E*-plane branch which goes to the receiver, thus transferring the received energy to the receiver rather than to the dummy load.

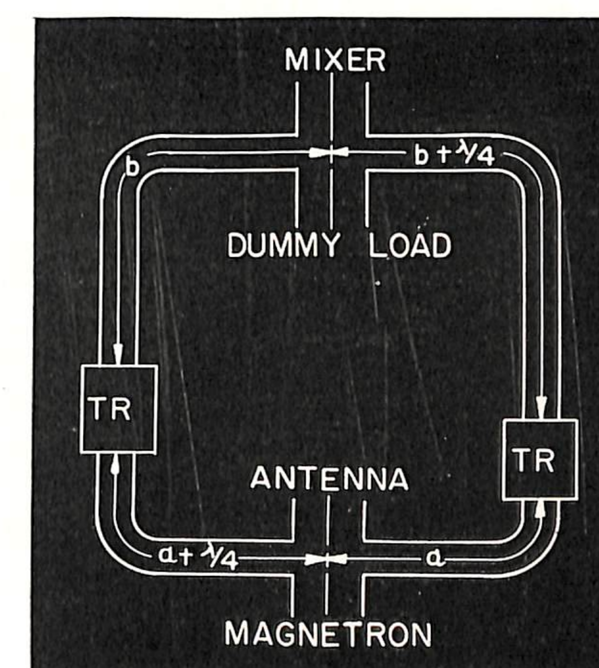


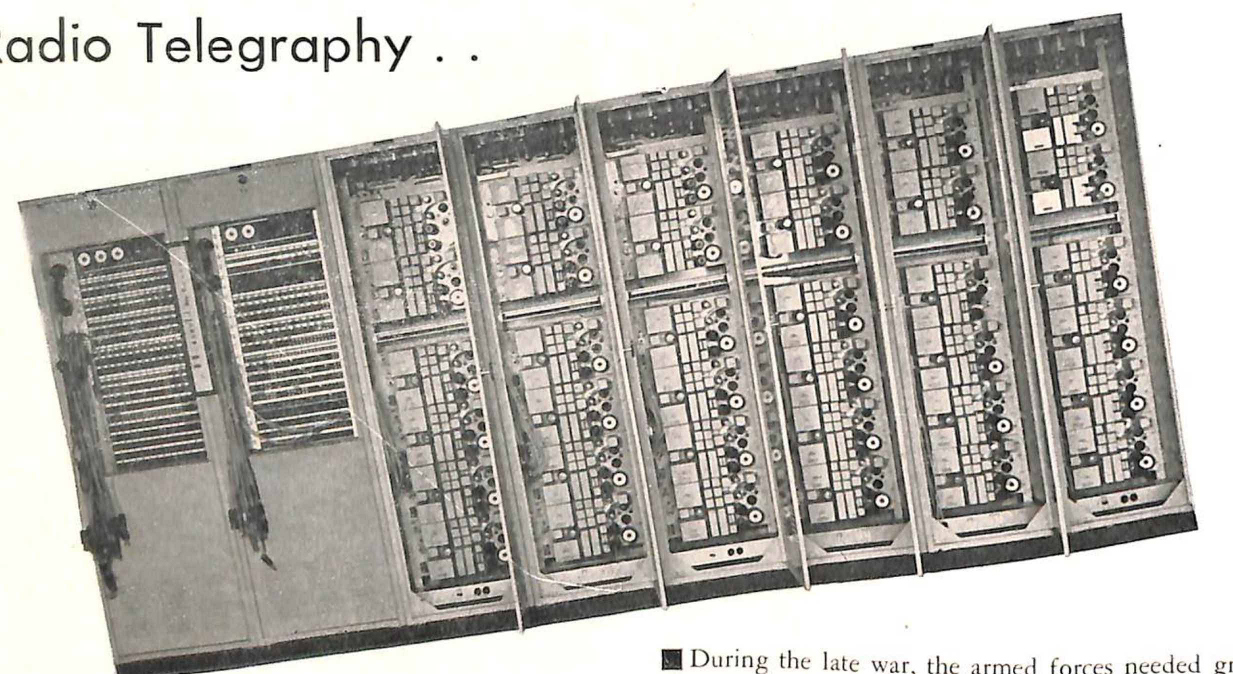
Figure 8—*Schematic diagram of a magic tee duplexer utilizing two rectangular magic tees and two TR tubes but no anti-TR tube.*

The main advantage of this type of duplexer is the elimination of the anti-TR boxes. Since in a magic tee there is no coupling between the opposite arms with equal loads on the adjacent arms, no received power will be lost into the magnetron. In the X-band model the total anti-TR loss (loss into magnetron, reflection out antenna, and power into dummy load) is less than 0.5 db over a 12% band for all possible magnetron impedances. Another advantage is the cancellation of the leakage power of the two TR boxes. Any received power leaking into the magnetron is either absorbed in the magnetron or reflected by the magnetron and reaches the second tee in such a phase that it will not go out the mixer arm.

The main disadvantage of this type of duplexer is its size. Another disadvantage is the fact that the TR tubes must dissipate 1.4 times as much power as they would if they were mounted in an ordinary duplexer. Since a TR is a gas switch, the voltage across it when fired is essentially constant regardless of the power level. The power dissipated in a tube is proportional to the current through it. Let us assume that we mount the tube on the top face of the guide. Then the power dissipated in it is equal to I. In a magic tee, the power in arms L or R traveling toward the TR tube is half that in the main guide. Therefore, the amplitude of the current wave is equal to $1/\sqrt{2}$ or 0.707 times the main line current. The TR tubes present a short circuit which is the current maximum and the magnitude of the current at the TR tube is 2 times that in the main line, so that the power dissipated is 2 times that in a normal duplexer. A third disadvantage is that the leakage power which gets into the mixer from high-level signals coming in the antenna is the sum of the leakage from two TR tubes instead of one as in a normal duplexer. For this reason leakage tolerances on the TR tubes must be minimized.

The rectangular magic tee has many applications such as (1) a variable phase-delay device, more commonly known as a line stretcher, (2) an impedance transformer for matching various devices to a matched line, (3) a balanced mixer, (4) the magic tee duplexer as described previously in this discussion, (5) a balanced mixer plus automatic frequency control, and (6) a double balanced-mixer.

Multi-Channel Two-Tone Radio Telegraphy . .



By L. C. Roberts,
Bell Telephone Laboratories

During the late war, the armed forces needed greatly expanded communication facilities between a multitude of widely separated points. This need was filled to a large extent by the use of radio-teletype circuits, employing the two-tone or frequency-shift type of transmission. One of the main factors which led to this widespread use of teletypewriters on radio circuits was the success of the Multichannel Two-Tone Radio Telegraph System, which was used by the Navy and the Army for long-distance communication. These frequency-shift radio circuits were used as the backbone links in a world-wide network of communication facilities.

Shortly after Pearl Harbor, the armed forces were confronted with the need for increased telegraph communication between the United States and many distant parts of the world. At the same time, many of the radio-telephone terminals of the Bell System were not fully used either because the distant terminals were in enemy country or because of Government restrictions on overseas telephone conversations. Representatives of the American Telephone and Telegraph Company, aware of this situation and of the need for additional facilities, pointed out that many additional telegraph circuits could probably be provided by applying voice-frequency carrier-telegraph systems to radio-telephone circuits. It was requested that arrangements be made to investigate this possibility, and it was decided that tests would be made by engineers of the American Telephone and Telegraph Company and Bell Telephone Laboroatories. The demand was urgent. There was no time to develop devices particularly suited to the purpose, and thus equipment already in production had to be adapted, if possible

An obvious starting point for the tests was to try the operation of a standard VF (voice-frequency) telegraph system (similar to the Navy Model UN Equipment described on page 12, Electron for April, 1946) on a channel of a twin single-sideband radio system. It was surprising to no one, however, that a very brief trial indicated this was impracticable. The received tone of one channel of a VF telegraph system operating over such a radio channel fluctuates over a range of many db from instant to instant. At one moment it may be received at normal level, and a few seconds later the level may be 20 or 30 db lower. It might at first be thought that an automatic volume control could be made to compensate for such level fluctuations, and doubtless considerable improvement could be obtained. In the standard VF telegraph system, however, a single tone is used for on-off keying of each channel, the tone being connected to the circuit for dots and dashes (commonly called *marks*), and removed for spaces. If a volume control were made fast enough to follow the very rapid fading that is sometimes experienced ,the noise during spaces would be amplified to the same level as the signals, and thus no intelligence could be received. This sets a limit on the possibility of improvement by such means.

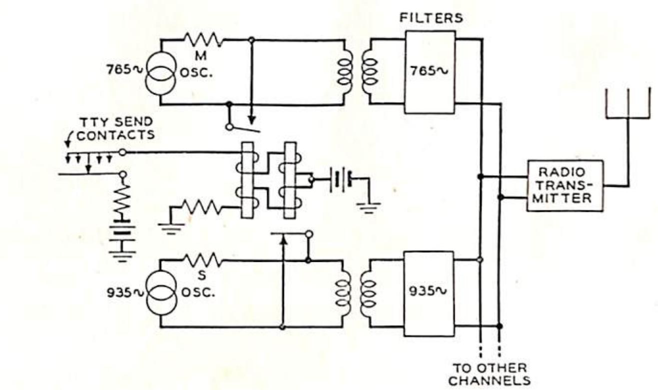


Figure 1—*Circuit arrangement of transmitter terminal that supplies six two-tone radio-telegraph channels.*

These considerations led to abandoning the attempt to use single-tone transmission, and it was decided to adopt two-tone transmission (frequency-shift keying) instead. This latter method of transmission was developed by the Laboratories and, beginning in 1928, was used for passing information by teletypewriter to assist in handling telephone traffic over the radio-telephone circuits between London and New York. For two-tone transmission, one channel of the standard system is used for marks and an adjacent channel, employing a tone 170 cycles higher in frequency, is used for spaces. With such an arrangement, the amplitude of the transmitted signal is substantially constant, and a fast-acting gain-control device may be used without danger of raising the noise to the level of the signal. [See p. 5, Electron for Sept. 1945]. This two-tone transmission, however, has the disadvantage of requiring two channels for each message, and thus provides only six telegraph circuits for a twelve-channel system.

The results obtained with this two-tone system were much better, but they were still not considered satisfactory to meet present-day requirements. What was needed was a limiter, a fast-acting device that delivers a constant output for wide variations in the input signal level. No limiter was in production, but one had been built at the Laboratories for some experimental work, and this was borrowed for the tests.

With the limiter, there was a marked improvement. The circuits were now good enough for automatic transmission of International Morse code, in which the received dots and dashes are recorded on a paper tape, but considerable further improvement was desired for teletypewriter transmission, because even with the limiter, deep selective fading would at times reduce the signals below the noise level. With the former methods of transmission, the receiving operator can use judgment

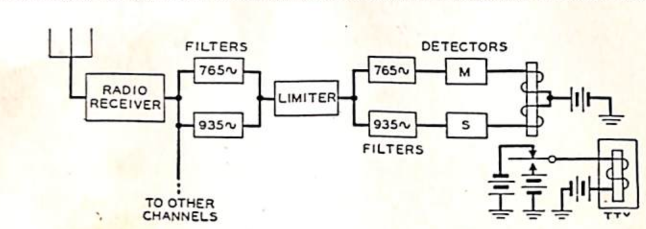


FIGURE 2—*Circuit arrangement of receiving terminal for two-tone radio-telegraph transmission.*

in interpreting the message, but a teletypewriter cannot use judgment, and better transmission is consequently required.

It is a well-known characteristic of selective fading that when a signal received at one frequency has faded so that it cannot be detected because its intensity is less than that of the noise or static, a signal at a frequency only a few hundred cycles away is usually being received at a much higher level; and by the time this second frequency has faded, the first will generally have returned to a usable value. It seemed reasonable, therefore, that if the signal were sent simultaneously on two frequencies, one or the other frequency could be received most of the time.

This "frequency-diversity" system was tried and the improvement was outstanding. The sending relays of two channels carrying frequencies that differed by about 1000 cycles were connected at the sending end so that the same two-tone signals were sent out simultaneously on two pairs of frequencies. The detectors at the receiving end were connected to a single receiving relay. Now the circuit was satisfactory for multi-channel teletype operation and made possible the provision of much-needed facilities.

Standard voice-frequency carrier-telegraph equipment was modified quickly by the Western Electric Company for two-tone operation, limiters were built, the equipment was assembled in cabinets and delivered for shipment to overseas points where it was most urgently needed. Single-sideband transmitters and receivers were supplied also for locations where they were not already available. The Long Lines Department made the necessary arrangements for the home terminals of these systems.

The circuit arrangement for one channel of the system is indicated in the first two illustrations. On a marking pulse, the transmitting relay short-circuits the 935-cycle supply and allows the 765-cycle supply to pass to the radio transmitter, while for a spacing pulse the reverse action takes place. At the receiving end. band-pass filters select the two frequencies for this channel and pass them to the limiter. At the output of the limiter, similar band-pass filters select the two frequencies and pass them to separate detectors, the outputs of which operate the receiving relay.

From each such system, six two-tone circuits could be obtained using the International Morse code with Boehme recorders for receiving. To obtain teletypewriter circuits, however, two of these two-tone circuits had to be used for each message, and then there were only three channels per system. The advantages of teletypewriters in furnishing immediate typewritten copy and not requiring skilled operators were appreciated, but the attendant reduction in the number of circuits per system to three was unsatisfactory on some routes. Some means were therefore sought to increase the number of telegraph messages that could be transmitted over a single radio channel.

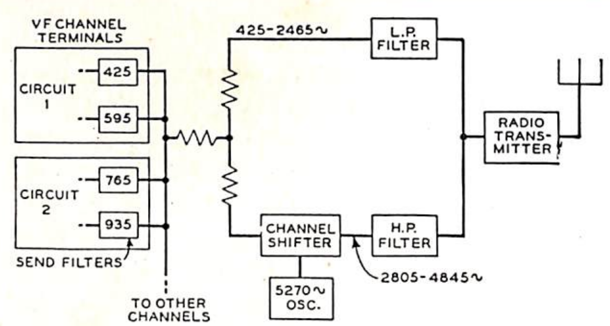


FIGURE 3—*Transmitter terminal for multi-channel two-tone radio teletypewriter transmission.*

A voice-frequency telegraph system suitable for providing six two-tone circuits occupies a frequency band less than 2000 cycles wide, while each channel of the single-sideband system can transmit a band about 5000 cycles wide. On one radio channel there was thus space for two voice-frequency telegraph systems, but no channel filters for frequencies above 3,145 cycles were available. To design and build them would have required too much time. There was a channel shifter, however, that was used on radio circuits to move the voice transmission from the lower frequencies to the upper frequencies of one channel of a single-sideband circuit. By using such a shifter, a method was designed for transmitting six channels of the frequency diversity telegraph system—twenty-four tones—over a single radio channel without requiring much additional equipment.

The arrangement of the transmitter is shown in figure 3. Outputs of six two-tone telegraph circuits, and a single-tone circuit used as an order wire, are connected together and then passed through a resistance network to a two-branch circuit—all frequencies flowing equally into each branch. Along the upper branch they pass directly to the radio transmitter through a low-pass filter that passes all frequencies below about 2600 cycles. Along the lower path, they enter the shifter circuit, where they are modulated with the current from a 5270-cycle oscillator. A balanced copper-oxide modulator is employed that eliminates the carrier, and the upper sidebands are eliminated by a low-pass filter in the shifter. The lower sideband frequencies, which are higher than those in the upper branch, are then passed through a high-pass filter to the radio transmitter.

The twelve frequencies from the six two-tone telegraph channels are spaced 170 cycles apart from 425 to 2295, inclusive, and the order-wire frequency is 2465. The lower sideband frequencies resulting from the modulation of these frequencies in the shifter with 5270 cycles are spaced 170 cycles apart from 4845 to 2805. The radio transmitter thus transmits thirteen frequencies spaced 170 cycles apart from 425 to 2465 cycles and a corresponding set of thirteen frequencies from 2805 to 4845. Each teletype signal pulse is represented in this group by two frequencies. Thus, a marking signal for the No. 1 teletypewriter circuit is represented by frequencies of 425 and 4845 (5270-425), while a spacing signal for the same channel is represented by 595 and 4675 (5270-595) cycles, and so on for the other five channels. If selective fading over the radio path should drop out the radio frequency corresponding to 425 cycles, the same information would nearly always be carried on to the receiver by the radio frequency corresponding to 4845 cycles, which is about 4000 cycles higher.

Variations in the radio path cause large changes not only in signal strength but also in the phases of the alternating currents received. At the receiving end, therefore, if the 4845-cycle current were restored to 425 cycles and combined with the 425-cycle current transmitted directly without being shifted in frequency, the two currents would reinforce each other at times, but at other times they would tend to cancel each other. To avoid this cancellation, the frequencies that were shifted to higher values at the transmitter are restored to frequencies differing from their original values by modulating with an oscillator frequency of 5610 cycles instead of 5,270. Thus, an original frequency of 425 cycles, which is changed by the shifter of the transmitter to 4845 cycles, is restored at the receiver not to 425 but to 765 cycles. The corresponding spacing signal of 595 cycles would be restored to 935 cycles. At the receiver, therefore, the two pairs of frequencies for this particular channel would be 425 and 595, 765 and 935 cycles. These tones are combined in a hybrid coil, and amplified in a common limiter. At the output of the limiter, they are once more selected by band-pass filters and rectified in marking and spacing detectors. This arrangement thus provides a six-channel frequency-diversity system without the duplication of detectors or the development of new filters.

At the receiving end, therefore, the circuit is arranged as indicated schematically in figure 4. At the output of

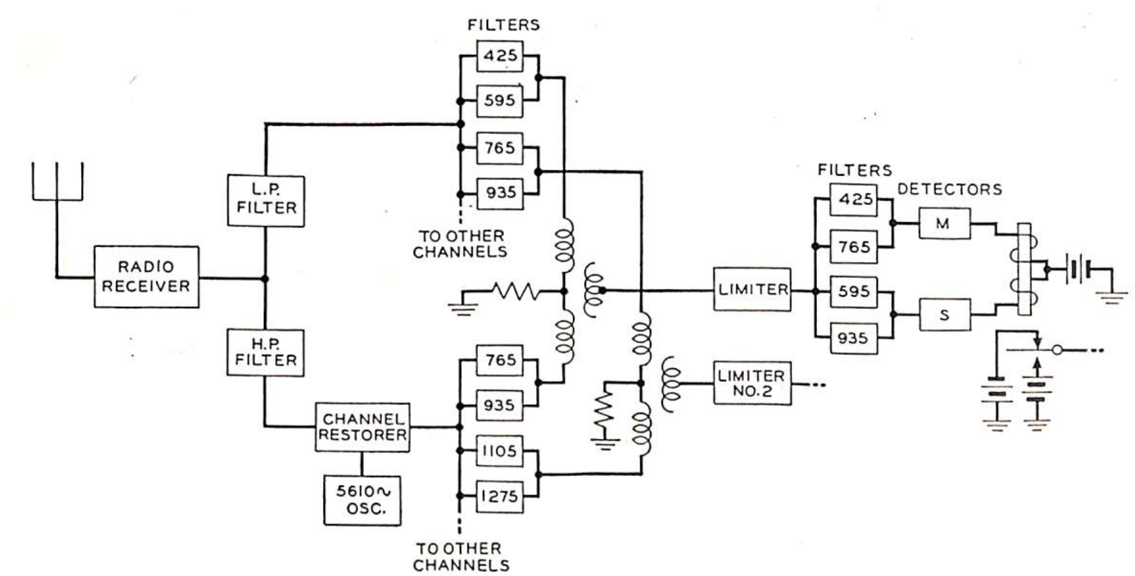


FIGURE 4—*Receiving terminal for multi-channel two-tone radio teletypewriter transmission.*

the radio receiver, low-pass and high-pass filters separate the frequencies below about 2600 cycles from those above it. The output from this low-pass filter is connected to the input of thirteen band-pass filters for the frequencies 425 to 2465 cycles, inclusive, while that from the high-pass filter passes to a channel restorer, where the frequencies are modulated with the current from a 5610-cycle oscillator. Channel filters in this branch then separate the various frequencies, and the pairs of frequencies from each branch corresponding to a single channel are combined in a hybrid coil and then amplified in a limiter. At the output of the limiter are four channel filters. Two of them select the two frequencies corresponding to marking signals and pass them to the marking detector, and the other two select the frequencies for the space signaling and pass them to the spacing detector. Although one frequency of a pair may have been eliminated by fading, the other will usually be present to operate the receiving relay.

This multi-channel two-tone system [Navy Model UP Equipment] is capable of handling a large amount of traffic over a single radio-frequency assignment with comparatively low power per channel. Unlike other systems of large traffic capacity, it furnishes independent start-stop teletypewriter circuits which have maximum flexibility in that they can be readily terminated in teletypewriters of types in heavy production and general use, or extended over land lines to such machines at different locations by simple connections which permit use of standard forms of start-stop regenerative repeaters where these are necessary. Operation with narrow frequency bands for the individual channels was made possible by the inherent frequency stability of the single-sideband circuit. The system was designed and made available quickly, utilizing for the most part standard components already in production.

Multi-channel two-tone circuits have been used to connect headquarters at Washington with the Armed Forces in distant parts of the globe. The Bell System owned and operated one terminal of systems extending to England, the continent of Europe, Hawaii, Australia, and two locations in Africa The Navy and Army owned and operated both terminals of other systems. It is understood that their use was very satisfactory and of great value in the prosecution of the war.

• • •

OCT FREQUENCY-SHIFT MONITOR

Reports from certain field activities indicate some OCT's are being received in an inoperative condition. The adjustments necessary to restore normal operation are in some cases considered "factory" adjustments and have not been included in the instruction book. To assist field personnel, the noted malfunctions with the proper correction steps are listed below.

Instability of R-F Oscillator Tuning Controls:

1—Remove oscillator oven cover and tighten thrust bearing of main tuning control shaft.

2—Tighten coupling of main tuning control shaft and the shaft extension carrying the main tuning knob. A long (approx. 6-inch) "Allen" set-screw wrench is necessary to perform this adjustment.

3—Tighten vernier tuning shaft bushing.

Excessive Distortion in Audio-Frequency Output:

1—Place a-f oscillator switch (C) S104 to EXT., the r-f BFO switch (G) S101 to OFF, and disconnect any r-f input to connector J192 (located on rear of chassis).

2—Note current indicated on level and beat indicator on both R-F BEAT AND TUNE and FREQUENCY-SHIFT CHECK positions of the meter switch. This current should be between .05 ma and .1 ma in either position.

3—Provided these currents are not between the limits specified, remove the bottom plate from the monitor equipment and adjust grid bias potentiometer R148 (located in the rear right section) until the proper current is obtained. If unable to adjust these currents to equal and proper values, the larger current should be set to 1 ma, then if the smaller current is less than one-half this value a different tube should be substituted for V105 and the above procedure repeated.

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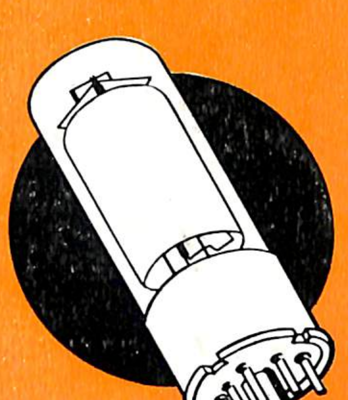

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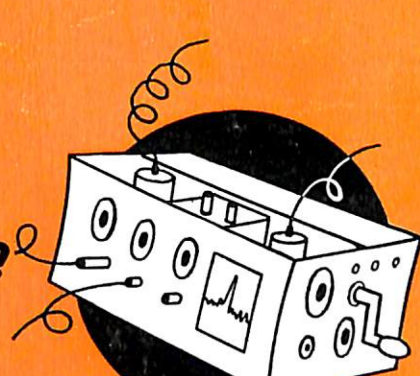

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