Power System

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This paper describes the power required by the TD-3 radio relay system. It discusses the battery plant which serves as the basic source of power, the traveling-wave tube power supply, the regulated −19-volt power supply, the transmitter-receiver test set power supply, the dc distribution arrangement, and the radio grounding circuit.

I. INTRODUCTION

The transmission equipment in the TD-3 radio system is designed to be powered from common, −24-volt battery plants. Where voltages other than −24 volts are required, for the traveling-wave tube, the IF circuits, the microwave generator, and the like, they are furnished by power supplies which are powered from the common −24-volt battery plant. An exception is the transmitter-receiver test set power supply which is powered from commercial 60 hertz ac.

The stringent noise requirements of the TD-3 radio system dictated a precisely-controlled approach to dc power distribution. DC power feeders from the common −24-volt battery plant through a battery distribution circuit breaker board are segregated into noisy, quiet, and undesignated groups. The noisy group, those feeders on which there is appreciable noise, feed primarily converter-type power supplies. The quiet group consists of feeders whose loads are susceptible to noise, such as the regulated −19-volt power supply. The undesignated group primarily feeds alarm battery supply loads which generally are not noisy, but will on occasion, such as when a relay drops out, produce noise.

With rare exceptions, a separate ground return feeder of equal cross sectional area is run with each hot (off ground) feeder from the circuit breaker board to the equipment bays. This minimizes current flowing in the equipment bay frameworks and thus reduces system noise.

In the TD-3 main and repeater stations of the initial installation, the tower is an integral part of the building. Therefore, it was essential that the radio grounding circuit be designed with extreme care to protect persons and equipment from lightning. In addition to the usual internal and external ring grounds, another ring ground is embedded in the roof of the building. The four tower legs are connected to the internal and external rings as well as to the roof ring. Inside the building, all equipment bays are directly connected to the internal ring ground; and when mechanical bonding of adjacent bays does not result in a good electrical connection, these bays are interconnected electrically.

II. BATTERY PLANT

From a power point of view, one of the objectives in the design of the TD-3 radio system was that it be compatible with existing, common, −24-volt battery plants. This includes 11-cell plants with emergency cells, and 12-cell plants with or without emergency cells. This design objective was met. However, a 12-cell plant with emergency cells is preferred because there is greater reserve time during a commercial power failure, and less dc distribution copper is needed because of the increase in the allowable loop feeder drop from the battery to the equipment bays with such a plant.

The float voltage of 11-cell plants is 23.9 volts ±1 percent, while that of 12-cell plants with or without emergency cells is 26.0 volts ±1 percent. The TD-3 radio system will perform satisfactorily with battery plant voltage from 22 to 28 volts.

III. POWER SUPPLIES

3.1 *Traveling-Wave Tube*

The traveling-wave tube power supply is a solid state, dc to dc converter which furnishes power to all of the TWT electrodes. The electrical requirements for the supply are shown in Table I.

A dc to dc converter was obviously required to convert the battery voltage to the relatively high dc voltages required by the TWT electrodes. The converter was designed to have an oscillating frequency of 2 kHz. This frequency was selected because it offered the best compromise between power supply size and cost. At 2 kHz, reasonably small transformers and filters are required, yet relatively slow switching, inexpensive transistors can be tolerated.

Figure 1 is a simplified block diagram of the power supply. Notice

TABLE I—TWT SUPPLY REQUIREMENTS

Electrode	Voltage	Voltage stability	Current	Ripple (rms)
Anode	Adjustable, +60 to +500 V with respect to the helix voltage	±60 V with respect to cathode	0–1 mA	0.3 V
Helix	Adjustable, +2500 to +2900 V with respect to the cathode voltage	±12 V with respect to cathode	0–4 mA	0.14 V
Cathode	Fixed, −1420 V with respect to the collector voltage	1185 to 1615 V with respect to collector	35–40 mA	1.0 V
Collector	Connected to ground	—	—	—
Heater*	7.5 V below the cathode	±0.15 V (70°–80°F) ±0.375 V (40°–140°F)	0.8–0.95 A	0.075 V

* Heater voltage is 9.1 V upon initial turn-on of the power supply and automatically drops to 7.5 V after an adjustable 120 to 300 seconds.

that complete input-to-output dc isolation is obtained from the transformers in the supply. The description which follows relies on Fig. 1. Input power from the −24-volt battery plant, by way of an input filter, flows into the 2 kHz inverter which serves as the source of power for all of the rectifiers in the supply. Power for the cathode is derived from the 2 kHz inverter through the cathode transformer and the cathode rectifier and filter; one side of the cathode rectifier and filter output is connected to the collector which is grounded. The other side is connected to the cathode. Anode and helix power is furnished from their respective rectifiers and filters, by way of their transformers, through a common ac series regulator. Power for the heater flows through an electronic time delay relay to the heater transformer and then to the heater rectifier and filter.

The helix potential and, to a lesser extent, the anode potential, both relative to the cathode, are regulated by sampling the helix-to-cathode voltage with a voltage divider and comparing this sampled voltage to a reference voltage. The difference or error voltage is amplified, chopped at a 2 kHz rate, passed through a dc isolating transformer, and used to adjust the bias of the ac series regulator so as to vary the voltages applied to the primary windings of the helix and anode transformers

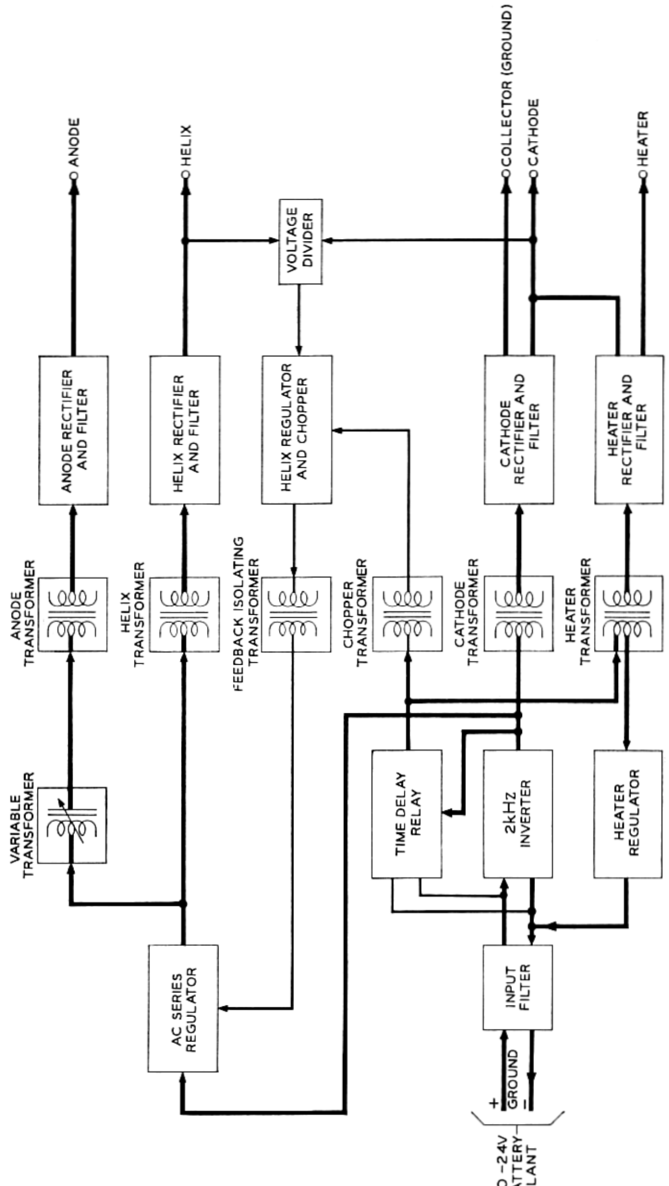

Fig. 1 — Simplified block diagram of TWT supply.

according to the dictates of the error signal. Because the helix-to-cathode voltage is sampled, it is regulated to better than ±12 volts for any helix voltage between 2500 and 2900 volts. The anode voltage, because of the open-loop output impedance of the helix circuit and the output impedance of the anode circuit, will be regulated to a lesser degree, ±60 volts for any anode output voltage between 2560 and 3400 volts. The heater voltage is regulated by the heater regulator which maintains the primary voltage to the heater transformer to better than ±2 percent during normal operation.

Figure 2 illustrates, in simplified form, the high voltage circuits, excluding the heater, and the ac series regulator. Variable transformer T_1 permits the anode voltage to be level-set from 60 to 500 volts above the helix. The regulated rectifier consisting of diodes CR_1, CR_2, CR_3, CR_4, and resistor R_1 provides a 44-volt bias which insures that the anode will always be positive with respect to the helix.

The helix-to-cathode voltage divider consisting of resistors R_2, R_3, and R_4 is designed so that the input voltage level to the error detector circuit is near ground potential. The output voltage of the feedback isolation transformer is rectified by diodes CR_5 and CR_6 and controls the collector-emitter voltage drop of the transistor in the ac series regulator. Because this transistor is in series with the parallel combination of variable transformer T_1 and transformer T_3, it controls the amplitude of the square-wave voltage applied to these transformers according to the dictates of the helix voltage regulator feedback loop.

Figure 3 is a simplified schematic diagram of the heater regulator circuit. Heater regulation is accomplished by maintaining voltage V of Fig. 3 constant. This voltage plus the drop across either diode CR_3 or CR_4, (which conduct on alternate half-cycles), is the voltage applied to the primary of heater transformer T_2. The power supply has an adjustable electronic time delay relay which permits the heater voltage at the tube to be high initially for a period which is adjustable from 120 to 300 seconds. When the TWT supply is shipped from the factory, the time delay is set to 180 seconds. During this initial time the voltage at the heater is −9.1 volts. After the relay has timed out, the heater voltage is reduced to −7.5 volts.

When the polarity of the primary winding on cathode transformer T_1 is positive at terminal 1 and negative at terminal 2, diode CR_2 will conduct and diode CR_1 will block. For this condition, current will flow from terminal 1 of T_1 through CR_2, through the time delay

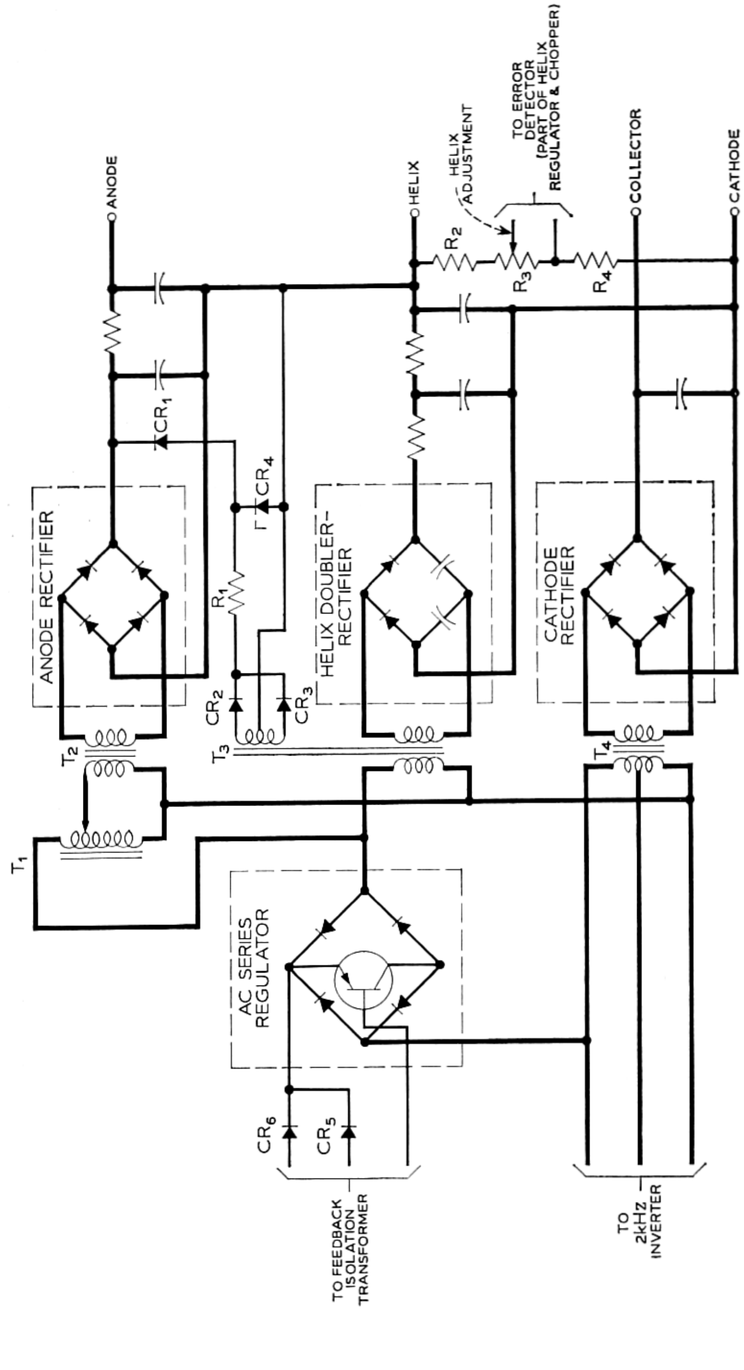

Fig. 2 — Simplified high voltage circuits, excluding the heater, and the helix ac series regulator arrangement.

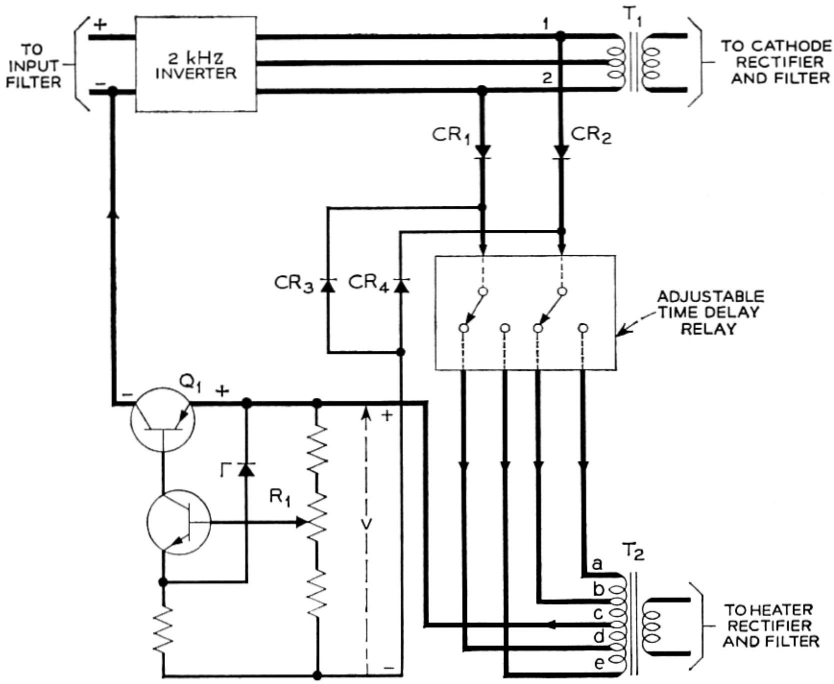

Fig. 3 — Simplified heater regulator circuit.

relay, and into terminal **b** of heater transformer T_2. This current leaves the primary of T_2 by way of center tap terminal **c**, through heater regulator series transistor Q_1, and back to the negative side of the input filter. On the alternate half-cycle, primary current will flow through CR_1, through the time delay and into terminal **d** of T_2. This current also leaves by way of terminal **c** of T_2. During the initial overvoltage period, the time delay relay connects terminals **b** and **d** of T_2 to the cathodes of CR_2 and CR_1, respectively. After the overvoltage period has passed, terminals **a** and **e** are connected to the cathodes of CR_2 and CR_1. The heater is regulated by the automatic variation of the dc voltage across transistor Q_1 according to the dictates of voltage V. Potentiometer R_1 level-sets the heater voltage.

The TWT power supply will be made in considerable quantity; its mechanical design, testing, and assembly, and their associated costs, are of considerable importance. In addition, it should have a pleasing appearance. Figure 4 shows the general mechanical features of the power supply, which consists of two units in a metal case. The inverter and heater regulator unit (left) and the rectifiers and helix regulator unit are both inserted into an over-all metal housing. The two are joined through connectors at the rear of the housing and at the rear of the plug-in units. A plug-equipped cord from the rectifiers and helix regulator unit connects to the traveling wave tube which is mounted above the power supply. The same cord connects to the test load, described later in this section.

Because of the electrical potentials in this unit, personnel safety had to be considered. The entire power supply is mounted in the metal housing in such a way that the inverter and heater regulator unit on the left must be removed before the high voltage right-hand unit. The right unit actually extends behind the low voltage left-hand unit, and an attempt to remove the high voltage unit first will automatically eject the low voltage unit. Removing the left-hand unit disables the circuits to the high voltage unit so that high voltages are no longer present. There is further electrical interlocking to the traveling-wave tube by the internal wiring through the associated connectors of the power supply and the traveling-wave tube.

Figures 5 and 6 show a number of design details. The low voltage

Fig. 4 — TWT power supply.

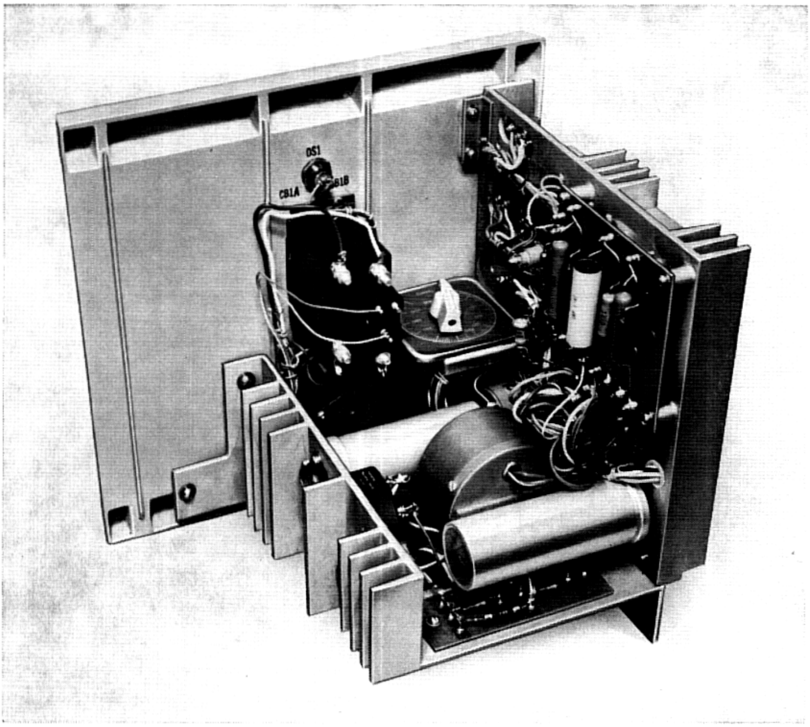

Fig. 5 — Inverter and heater regulator unit of the TWT power supply.

unit in Fig. 5 uses three castings for mounting components, transistors, diodes, and connectors. This permitted the use of an integral heat sink and a mechanical structure to dissipate the heat generated within the low voltage package. The unit may be opened for assembly and repair by dropping the hinged front panel and dropping the vertical casting on the left (viewed from the front). The castings on the left unit include fins for dissipating the heat from the transistors and diodes mounted on it with insulating washers.

The rectifier and regulator unit shown in Fig. 6 has two die castings; the panel casting with beveled edges for the meter openings and a chassis casting which holds the transformers, capacitors and associated high voltage components (mounted on insulating panels because of the high voltages). A printed wiring board in the rectifier regulator unit holds the helix regulator circuit which operates at high voltages. When the hinged front panel and a hinged plastic panel

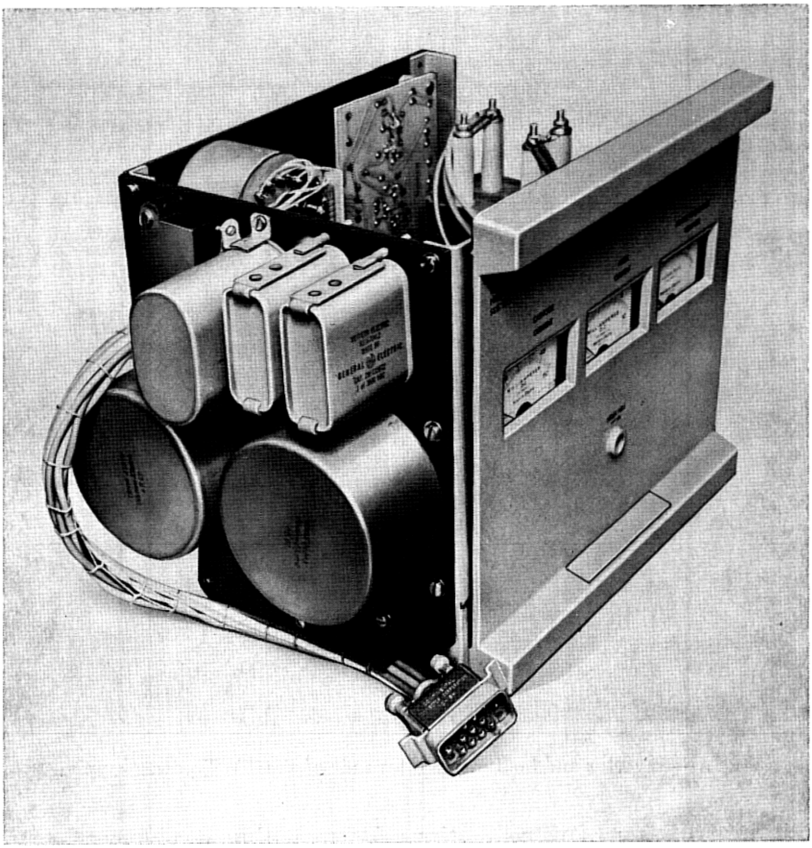

Fig. 6 — Rectifiers and helix regulator section of the TWT power supply.

at the rear are opened the apparatus is accessible for assembly, repair, and troubleshooting. The panels can be dropped only when the power unit has been removed from its housing. Insulating sheets and high voltage wire have been used extensively because of the high potentials.

The coils in the power unit are given standard dielectric and corona tests. The high voltage coils are epoxy encapsulated with metallic shields to reduce noise which could couple into other circuits in the repeater bay and finally appear in the baseband of the TD-3 system.

Figure 7 shows two molded high voltage diode assemblies developed for the TD-3 power supply.[1] With these molded assemblies, the diodes occupy less space compared with conventional individual mounting, and there are fewer exposed solder connections (with their corona generating possibilities). These packages permit the use of the enclosed diodes to the full limit of their voltage rating without derating for altitude, as has been necessary for discrete diodes because of the very small tubulation to body spacing.

If a faulty TWT power supply is connected to a good TWT, it is possible that the power supply will damage the tube. For this reason, and for one other, a test load for the TWT power supply was designed and is provided at each radio station. When the TWT power supply is first installed on a transmitter-receiver bay it is checked with the test load connected to its output terminals. Once it has been determined that the TWT power supply is functioning properly, the test load is removed and the TWT connected. The second reason for a test load is to help maintenance people determine, in the event of a TWT amplifier failure (TWT and its power supply combined,) whether the TWT or the power supply is faulty.

The test load is shown in Fig. 8. It consists of resistive loads which simulate several quiescent states of TWT electrode voltages and currents, a multipurpose voltmeter, a cathode current milliammeter, a helix current milliammeter, and a heater voltmeter. The multipurpose voltmeter can be switched to measure the anode-to-cathode, helix-to-cathode, and collector-to-cathode voltages. The test load attaches to the same plug-in connector as the TWT.

When used to check the TWT power supply, the test load is mounted on top of the power supply in front of the TWT, as Fig. 9 shows. Connections pass through a cutout in the top of power supply case and the bottom of the test load. The test load has a handle at the

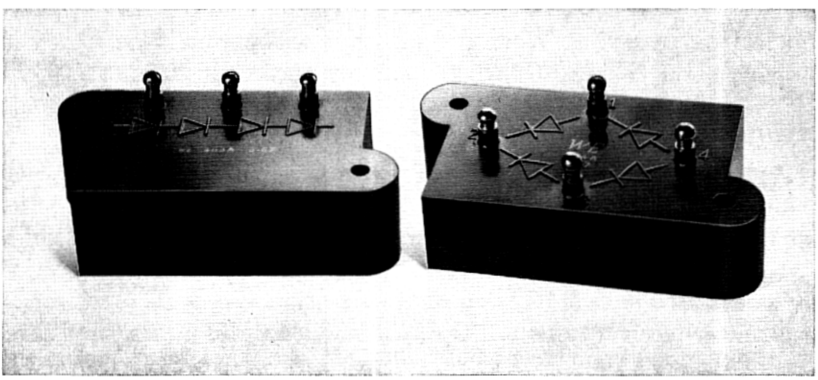

Fig. 7 — Molded high voltage diode assemblies used in the TWT power supply.

Fig. 8 — Test load for the TWT power supply.

top for easy carrying. When not in use it will normally be stored in a spare parts cabinet. One test load per station is sufficient.

3.2 *Regulated −19-Volt Supply*

This supply which powers the IF circuits, microwave generator, and so on, in the transmitter-receiver bay is a solid state, active, series line regulator which drops the battery plant voltage to -19 ± 0.2 volts. Two of these supplies are used in each bay in a switching main station and one is used in each bay in a repeater station. One is also used in the transmitter-receiver test set. The requirements for this power supply are:

Input range	21–27 V dc
Output	−19 V dc

Output stability (75 ± 5°F)	±0.2 V
Output stability (40–140°F)	±0.4 V
Output current	0–4 A
Output ripple voltage	1 mv rms
Output high voltage alarm at	−20 V
Output low voltage alarm at	−18 V.

Fig. 10 depicts a simplified circuit of the regulated, −19-volt power supply. Output voltage is regulated by varying the emitter-collector dc voltage drop of transistor Q_1, which is in series with the

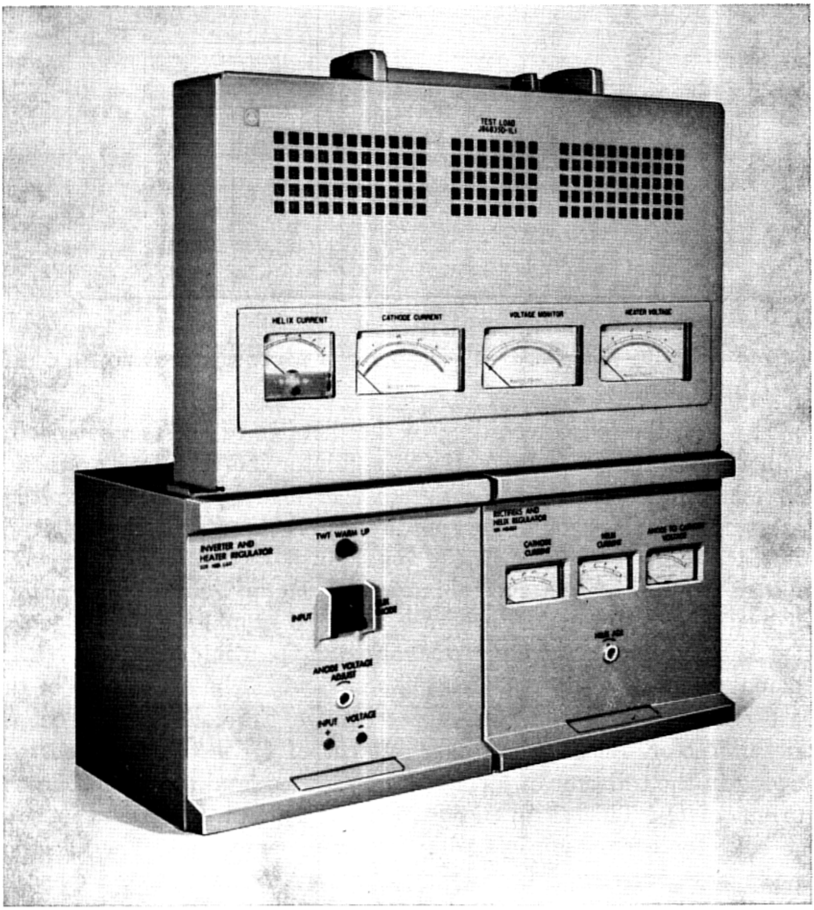

Fig. 9 — Test load atop TWT power supply.

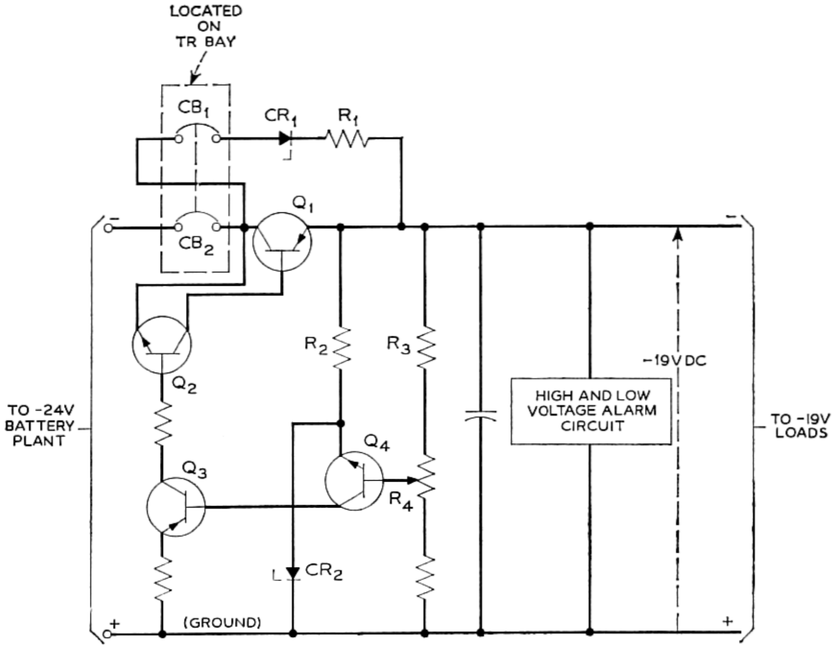

Fig. 10 — Simplified —19-volt regulator power supply circuit.

battery and the load, according to the dictates of the feedback loop.

Should the output voltage of the regulator increase by an amount Δv, (this could result from a decrease in load current), the voltage across resistor R_2 would increase by Δv because CR_2 is a voltage reference diode operating in the breakdown region. The increase in voltage across the series combination of R_3 and the upper part of R_4 would be equal to $k\Delta v$ where k is a real number less than unity. The base to emitter voltage of transistor Q_4 would decrease by an amount equal to $(1\text{-}k)\ \Delta v$. The net result would be a decrease in the base current of Q_4 and thus a decrease in the collector current of this transistor. Because the base current of Q_3 is the same current flowing in the collector of Q_4, it is also reduced, and so is the collector current of Q_3. This chain of events will result in a decrease in both the collector current of Q_2 and the base current of Q_1. The decrease in the base current of Q_1 will result in an increase in the emitter-collector dc voltage drop of this transistor and this, in turn, will return the output voltage of the regulator to —19 volts.

Similar reasoning can be applied if the output voltage of the regulator decreases by Δv. The result will, of course, be a decrease in the emitter-collector dc voltage drop of transistor Q_1. The −19-volt output is level-set with potentiometer, R_4.

Circuit breaker CB_2, rated at 5 amperes, is the overload protection device for the power supply when the battery voltage is in the normal range of 24 to 26 volts. CB_1, a companion circuit breaker to CB_2, is rated at 2 amperes and serves as the overload protection device when the battery voltage is low. The series combination of CR_1 and R_1 provides a starting current path for the power supply during turn-on.

The regulated −19-volt power supply is shown in Fig. 11. It is a plug-in unit which consists of a combined one-piece, die-cast frame, heat sink, and handle. The volume allotted for this unit at the bottom of the radio bay, coupled with the need for a heat sink that could dissipate 38 watts, indicated that the most efficient and economical

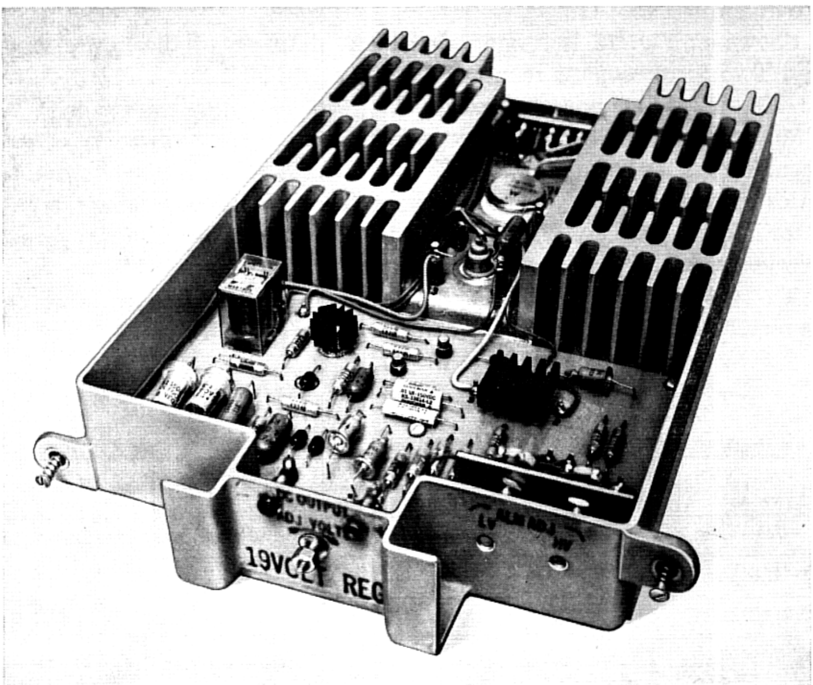

Fig. 11 — The regulated −19-volt power supply.

approach would be an aluminum die-cast one-piece plug-in unit. Overall, it is about 10 inches wide, 2 inches high, and 13½ inches deep. The epoxy glass printed board which contains most of the components is mounted within the frame. The heat sink area accommodates a power transistor and several other heat dissipating components. The face of the unit has such maintenance components as a pair of pin jacks for external connection to a dc voltmeter, and a potentiometer for adjusting the output voltage. A plug which makes external connections is mounted on the rear of the frame. The unit is fastened in place by two quick-release fasteners attached to the frame assembly. It is designed so that two power supplies may be placed beside each other in the bottom space of a TD-3 radio bay.

3.3 *Transmitter-Receiver Test Set*

The power supply for the transmitter-receiver test set[2] is a magnetically and electronically regulated unit which furnishes power at five different voltage levels. The requirements for this power supply are given in Table II.

Shown in Fig. 12 is a simplified block diagram of the power supply. Two ferroresonant regulators designated No. 1 and No. 2 receive 60 Hz, 117 V ac power through the 4-ampere circuit breaker, CB. Two ferroresonant regulators were needed to prevent excessive cross-regulation and because two different short circuit droop characteristics were required. The droop characteristic of ferroresonant regulator No. 2 protects the +300-volt active series regulator against overloads. All other outputs are protected by fuses.

The 6.4 V ac output is derived from an unregulated winding on ferroresonant regulator No. 1. Therefore this voltage follows the 60

Table II — Transmitter-Receiver Test Set Power Supply Requirements

Output voltage	Voltage stability	Output current	Ripple (rms)
+300 V dc	±0.3 V	80–130 mA	1 mV
−150 V dc	±0.8 V	7–10 mA	1 mV
−40 V dc	±0.3 V	5–10 mA	1 mV
−24 V dc	−22.5 to −26 V	250–950 mA	300 mV
6.4 V ac	±0.83 V	3.3–3.9 A	—

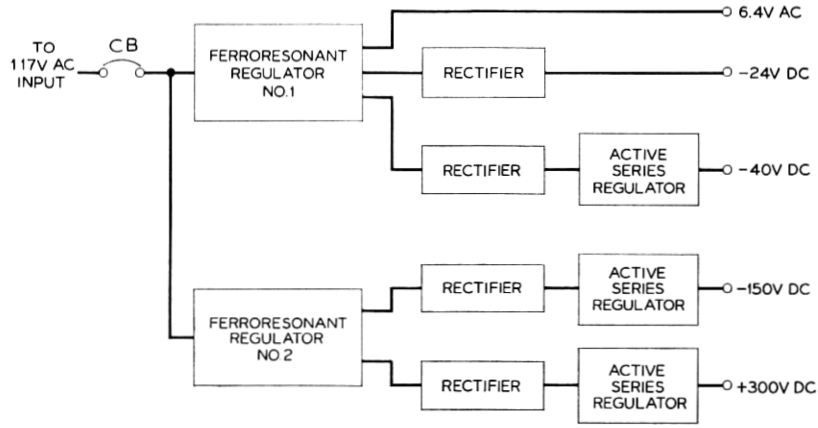

Fig. 12 — Simplified block diagram of the test set power supply.

Hz input voltage. The ac input voltages to the four rectifiers are regulated to minimize the voltage variations at the inputs of the three active series regulators. All of the active series regulators are conventional in design.

Figure 13 shows the power supply for the test set. It mounts at the rear bottom of the test set. The power supply consists of an open aluminum structure with most of the apparatus mounted on top, and the wiring on the bottom of the chassis. The transformers, resonating capacitors and −24-volt filter capacitors are on the chassis. The front panel of the power supply has fuse holders, fuses, circuit breaker, and access to the four plug-in units. Die-cast frames and guides are used to mount the four plug-in cards. One card contains all the rectifiers and protective diodes for the entire power supply. The other three cards are the voltage regulators for the +300-, −150-, and −40-volt outputs.

The input to the power supply is protected by a circuit breaker on the front panel. The input and output connections are made through quick-disconnect plug and jack assemblies located on the rear of the chassis. Various voltage adjustments, test points, and controls are mounted on the front panel. An extender assembly is used for servicing the power supply. The extender has a protective grid so that the plug-in units, when inserted, may be checked with safety. In order for the extender and the plug-in to be engaged the grid must be in a position to protect the users against the potentials present.

Fig. 13 — Test set power supply.

IV. THE DC DISTRIBUTION CIRCUIT

The two paramount considerations which influenced the design of the dc distribution circuit were system electrical noise, and reliability. To minimize electrical noise, dc power feeders from the −24-volt battery plant fuse panel via the battery distribution circuit breaker bay are segregated into three groups: the noisy group which primarily feeds converter power supply loads, the quiet group which feeds noise-sensitive loads, and the undesignated group which feeds loads which can, on occasion, produce noise on their dc power feeder leads. The reliability criterion is that no more than half of the channels in one transmitting direction (one end) shall be lost as the result of a battery distribution fuse failure.

The allowable loop voltage drop from the −24-volt battery is determined by the type of battery plant used. For an 11-cell plant with emergency cells, 1.25 volts are permitted; for 12-cell plants with emergency cells, 1.75 volts are permitted; and for 12-cell plants without emergency cells, 1.0 volt is permitted. These allowable drops include the voltage drop across the circuit breaker in the circuit breaker bay, and agree with the recommended discharge loop voltage drops which appear in common systems −24-volt battery plant drawings.

Figure 14 illustrates a simplified schematic of the −24-volt dc distribution circuit for one direction of transmission. Half of the channels transmitting in one direction receive their −24-volt distribution from quiet Q bus 1 and noisy N bus 1; the other half receive theirs from Q bus 2 and N bus 2. Not only is dc power distributed to the transmitter-receiver bays in such a manner as to preserve the reliability objective of the system, but both plus and minus 24-volt dc power also is distributed to all equipment associated with each transmitter-receiver bay in such a manner as to preserve the reliability objective. The other equipment includes 100A protection switching and 3A FM terminals.

In other words, it is not possible for the loss of one fuse at a battery plant fuse panel to cause a station to lose, in one transmitting direction, the transmitter-receiver bays associated with channels 1 through 6 (or any other designations they may have) and channels 7 through 12 of the 100A protection switching or other channel associated equipment. Four circuit breakers at the circuit breaker bay are required for each transmitter-receiver bay in a main station, and three for each in a repeater station.[3] Figure 14 shows that at least five −24-volt dc distribution fuses at the battery plant fuse panel are required for each direction of transmission.

Overcurrent tripping or the inadvertent turn-off of any circuit breaker in the breaker bay will set off a major office alarm. An alarm cutoff button on the circuit breaker bay can be pushed to silence the bell, turn off the red aisle guard lamps and turn on the white. Lamps on the alarm panel indicate which bus is affected.

The battery distribution circuit breaker bay is available as a 7-foot high unit in the same kind of cabinet as the newer −24-volt battery plant, or as a 9-foot duct type bay typical of radio equipment. The 7-foot cabinet is typically positioned adjacent to the battery power plant. The duct bay, which is compatible with 100A protection switching and 3A FM terminal equipment, is placed close to the load center of the equipment. In most instances it is expected that the 7-foot cabinet will be adequate for the TD-3 radio bays in main or repeater stations, and the 9-foot duct bay will be used to distribute to the various IF terminal and associated equipment. Both arrangements may be furnished with groups of circuit breaker panels.

The 7-foot cabinet includes ground bus-bar details so that a metallic

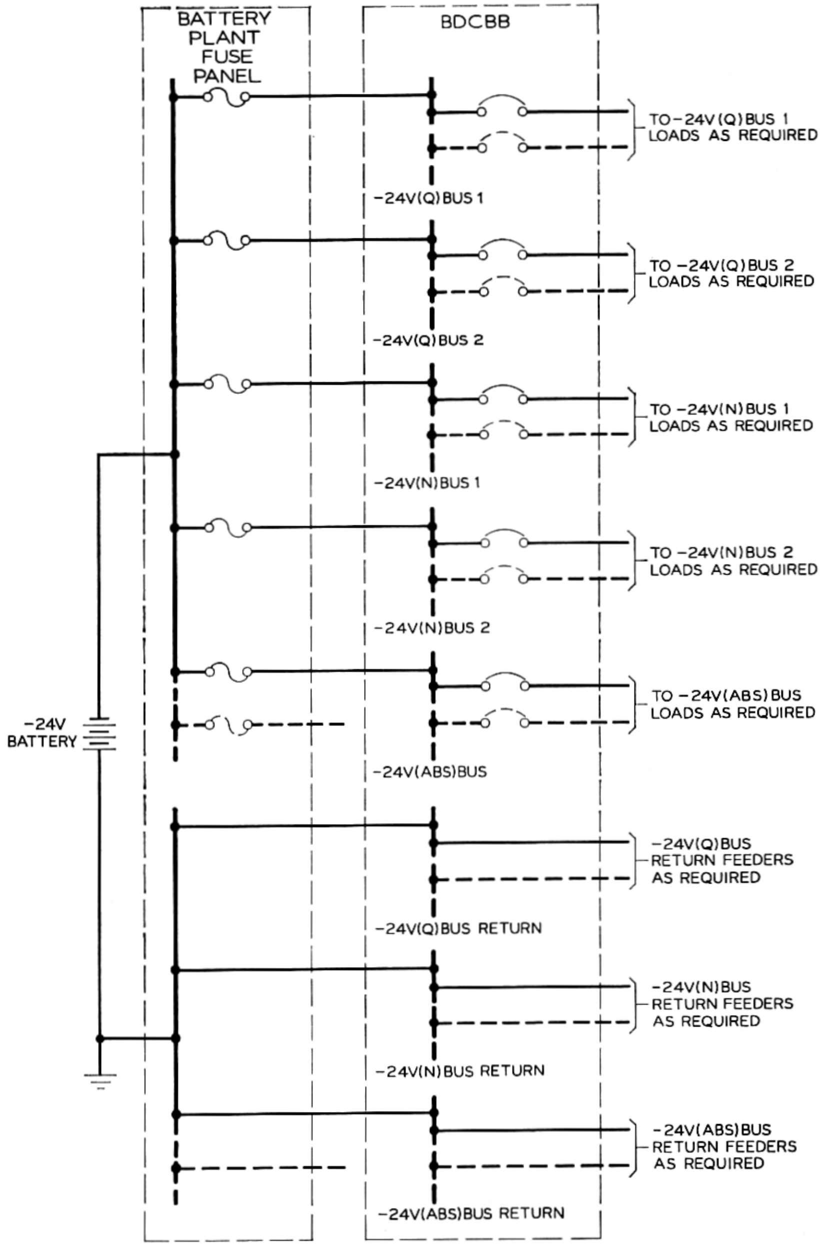

Fig. 14 — Simplified schematic diagram of the −24V dc distribution circuit for one direction (one end) of transmission.

pair is available for each circuit to be served by the cabinet. The 9-foot bay has two removable rear covers, for the upper and lower sections. Covers are for access where circuits are being added.

V. RADIO GROUNDING CIRCUIT

Tower-integrated buildings, as might be expected, are extremely vulnerable to lightning strokes. It is very important, therefore, that the radio grounding circuit for such a building be extremely well designed. The circuit design objective is to minimize the impedance to ground seen by the lightning-produced current. This, in turn, minimizes the potential differences within the building produced by this current.

Figure 15 illustrates, in simplified form, the radio grounding circuit for the tower-integrated, TD-3 radio buildings. Outside the building the external ring ground, which consists of No. 2, bare, tinned, copper wire, connects 5-foot, ½ inch diameter ferrous ground rods a maximum of 10 feet apart. The external ring ground is buried not less than 1-½ feet below the final grade level. The internal ring ground consists of bare, No. 2 copper wire and is on the walls inside the building high enough to eliminate possible mechanical damage, yet low enough for visual inspection. The roof ring ground, which is also bare, No. 2 copper wire, is embedded in the concrete roof slab. The three ring grounds are electrically connected at many well spaced points, and are connected to the reinforcing steel of the building. Structural building steel, including the tower, is connected to the three ring grounds in many places. The four waveguide hatch plates are connected directly to the roof ring ground and all waveguides are connected to their respective hatch plates as well as to the internal ring ground.

Inside the building, two bare No. 2 copper wires run the length of the building, one on each side of the main aisle. These two wires are connected at both ends to the internal ring ground and, thus, form part of the internal ring. Each equipment bay is directly connected with a bare No. 6 copper wire to a bare No. 2 copper wire which runs along the cable rack of each bay line-up. This arrangement can be seen in Fig. 15. When the station is completely filled, the internal ring ground will be a mesh suspended above and electrically connected to all equipment with leads as short as practicable. When a station is grounded in this manner, large differences of potential between adjacent equipment during a lightning stroke are impossible.

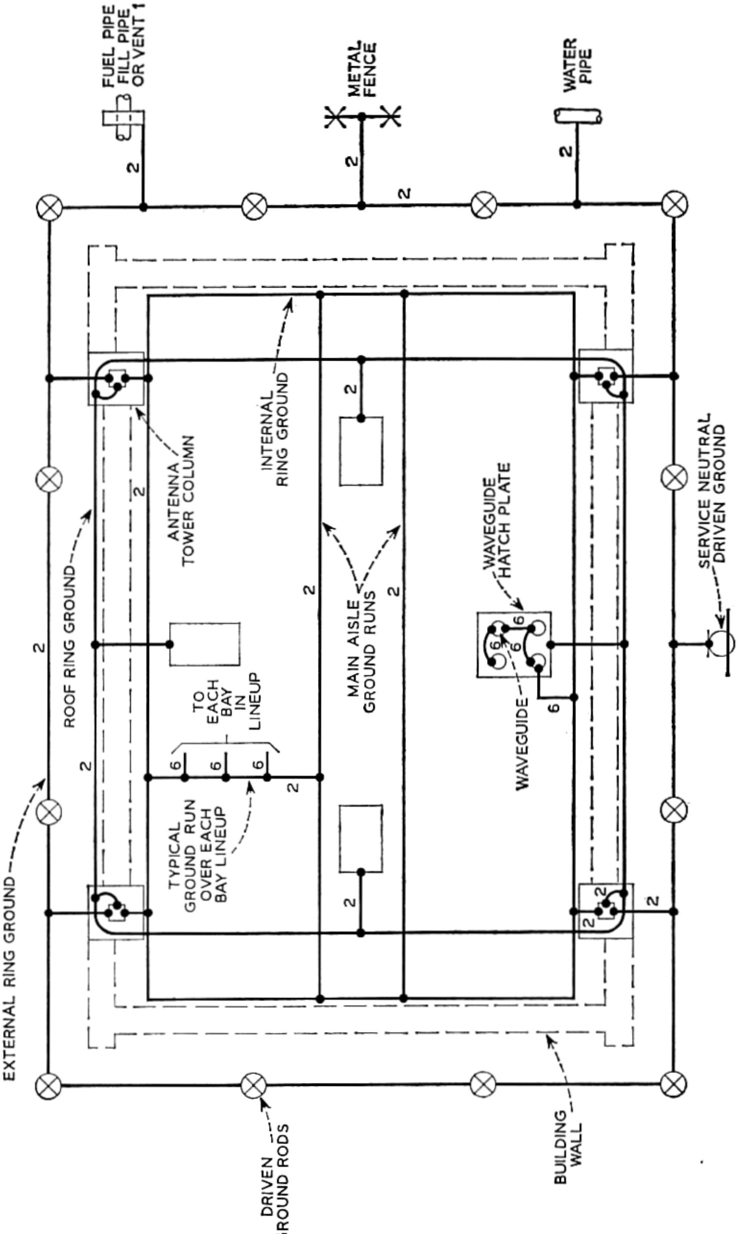

Fig. 15 — Simplified radio grounding circuit for the tower-integrated buildings.

VI. ACKNOWLEDGMENTS

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