Power Systems for the TH Radio System

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The basic source of power for the TH radio equipment is reliable 230 volts ac obtained from a bank of special motor-alternator sets. These are normally driven by commercial ac power but switch automatically to battery drive on loss of commercial power. This firm ac power is distributed to the individual units of equipment where local rectifiers, of various types and sizes, produce dc power of the required voltage and stability. One of the more advanced of these is the 2900-volt regulated supply for two traveling-wave tubes.

I. GENERAL

The transmission and control equipments in the TH radio system require dc power at a multiplicity of voltages from 7 to 3100 volts. A broad range of stability, noise and other performance requirements is established according to the sensitivities of the individual loads. High reliability is an objective common to all of the power equipment. Other important objectives are flexibility for growth, simplicity for maintenance, protection of personnel from hazardous voltages, and minimum cost.

1.1 *Characterization of Loads*

The dc loads can be placed in four general categories:

(i) Low to medium voltages (7 to 250 volts), characterized by constant load, tolerance to normal voltage variations of ± 2 per cent, and noise or ripple requirements that can be satisfied economically with passive filters.

(ii) High voltages (1200 to 3100 volts) for the traveling-wave tubes, characterized by $\pm\ \frac{1}{2}$ per cent stability requirements and several special control and protection features.

(iii) Medium voltages (-170, $+220$, and $+450$ volts) for the klystrons and video amplifiers in the FM terminal equipment, characterized by ±0.2 per cent long-term stability requirements, and noise requirements as low as 0.0001 per cent in the frequency range of $\frac{1}{2}$ to 30 cps where passive filtering is impractical.

(iv) +24 and −24 volts for the protection switching equipment with especially stringent reliability requirements.

1.2 *Design Approach*

While many of the voltages (12, 24, 130, and 250) could be supplied directly from standard battery plants, the traveling-wave tube voltages are too high for this type of approach. Instead, special motor-alternator sets are employed to generate reliable and continuous (firm) ac power. The motor-alternators are normally driven by commercial ac power but switch over to battery drive in the event of a commercial power outage.

All dc voltages are produced by dc power supplies connected to one of the firm ac busses. All dc power supplies are decentralized such that a single failure can affect no more than a single one-way broadband channel. (An exception to this principle is the supply to the protection switching equipment where redundant rectifiers and direct battery reserve are provided.) Decentralization of the dc power supplies simplifies the distribution of power and provides flexibility for growth.

II. PRIME AND STANDBY POWER SOURCES

Commercial service is considered the normal prime source of power for a TH radio station. Under commercial power failure conditions, emergency power is provided by single or multiple diesel engine-alternator sets. Power service for the TH system has been standardized at three-phase, four-wire 120/208-volt input because of high power requirements. The ac distribution system for a typical installation, including the firm ac motor-alternator arrangements described in Section III, is shown in Fig. 1.

Commercial ac loads are divided into two separate categories, namely, protected and unprotected. Protected loads are those which require emergency service during commercial power failure conditions. Unprotected, or nonessential, equipment loads are supplied from a separate distribution cabinet and include such items as normal office lighting, air conditioning and the motor-generator or rectifier used for recharging the 130-volt battery. Protected, or essential, equipment loads form, by far, the larger percentage of the total office equipment, as may be seen from Fig. 1. The prime subdivision of these loads is accomplished through

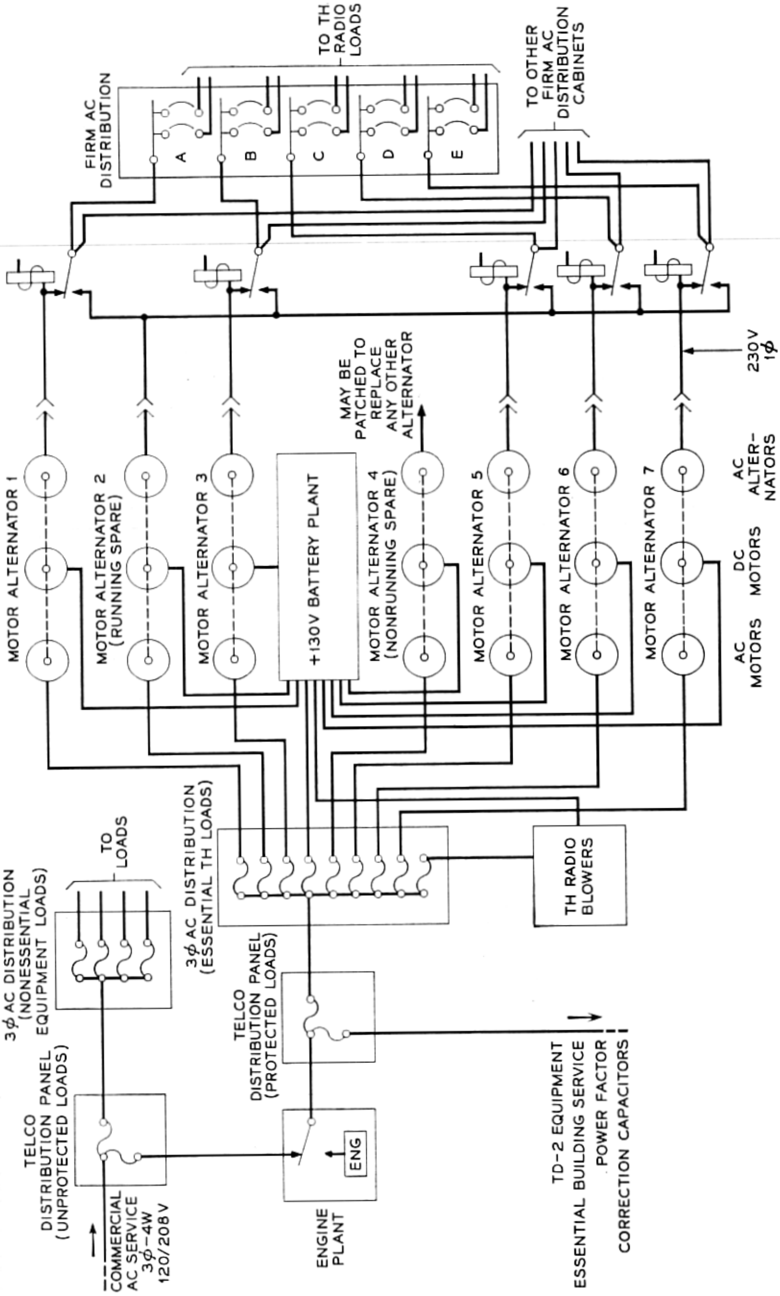

Fig. 1 — AC power distribution for typical TH installation.

a customer-furnished distribution cabinet. This cabinet serves all essential building services and power factor correction capacitors when required to obtain maximum engine-alternator capacity, and is the main feed when TH systems are combined with TD-2 stations. All TH loads are derived from this cabinet via an intermediate three-phase distribution cabinet. This latter unit distributes power to essential loads such as the 508A motor-alternator plant, the 130-volt battery plant, the radio tube cooling system, tower lighting, utility outlets, etc.

III. FIRM AC POWER GENERATION

The firm ac power system is designed for completely automatic unattended operation at remote and, at times, inaccessible mountain locations. This supply is provided by a two-motor generator set which couples together on one shaft a synchronous induction ac motor, a dc motor and a brushless ac type alternator. Under normal operating conditions the set is started manually by its dc motor from the station 130-volt battery. After reaching normal speed and voltage, the set is placed in normal automatic operation by connecting it to the load and transferring to ac motor drive. With normal line frequency, synchronous motor drive, and essentially fixed load, the alternator output voltage is constant and insulated from line voltage transients and variations. Line voltage monitors, set above the pull-out torque point of the ac motors, control automatic transfer to dc motor drive in the event of marginal line voltage and permit return to ac drive when the ac input is restored to its normal voltage and frequency range. Dc operation for about three minutes after power returns gives the line a chance to stabilize before permitting ac drive. If the line frequency is outside allowable limits, causing abnormal alternator speeds and, thereby, abnormal load voltages, monitors on each alternator output control automatic transfer to dc drive until the supply frequency returns to its normal range. If the output of any alternator goes beyond allowable limits for other than excessive supply frequency variations (e.g., an individual ac motor failure), then the output voltage monitor controls automatic transfer and lockover to dc motor drive with alarms to indicate a trouble condition on a particular alternator.

The output monitor on each alternator also guards against a continued abnormal voltage if the output drops below 90 per cent of the normal 230-volt value for more than 30 milliseconds or below 95 per cent for more than three seconds. Under these unlikely conditions, the control circuits transfer the load to the running spare, shut down the alternator involved, and cause an alarm to be given. As shown in Fig. 1, alternator

2 is a common running spare for all the regular alternators. It takes over the load of any regular alternator which fails or which is manually shut down for maintenance. Should more than one alternator fail at one time, then the lowest numbered alternator gets preference on the basis that the most important loads are allocated to the first alternators. A minimum installation requires four alternators serving the two busses A and B. This involves regular alternators 1 and 3, hot running spare alternator 2, and cold spare alternator 4. Added loads on busses C, D and E require another regular alternator for each bus. Alternator 4 is for use on a plug-in basis to replace any other alternator for major repairs. It uses the output control circuits of the alternator it replaces but has its own motor input circuits.

3.1 *Two-Motor Alternator Design*

A new type of two-motor alternator set has been developed for the coded 508A plant for this application. It is designed for normal brushless operation; a rotating field exciter using rotor mounted rectifying diodes for the alternator field self excitation eliminates the heretofore conventional use of a shunt generator exciter.

The set has a new design of induction motor to operate at synchronous speeds instead of at slip speeds as with the ordinary squirrel cage induction motor. The synchronous characteristics of this new type of motor are produced by the special construction of a die cast aluminum rotor. This not only has salient poles, as in a reluctance type synchronous motor, but also has internal flux guiding paths which exert many times the synchronizing torque of a reluctance synchronous motor. The motor acts like an ordinary induction motor, accelerating until it almost reaches synchronism, whereupon the synchronizing torque pulls the rotor into synchronism with the magnetic field of the stator. These motors give synchronous operation without rotor windings and without slip rings and brushes for dc excitation.

In keeping with the brushless ac motor, the dc motor is operated normally with its brushes lifted by ac solenoids but with its field continuously excited from battery. Failure of ac will drop the brushes to pick up battery drive. Brush lifting has presented design problems involving proper brush travel and insulation to break 130-volt dc arcs safely, proper brush positioning and contact when released, and positive lifting when the solenoids are energized.

The dc motor speed characteristics are designed to work with an external regulating circuit to maintain speed within one cycle of normal 60-cycle speed for battery voltages between 145 and 120 volts. This

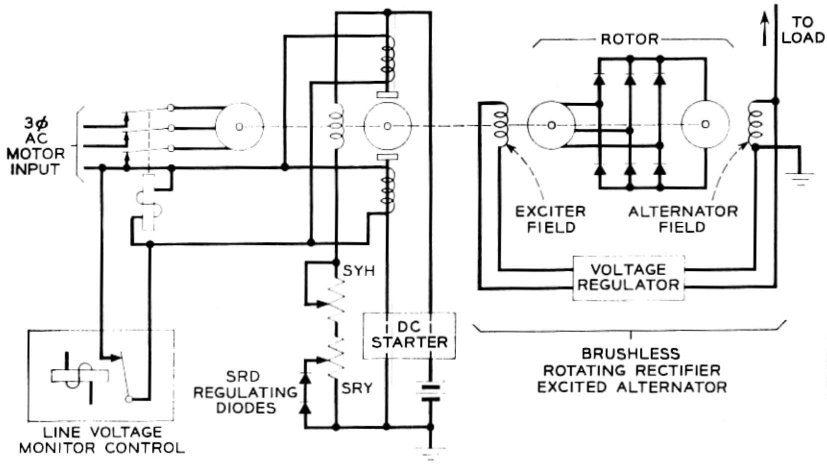

Fig. 2 — Circuit of the two-motor alternator set.

regulating circuit, shown in Fig. 2, utilizes the reverse characteristics of Zener diodes to provide a nonlinear shunt around fixed resistance in series with the shunt field. At the minimum battery voltage, 120 volts, and with the diodes nonconducting, the resistance in series with the field is adjusted by SYH to give 60 cycles at a speed of 1800 rpm. The setting of the SRY potentiometer is such that any increase in battery voltage above 120 volts increases the drop across this portion of the external field circuit, until the diodes break down to hold this drop constant. Battery voltages above 120 volts thus increase the field current faster than in direct proportion to the voltage rise. For example, without diodes the increase in field current would equal the ratio of 145/120 or 1.21, whereas with the diodes the ratio is increased to 1.34. The dc motor speed characteristic is designed so that this nonlinear increase in field current offsets the direct increase in armature current and thus maintains approximately constant speed over the battery discharge voltage range.

As an example of the dc motor speed regulation with varying battery voltage, Table I is taken from laboratory test data.

Table I — DC Motor Speed Regulation

Battery Volts	Field Volts	Diode Volts	Field Amps	Diode Amps	Alternator Freq
125	48.5	50	0.542	0.017	59.9 cps
145	60.5	51.3	0.678	0.678	60.1 cps

Continuing with the brushless theme, the set uses a recently developed type of alternator, which employs an ac generator winding with rotor-mounted rectifiers to furnish dc for the alternator field. A voltage regulator controls the direct current on the exciter field and maintains the load voltage within ±1 per cent from no load to full load for power factors 0.7 to unity. The machine design, together with the fast acting transistor amplifier driven magnetic regulator, minimizes transient surges and voltage overshoots for load changes. The effect of transferring the alternator drive from ac to dc results in a $2\frac{1}{2}$ per cent voltage dip over a 100-millisecond interval until normal output voltage is restored.

Fig. 3 shows a typical power installation including the firm ac plant, the associated emergency 130-volt battery plant, and the commercial ac distribution cabinets.

The over-all alternator set is a single frame two-bearing unit with the dc motor at one end to give access to brushes and commutators and the alternator at the opposite end to provide ready access to the rotating rectifiers. The set mounts on the two-tier framework seen in Fig. 3. The associated control equipment is in the adjoining control bay cubicle. The bay is arranged for single side maintenance with swinging gate and hinged panels.

The equipment is completely coded in shop assembled and wired units ready for a minimum of connections in the field and requiring little job

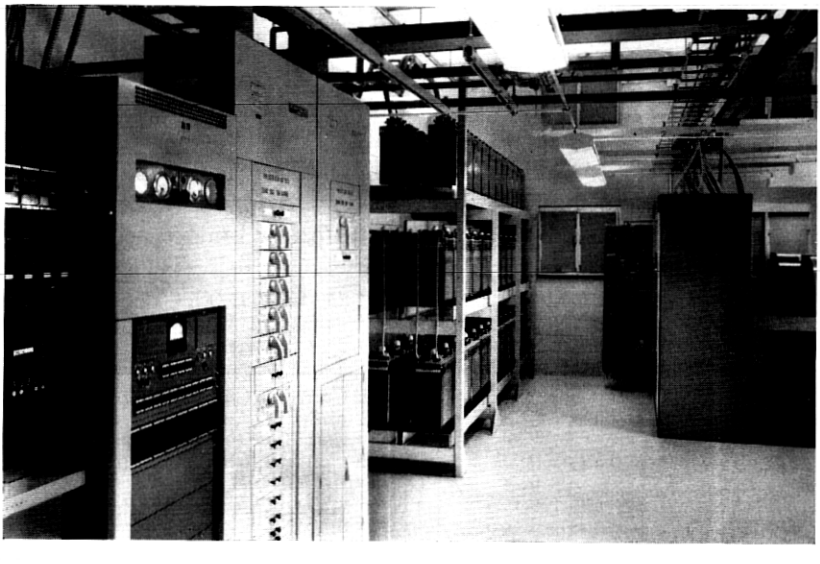

Fig. 3 — Typical power installation for the TH Radio System.

engineering for ordering initially and for additions. One equipment bay and framework are required for each two alternators for a maximum of four units for the ultimate of seven alternators.

3.2 *Firm AC Distribution*

The distribution arrangements for the firm ac power plant are engineered to utilize fully the capacity of the motor-alternators, not only initially but ultimately, and at the same time to realize the maximum in reliability for the working radio circuits. This requires considerable engineering and planning initially to anticipate future requirements and to avoid assignments which would make protection or standby facilities unavailable in the event of multiple failure in the motor-alternator plant resulting in loss of power on a firm ac distribution bus (A to E of Fig. 1). An ordinary repeater station, when fully equipped, has four normal running motor-alternators, each carrying two two-way broadband channesl; the microwave carrier supply and auxiliary channel equipment are evenly divided between busses A and B. For other types of stations, such as switching main stations, where auxiliary services like protection switching and terminal facilities are required, careful planning of ac assignments enables the service protection features to be met. Stations of this latter type require the ultimate of five normally running machines.

IV. POWER SUPPLIES

4.1 *Unregulated Rectifiers*

For general purpose use, a number of unregulated rectifiers were designed, as shown in Table II.

These rectifiers operate from the firm 230-volt ac and employ diffused silicon diodes and conventional passive filters. A limited voltage adjustment range is provided by a variable transformer bridged across a por-

TABLE II — UNREGULATED RECTIFIERS

dc Voltage	Current Rating	RMS Ripple	Applications
7 v	1 amp	0.07 v	Switch Control (Carrier Supply)
11	2	0.5	Heater and Bias
11	6	0.5	Heater and Bias
24	2	0.35	Switch Control (Carrier Supply)
48	1.5	0.5	ON Terminals (Aux. Chan.)
135	0.125	0.025	Plate Supply
135	0.325	0.025	Plate Supply
250	0.22	0.025	Some Plate Loads (Carrier Supply)

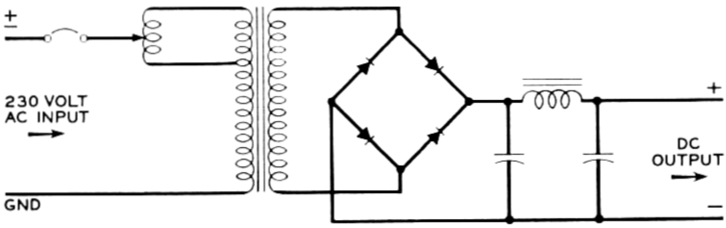

Fig. 4 — Typical circuit of adjustable, unregulated rectifier.

tion of the transformer primary winding. A typical circuit is illustrated in Fig. 4. The transient surge currents occurring in the diodes (capacitor charging current) and in the transformer primary winding (transformer inrush current plus capacitor charging current) were carefully investigated to avoid diode failure and nuisance circuit breaker operation. These transient investigations were aided by use of a special ac input switch which may be preset to close at a selected phase angle of the 60-cycle ac voltage wave.

All of these rectifiers are individual packages and bear a strong family resemblance. Several are shown in Fig. 5. Since the rectifiers are designed for minimum volume, there results a variety of sizes. They hang on vertical panels in the TH bays by means of keyhole slots in the bay panels which are engaged by captive screws in the underside of the rectifier chassis. Capacitors and inductors are mounted on the chassis in a conventional manner. An open-type power transformer and the autotransformer used for output voltage adjustment are mounted under

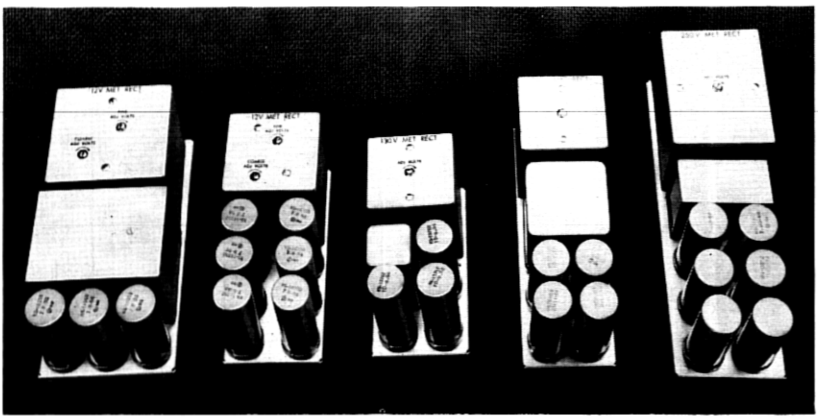

Fig. 5 — Rectifier packages showing family resemblance of designs.

a removable cover which is provided for personnel protection. The underside of the chassis is closed by a hinged cover which also mounts the silicon diode rectifiers. With the hinged cover closed all wiring except the input and output leads is protected. These leads may exit from the rectifier in either of two ways: from the side of the chassis or through the hinged bottom cover, depending upon the specific application of the rectifier. A typical rectifier is shown in Fig. 6.

4.2 *High-Voltage Traveling-Wave Tube Supply*

A supply with several special features was developed to power either one or two traveling-wave tubes. A summary of the high-voltage requirements is given in Table III.

A block diagram of the basic power supply is given in Fig. 7. The 1200-volt output is developed by a conventional unregulated rectifier and filter circuit. The independently adjustable helix and anode poten-

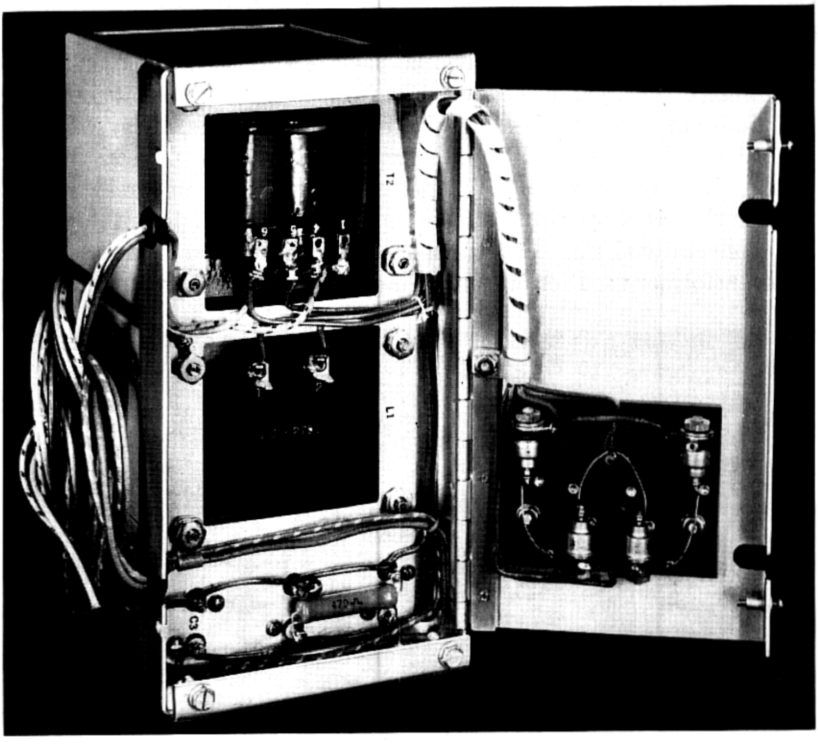

Fig. 6 — Typical unregulated rectifier, showing treatment of leads under hinged bottom cover.

TABLE III — HIGH-VOLTAGE REQUIREMENTS

Electrode	Voltage	Voltage Stability	Current Drain	Ripple (rms)
Anode	Adjustable, 2530 to 3100 volts	$\pm\frac{1}{2}$ per cent	0–1 ma	1.5 v
Helix	Adjustable, 2160 to 2610 volts or 1900 to 2200 volts	$\pm\frac{1}{2}$ per cent	0–1 ma	1.5 v
Collector	Fixed 1200 volts	± 2 per cent	45 ma	37.5 v

tials are derived by potentiometers connected to a regulated 2900-volt* dc bus. Feedback regulation is accomplished using a cold cathode gas tube for voltage reference, a two-stage electron tube amplifier, and a magnetic amplifier for control of the ac input voltage to a high voltage rectifier.

Silicon diffused junction diodes are used in a single-phase bridge circuit for high voltage rectification. Each arm of the 2900-volt rectifier bridge contains four diodes in series. The 1200-volt bridge has two series diodes per arm. Each diode consists of several diffused junction wafers bonded together by a thermal-compression technique. In this manner 2000 volts minimum reverse voltage blocking is achieved in a single

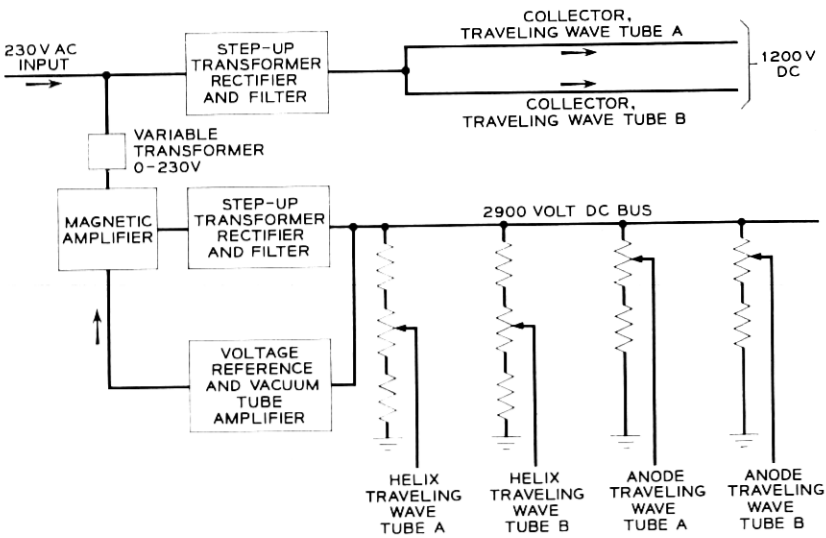

Fig. 7 — Block diagram of basic high-voltage power supply for traveling-wave tubes.

* This is the normal value. A few traveling-wave tubes require as high as 3100 volts on the anode.

two-terminal device. The transient peak inverse voltages due to random on-off switching of the ac input were carefully investigated. Peak transients of 3600 volts were found in the 1200-volt rectifier when ac power was removed at no load; the normal recurrent voltage peak is 2200 volts. Rather than add additional series diodes to block the 3600-volt transient peak, an RC network is connected across the transformer secondary winding. This eliminates transients in excess of the normal recurrent peak voltage.

After initial adjustment of the traveling-wave tube, the currents taken by the anode and helix electrodes are less than 1 ma, typically 0.1 ma. If, however, during the initial adjustment process or subsequent use the tube becomes defocused, destructively large current can flow to these electrodes. In addition, the major power dissipating element, the collector, which normally operates at 40 ma, can be damaged if the current exceeds 53 ma for a prolonged interval. To protect the tubes, an overcurrent detection and shutdown feature is provided on each of the six high-voltage outputs shown in Fig. 7. The circuit approach is outlined in Fig. 8. The current, I_H, delivered to the helix flows through the control winding of a small linear saturable reactor. The rectified output current, KI_H, of the saturable reactor is isolated from high voltage and is closely proportional to the helix current. This furnishes a safe and convenient means for measuring helix current at jacks J1 and J2. The current, KI_H, is the input signal to a bistable magnetic amplifier. The magnetic amplifier is normally biased such that no output signal exists

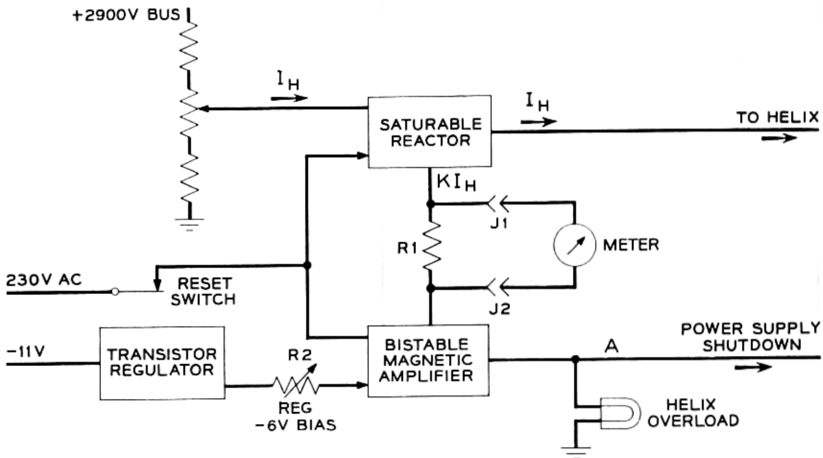

Fig. 8 — Circuit outline of overcurrent detection and shutdown feature.

on lead "A" for any helix current less than 2.5 ma. If, however, the helix current exceeds 2.5 ma, the bistable device is triggered on and a signal appears on lead "A" which automatically turns off the ac input power to the high voltage rectifiers. The helix overload signal remains on until the reset switch is actuated. The trip point is controlled by adjusting the bias current. The bias is derived from the 11-volt supply to the traveling-wave tube heaters and is stabilized at 6 volts by a transistor regulator. Should heater power be accidentally turned off, the loss of bias triggers on the bistable magnetic amplifier and protects the tubes by shutting down power. Similar circuits protect the anode and collector.

For further protection of the traveling-wave tube, a definite sequence is followed in the application of dc power. First the heater is energized, then the collector, and finally, after a five-minute warm-up interval, the helix and anode. The reverse order is followed for a normal turnoff. To facilitate initial tube alignment, a variable transformer ahead of the magnetic amplifier in Fig. 7 provides continuous manual control of the 2900-volt bus from zero to full voltage.

A three-position ac input rotary switch and a motor-driven timer are used to obtain the sequencing of the high voltages. No output is available in the first or OFF position of the switch. The second position turns on the 1200-volt collector supply. The third position starts a motor-driven timer which connects ac power to the 2900-volt rectifier after a five-minute delay. To avoid repetition of this delay on a momentary interruption of ac power, a 15-second pneumatic timer is arranged to bypass the five-minute delay if power is restored within 15 seconds.

The equipment design of the high-voltage power supply, shown in Fig. 9, presents a problem of packaging a mass of components operating at high potential within a small volume. This requires the recognition of areas where difficulties could arise due to dielectric breakdown, corona generation and personnel safety hazards. Also required is accessability to components to simplify maintenance and reduce the down time of equipment.

The entire supply is in a steel cabinet arranged for rack mounting. To utilize the volume available to the maximum extent, the dc supply is arranged in three packages consisting of a 1200-volt rectifier, a 2900-volt rectifier and a control unit which houses the ac input controls and the metering and overload protection circuit elements. As seen in Fig. 10, the individual equipment units are installed in the power supply cabinet using metallic slides on the chassis which mate with metallic guides in the cabinet. By disconnecting leads, units are removed individually for maintenance.

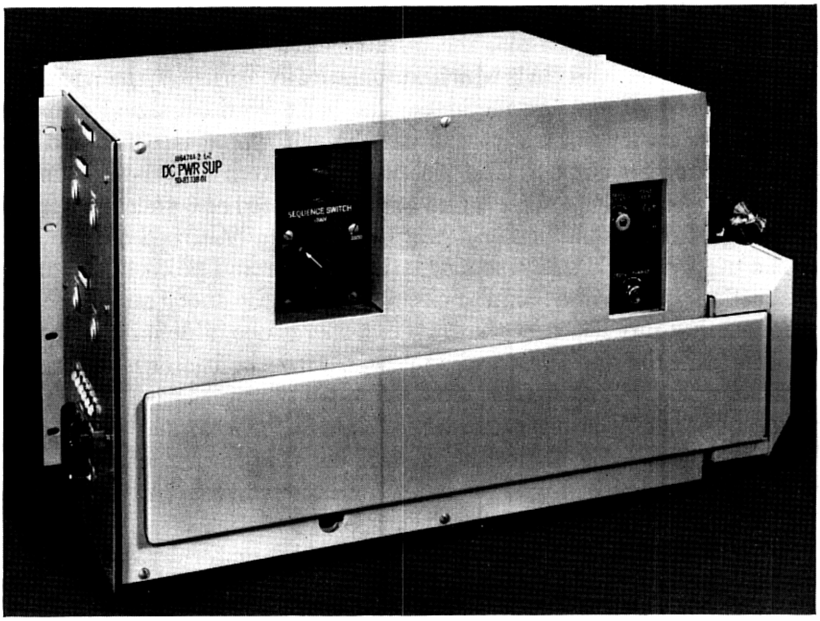

Fig. 9 — Equipment design of the high-voltage power supply.

To permit a compact mechanical design consistent with the high ac and dc potentials present, extensive use has been made of glass-fabric reinforced plastic molded chassis. This probably marks the first use of this construction for equipment chassis, although glass-mat covers have been used for some time on telephone answering sets and small power plants for subscribers' premises. These chassis make an important contribution toward the achievement of corona-free operation in equipments on a production basis. Forced air cooling is provided by a fan mounted on the side to minimize the temperature rise and obtain long life from the circuit components. In Fig. 10 the various equipment units may be seen partially removed from the cabinet. The control unit is at the left, the 2900-volt rectifier at the right, and the 1200-volt rectifier in the center.

In keeping with Bell System practices for personnel safety, several precautions have been observed in the equipment design of this power supply. The steel cabinet is arranged so that entry is not possible with the 1200 and 2900 voltages present. A mechanical key interlock system, similar to those used on TD-2 250-volt battery cabinets and the high voltage power supplies for the SB submarine cable systems, is employed.

The system requires that the rotary ac input switch previously described be locked in the OFF position before the door to the power supply or the cover to either of the two associated traveling-wave tube housings can be opened. Of course it is necessary that the door or covers be closed before ac power may be reapplied.

4.3 *Supplies for the FM Terminal*

Two power supplies were developed to meet the requirements of the FM terminal equipment. One of these supplies the heater, repellers and resonators of the two klystrons in the FM transmitter. The specific requirements are listed in Table IV. The heater requirement is satisfied with an adjustable, unregulated rectifier of the type described earlier. An electron tube regulated rectifier is employed to obtain +450 volts with high stability and low noise. The circuit consists of series triodes driven by a two-stage differential amplifier (electron tube) with cold cathode gas tubes for voltage reference. Until quite recently, it would not have been possible to achieve these operating requirements with a circuit of this simplicity because of the fluctuation and drift performance

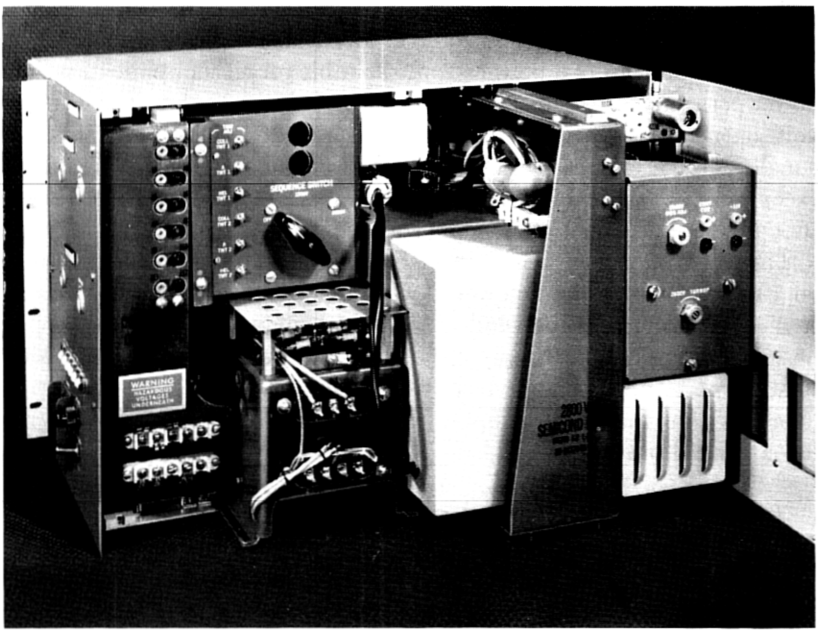

Fig. 10 — High-voltage power supply with various equipment units partially removed.

TABLE IV — REQUIREMENTS OF KLYSTRON SUPPLY

Tube Element	Voltage	Current	Voltage Stability	RMS Noise	
				½–30 cps	>30 cps
Resonator	+450	0.120 amp	±0.2 per cent*	0.5 mv	2 mv
Repeller	−170	0.004	±0.25 per cent*	0.7 mv	25 mv
Heater	−11	2.0	±2 per cent	17 mv	70 mv

* Limits apply to maximum voltage change due to line, load and 1000-hour drift.

of older voltage regulator tubes. However, tubes with adequate performance are now available.

The repeller output actually feeds two potentiometers in the FM transmitter from which independently adjustable repeller voltages are derived. It was not necessary, then, for the power supply to be adjustable to exactly −170 volts. By virtue of this factor and the constant nature of the load, it is possible to use a simple two-stage tandem VR tube regulator to satisfy the voltage stability and noise requirements.

The other FM terminal power supply furnishes the video and IF amplifiers, limiter, discriminator, AFC, etc. in either the transmitter or receiver. The similarity of the receiver and transmitter requirements led to the development of a power supply suitable for either application. The power performance is outlined in Table V. Both the −11-volt and +135-volt outputs are furnished by adjustable, unregulated rectifiers. An equally simple circuit could have been used for the +220-volt output except for the low noise specification. Instead, a conventional series tube regulated rectifier circuit was adopted.

The klystron supply is shown in Fig. 11. It is arranged for mounting on 19-inch cable duct frameworks. Opening the front doors permits access to the electron tubes and other components for maintenance purposes. Forced air from the bay cooling system is directed into the cabinet to supplement the cooling effect afforded by the grillwork in the supply doors. Within the power supplies extensive use is made of plastic grids for personnel protection.

TABLE V — PERFORMANCE OF TRANSMITTER-RECEIVER SUPPLY

Voltage	Current	Stability	RMS Noise	
			½–30 cps	>30 cps
+220	0.500 amp	±2 per cent	0.4 mv	2 mv
+135	0.375	±2 per cent	25 mv	15 mv
−11	10.0	±2 per cent	—	500 mv

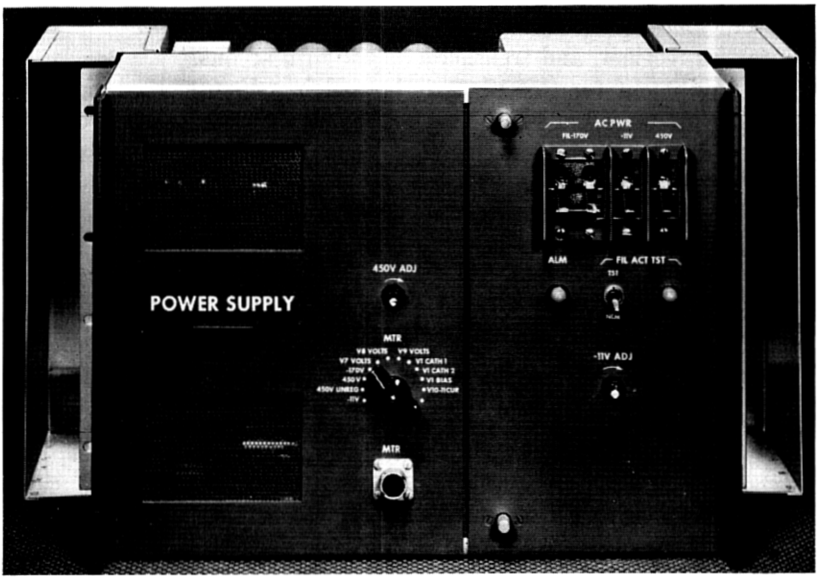

Fig. 11 — The klystron power supply.

4.4 *Power Plants for the Protection Switching Equipment*

A new power plant was developed to provide regulated +24 volts and −24 volts to the protection switching equipment. The requirements include:

Nominal voltage under full load	±23.9 volts
Long term voltage stability	±1.0 volt
Voltage deviation under emergency conditions	+1 volt to −3 volts
Ripple	<50 mv rms
Capacity	0–30 amp

This plant is designed on a centralized scheme using rectifiers on a building block basis for plant capacities of 10, 20 or 30 amperes for either the +24-volt or −24-volt applications. Magnetically regulated rectifiers are used with additional supplementary filtering to reduce the ripple level to within the specified limit. For an initial 10-amp load, two 10-amp rectifiers are furnished with each additional 10 amperes of load requiring an additional rectifier up to a maximum of four rectifiers per polarity. Each rectifier is connected to a separate firm ac bus for added reliability.

A relatively low capacity battery (100 ampere-hours) is provided to assure that the output voltage limits will be maintained under any transient or emergency condition, such as switching rectifiers on and off, failure of a rectifier, and transients on the firm ac bus.

The equipment for this plant is housed in self-supported eight-foot high floor mounted cabinets. The initial bay for each polarity contains the batteries, two rectifiers, controls, and charge and discharge fuses, and is rated at 10 amperes. The supplementary bay provides space for four additional rectifiers, two of each polarity, to build each plant out to its 30-amp capacity.

V. AUXILIARY ARRANGEMENTS

5.1 *Test Set Power Supplies*

In addition to the power arrangements described above, some special power supplies were developed for test equipment: (1) radio repeater test bench, (2) FM terminal test set and (3) protection switching test set.

The test bench is intended for use at maintenance centers remote from a working station. Commercial ac power is stabilized by a line regulator built into the test bench. With a regulated source of ac available, the dc power requirements are met by using dc power supplies already described for the radio equipment. The line regulator is rated at 5 KVA and arranged for nominal 208- or 230-volt input and 230-volt output. Regulation is by a motor-driven, variable transformer which is coupled to a "buck-boost" transformer in series with the output.

The FM terminal test set is mounted in a mobile bay and operates from convenience outlets for 117-volt ac power. Plate voltage is provided by two series tube regulated rectifiers which are adjustable from 200 to 300 volts dc and rated at 0.1 ampere. A ferroresonant regulated power supply furnishes heater power at 6.4 volts ac, 15 amperes, and 6.4 volts dc, 1.5 amperes. At constant load, the heater voltage is constant within ± 1 per cent for a ± 10 per cent variation in input voltage.

The protection switching test set, also mounted in a mobile bay, is equipped with two regulated rectifiers which furnish $+24$ and -24 volts. A single design suitable for either the positive or negative application is used. The output voltage is adjustable from 23.5 to 24.5 volts dc; it is stabilized within ± 1 per cent for ac input voltages of 117 volts ± 10 per cent, frequency 60 cps ± 2 per cent, and load 0 to 1.5 amperes. The output ripple is 40 mv rms. Regulation is accomplished with a series transistor, driven by a two-stage transistor amplifier and a silicon voltage reference diode. A ferroresonant regulator is built into the stepdown transformer preceding the rectifier portion of the circuit. This stabilizes the dc input voltage to the regulator against line voltage changes and reduces the maximum series transistor dissipation from 12.5 to 4.5 watts. The rapid decrease in output voltage with overload currents, characteristic of ferroresonant regulators, coupled with a bias circuit which maintains the series transistor in a saturated state, protects the series transistor from excessive dissipation if an overload is applied to the regulated dc output terminals.

5.2 *Lightning and Grounding Arrangements*

Radio and microwave relay facilities, by their nature and location, are vulnerable to lightning strokes to their antennas and towers, much more so than local and toll central offices. Therefore, at radio and microwave relay stations all the established engineering practices to achieve central grounding are supplemented by extensive measures to provide lightning protection for the operators of the equipment, the equipment and the building.

The effectiveness of the protection afforded to equipment and personnel is primarily a matter of creating a unipotential area by extensive interconnection of all components within the area. A basic grounding arrangement is shown in Fig. 12. At repeater stations the practice has

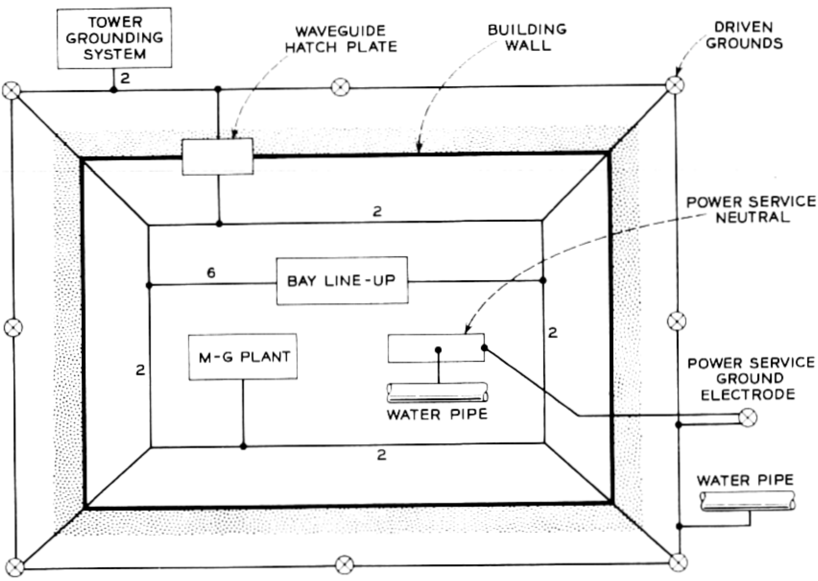

Fig. 12 — Arrangement of the basic building grounding system.

been adopted of providing a buried ring around the exterior of the building using #2 bare copper wire with driven grounds at intervals of ten feet. A similar ring within the building is provided at a convenient height, mounted on the walls or supported from cable racks; it is connected to the outside buried ground ring at several points. The ends of various equipment lineups are tied to this internal ring with at least #6 wire. These include the engine control bay, 508A motor alternator plant, 130-volt power bays, TH Radio Bays, tube cooling system equipment, conduits, miscellaneous radio bays and waveguides. The grounding arrangements for the self-supported tower at repeater stations are tied into the buried ground ring outside the repeater building to direct lightning strokes to ground by the shortest path. Unusual measures are taken to ground the waveguides at the waveguide hatch plates to both the internal and external ground rings. When a water pipe system is present it is bonded to the buried ground ring.

Power service to TH stations is of the three-phase four-wire type because of the heavy load. Two stages of secondary lightning protection are provided for the service leads. Secondary arrestors rated at 1750 volts to ground are connected from each phase to ground at the weatherhead on the service entrance. These arrestors have a spark-over value of 1600 volts. Branch circuit arrestors are connected across branch secondary circuits on the load side of low-capacity fuses. These branch circuit arrestors consist of nonlinear elements in series with a gap which sparks over at about 850–1000 volts. To insure the operation of the 1600-volt arrestors, the service leads must be in at least twenty feet of grounded conduit between the 1600-volt arrestor and the branch circuit arrestors. This length of conduit at lightning frequencies provides a beneficial choking effect to surge currents.

The power service neutral is grounded to the buried ground ring or water pipe system, when available, or to a separate grounding electrode if required by the power company. These three, if all are present, are bonded together.