The TL Radio Relay System

By S. D. HATHAWAY, D. D. SAGASER and J. A. WORD

(Manuscript received May 15, 1963)

The TL radio relay system is a telephone message broadband microwave facility that operates in the 10.7- to 11.7-gc common carrier frequency band. It has been specifically designed for high reliability, low maintenance and small power consumption by the exclusive use of solid-state circuitry except for the transmitter and local oscillator klystron tubes. Transmission performance and over-all system description are presented, as well as a description of some early field applications.

CONTENTS

I. INTRODUCTION

In the past, short-haul microwave radio relay development in the Bell System has progressed along the general lines of heavy-route, cross-country systems. The use of high towers on substantial plots of land located on prominent sites often requiring expensive access roads and power lines was typical. Buildings were sufficiently large to accommodate not only a large number of radio equipment bays but also 5- to 10-kilowatt rotating machinery to provide backup in the event of power failure. Radio equipment costs seldom approached one-half of the total costs of such repeaters.

Today, ideas originally proposed by the Radio Research Department of Bell Telephone Laboratories to reduce over-all microwave station costs have become a reality.[1] The TL radio relay is a new microwave system designed specifically for short-haul service. Low equipment costs, minimum engineering and installation effort, outdoor housing, low-cost antenna support structures, small power consumption, and moderate telephone circuit capacity all contribute to substantially lower over-all TL radio station costs. A high degree of reliability is provided by extensive use of solid-state circuitry, float-charged reserve battery power supply system, and simplified maintenance procedures.

II. OBJECTIVES

2.1 *Applications*

There are a great number of uses for a flexible, economical and reliable short-haul microwave system such as TL. It is intended to have applications in three broad areas: namely, short-haul toll or tributary trunk routes, supplementary circuits along heavier routes, and special service telephone routes. Nondiversity TL can provide economical relief of overburdened open-wire and cable routes. Additional possible applications of TL radio are: (1) open wire replacement, (2) difficult geographical situations, (3) suburban industrial areas, (4) metropolitan and intersuburban trunk groups, (5) routes for the military services, (6) alternate routing, (7) broadband or high-speed data services, (8) short-term or seasonal services, (9) emergency service restoration, (10) spurs on other routes, and (11) order wire and alarm circuits for existing heavy-route microwave systems.

2.2 *Development Objectives*

Concurrent with the beginning of the TL development program, a set of objectives was specified reflecting the best judgment at that time as to the features and capabilities necessary for the new system. These objectives have been reviewed and modified from time to time as the development of the new system progressed and, in most instances, the original requirements for the TL system have been met. The latest change in the requirement, for TL to transmit TV, is not reflected in TL at this time but will appear in later versions of this equipment.

2.2.1 *Frequency Band and Allocation Plan*

The TL system operates in the 11-gc common carrier frequency band and provides telephone message service for end-link or short-haul application. The TJ frequency allocation plan has been adopted, which permits the operation of six two-way TL channels on the same route with common antennas for transmitting and receiving. One-for-one frequency diversity has been provided on an optional basis.

2.2.2 *Telephone Message Capacity*

The TL system has been engineered to transmit 48 channels of N carrier, 96 channels of ON carrier or 300 channels of L carrier multiplex over 10 hops for a total distance of about 200 miles.

2.2.3 *DC Power Drain*

The TL system employs all solid-state circuitry except for the transmitter and receiver local oscillator klystrons, and requires 170 watts of power. The continuously charged battery power supply has sufficient reserve to carry the system for 20 hours under average ambient conditions in the event the ac power fails.

2.2.4 *Order Wire and Alarm*

A simple but effective order wire and alarm system has been provided for the TL system which will operate over the radio. This saving of space and equipment cost has been a substantial factor in the economy of the system.

2.2.5 *Economics*

One of the primary objectives of this development has been to provide system arrangements and operating features at the lowest first cost and annual charges consistent with meeting Bell System transmission requirements. Particular emphasis has been placed on equipment arrangements to minimize job engineering and installation expense. Suitable outdoor housing has been provided with its attendant savings in building and land costs. Ease of maintenance is of prime importance in its relation to annual charges, and equipment arrangements have been devised with this in view.

2.3 *Transmission Objectives*

2.3.1 *General*

The TL hops should be engineered to have a large carrier-to-noise ratio during periods of free-space transmission in order to provide adequate margin over first circuit noise during periods of signal attenuation caused by propagation, especially rainfall. Reliable protection against selective fades and equipment failure outage can be obtained with frequency diversity. Protection against rain attenuation can be assured by engineering sufficient fading margin into the system by using path lengths appropriate to the particular area of the country. Path lengths will range from 10 miles or less in the heavy rain areas to 25 to 30 miles in the dry areas.[2]

2.3.2 *Telephone*

The TL system should be engineered to meet short-haul toll circuit noise objectives of 31 dba at the 0-db transmission level point for 10 hops. This 31 dba includes both radio and multiplex terminal noise. Of this noise, 30 dba is assigned to the radio circuit and 24 dba allocated to the multiplex. Shorter systems should be engineered to correspondingly tighter over-all requirements so that if extended later to 10 hops, they would meet the 31-dba objective. Single-hop performance can be derived from the knowledge of how intermodulation and fluctuation noise add as the number of repeaters is increased. For the TL system, the total noise power increases proportionally with the number of repeaters.

2.3.3 *Stability*

The objective for the short-term net loss variations in a telephone channel is less than ±0.25 db, and the long-term net loss variations should not normally exceed ±1.5 db. These limits are necessary for the system to meet direct distance dialing and other similar Bell System requirements.

III. TRANSMISSION PLAN

The TL radio system offers a maximum of six two-way broadband channels. For radio systems paralleling other communication facilities or transmitting only a modest number of telephone circuits, TL may be used on a nondiversity basis. However, to provide the high degree of reliability needed for systems carrying large numbers of telephone circuits, one-for-one frequency diversity protection may be used, with automatic switching at each repeater offering a maximum of three two-way broadband channels.

The radio signals are transmitted to a dual polarized antenna by RF channelizing and duplexing arrangements. For repeater locations requiring high towers, it is expected that most systems will use a "periscope" type of antenna arrangement to minimize the loss associated with long waveguide runs. To meet these needs, five- and ten-foot paraboloidal antennas and 6 × 8, 8 × 12 and 10 × 15-foot reflectors are available. The paraboloidal antennas may also be used alone as direct radiators in those systems employing short towers on natural elevations.

A block schematic of a two-section, nondiversity TL system is shown in Fig. 1. The multiplex and control signals are combined through high-pass – low-pass filters and transmitted on the radio channel. At the receiver, similar filter arrangements separate the multiplex from the control signals. A 2600-cps pilot, continuously transmitted over the radio system, is used to determine the alarm status of the various repeater and terminal stations.

The TL frequency plan is shown in Fig. 2. Because of the expected use of the "periscope" antenna system, the plan is based on the use of four frequencies for each two-way radio channel. The 10.7- to 11.7-gc common carrier band is divided into 24 channels, each about 40 mc wide. In a given repeater section, only 12 of these are used, resulting in 80-mc spacing between midchannel frequencies. These channels are further divided into two groups of six for transmission in each direction. Polarization of the channels alternates between vertical and horizontal to provide 160-mc separation between signals having the same polarization, thereby substantially easing requirements on the channel-separation networks. The remaining 12 channel assignments are used in adjacent repeater sections. These frequencies are repeated in alternate hops. Potential "overreach" interference is reduced by reversing the polarization of the third section with respect to the first section. Co-channel interference from adjacent repeater stations is eliminated by the use of the four-frequency plan. At a given repeater, adequate frequency separation between transmitters and receivers is achieved by using the upper half of the band for transmitting and the lower half for receiving. This arrangement is inverted in adjacent sections.

Actual TL route cross sections may vary from a single two-way,

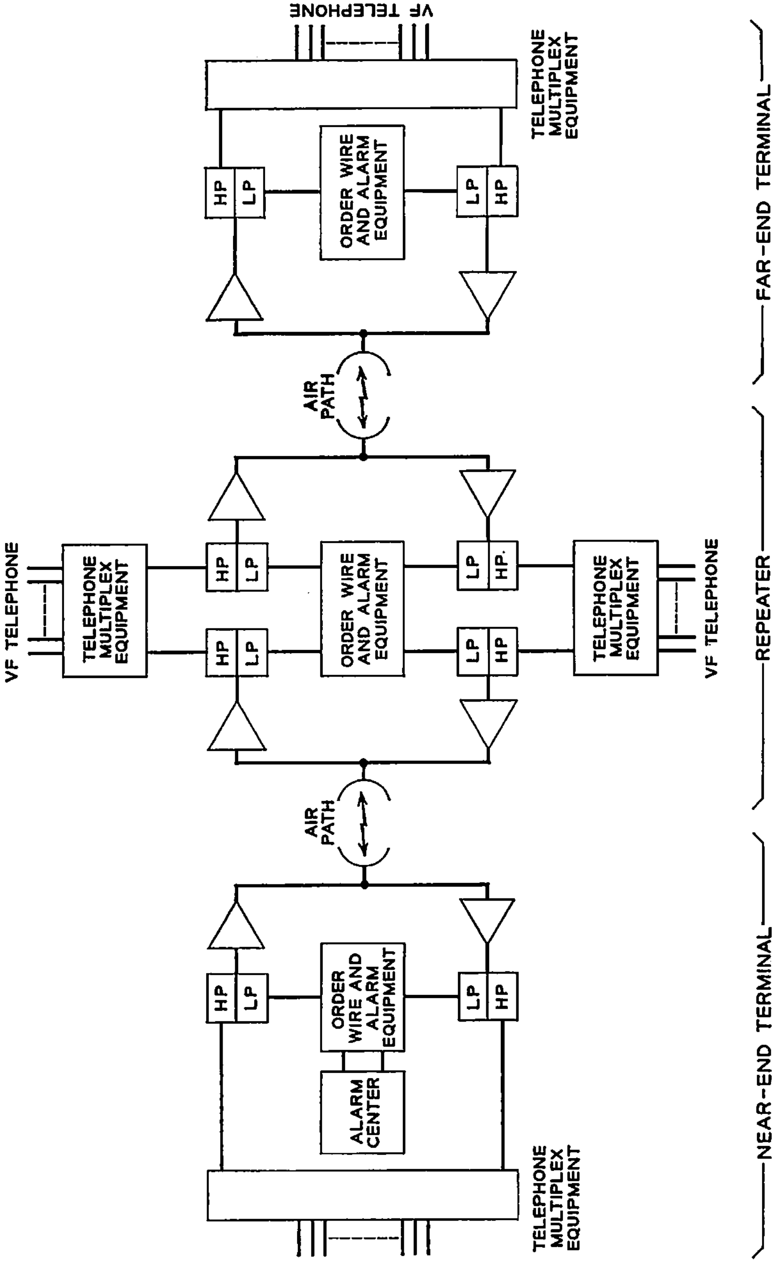
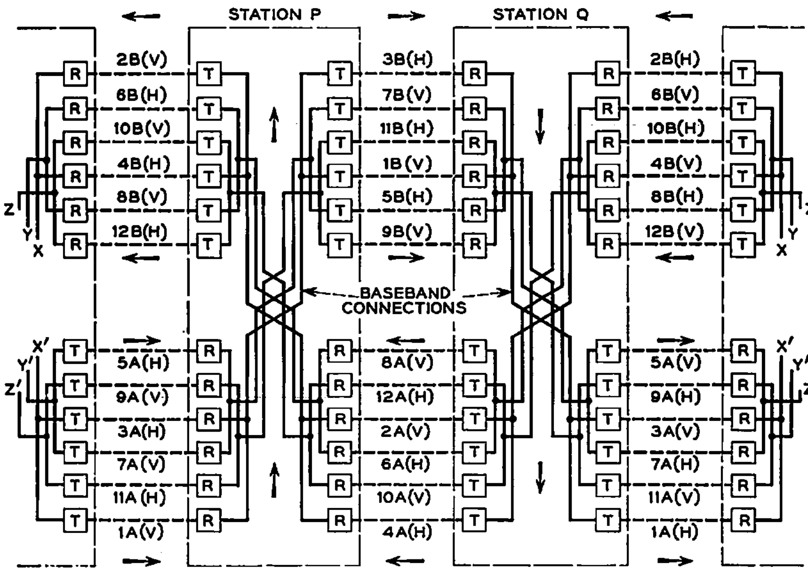


Fig. 1 — Block schematic of two-section TL system.



Channel Number	Transmitter Frequency, kmc	Beat Oscillator Frequency, kmc	Channel Number	Transmitter Frequency, kmc	Beat Oscillator Frequency, kmc
4A	10.715	10.785	9B	11.245	11.315
1A	10.755	10.825	12B	11.285	11.355
10A	10.795	10.865	5B	11.325	11.395
11A	10.835	10.905	8B	11.365	11.435
6A	10.875	10.945	1B	11.405	11.475
7A	10.915	10.985	4B	11.445	11.515
2A	10.955	10.885	11B	11.485	11.415
3A	10.995	10.925	10B	11.525	11.455
12A	11.035	10.965	7B	11.565	11.495
9A	11.075	11.005	6B	11.605	11.535
8A	11.115	10.045	3B	11.645	11.575
5A	11.155	11.085	2B	11.685	11.615

Fig. 2 — TL frequency allocation plan.

nondiversity channel up to a full system of three protected two-way channels. Additional radio channels may be added in the future to a diversity system whose initial requirements are less than its maximum capabilities without disrupting service on the working channels.

IV. SYSTEM DESCRIPTION

4.1 *General*

The basic unit of the TL system is the transmitter-receiver bay. It consists of a radio transmitter-receiver panel, an order wire and alarm

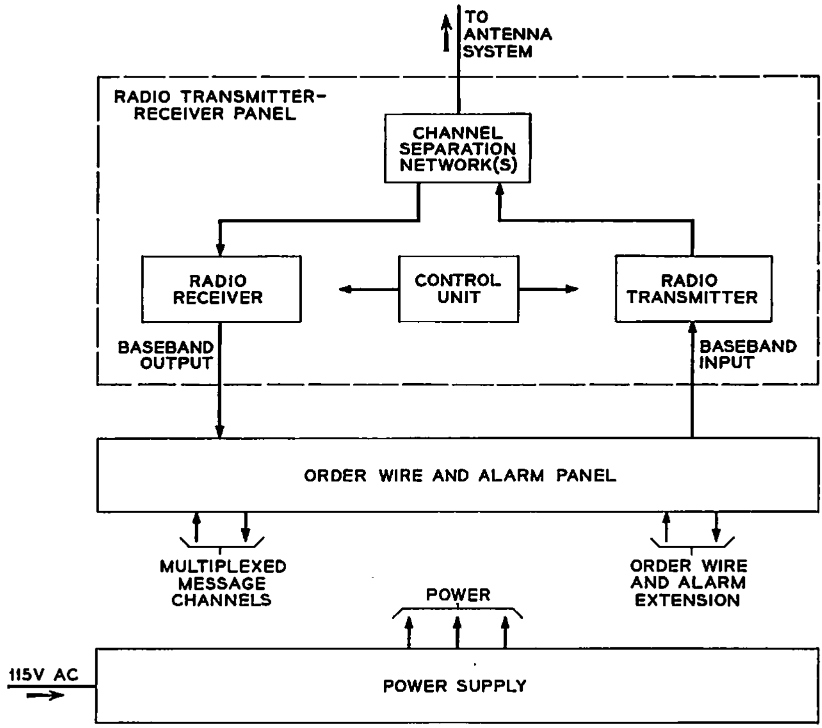


Fig. 3 — TL bay block diagram.

panel or a diversity switch panel, a power supply panel, and batteries. This equipment is mounted on relay-rack type framework for indoor installations or in a weather-proof cabinet for outdoor installations. With appropriate antenna systems, this basic unit forms a nondiversity terminal; two units may form either a nondiversity repeater, or a diversity terminal, etc., with only minor variations in the make-up of the bay. A block diagram of the basic bay is shown in Fig. 3. Fig. 4 illustrates how the basic bays may be interconnected at microwave frequencies by means of channel separation networks and a polarizer to form the minimum and maximum capacity terminals. A repeater would consist, in effect, of two terminals back-to-back with the receiver output from one bay feeding the transmitter of the other bay at baseband frequencies. These configurations are used for either frequency diversity or nondiversity systems. In diversity systems, one bay of a diversity pair would be on one polarization, the other on the opposite polarization.

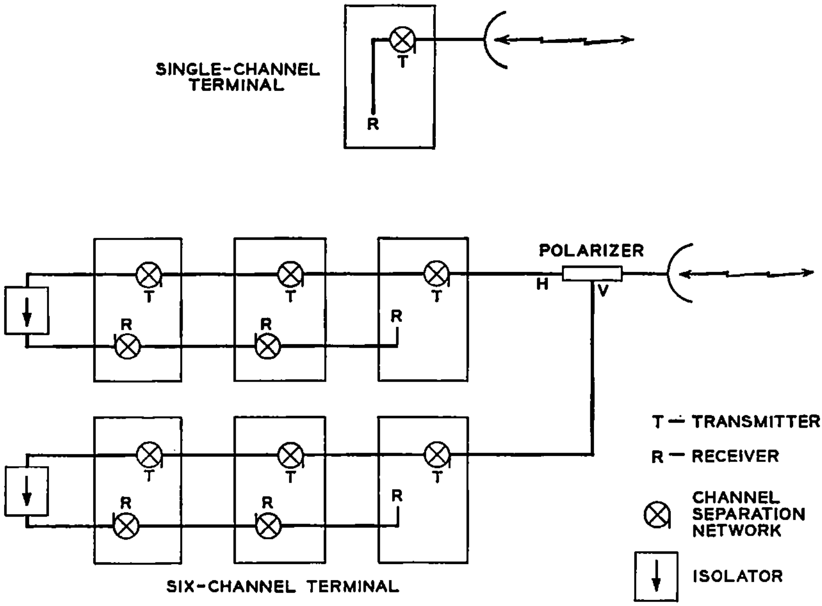


Fig. 4 — TL bay waveguide interconnection diagram

This permits waveguide maintenance on one group of bays without service interruption on the other. The bays would be identical except that one would contain a diversity switch; the other, the order wire and alarm panel for that channel.

To explain the operation of the basic bay in general terms, consideration will be given to the middle bay on vertical polarization of the six-channel terminal of Fig. 4. The vertically polarized received signal would be transmitted from the antenna essentially unattenuated through the following: (1) the port of the polarizer aligned with vertical polarization; (2) the three channel separation networks connecting the lower transmitters to the antenna system; (3) the isolator (purpose to be described later); (4) one receiving channel separation network; and (5) the path to the receiver in the selected bay through the receiving channel-separation network, it being tuned to this particular frequency. (The principle of operation of the channel separation networks has been described elsewhere.[3] Representative transmission characteristics of this waveguide network are given in Fig. 5).

In the radio receiver selected, the received signal is filtered and heterodyned with the output from a local oscillator to produce an intermediate

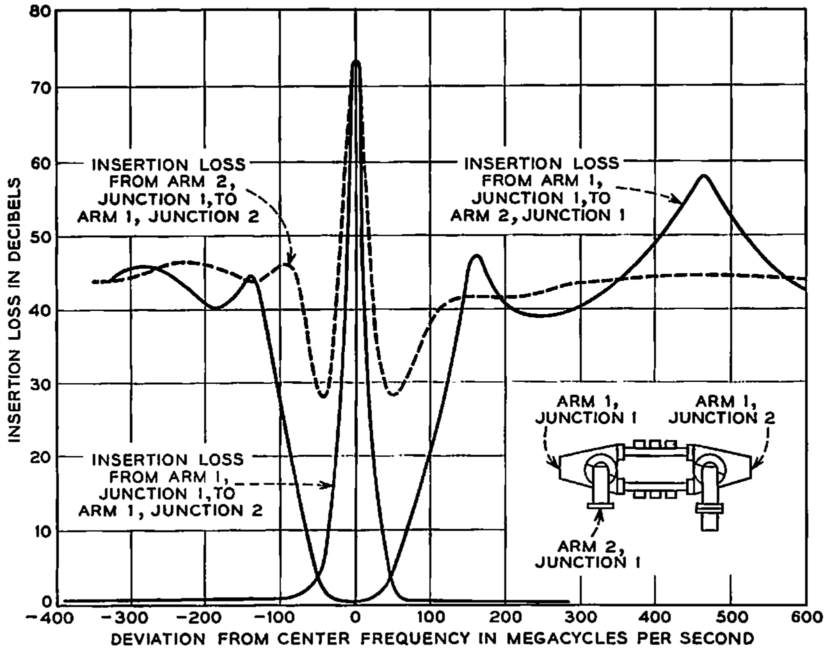


Fig. 5 — Transmission characteristic of channel separating networks.

frequency (IF) of 70 mc. The IF signal is amplified and detected to yield the original baseband intelligence, which is then further amplified. In a diversity system, the signal is then fed to the diversity switch, which selects either this signal or the one from the other receiver of a diversity pair to be applied to the order wire and alarm panel. In this panel, the baseband is split into two parts by high-pass–low-pass filters, the high frequencies being used for the multiplexed message channels and the low frequencies for order wire and alarm purposes. At a terminal, these portions of the baseband are applied to appropriate terminal equipment. At a repeater, any dropping or adding of message circuits that is desired is done at this point, and the order wire and alarm operations are performed. The two portions of the baseband are then recombined with another set of high-pass–low-pass filters and supplied to the transmitter, or transmitters for a diversity system, via a splitting pad.

A transmitter baseband amplifier increases the signal voltage to be applied to the repeller of the transmitting klystron. The resulting frequency-modulated RF signal is combined with outputs of the other transmitters by means of channel separation networks and connected to the antenna via the polarizer.

The baseband-type of repeater just described is especially useful and economical in short-haul microwave systems. Message circuits are frequently dropped at repeater points. Having the message multiplex frequencies available without requiring special terminal equipment, as would be required in an IF-type repeater, is economically advantageous. It also facilitates the order wire and alarm appearances.

4.2 *Radio Transmitter-Receiver*

The radio transmitter-receiver panel consists of the frequency-modulated (FM) transmitter, a heterodyne-type FM receiver, a control unit to provide certain metering and adjustment features, and one or more channel separation networks appropriate to the application of the bay. The radio transmitter section of the panel is shown in the more detailed block diagram of Fig. 6. The transmitter baseband amplifier is a three-stage feedback amplifier using Western Electric 15C germanium diffused-base transistors. It provides a nominal voltage gain of 31 db from the 75-ohm unbalanced input to the high impedance of the klystron repeller, supplying a maximum voltage of eight volts peak-to-peak required to modulate the klystron ±6 mc from rest frequency. Adjustable over a gain range of ±4 db to accommodate the modulation sensitivity of all klystrons, the amplifier has a frequency characteristic flat to ±0.4 db from about 100 cycles to 6 mc. A photo of the amplifier and a typical characteristic are shown in Fig. 7.

The transmitter output is obtained from a Western Electric 457A

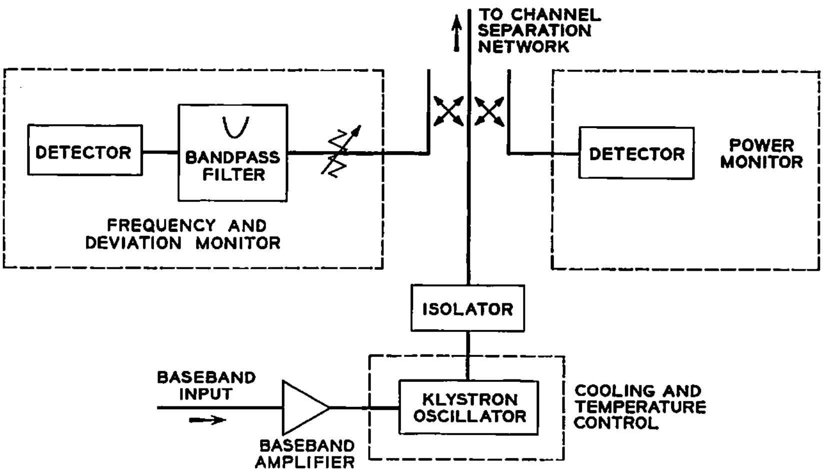


Fig. 6 — Transmitter block schematic.

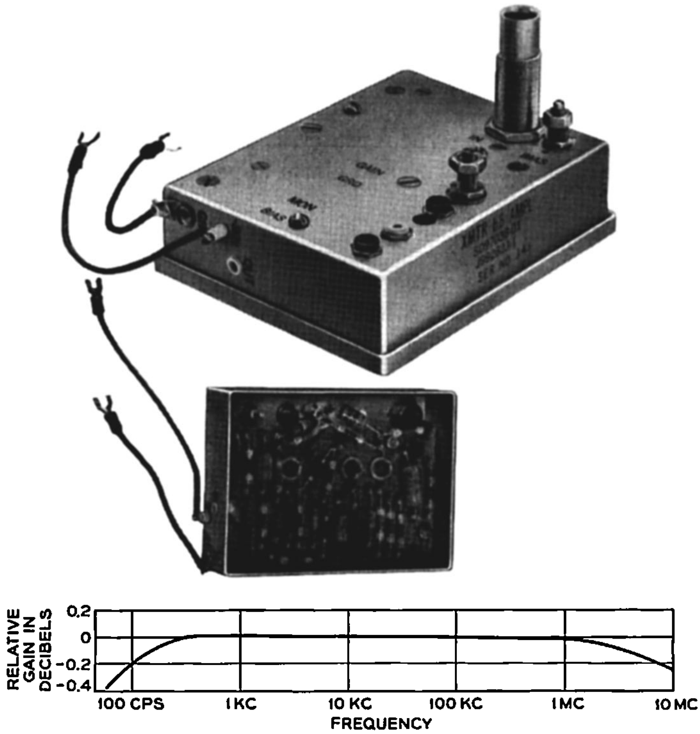


Fig. 7 — Transmitter baseband amplifier.

klystron oscillator, which is illustrated in Fig. 8. This tube was developed specifically for the TL system with special emphasis in the design on obtaining long life and a low frequency-vs-temperature coefficient.[4] The same tube is used for the receiver local oscillator. Since both tubes are operated in the $3\frac{3}{4}$ mode, only one set of voltages is required from the power supply. Typical operating characteristics are summarized in Table I.

The average dependence of the power output of the tube upon its operating frequency is shown in Fig. 8, from data on a typical tube.

The desired frequency stability for the transmitter and receiver is achieved by controlling three important parameters of klystron operation: (1) the frequency-temperature coefficient of the tube; (2) the electrode voltages; and (3) the klystron temperature environment. The first is determined by the design of the tube itself. A low coefficient of 0.15 mc/°F or less has been achieved. The second is accomplished by the design of an extremely stable power supply, aided by the fact that

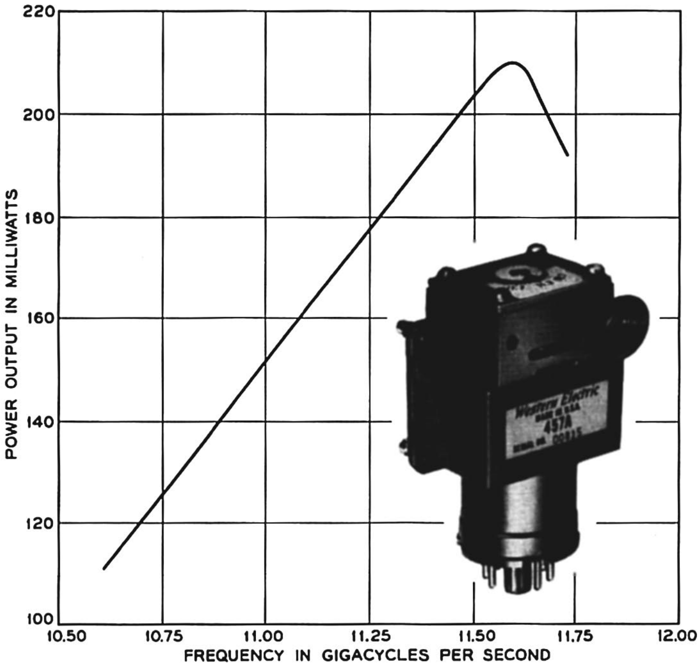


Fig. 8 — 457A klystron.

the voltage-frequency coefficients of the repeller and resonator of the tube are to a large extent canceling and that the small variation of the −600 and −400-volt outputs of the power supply, as a function of temperature, are in the same direction.

The third factor is controlled by an extremely well performing, yet

TABLE I — WE 457A KLYSTRON: TYPICAL OPERATING CONDITIONS

RF power output	100 milliwatts (minimum)
Resonator voltage	400 volts
Resonator current	40 ma
Repeller voltage	115 volts
Repeller modulating sensitivity	1.5 mc/volt (minimum)
Electronic tuning range	116 mc at 10.7 gc
	80 mc at 11.7 gc
Mechanical tuning range	10.7 - 11.7 gc
Repeller capacity	2.5 $\mu\mu$f, typical
Mechanical tuning sensitivity	1/3 mc/angular degree
Output	matched to WR90 waveguide
Heater current	0.9 amp
Heater voltage	6.3 volts
Oscillating mode	$3\frac{3}{4}$
Frequency-temperature coefficient	$<\pm 0.15$ mc/°F, mid-band
Anticipated life	$>$40,000 hours

simple and economical, cooling system called the "vapor phase cooler" (VPC). The system operates on the physical principle that a liquid boils at a constant temperature at a given pressure. If the heat input to the liquid increases or decreases, it simply boils more or less vigorously, but at the same temperature. In the TL VPC, the liquid is a fluorochemical which boils at approximately 214°F at sea level. It is contained in a small copper boiler designed to permit vigorous boiling of the liquid without restricting the flow of vapor out of the boiler into the condensing system or of the condensed liquid in the opposite direction. The two klystrons are clamped to the sides of the boiler for good heat transfer, as shown in Fig. 9. The heat input to the boiler is obtained from the dissipation in the klystrons, which is sufficient to keep the liquid boiling even at outside temperatures below −40°F. This is insured by enclosing boiler and klystrons in a well-insulated box. Heat transfer by conduction away from the boiler is minimized by using stainless steel tubing having low heat conductivity for connection between the boiler and the condensing system.

The condenser consists of a copper tube clamped to the aluminum panel on which the radio transmitter and receiver equipment are mounted. It thus has a large heat sink for dissipation of the heat released during condensation of the fluorochemical. The copper tube is terminated in a flexible neoprene compound bag, especially formulated to be resistant to passage of the fluorochemical gas through its walls and to remain flexible for many years without drying out with consequent cracking. The flexible bag permits substantial changes in volume of the enclosed system without appreciable changes in pressure. This satisfies the fundamental condition for a constant boiling temperature, even though there may be considerable changes in the heat input to the boiler. These changes are caused primarily by large variations in the ambient temperature.

The performance of the tube, power supply, and VPC system in maintaining good over-all frequency stability as a function of ambient temperature is illustrated in Fig. 10. This figure also shows the performance of the VPC system alone in stabilizing the klystron temperature. These data were taken on a run when the entire transmitter-receiver bay was exposed to the indicated temperature. Changes in barometric pressure of 2 inches of mercury would cause corresponding changes of operating temperatures of approximately 3.5°F.

The body of the klystron, being clamped to the boiler, is operated at ground potential. This minimizes exposure to high voltage on the part of operating personnel and eliminates the necessity for protective interlock switches. Precautions against klystron damage by positive repeller-

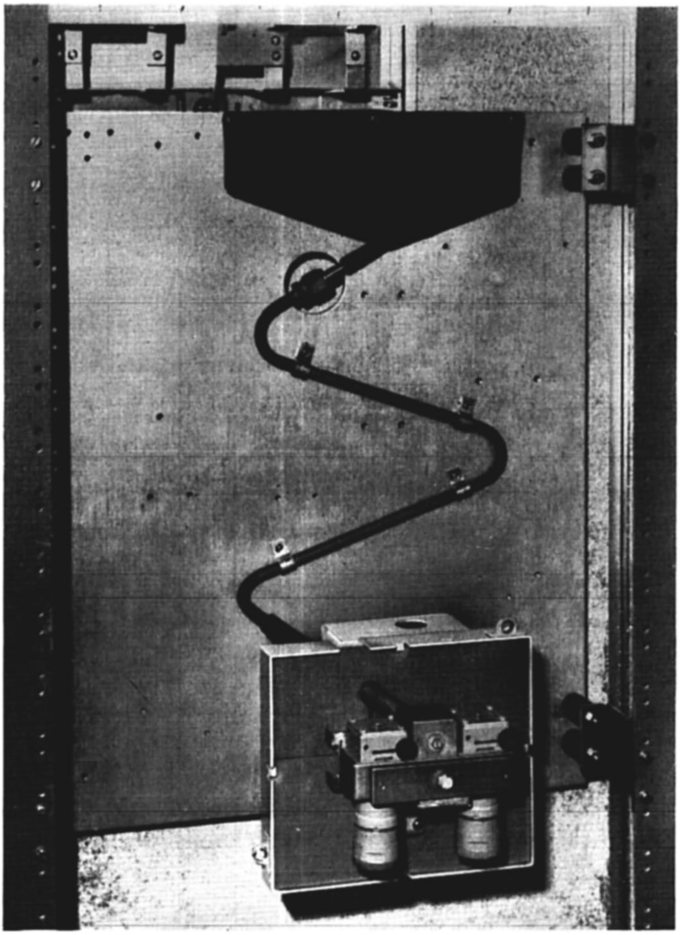


Fig. 9 — Klystrons and vapor phase cooling system.

to-cathode voltage have been included in both the transmitter and receiver klystrons in the form of clamping diodes between these electrodes.

The output of the transmitter klystron is first fed through a Western Electric 1B isolator, shown in Fig. 11. This high-performance field displacement type ferrite device practically eliminates any effect on linearity of frequency-changes vs repeller-voltage-changes caused by reflections in the antenna feed. Performance characteristics of the isolator are shown in Fig. 12.

Connected to the output of the isolator is a 20-db double directional

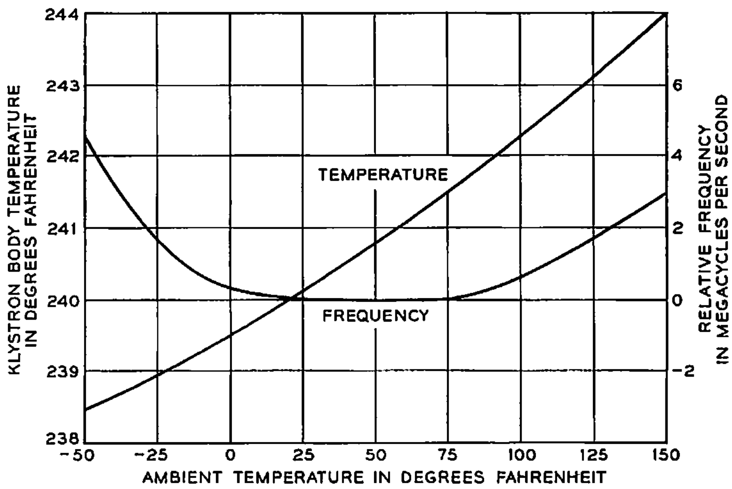


Fig. 10 — Frequency stability of 457A klystron, power supply and VPC vs ambient temperature.

coupler which gives two samples of the transmitted energy for monitoring purposes. One sample is immediately detected for power monitoring; the other is transmitted through a calibrated attenuator, high-Q cavity filter, and then to a detector for frequency monitoring and deviation adjustment purposes. This latter function will be described in the section on maintenance and test equipment.

From the output of the directional couplers, the transmitted signal is applied to the antenna system via the channel separation networks previously described.

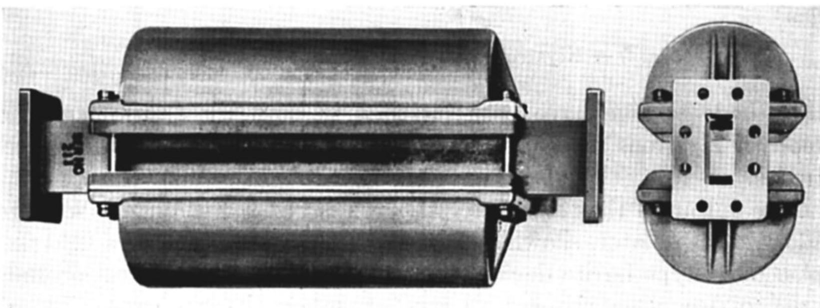


Fig. 11 — Isolator.

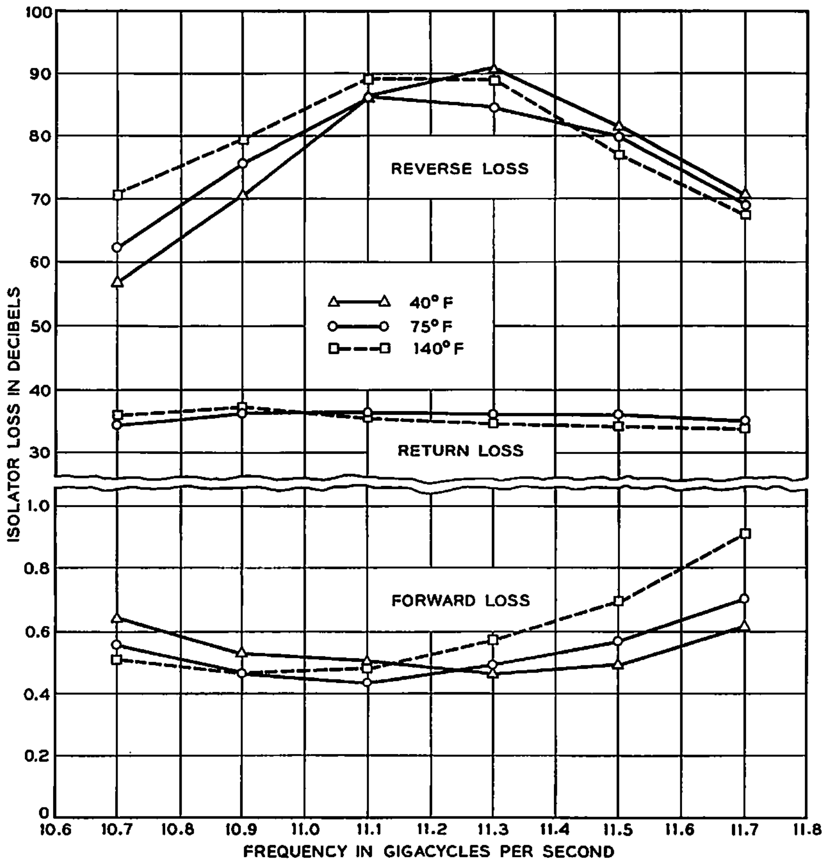


Fig. 12 — Forward and reverse loss characteristic of the 1B isolator.

The radio receiver section of the transmitter-receiver panel is shown in Fig. 13. The incoming RF signal from the antenna is selected and routed by the channel separation networks to the proper receiving modulator through a bandpass filter, a waveguide tuner, and a waveguide spacer. The filter provides attenuation to interfering out-of-band signals, and improves the noise figure of the modulator by reflecting out-of-band modulation products back into the converter in the proper phase. The proper phase relationship is maintained at the different channel frequencies by choosing a suitably dimensioned waveguide spacer, which determines the electrical path length traversed by the modulation products between the converter and filter. The modulator input im-

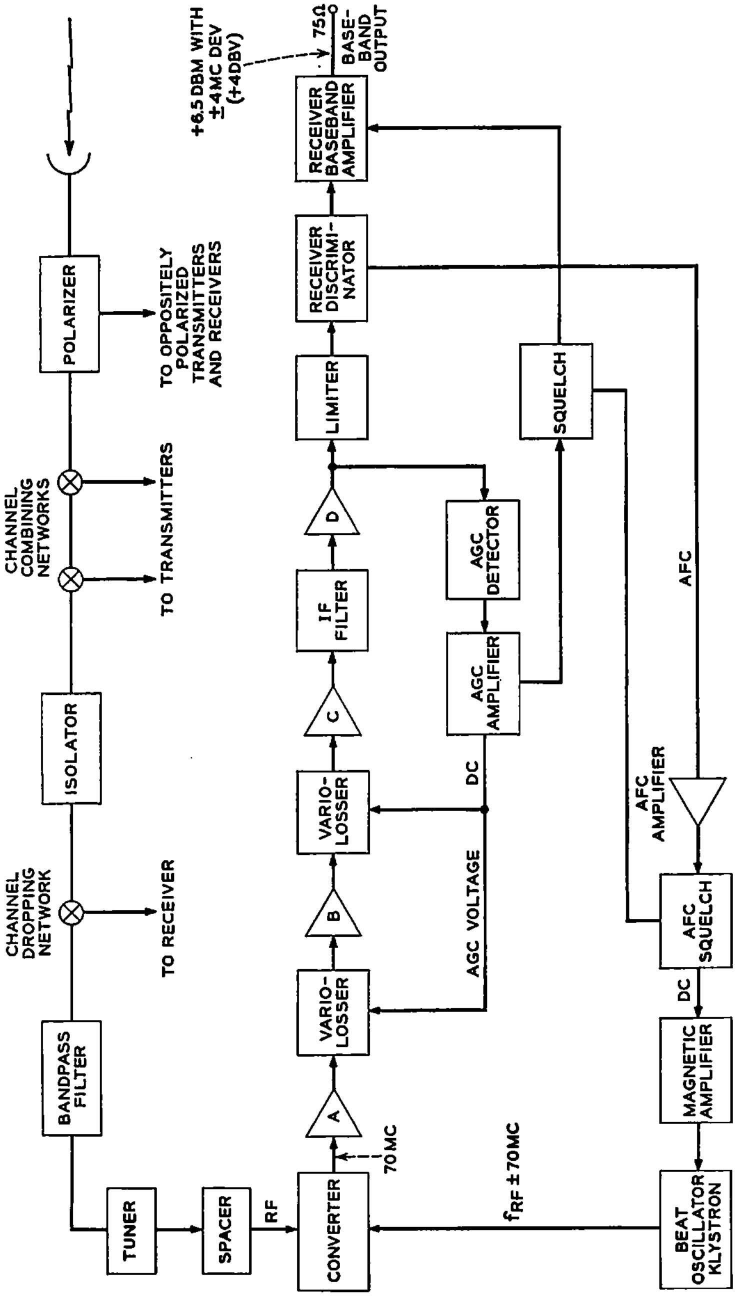


Fig. 13 — Receiver block diagram.

pedance must be closely matched to the waveguide impedance to minimize reflections between the bandpass filter and modulator input. This is achieved by the adjustable two-stub tuner located between the bandpass filter and the converter.

Two types of bandpass filters are used, one having three, and the other four, resonant cavities. As shown in Fig. 4, the last receiver in a bay line-up does not require a channel dropping network, since at this point the number of RF channels has been reduced to one. In this last receiver, the out-of-band attenuation not provided by the channel separation network is obtained by using a four — rather than a three — cavity bandpass filter. Typical transmission characteristics of the two types of filters are shown in Fig. 14.

The modulator is a balanced hybrid junction assembly having diodes in the junction reversed with respect to each other. The balanced structure greatly reduces noise from the local oscillator; the reversed diodes permit paralleled unbalanced output connections, giving the desired 75-ohm unbalanced coaxial output at 70 mc. Waveguide inputs are provided for the incoming signal and the local oscillator input, as shown in the schematic of Fig. 15.

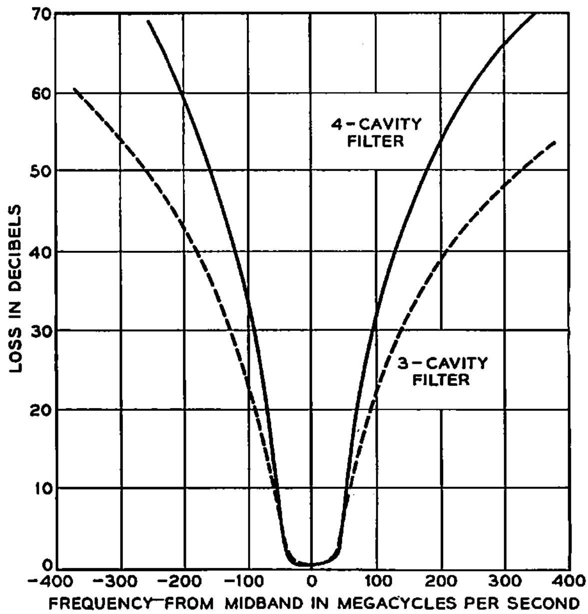


Fig. 14 — Transmission characteristic of receiving bandpass filter.

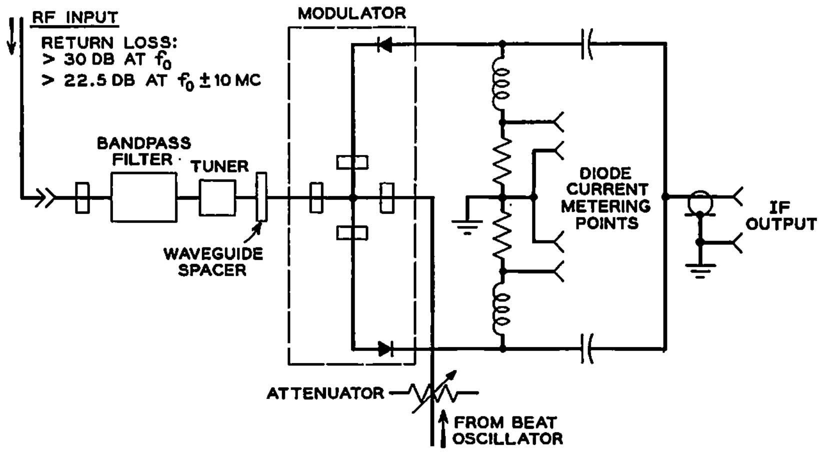


Fig. 15 — Receiving modulator schematic.

As mentioned above, the local oscillator is a Western Electric 457A klystron operated in the same fashion as the transmitting klystron. It feeds the modulator through an adjustable attenuator and two waveguide-to-coaxial cable transducers for mechanical convenience. The attenuator permits adjusting the power input to the modulator to approximately 0 dbm. The hybrid balance of the modulator limits the local oscillator leakage back towards the bandpass filter to −25 dbm. The frequency plan is such that this leakage causes no interference in the receivers on the same polarization (see Fig. 4). To avoid beating oscillator interference with receivers on the opposite polarization, a 1B isolator is placed in the waveguide path of a four- or six-bay line-up to sufficiently reduce the level of the leakage from the beating oscillator. The frequency of the beating oscillator is maintained at 70 mc from the incoming signal by means of the AFC circuit described below.

The 70-mc, frequency-modulated output from the modulator is first amplified and regulated in level in the preamplifier section of the IF and baseband unit.[5] The preamplifier consists of three sections of broadband transistor amplifier stages with two diode variolossers dividing the three sections. The variolossers are controlled to maintain a nearly constant input to a delay-equalized bandpass filter separating the preamplifier from the main IF amplifier. The filter limits the bandwidth of the receiver to 20 mc at the 3-db down points. The main amplifier increases the signal level sufficiently to be limited by a Ruthroff-type limiter[6] for amplitude modulation suppression. The signal is then detected by the discriminator and is amplified by the receiver baseband amplifier. The gain of the receiver baseband amplifier, adjustable by approximately ±2.5 db, is such as to deliver +10 dbm to the 75-ohm unbalanced load with a frequency deviation of ±6 mc.

Two dc amplifiers and a squelch circuit are also included in the IF and baseband unit. One is the AGC amplifier, which applies the detected and differentially compared output of the main IF amplifier to the vario-lossers; the second is the AFC amplifier which supplies the dc output of the discriminator (a measure of the position of the incoming carrier in the IF band) to other circuitry for control of the receiver beating oscillator. The output of the AGC amplifier is a measure of the received signal strength. This voltage is used to actuate the comparator circuit of the diversity switch in a diversity system. The squelch circuit operates from the AGC output and biases off the first stage of the receiver baseband amplifier when the receiver input level falls below a predetermined low level. This avoids the possibility of the high baseband output noise, characteristic of an FM receiver with no input, from interfering with other aspects of system operation, such as interfering with other message circuits that might be introduced into the system at some subsequent repeater. The level at which the squelch operates is adjustable, but is normally set to operate at a receiver RF input of −83 dbm.

Automatic frequency control of the receiver beating oscillator is achieved by first applying the AFC amplifier output to the control winding of a magnetic amplifier, as shown in Fig. 16. The power input to the magnetic amplifier is an 1800-cps square wave obtained from the power supply. The output is rectified and applied in series with the nominal −200 volts, supplied by the power supply between the resonator and

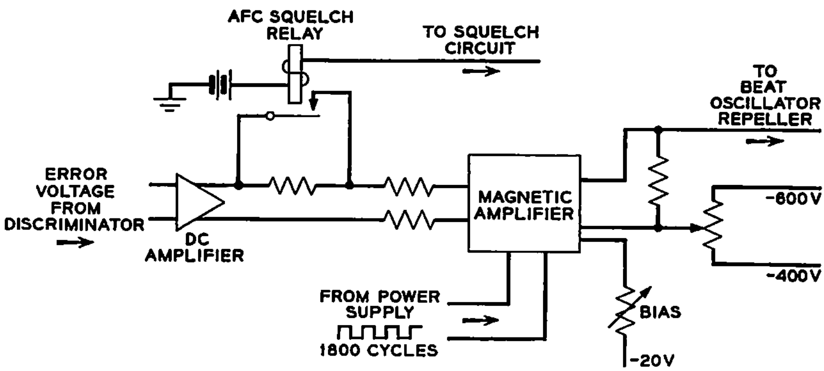


Fig. 16 — Receiver AFC functional schematic.

the repeller of the klystron, in proper phase to form a stable feedback loop and maintain the intermediate frequency essentially at the discriminator crossover frequency. If the crossover frequency is not at exactly 70 mc, an adjustable bias in the AFC amplifier input corrects for the slight error. The magnetic amplifier is particularly applicable here because it readily provides the isolation required between the approximately −600 volts of the repeller circuit and the low voltage of the AFC amplifier, and at the same time provides dc amplification. The magnetic amplifier has a nominal transfer impedance of one megohm and has an overload characteristic designed to act as a clamp on the AFC. This limits the output voltage to a value such that the receiver beating oscillator frequency cannot be changed to such an extent that the receiver can lock onto signals of the adjacent channel. The AFC loop has a gain of approximately 32 db, thus reducing a potential frequency change of, say, 5 mc caused by transmitting and receiver beating oscillator klystron changes, to an actual change in the receiver IF of 125 kc. The characteristic of the AFC loop from discriminator output to beating oscillator repeller voltage is shown in Fig. 17. Since the frequency of the beating oscillator may be below or above the incoming signal frequency, depending upon the particular channel, a phase reversal must be available in the AFC loop to adjust for the condition

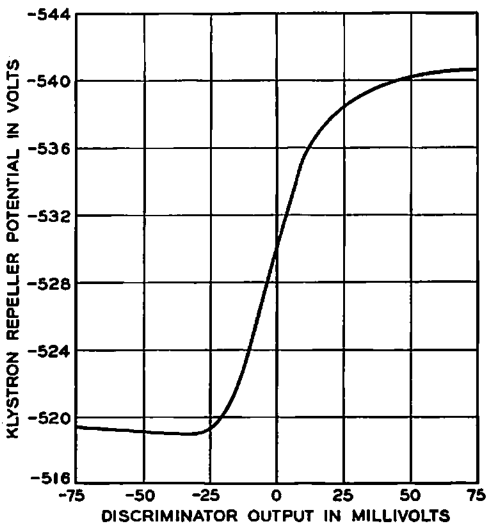


Fig. 17 — Characteristic of AFC loop.

that obtains. This is made by an optional turnover in the wiring of the balanced input to the magnetic amplifier.

When the receiver loses its input signal for any reason, the preamplifier gain goes to its maximum value as the vario-lossers are driven to their minimum loss condition by the AGC amplifier. This causes a high noise output from the discriminator. The dc output from the discriminator in this condition may not be exactly zero, since the noise or the discriminator may be slightly unbalanced. Furthermore, a correction for the crossover frequency not being at exactly 70 mc may have been introduced by the adjustable bias in the AFC amplifier input. To avoid having the resulting residual dc output from the AFC amplifier swing the beating oscillator frequency away from its normal rest frequency, an AFC squelch relay is introduced. This relay is controlled by the previously described squelch circuit. Normally operated (when a received signal is present), the relay releases upon loss of signal and inserts a large series resistor at the input to the magnetic amplifier, greatly reducing the AFC loop gain. This permits the beating oscillator to remain fairly close to its normal rest frequency, so that the signal to the IF amplifier will be within the IF passband when it reappears and will be captured by the AFC circuit. At the same time, some AFC control is retained so that system operation will not be seriously affected should the squelch circuit or relay malfunction.

The IF and baseband unit is shown in Fig. 18. It is made up of four subassemblies: (1) the preamplifier section; (2) the filter section; (3) the IF main amplifier section; and (4) the limiter, discriminator, and baseband amplifier section. Each subassembly, H shaped in cross section, has the transmission elements in one side of the H and the dc supply section on the opposite side. Power is fed to the transmission section through feed-through capacitors. The signal progresses back and forth through the four sections; maximum shielding is obtained by placing transmission components on opposite sides of adjacent sections. The complete unit is easily removable for maintenance. All connections are through plugs and jacks.

The third major component of the transmitter-receiver panel is the control unit. This plug-in unit (see Fig. 19) contains the components required for controlling the transmitter and receiver, testing and monitoring important operating parameters, and powering the klystrons. It also contains the magnetic amplifier and squelch relay of the receiver AFC circuit. A detailed description of the monitoring and control features will be found in the section on maintenance and test equipment.

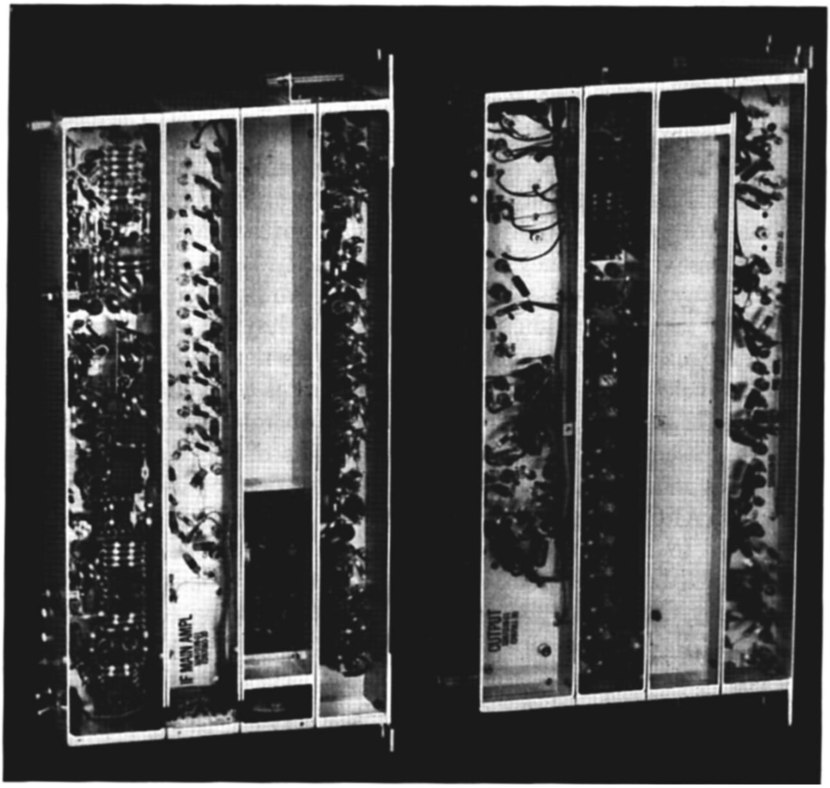


Fig. 18 — IF and baseband unit.

4.3 *Diversity Switching Arrangements*

4.3.1 *General*

It is expected that there will be many applications of TL radio which take advantage of the most economical arrangement possible, that of the nondiversity system. However, where the additional reliability is required, a one-for-one frequency diversity system provides protection against service interruptions caused by multipath fading and equipment failures. In addition, alternate facilities are then available during maintenance periods. With diversity, these periods can be scheduled at convenient times.

The unit which selects the better of the two radio channels for diversity operation is the diversity switch panel (Fig. 20). At each repeater

Fig. 19 — Control unit.

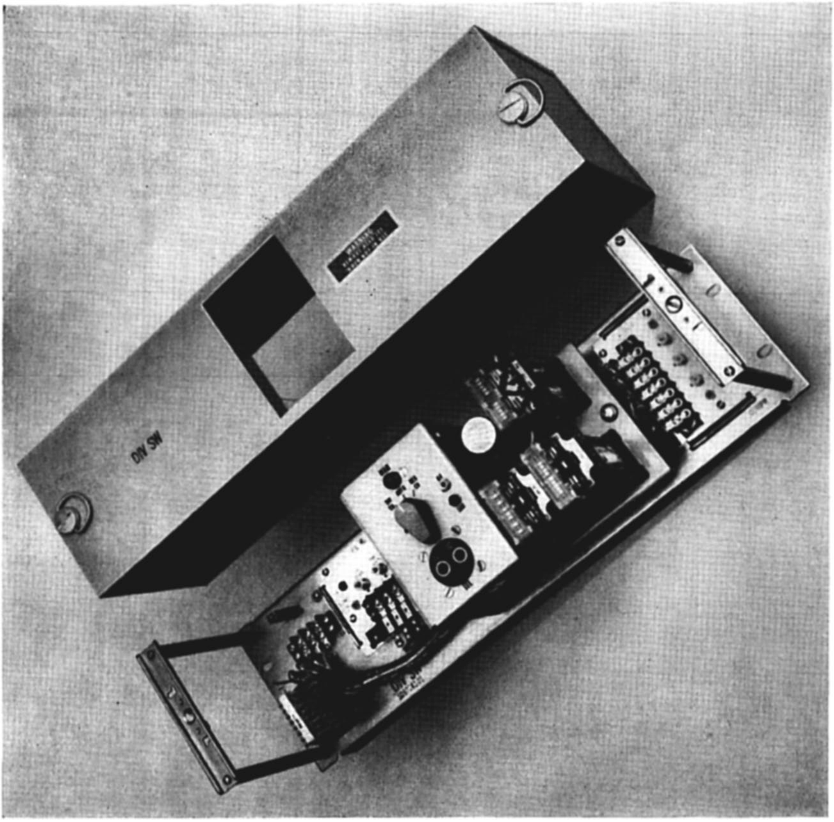


Fig. 20 — Diversity switch panel.

station, this panel selects one baseband output from the two receivers and in turn supplies the selected output to the order wire and alarm panel. The signals are split by means of a three-way pad and applied simultaneously to two transmitters operating on two frequencies separated by 240 mc. The selection of the better signal from the receiver output is controlled by a logic circuit utilizing information from two pilot monitoring circuits and a signal comparator circuit.

4.3.2 *Detailed Description of Diversity Switch Panel*

A block diagram of the diversity switch panel is shown in Fig. 21. A pilot monitor having a high impedance input is bridged across the baseband output of each radio receiver to sense the presence of the 2600-

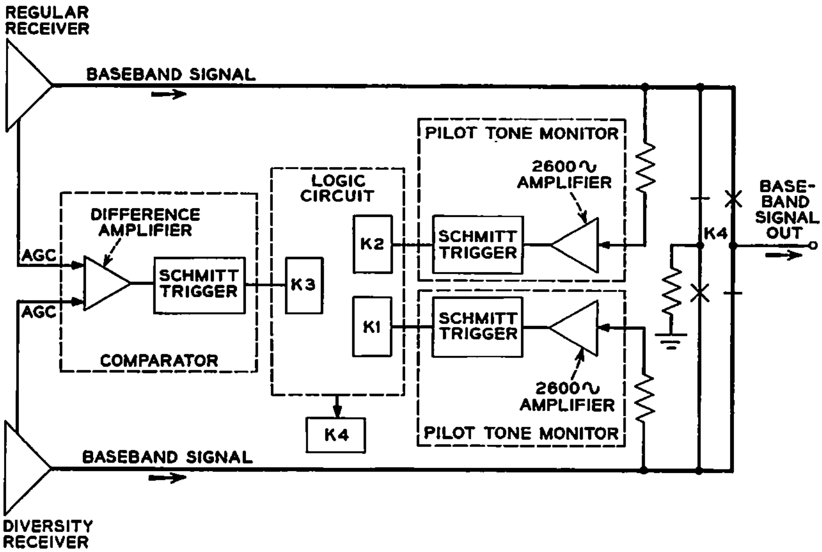


Fig. 21 — Block diagram of diversity switch panel.

cps pilot tone transmitted over the system for alarm and switching purposes (described fully in Section 4.3). Each monitor consists of a feedback amplifier, a full-wave rectifier, and a bistable trigger circuit. The amplifier uses three diffused-base silicon transistors in the common emitter configuration with a sharply tuned 2600-cps network in the beta circuit, removing most of the feedback at this frequency. The output of the resulting highly selective 2600-cps amplifier is rectified in a bridge rectifier. An adjustable dc voltage of the opposite polarity is added to the rectifier output, and the result is applied to the trigger circuit. The trigger circuit then controls a relay in the logic circuit. Improper operation of the pilot monitor from 2600-cps components of talkers on the order wire circuit is prevented by band elimination filters which remove those components at each head set connection. A functional schematic of the pilot monitor and its characteristics are shown in Fig. 22.

The comparator circuit compares the received signal level of the two radio receivers by means of the receiver AGC voltages. A difference amplifier, sensitive to the difference between the AGC voltages but insensitive to the absolute values, provides a dc output voltage, the magnitude of which is a function of the relative signal strength being received by each receiver. The output voltage controls a trigger circuit; it in turn controls a relay in the logic circuit. Controlled hysteresis in the trigger circuit avoids excessive switching on minor differences in signal level.

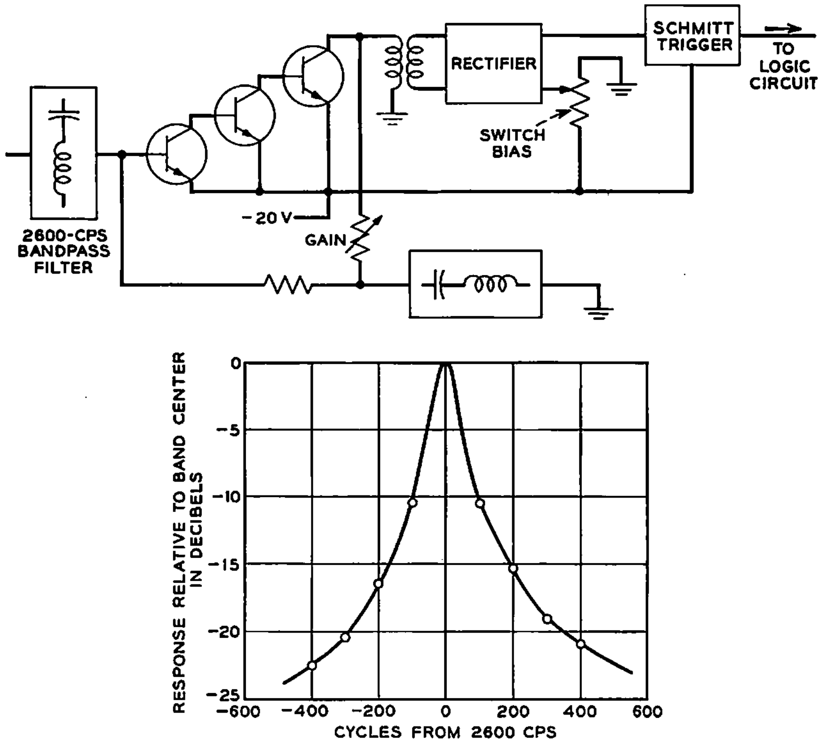


Fig. 22 — Functional schematic and selectivity characteristic of pilot monitor.

A simplified schematic of the comparator and its characteristics are given in Fig. 23.

The information supplied to the logic circuit from the two pilot monitors and the comparator is sufficient to determine which of the two receivers should be connected to the succeeding transmitters. Table II gives the system conditions and the resulting signal to the diversity switch.

If the pilot tones are present or absent simultaneously on both channels, fading controls the switch; if the pilot tone is absent on one channel, fading is disregarded. Removal of the pilot tone from both channels simultaneously for signaling or alarm purposes does not cause a switch. A manual control is also provided to permit a maintenance man to select either receiver output without regard to pilot or fading conditions.

The switch itself is a wire-spring relay with make-before-break contacts. During switchover, the contacts are bunched for approximately

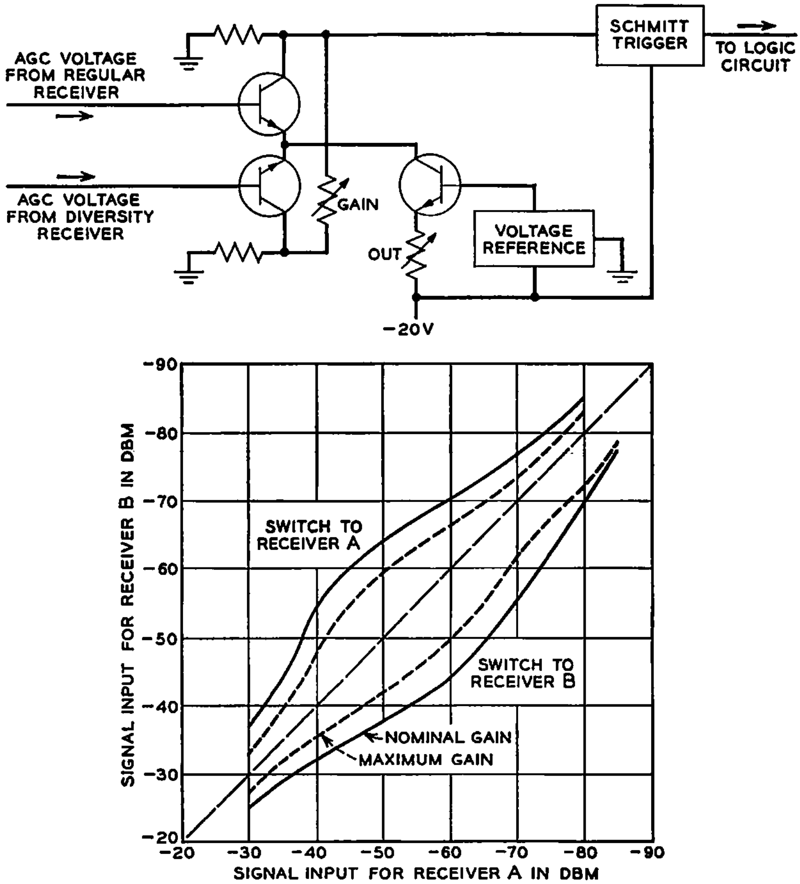


Fig. 23 — Functional schematic and operating characteristic of comparator.

Table II — Logic Table for Diversity Switch

Regular Pilot Tone	Diversity Pilot Tone	Signal Level in Regular Channel	Signal Level in Diversity Channel	Switch Instruction from Logic Circuit
Present	Present	Faded	Normal	Switch to diversity channel
Present	Present	Normal	Faded	Switch to regular channel
Present	Present	Same as diversity	Same as regular	No switch
Absent	Absent	Faded	Normal	Switch to diversity channel
Absent	Absent	Normal	Faded	Switch to regular channel
Absent	Absent	Same as diversity	Same as regular	No switch
Present	Absent	Any condition		Switch to regular channel
Absent	Present	Any condition		Switch to diversity channel

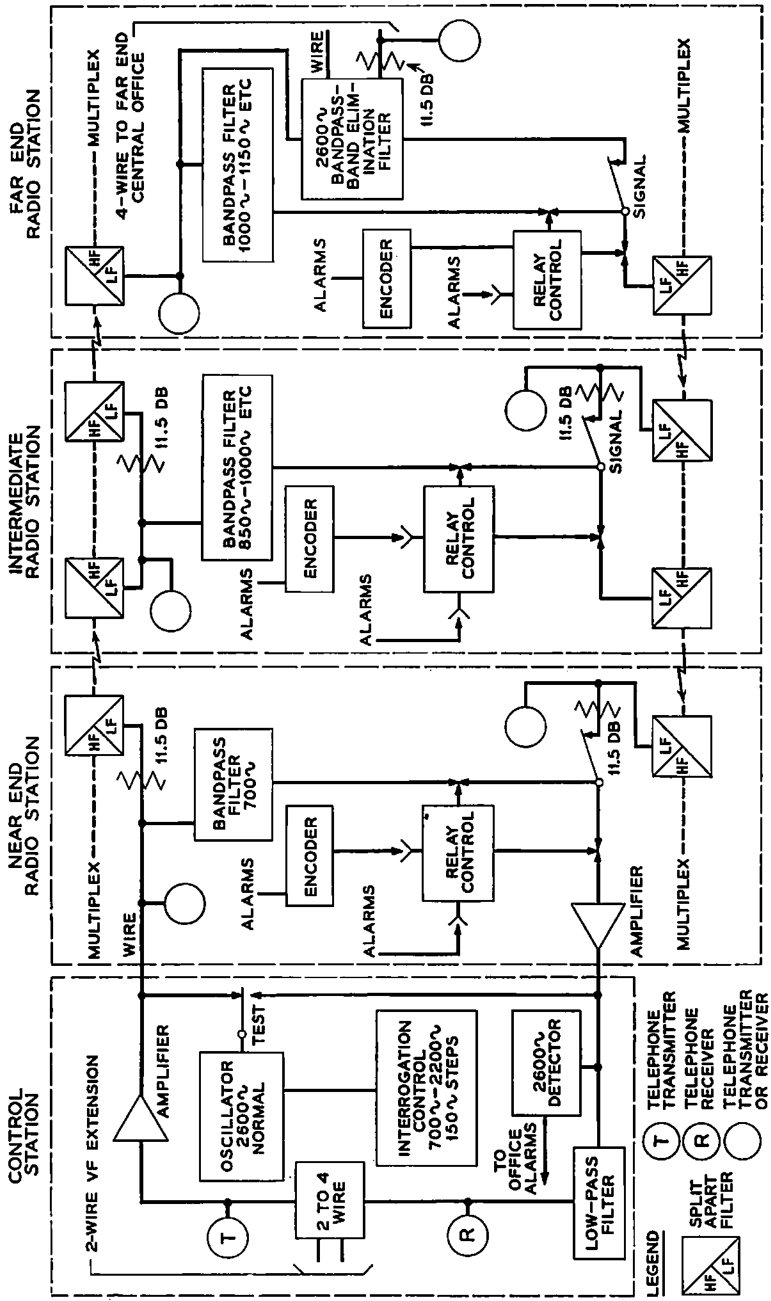


Fig. 24 — Order wire and alarm block diagram.

one millisecond, paralleling the outputs of the two receivers. If the receiver outputs are in phase and of equal magnitude, paralleling the outputs will cause no change in level. With fading, the condition of equal magnitudes will generally be met, since a fade must be very severe to change the receiver baseband output level. Thus, with proper adjustment, switches caused by fading will not cause transmission interruption. The same is true for manual switches made during system maintenance.

For equipment failure causing instantaneous loss of the pilot tone (and signal) in one channel, recognition of the loss by the pilot monitor, operation of the trigger circuit, the logic relay, and the switch to the other channel occurs in approximately 35 milliseconds. This causes negligible interruption to message circuits. Errors would occur in data circuits but because of the infrequent occurrence of equipment failures, this is not considered to be a serious condition.

4.4 *Order Wire and Alarm*

TL radio stations are normally unattended. In order to insure reliability of service and meet the requirements for unattended operation, an alarm system is necessary to report equipment failures and abnormal conditions to an attended control point from which maintenance personnel may be dispatched. A voice-frequency telephone facility to enable communication between radio stations is also needed to expedite maintenance. The TL radio alarm and order wire which makes use of the baseband frequency spectrum below 4000 cycles provides this service. However, in keeping with the objective of a low-cost equipment, the design only incorporates the reporting of those alarms which are essential to maintenance of service. These are:

1. *commercial ac power failure*. This is important since the batteries will discharge within 10 to 24 hours, depending on temperature, and result in system failure.
2. *transmission failure*. Short fades are timed out and not reported to the control center.
3. *low battery voltage and lightning arrestor failure.*
4. *failure of the air-navigation tower warning lights.*
5. *recovery of tower warning lights* when due to resumption of commercial power.
6. *"Signal In" by maintenance personnel* from one of the radio stations.

In this system, (see Fig. 24) a 2600-cycle tone is originated at the control station and is continuously transmitted over the outward radio path to the far radio terminal where, by means of a bandpass filter, it is looped back over the return radio path to the control station. If this tone fails to return, or if it is interrupted, office alarms are activated, indicating a trouble or abnormality. Except in the case of a transmission failure in a nondiversity system, the 2600-cycle tone is interrupted only sufficiently long enough to lock up and hold in the office alarms. Approximately 30 seconds is required for this operation because of built-in delay to avoid unnecessary alerting of personnel due to short-term fades. After the interruption, the alarm loop restores to normal so that indications from other stations may be reported. The system is limited to a single trouble report from each station except where an encoder is used, in which case higher-priority troubles at a station may be reported.

Once an alarm is registered, the next operation is to locate and determine the trouble. The 2600-cycle oscillator can be tuned to other frequencies by means of control keys. These other frequencies, called interrogation tones, are 700 to 2200 cycles in 150-cycle steps. At the first radio station a 700-cycle bandpass filter is bridged between the two directions of transmission, at the second station an 850-cycle filter, at the third station, a 1000-cycle filter, and so on to the far end of the system up to a maximum of eleven stations.

If an interrogation tone key is operated at the control station, an interrogation tone will go out over the system to be routed back at the station having the filter tuned to that frequency, and will be heard by the control station attendant in his telephone head set. Fig. 25 shows the loss characteristic of the adjacent filters 850, 1000 and 1150 cycles. When the 1000-cycle path is opened, the 1000-cycle leakage through the adjacent filters is approximately 53 db down from the normal level. Recognition of the particular frequency is not necessary, since each key marks a definite station. In a nondiversity system having a transmission failure, the tones will return from all stations on the near side of the failure and, of course, from no stations beyond the failure. Where transmission failures are made good by a diversity switch, or for other types of trouble, the interrogation filter bridge path is either opened continuously or on a pulsed basis under relay control, marking that station as a trouble point.

On interrogation, either a tone, no tone, or a pulsed tone will be heard at the control location. A continuous tone indicates no trouble. No tone indicates transmission failure. A pulsed tone indicates commercial power failure or low battery voltage. Where air-navigation lights are installed, an encoder is provided to code-pulse the tone to obtain additional information required by the air-navigation authorities, namely:

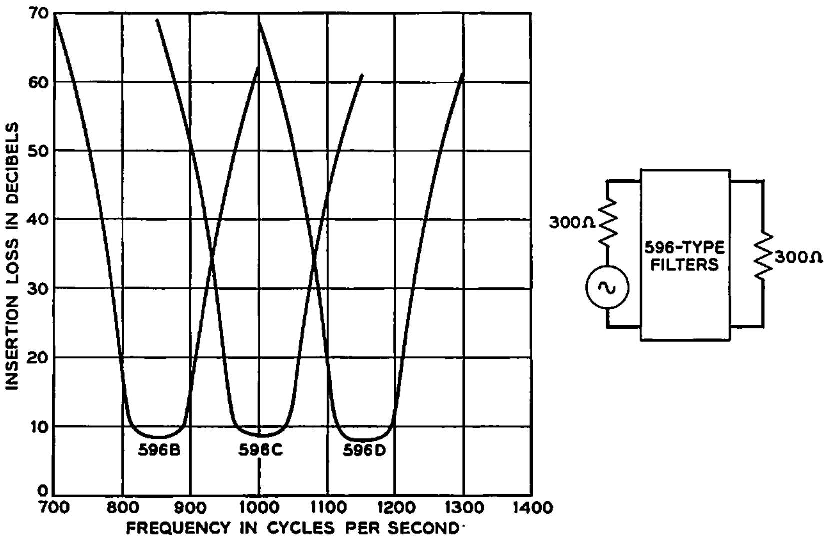


Fig. 25 — Order wire and alarm filter characteristic.

1. Both tower lights. This also indicates commercial ac power failure .... (3 shorts)
2. Top light flasher failure .... (2 shorts)
3. Low battery voltage or lightning arrestor failure .... (pulses)
4. Tower side light or single top light .... (1 short and 1 long).

The encoder provides a pulse generator and an eight-step counting and coding circuit operating under control of a directing or start relay for each of the above alarm codes. This circuit is arranged to give priority to the alarms in the above numerical order. If a low-priority alarm is present, a higher-priority alarm will originate a new alarm indication at the control point. Likewise, if the high-priority alarm clears, the lower-priority alarm will be maintained.

A transmission failure cannot be pin-pointed to a particular station because the system is not able to detect whether a failure exists in a transmitter in one station or in the associated receiver in the next station. Therefore, in a nondiversity system, the failure may be in the last station returning an interrogation tone or in the next station which does not return the tone. In a diversity system, the failure may be in the receivers of the station reporting the failure or in the transmitters in the adjacent stations.

The order wire is on a four-wire basis and shares the low-frequency part of the baseband with the alarm signals. The telephone set transmitter and receiver at a radio station under key control may connect to either direction of transmission to enable a conversation either way from the station. An amplifier in the receiver circuit is required to provide adequate listening level. The net loss between transmitter output and receiver input is approximately 15 db. Band elimination filters in the telephone receiver circuit provide about 27 db discrimination against the 2600-cycle alarm tone, which is essentially always present. Filtering is also provided in the transmitter output to attenuate any 2600-cycle components of voice energy entering the alarm loop.

Provision is made to serve spur routes as long as the stations involved do not exceed eleven and as long as no more than one spur is involved at a junction point. Through use of a six-hybrid bridge and proper placement of band elimination filters, the 2600-cycle tone traverses the total loop through all stations, while communication and interrogation are handled on a bridged basis.

In the design of this equipment, every effort has been made to reduce maintenance by simplifying the radio station equipment and confining it insofar as possible to passive circuit elements. The more complex active elements such as the oscillator and detector are located at the attended control point.

If more than one regular two-way radio channel is provided on a route, each is provided with an order wire and alarm facility. Thus a fully loaded three-channel diversity system would require three separate order wire and alarm facilities.

At near and far radio terminals, the order wire and alarm equipment consists of a single $5\frac{1}{4}$-inch × 19-inch panel arranged for single side maintenance (see Fig. 26). At repeater stations, two similar sized panels are required; one is located in the near repeater cabinet or bay and the other in the far repeater cabinet or bay. At a repeater point, the transmitter-receiver operates on a back-to-back basis. The microwave transmitter-receiver equipment facing the near terminal is called the near repeater bay or cabinet, and the one facing the far terminal is called the far repeater bay or cabinet. The first panel incorporates the "near" split-apart filter, the interrogation filter, the relay controls, and the telephone set circuit. The second panel has the "far" split-apart filter, transmission pads and a multiple of the telephone set. It also incorporates the spur hybrid arrangements when required.

The control station equipment, which includes the oscillator, detector and attendant's telephone set circuit, is mounted on a single panel $12\frac{1}{4}$

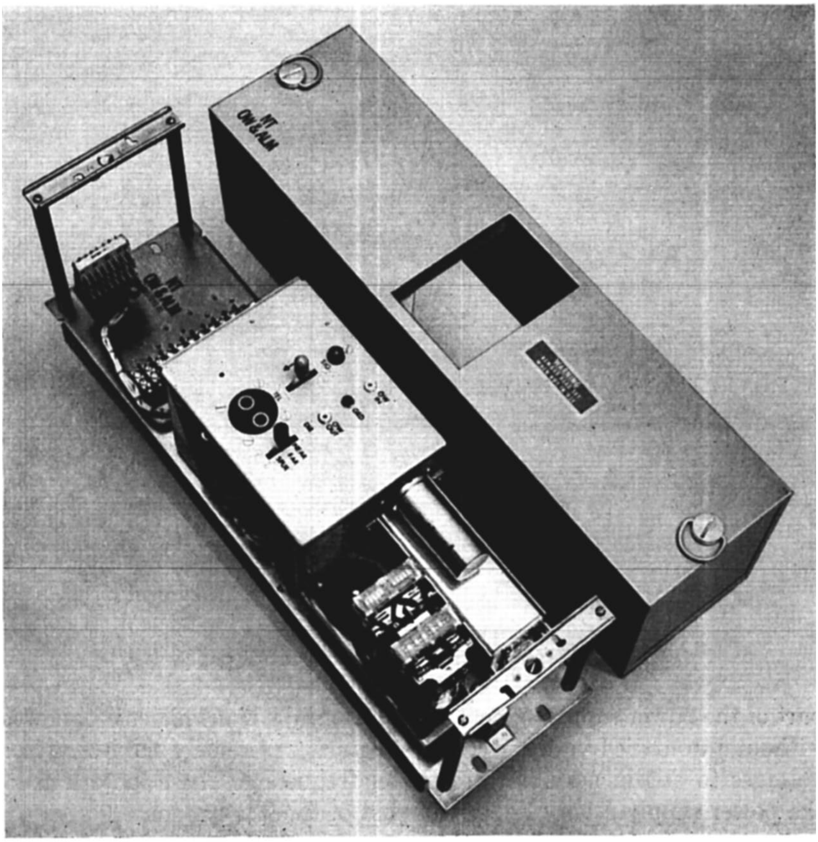


Fig. 26 — Order wire and alarm panel.

inches high by 19 inches wide. This panel is arranged for double side maintenance and has been designed for flush mounting on a bay or console (see Fig. 27).

4.5 *Power System*

4.5.1 *General*

One of the major features of the TL system is that it is not necessary to provide for emergency ac power generation during commercial power outages of normal duration. Continuous service is maintained by operating the repeater or terminal bay from storage batteries which form a

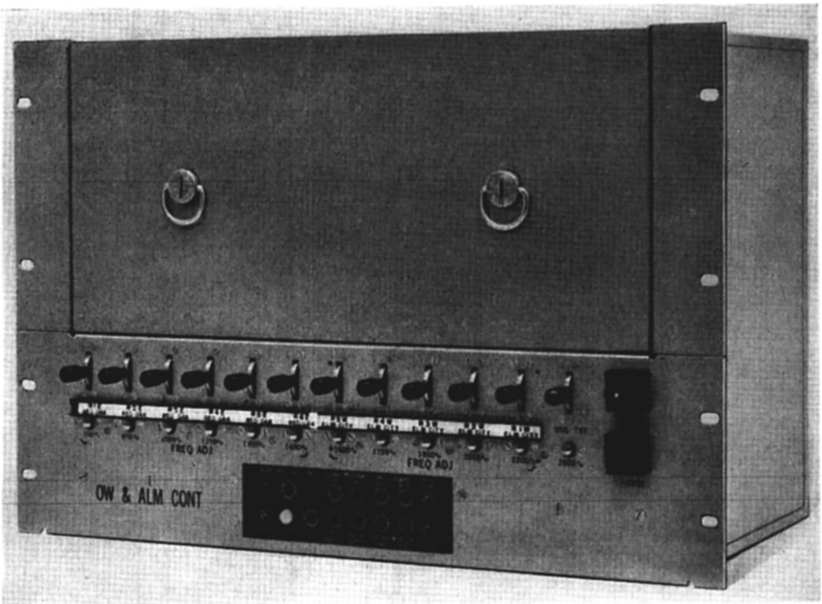


Fig. 27 — Order wire and alarm control panel.

part of the power supply system. In addition, the transmitter is operated without automatic frequency control, requiring extremely stable klystron voltages to obtain a stable transmitter frequency. These factors make the power supply a very important part of the TL system.

As shown in the simplified block diagram of Fig. 28, a ferroresonant transformer and rectifiers, fed from 117-volt commercial ac power, supplies a stabilized dc voltage which float-charges four 6-volt batteries in series. From the batteries, power for the transistor circuits and a dc-dc converter is supplied through two regulators. The converter provides the klystron voltages and the power for the AFC magnetic amplifier. Also included is a low battery voltage alarm. If the bay is operated in an office, the supply may be operated from the −24-volt office battery, omitting the charger and the four batteries normally provided in the bay.

4.5.2 *Detailed Description*

The ferroresonant transformer has two separate toroidal cores having characteristics such as to maintain a secondary voltage relatively insensitive to line voltage. Two silicon diodes in a full-wave center tap

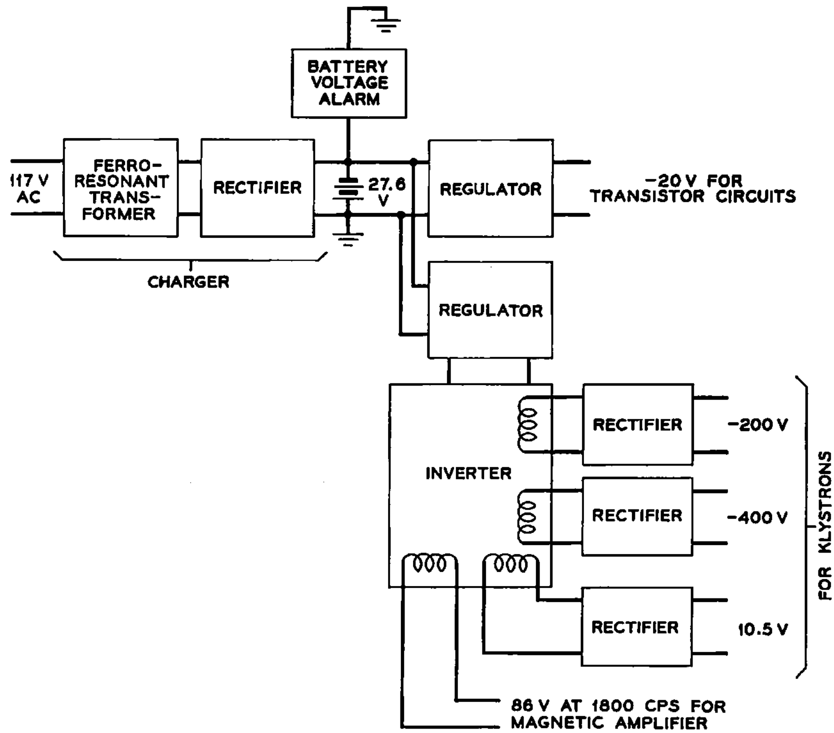


Fig. 28 — Block diagram of power supply.

arrangement give a regulated dc output, which is applied to the batteries for floating or charging.

The four batteries are high specific gravity lead-acid types connected in series, and float at −27.6 volts. They were chosen to provide maximum reserve at an economical cost, in an environment which involves a wide temperature range. Most of the time the batteries are being float-charged. This desirable condition contributes to very low battery maintenance. The high specific gravity aids in protecting the batteries at low temperature: at −40°F they do not freeze, even if fully discharged.

The −20-volt supply for the transistor circuits is obtained through a series regulator transistor which is controlled by an error-voltage amplifier. The reference voltage is obtained from a temperature-compensated voltage reference diode.

The dc-dc converter consists of two transistors and a saturable transformer switching at a rate of 1800 cps. The square-wave output is stepped up in a power transformer and rectified to provide voltages of −400

TABLE III — POWER SUPPLY CHARACTERISTICS

Voltage	Stability*	Current
−600 dc	±0.45%	10 ma
−400 dc	±0.45%	100 ma
10.5 dc	±0.45%	1.75 amps
43.0 ac (rms)	±0.45%	10 ma
−20.0 dc	±1%	750 ma

* Over the temperature range of −40 to +140°F and ac line voltage input of 95 to 135 volts.

volts for the klystron resonators and −200 volts (which is added to the −400 volts to obtain −600 volts for the repellers). Other windings on the power transformer provide an 86-volt center-tapped square wave for the receiver AFC magnetic amplifier, and a 10.5-volt dc supply for the klystron heater circuits.

Regulation of these supplies is accomplished in the same manner as for the −20-volt supply. The feedback is obtained from the −400-volt output, advantage being taken of the fact that the output from the other windings of the transformer will closely follow its output.

The battery voltage alarm circuit is a single transistor circuit which operates a relay when the magnitude of voltage becomes less than 25 volts. This initiates an alarm whenever the ac power fails, the charger fails, a fuse blows, or any event occurs that causes the batteries to cease being charged.

The characteristics of the power system are shown in Table III and in Fig. 29.

The power supply panel (approx. 15¾ inches × 19 inches), Fig. 30, is designed for maintenance from the front side only. To expedite replacement in the field, the regulator and invertor for the klystrons, the transistor circuit inverter, and the battery voltage alarm sections are mounted on removable panels using twist-type fasteners. The electrical connections are made by screw terminals. The battery voltage alarm section is not used in central offices where power is supplied from an existing office battery.

The major heat-producing components (battery charger) are mounted on the rear of the panel to obtain maximum cooling through unrestricted air flow.

4.5.3 *AC Distribution and Grounding*

Arrangements are provided at each station for the distribution of ac commercial power to the radio equipment and to associated facilities

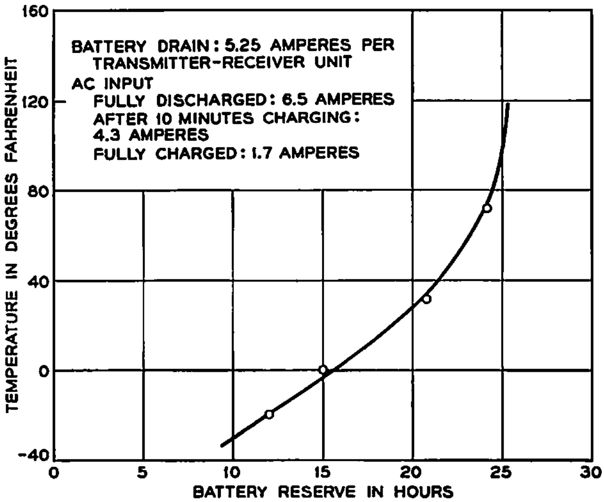


Fig. 29 — Battery reserve vs temperature.

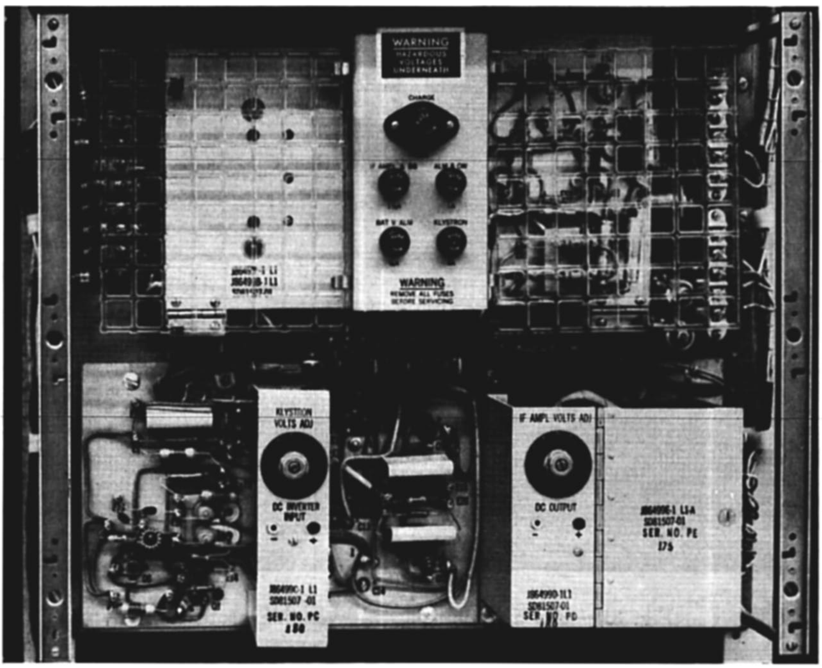


Fig. 30 — Power supply panel.

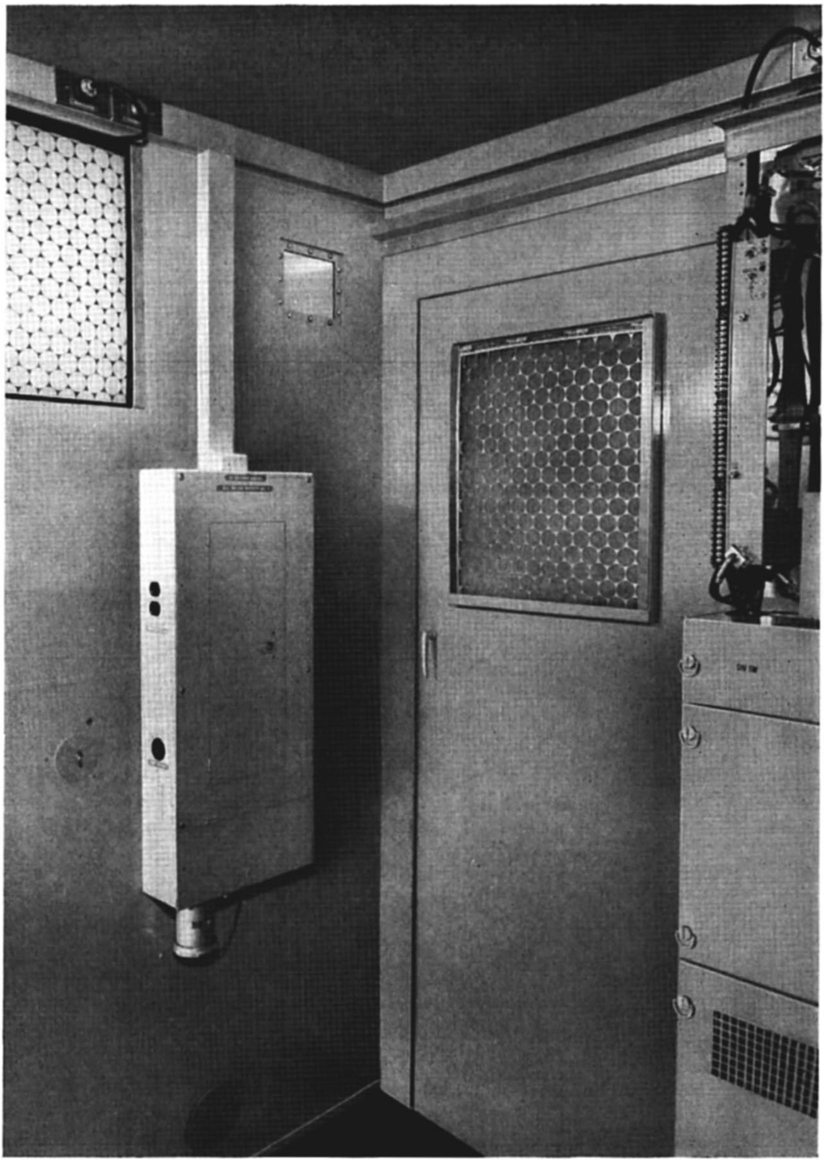


Fig. 31 — AC distribution and lightning protection.

and for adequate grounding to protect both equipment and personnel. Features provided are:

1. *a double-pole primary power disconnect switch* which enables connection to an emergency engine alternator (mobile or transportable unit) in the event of prolonged commercial power failures.

2. *distribution of ac power with overload protection* to the several transmitter-receiver equipments, to the antenna heaters, and to the aircraft warning light circuits on the tower.

3. *a secondary voltage protection circuit* which uses protectors with 6-mil gaps to protect the equipment against voltage surges on the ac power lines in excess of 1100 volts. This circuit provides alarm indications in the event of failure of its components. Fig. 31 illustrates an integrated design for housing the hardware for items 1, 2 and 3 above in a small shelter. A comparable size waterproof housing is available for outdoor cabinet installations.

4. *an aircraft warning light control circuit* which provides for flashing and steady lights on the tower and for alarm indications in the event of light or flasher failure.

5. *a grounding system* which provides for grounding all exposed metal parts in and around the station to a well established grounding grid. In addition to the electrical grounds, this includes grounding of such items as lightning rods, frameworks, building steel, towers, waveguide runs and guy lines.

4.6 *System Characteristics*

The gain-frequency characteristic of a typical single TL link is shown in Fig. 32. The transmitter input for nominal maximum carrier frequency deviation of ± 6 mc is -10.5 dbm. The receiver output for this deviation is $+10$ dbm, a difference of 20.5 db. A 6-db splitting pad for feeding a diversity transmitter is incorporated in the system, so that the nominal usable system gain is 14.5 db.

Since many TL repeaters will be exposed to rather large temperature variations, the stability of the system gain as a function of temperature is an important performance parameter. Fig. 33 shows this from data taken on one hop during laboratory environmental tests.

The message-carrying capacity of the system was measured by applying a band of white noise simulating a number of single-sideband message circuits. A band rejection filter at the transmitting end clears a "slot" of the noise near the top channel of the number being simulated. At the receiving end, the noise introduced into this slot by the thermal

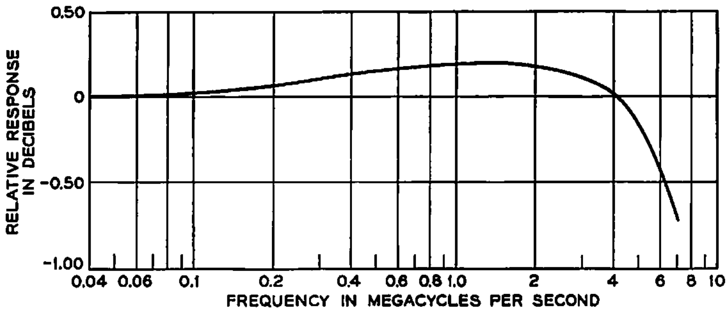


Fig. 32 — Single-hop gain-frequency characteristic.

and cross-modulation characteristics of the system is measured as a function of the level of the "message circuits" applied to the transmitter. Fig. 34 gives typical results of such tests on the Conway-Harrison, Arkansas system.

The contribution of thermal noise to the total noise in a message channel output will depend upon the carrier-to-noise ratio in the IF amplifier at the limiter. The noise figure of the receiver, including the three- or four-cavity bandpass filter preceding the modulator, is a maximum of 15 db at low RF signal levels, and averages somewhat less than this. The relationship between the RF carrier level and the thermal noise in the top channel of 240 channels in a typical link is shown in Fig. 35 for a peak frequency deviation of ±6 mc and a deviation per channel 17.5 db below 6 mc for a 0-dbm signal at the zero transmission level point.

An important characteristic of the system from the standpoint of the maintenance man is the performance of the order wire. The frequency

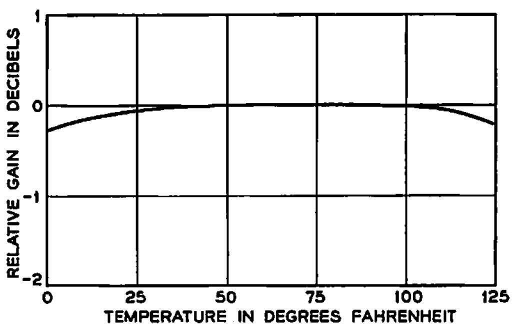


Fig. 33 — Net loss stability vs temperature for one hop.

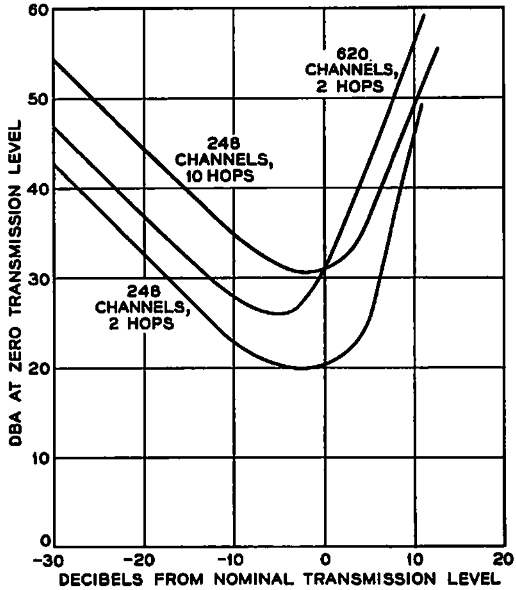


Fig. 34 — Typical noise loading characteristic of TL system.

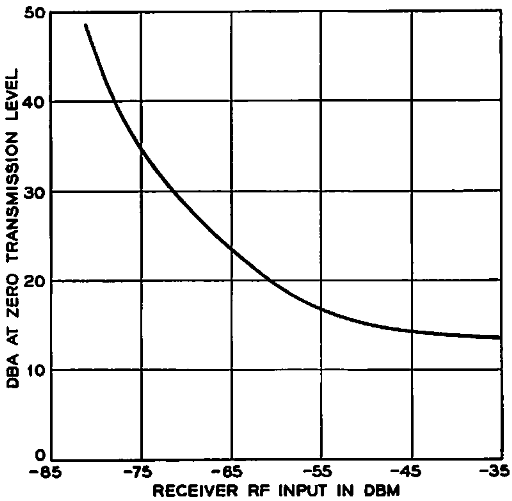


Fig. 35 — Thermal noise vs RF input signal level.

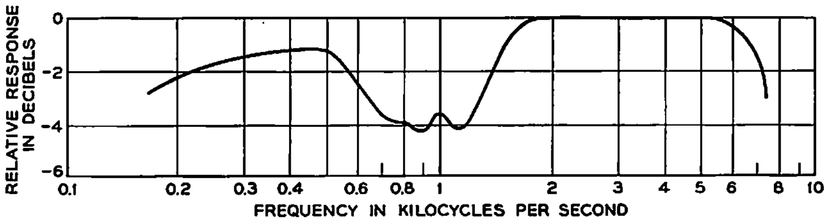


Fig. 36 — Order wire gain-frequency characteristic, four hops.

characteristic is shown in Fig. 36 for four hops. The notches caused by the bridging on of the interrogation filter at each repeater are evident.

V. EQUIPMENT FEATURES

5.1 *General*

The TL radio transmitter-receiver equipment is provided in either a weatherproof pole-mounted type of cabinet for outside, or in bay frameworks for indoor applications.

The cabinet arrangement illustrated in Fig. 37 is 46¼ inches wide by 62¼ inches high by 18½ inches deep. It incorporates two parallel frameworks, each accommodating standard 19-inch wide panels. In the right-hand framework from the bottom up are the power supply unit, the order wire and alarm panel, and the transmitter-receiver panel equipment. Above this frame supported by the cabinet structure are two ventilating fans. These fans are thermostatically controlled to turn on at 105°F and off at 80°F. They furnish approximately 80 cubic feet of air per minute through a 1-inch spun glass filter. This holds the air temperature within the cabinet to approximately 6°F above the outside air temperature. In the lower half of the left-hand frame, two shelves provide for storage of the four batteries, which have protective covers over the terminals. Space in the upper half of this frame is reserved for carrier line equipment such as the line amplifiers and combining equipment for ON carrier. Typical of the method of support for these cabinets is the "H" pole structure for a repeater station of the Billings-Hardin, Montana, system illustrated in Fig. 38.

Two bay arrangements are available, a seven-foot high floor-supported channel iron frame (see Fig. 39) for small unattended stations or shelters, and a nine-foot high standard channel frame for central offices. The equipment layout is similar to the cabinet except for the battery location in the lower part of the frame. Ventilation becomes a building problem, and any required carrier equipment will be mounted on its

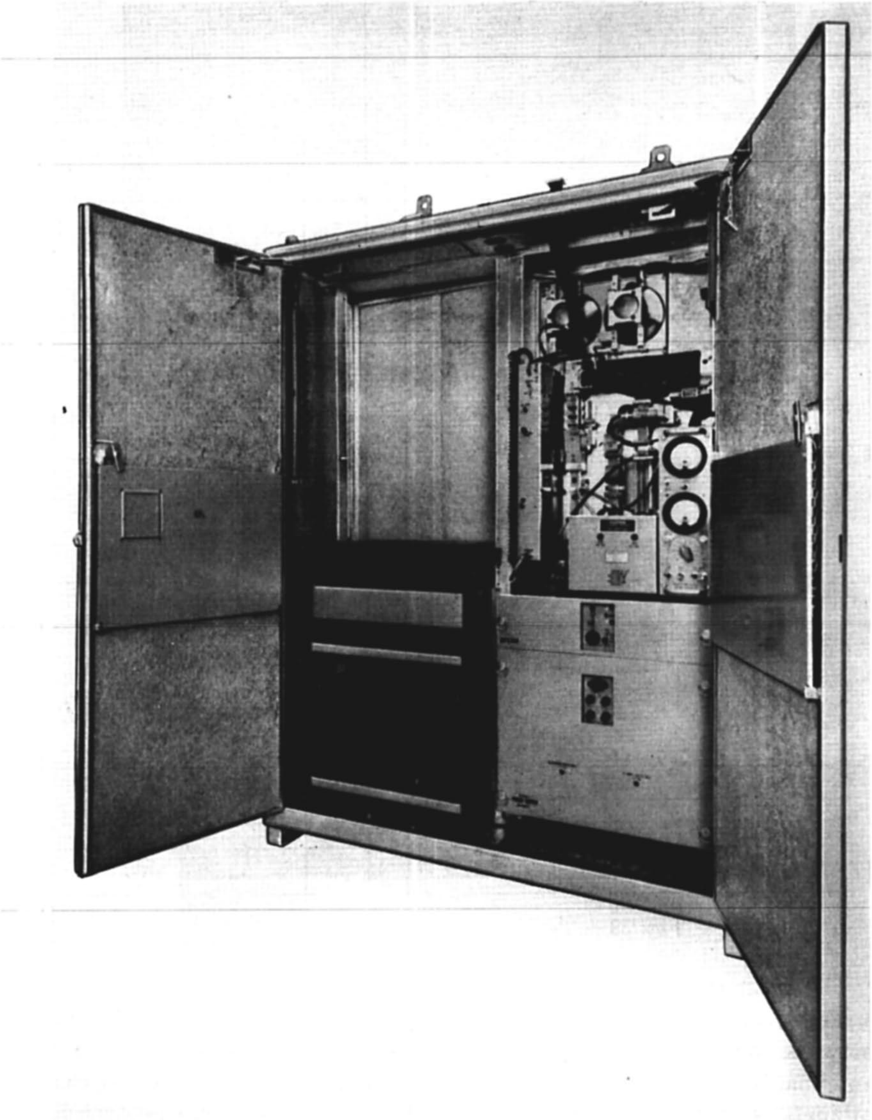


Fig. 37 — Pole-mounted cabinet for outdoor applications.

own separate framework. In a diversity system, the cabinets or bays serving the diversity channel have the diversity switch panel located just above the power supply in the space allocated to the order wire and alarm panel in regular channel equipments.

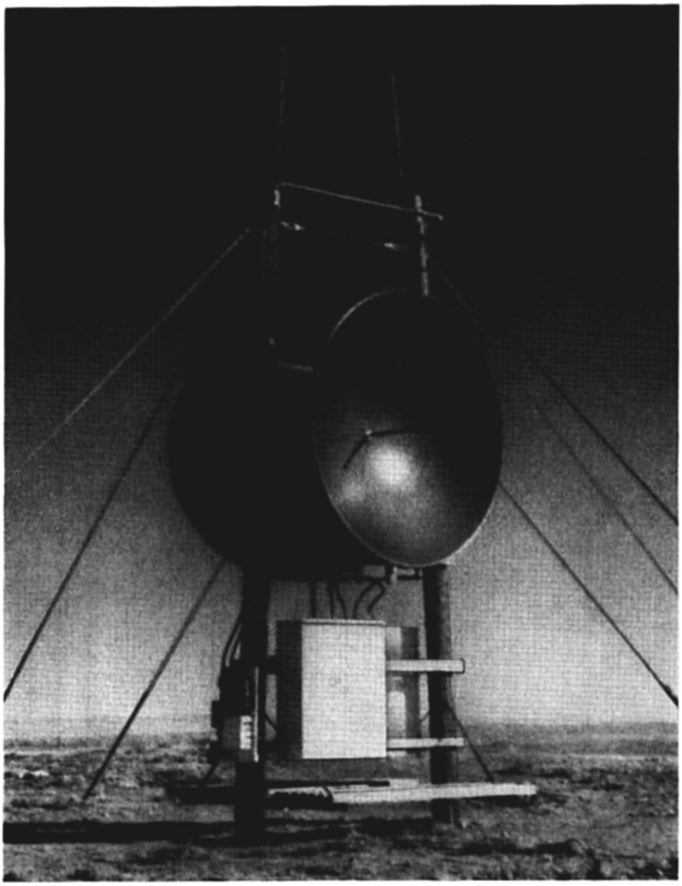


Fig. 38 — Typical "H" frame installation.

The primary difference between cabinet and bay equipments is the arrangement of the channel dropping networks. The cabinet has a single network mounted vertically with a single waveguide entrance to the antenna. A single-channel diversity terminal arrangement involving two cabinets is obtainable, since the individual waveguides run separately to a polarizer where the signals are combined in opposite polarities into the single antenna. Two such arrangements on a back-to-back basis, involving four cabinets, provide a diversity repeater. The bay arrangement mounts one or two networks horizontally at the top of the frame, making it possible to connect as many as three adjacent bays together to obtain the maximum three-channel system. The diversity bays have

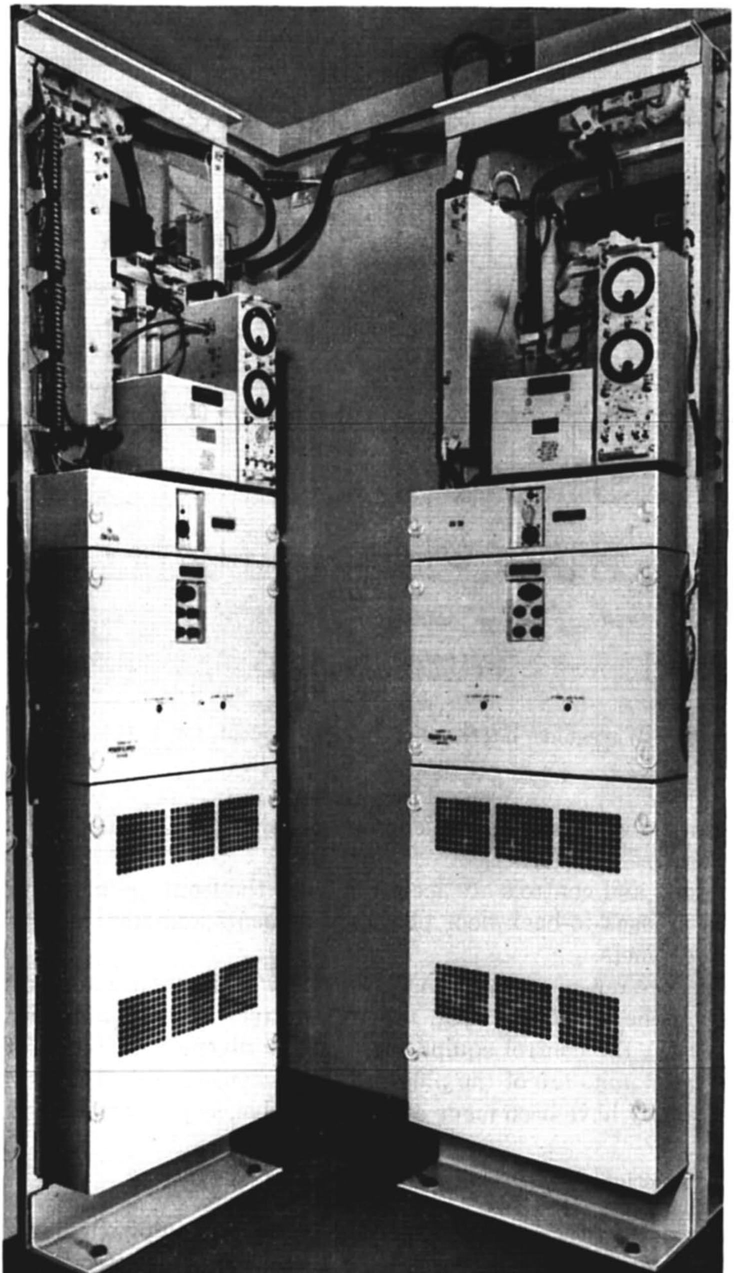


Fig. 39 — Two TL radio 7-foot frames in small shelter.

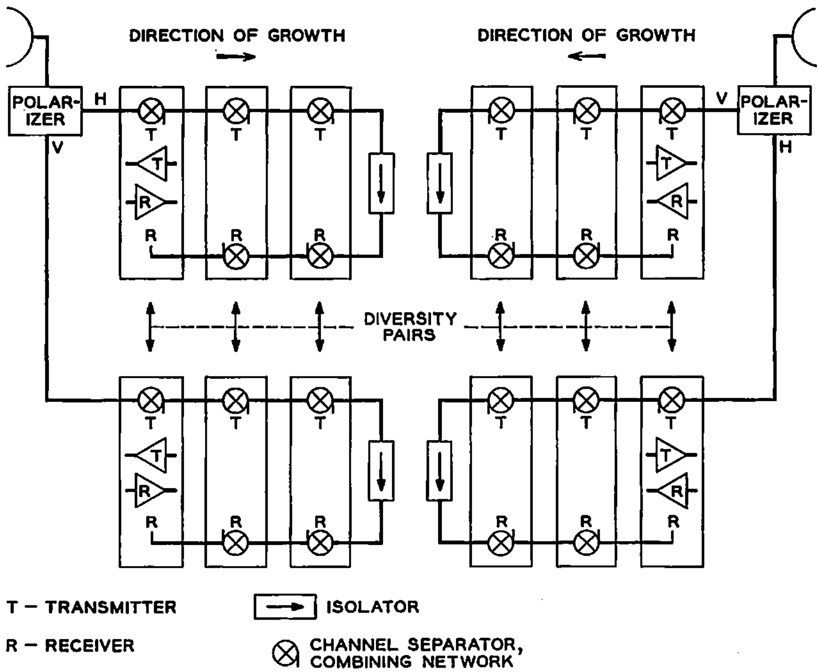


Fig. 40 — Waveguide interconnection arrangement for a three-channel diversity system.

a separate waveguide run which connects with the regular run at the polarizer (see Fig. 40).

All units and controls are accessible from the front, permitting back-to-wall or back-to-back floor plan arrangements and front door access for the cabinets.

To reduce out-of-service time, to simplify maintenance and to minimize "on the spot" servicing, the transmitter baseband amplifier, the receiver IF, the control equipment, and the diversity switch pilot and comparator units are of the plug-in type. Likewise, critical units in the power supply have been made easily removable, as previously described.

5.2 *Transportable Equipment Shelters*

Objectives in the provision of communication equipment have been to minimize effort on the part of the customer in job engineering and during the installation interval. This program of providing an essentially entire service has been termed "Turn Key"; thus the customer is provided a commercial system that is completely installed and tested, ready for him to turn on or up for service. In support of this program as applied to TL radio, a transportable equipment shelter is available which is equipped and wired at the factory, in accordance with customer requirements, prior to shipment to the radio sites. The objectives of this development are:

1. *assemble, wire, and test the major portion of the equipment at the manufacturing plant with experienced labor; minimize job engineering and field installation; and perform the work under controlled factory environment unaffected by outdoor climatic conditions.*

2. *minimize packaging of numerous items to reduce shipping costs; and reduce confusion resulting from many packages arriving at various intervals and the possibility of delayed and lost items.* This will allow more positive installation scheduling and reduced installation intervals.

3. *design the shelters so that they may be transported by standard commercial trucks on the roads of the various states.*

4. *minimize weight, use fireproof materials; incorporate adequate structural strength; provide ventilation and insulation; simplify installation and handling procedures; and incorporate such other features as are essential to the radio station.*

Two sizes of shelters are available:

Small shelter — intended to house a single-channel diversity repeater or for applications requiring a maximum of four 7-foot high transmitter-receiver bays and one miscellaneous bay. It is expected that this smaller shelter will be used rather than the pole-mounted cabinets in areas where general climatic conditions make outside maintenance impractical. This structure is approximately 7 feet wide, 7 feet, 6 inches long, and 8 feet high. Approximate weight of the unequipped shelter is 1400 lbs; maximum fully equipped for shipment, 2600 lbs; maximum in-place weight with batteries, 3800 lbs. Fig. 41 shows this small shelter equipped with two 5-foot paraboloidal antennas vertically beamed for use with a periscopic reflector. Fig. 42 illustrates how this shelter may be transferred from a truck to a prepared foundation (concrete piers) using a relatively small sign-erecting, truck-mounted crane.

Large shelter — intended for the ultimate three-channel diversity repeater or applications requiring a maximum of 12, 7-foot high transmitter-receiver bays and two miscellaneous bays. This shelter is approximately 7 feet wide, 16 feet, 4 inches long, and 8 feet high. Approximate weight of the unequipped shelter is 2500 lbs; maximum fully equipped for shipment. 6000 lbs; and maximum in-place weight with batteries, 10,000 lbs.

Fig. 41 — 7-foot × 7-foot shelter equipped with two 5-foot paraboloidal antennas.

5.3 *Towers*

An "H" frame wood-pole antenna tower specifically designed for TL radio, as shown in Fig. 38, is available. This guyed structure, having a maximum height of 60 feet, is particularly adaptable to installation by telephone company plant personnel, since handling this type of available pole hardware is a commonplace everyday task with them. This frame supports the antenna and reflector, and as many as four cabinets (single-channel diversity repeater) can be accommodated. Where high

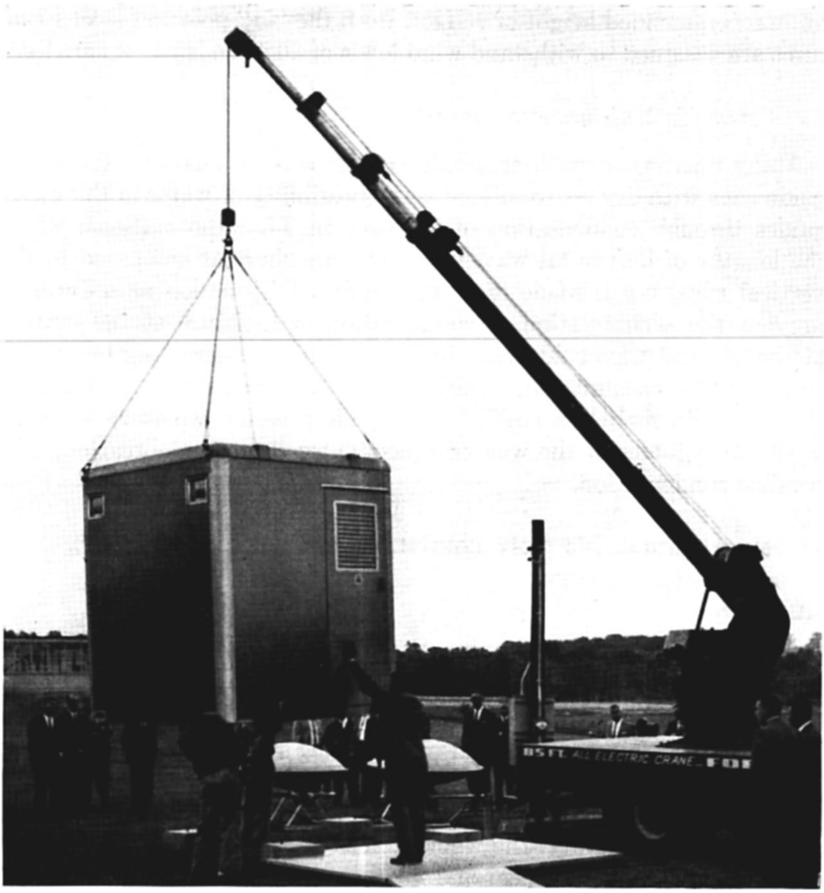


Fig. 42 — Installation of small shelter.

steel towers are required, a short "H" wood pole stub structure is used to support the outdoor cabinets and vertically beamed antennas.

A new series of general-use lightweight steel towers, either guyed or self-supporting ("C" type), is also available for use with TL Radio. These towers vary in height up to 105 feet and are triangular in cross section. The self-supporting tower is tapered from a 4-foot face at the top to approximately 17 feet at the bottom of a 105-foot tower. The guyed tower has parallel sides 2 feet in face width. Both of the above towers are designed to support two 6 × 8-foot reflectors up to maximum height or two 5-foot or 10-foot paraboloidal dish antennas up to a maximum recommended height of 75 feet. Both the "H" pole and steel structures are designed to withstand wind loads of 30 pounds per square foot.

5.4 *Waveguide Moisture Problems*

Many microwave stations provide equipment for charging the waveguide runs with dry air to minimize the possibility of water in the waveguides through condensation or leakage. In TL radio stations, where the lengths of horizontal waveguide runs are short as compared to the vertical runs, use is made of a waveguide "T" junction as a drain to prevent the accumulation of condensation or moisture at the bottom of the vertical waveguide run. In central offices where long horizontal runs may be encountered, available dry air systems may be used. In the TL radio shelter, a barrier (waveguide pressure window) is placed in the waveguides at the wall entrance plates to prevent breathing and possible condensation.

VI. MAINTENANCE AND TEST EQUIPMENT

6.1 *General*

The basic objectives of the TL system design, from the maintenance viewpoint, were to keep the testing to a minimum, to use simple procedures, and to require no elaborate test equipment. For the more complex circuitry, this was achieved by designing stability into the circuits, making the circuits easily replaceable, and requiring only simple over-all measurements for the determination of proper operation. If a unit is determined to be faulty, the whole unit is replaced. Many of the measurements are simple voltage and current measurements, so the means for accomplishing them have been built-in to achieve a high degree of convenience.

6.2 *Built-In Test Features*

A quick and convenient determination of the operating condition of a radio transmitter-receiver panel can be made by observing the two meters on the control unit. One is a zero-center meter which is used to monitor the IF frequency or the transmitter frequency. The second is a multi-scaled meter which can be used with a multiposition switch to monitor the klystron voltages and currents, battery voltage, modulator, diode currents, RF power output, received signal level, and the regulated transistor circuit supply voltage.

As mentioned in the section describing the transmitter, a diode detector, a high-Q invar cavity bandpass filter, and a two-position attenuator are used for monitoring transmitter frequency and adjusting transmitter deviation. A sample of the transmitter output is passed through the cavity filter for frequency monitoring. The filter is tuned to the particular transmitting frequency of the bay. When the transmitter is "on frequency," the reading on the control unit meter will be a maximum. When the transmitted RF carrier is frequency modulated, the detected output through the cavity filter will decrease because the sidebands that are generated (and take some of the power previously in the unmodulated carrier) are attenuated by the cavity filter. The reduction obtained can be calibrated for a given deviation, modulating frequency, and cavity filter. This calibration is made in the two-position attenuator in its "loss" position. Thus, by applying a particular frequency (100 kc is used for TL) at a given level, the transmitter baseband amplifier gain control is adjusted to give the same reduction in output from the cavity filter as is obtained when the attenuator is in its calibrated loss position and the carrier is unmodulated. Without this adjustment, klystrons having different modulation sensitivities being periodically put into the system would cause excessive noise in the message channels because of improper deviations.

Another transmitter adjustment built into the control panel is a simple means for improving klystron deviation linearity. It was determined that near-optimum linearity could be obtained by offsetting the repeller voltage by a small fixed amount from that which gives maximum output power. A final frequency adjustment is then made with the klystron cavity tuning.

Other built-in maintenance aids are pin jacks on the order wire and alarm panel, IF and baseband unit, transmitter baseband amplifier, and power supply which bring out important operating points primarily for trouble location.

6.3 *Test Sets*

The main item of test equipment for the TL system is an especially designed portable unit comprising three main sections: (1) the signal-generating section, which supplies IF and baseband frequencies for various tests at calibrated levels; (2) the voltmeter section, which permits measurement of baseband levels; and (3) the attenuator section, which permits adjustment of IF and baseband signal levels. Fig. 43 is a photograph of the unit, which measures approximately 10 × 10 × 16 inches and weighs less than 30 pounds.

This unit uses solid-state circuitry and is ac powered. With it, the

Fig. 43 — Test set.

important tests not built into the control panel can be performed. Some of these tests are: generation of an FM signal at IF for adjustment of the receiver baseband amplifier gain control; measurement of the 2600-cps pilot level; generation and measurement of baseband signals for gain-frequency characteristics; and generation of IF signals for measurement of received signal level, and IF amplifier and discriminator measurements.

The signal generator section has a pushbutton-controlled RC oscillator for generation of 2600 cps, 100 kc, 1 mc, and 4.5 mc; and crystal-controlled oscillators for 66, 70, and 74 mc. A circuit which switches between the 66- and 74-mc outputs at a 100-kc rate gives an FM IF signal which permits setting the gain control of the receiver baseband amplifier. A detector circuit monitors the oscillator outputs and permits accurate adjustment of the level.

The voltmeter measures baseband signals up to 4.5 mc at levels from -40 to $+13$ dbm. It provides for 75-ohm and 600-ohm terminated measurements and has a high impedance input for bridging measurements.

Other items of test equipment required are an accurate dc voltmeter for power supply adjustments and a general purpose volt-ohm-milliammeter.

Fig. 44 — Spare parts case.

6.4 *Spare Equipment*

Special carrying cases for the test equipment, spare equipment units and components, and tools have been designed for convenient and safe transport of these items with the service man. These are shown in Fig. 44.

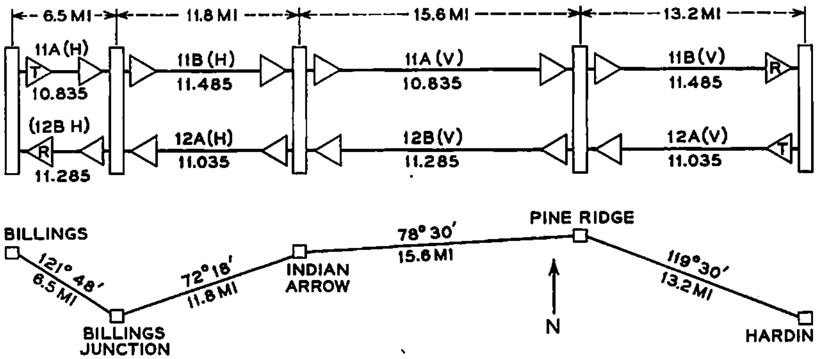
VII. APPLICATIONS OF THE RADIO SYSTEMS

7.1 *Billings-Hardin System*

The Billings-Hardin, Montana, TL radio route, shown in Fig. 45, extends eastward from Billings 48 miles to Hardin. This nondiversity radio system is multiplexed with 32 channels of ON carrier, providing additional facilities and back-up for an open wire line between Billings and Hardin. The radio repeaters lie along a plateau whose elevation is from 1000 to 2000 feet above the two terminals. Short wood-pole "H" towers, outside cabinets, and 5- and 10-foot paraboloidal antennas are used at the repeaters.

Performance on this system has been excellent. There have been no system failures or lost circuit time on this nondiversity system in its 15 months of operation.

STATION	BILLINGS MAIN	BILLINGS R1SE	BILLINGS R2SE	BILLINGS R3SE	HARDIN
LOCATION	BILLINGS	BILLINGS JUNCTION	INDIAN ARROW	PINE RIDGE	HARDIN CENTRAL OFFICE
ANTENNA	5′ DISH	(2) 5′ DISH	(2) 5′ DISH	(2) 10′ DISH	10′ DISH
ANTENNA HEIGHT	ROOF	40′	20′	20′	71′ APPROX.
TOWER	A FRAME	POLE H FRAME	H FRAME	H FRAME	B SELF SUPPORT (ROOF 16′)
TOWER HEIGHT	—	40′	20′	20′	60′



TERMINALS	LATITUDE	LONGITUDE	GROUND ELEVATION
BILLINGS	45° 46′ 33″	108° 30′ 34″	3126′
BILLINGS JUNCTION	45° 43′ 44″	108° 23′ 42″	4003′
INDIAN ARROW	45° 46′ 48″	108° 09′ 24″	4038′
PINE RIDGE	45° 49′ 42″	107° 50′ 42″	4081′
HARDIN	45° 43′ 52″	107° 35′ 57″	2902′

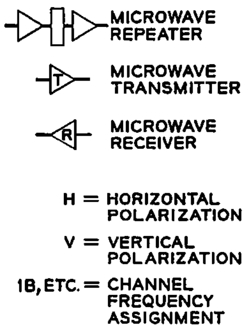


Fig. 45 — Billings-Hardin TL system.

7.2 *Denver-Limon-Burlington System*

Originally, this 8-hop TL system, shown in Fig. 46, extended eastward from Denver 85 miles to Limon and from Limon eastward 78 miles to Burlington. This system has now been extended two more hops to Cheyenne Wells. Initially equipped with 24 channels of ON, this rapidly growing system now carries 36 channels between Denver and Limon and 52 channels between Limon and Burlington. This system employs one-for-one frequency diversity protection.

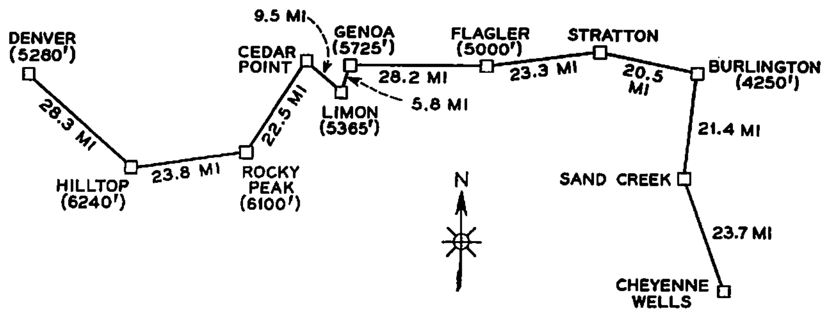


Fig. 46 — Denver-Limon-Burlington TL system.

VIII. ACKNOWLEDGMENT

The system described here is the result of the efforts of many departments of Bell Telephone Laboratories, including research, systems development, device development, outside plant, and system engineering.

REFERENCES

1. Ruthroff, C. L., and Tillotson, L. C., An Experimental "Short Hop" Microwave System, Bell Laboratories Record, **38**, June, 1960, p. 202.
2. Hathaway, S. D., and Evans, H. W., Radio Attenuation at 11 kmc and Some Simplifications Affecting Relay System Engineering, B.S.T.J., **38**, January, 1959, pp. 73–97.
3. Lewis, W. D., and Tillotson, L. C., A Nonreflecting Branching Filter for Microwaves, B.S.T.J., **27**, January, 1948, pp. 83–95.
4. Gucker, G. B., Long-Term Frequency Stability for a Reflex Klyston without the Use of External Cavities, B.S.T.J., **41**, May, 1962, pp. 945–958.
5. Ballentine, W. E., Saari, V. R., and Witt, F. J., The Solid-State Receiver in the TL Radio System, B.S.T.J., **41**, November, 1962, pp. 1831–1864.
6. Ruthroff, C. L., Amplitude Modulation Suppression in FM Systems, B.S.T.J., **37**, July, 1958, pp. 1023–1046.