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The TM-1/TL-2 Short Haul Microwave Systems

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This paper describes the design and discusses the performance of the TM-1 and TL-2 radio relay systems designed for short haul service in the 5925 to 6425 megacycle and the 10,700 to 11,700 megacycle common carrier bands, respectively. Used as a crossband diversity pair, they provide a highly reliable broadband message channel for up to 600 circuits and require little maintenance and relatively low power. These systems are also used to transmit television.

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I. INTRODUCTION AND BACKGROUND

Bell System short haul microwave was launched in 1958 with the completion of the development of the 11-gc TJ Microwave

Radio Relay System.[1] Generally well received, this all-electronic tube system suffered somewhat from an economic standpoint because of its relatively large power requirements (just under one-half kilowatt) and the expense entailed in providing standby power at remote locations. The TJ system had a radio frequency power output of at least one-half watt. Initially characterized as a 240-circuit system, its message capability has been gradually improved to its present capacity of 600 circuits with a noise performance of 35 dbrnc0 for a 250-mile ten-hop system.*

With the development of high-frequency capabilities of solid-state devices, the design of a lower cost and more economically operated system for the 11-gc band was undertaken. The new system, TL radio,[2] now referred to as TL-1, used solid-state circuitry throughout the system except for the employment of klystrons as the transmitter oscillator and the receiver beat frequency oscillator. The new transmitter-receiver required only 170 watts, which eliminated the need for an emergency 60-cycle power plant, permitting the equipment to operate directly from a 24-volt storage battery. The message capability for a ten-hop, 250-mile system was 240 circuits at 38 dbrnc0 including the multiplex. The use of solid-state devices in both the radio and power equipment permitted reduction in size hitherto not possible. The TL-1 radio system was notable, then, for its extensive use of semiconductors, low cost, simplicity and reliability.

Even as this new system was first being applied in the field, the need arose for greater circuit capacity, for improved noise performance, and for television capability. The development of the TL-2 Radio was then undertaken, followed in short succession by the companion TM-1 Radio System operating in the 6-gc common carrier band. The latter system was designed to provide, with TL-2, a crossband diversity arrangement by which further improvements in reliability might be obtained. The use of the crossband feature, involving transmission at both 6 and 11 gc, places reduced demands on the crowded 6-gc band yet provides the diversity pair with the greater freedom from rain fades which is inherent in the lower frequency band.

It should be emphasized that a change was taking place in the short haul radio field. When the earlier systems were conceived, they were intended for lightly loaded routes; but, as demands for message circuits mounted, and the existing cable network began to reach the ultimate in expansion capabilities which short haul carrier could sup-

* The measurement of noise is reviewed briefly in the appendix.

ply, the importance of the newer transmission medium was emphasized. Circuit cross sections were growing rapidly and new services such as data, commercial TV, and educational and industrial TV were coming to the fore. The new diversity pair was designed to provide TV capabilities and a highly reliable message transmission medium capable of handling 600 circuits with the basic transmission performance improved over the earlier systems.

II. SYSTEM OBJECTIVES

2.1 *General*

The general objectives for the TM-1/TL-2 radio pair are somewhat more severe than for TL-1 radio. TL-2 and TM-1 are intended to yield higher reliability, carry heavier message loads, give better noise performance, and furnish TV capability in the short haul field. Like the TL-1 radio, they are intended to provide short haul and tributary trunk facilities (*i*) in difficult geographical situations; (*ii*) where wire line facilities would prove uneconomical; (*iii*) where open wire requires replacement; (*iv*) where existing cable routes are being exhausted; and (*v*) as spurs leading from heavy route microwave systems. In addition, they can be used to provide order wire and alarm facilities for heavy route radio systems as well as to furnish facilities for television transmission in the TV broadcast network, or in industrial and educational fields.

2.2 *Telephone Message Capacity*

Both systems are designed to transmit up to 600 circuits of L-carrier, meeting modern noise objectives of 35 dbrnc0 over 10 hops covering a distance of approximately 250 miles.

2.3 *Power Drain and Reserve*

These systems employ all solid-state circuitry, except for the transmitter and receiver klystrons, and consume approximately 170 watts of power for a transmitter-receiver combination. Depending somewhat upon the battery supply arrangements, sufficient reserve is normally provided to carry the system for approximately 24 hours in the event the commercial ac power fails.

2.4 *Order Wire and Alarm*

The order wire and alarm system provided for the TL-1 system has been adapted with minor changes for use with the TL-2 and TM-1 systems.[2]

2.5 *Economics*

The objective is to provide, at low cost, a radio facility which, a short time ago, would have been considered a "heavy route" radio facility. Simplicity and compactness have been emphasized in design. Maintenance procedures and equipment have been held to a minimum consistent with the increased load requirements. Outdoor cabinets and standard shelters have been provided which may be shipped to the station site completely equipped, thus minimizing engineering and installation expense. Low-cost antennas and antenna supporting structures have also been made available for minimizing over-all station costs.

2.6 *Reliability*

The reliability of a radio system is expressed as the percentage of outage time that may be expected with respect to the total time. Reliability objectives in short haul radio have been raised steadily over the past few years due to customer demands and to the increasing dependence upon radio as the message loads on short haul systems have increased. The current reliability objective for the TM-1/TL-2 diversity pair is set at 0.02 percent for a 10-hop system.

Hazards to service which may cause outages include not only power and equipment problems, but also atmospheric phenomena. In TM-1 and TL-2, outages due to power failures are reduced by the employment of storage batteries with sufficient reserve to carry the equipment for a reasonable period. Equipment hazards are largely eliminated by full diversity operation. Outages caused by atmospheric conditions such as inversion, reflective layer phenomena and rain are combatted by means of a broad range AGC. However, because the raindrop size is an appreciable part of a wavelength at 11 gc these frequencies suffer much greater rain attenuation than the lower frequencies. For this reason the 6-gc band is measurably more reliable than the 11-gc band.

Experience has shown that the 0.02 percent reliability objective would be difficult to meet, and would involve an economic penalty with an 11-gc system, in areas subject to heavy rain incidence. The use of a 6/11-gc crossband diversity arrangement yields a highly reliable system with the advantage of 6 gc in connection with rain attenuation. By relying on the 11-gc band for the other half of the diversity pair, the dependence on 6 gc (and therefore, the congestion of that band) is reduced by one-half.

2.7 *Transmission Objectives*

To meet the general objectives set forth for these systems, the following transmission objectives were established.

	TM-1	*TL-2*
RF frequency range	5.925–6.425 gc	10.7–11.7 gc
Frequency plan	modified TH plan	modified TJ plan
Number of available RF channels	32 (split channel TH plan) 12 (staggered channel TH plan) 16 (TH co-channel plan)	24 (TJ plan) 24 (staggered channel TJ plan)
Minimum transmitted power	+20 dbm	+20 dbm
with TM-A1 amplifier	+33 dbm	—
Transmitter frequency stability	±0.02%	±0.05%
Minimum design receiver input	−45 dbm	
Receiver noise figure (receiver inputs of −45 dbm or lower)	11 db	
Fading margin (minimum)	30 db	
IF center frequency	70 mc	
Baseband width	10 cps-6 mc	
Pre-emphasis		
600 message circuits	9 db	
Television	7 db	
Maximum hops per alarm section	10	
System length		
message (10 hops)	250 miles	
ETV-ITV (10 hops)	250 miles	
NTSC-TV (6 hops)	150 miles	
Ambient temperature	−40°F to 120°F	

2.8 *Power Amplifier*

In order to lengthen a hop where circumstances demand, a power amplifier can be used with the TM-1 transmitter. The TM-A1 traveling wave tube power amplifier described in Section VI increases the power output from +20 dbm to +33 dbm. Coupled with a diversity switch that normally reverts to the preferred channel, the power amplifier permits the repeater spacing to be increased substantially with no appreciable degradation of system performance or reliability.

III. ENGINEERING CONSIDERATIONS

3.1 *Antennas*

Several types of antennas and antenna systems are available for the TM-1/TL-2 combination. A 6-foot parabolic antenna and a 10-foot parabolic antenna, each handling two polarizations at 11 gc and one polarization at 6 gc are available for use as direct radiators. A periscopic system is obtained with these antennas when used with appropriate reflectors.[3] The 6-foot antenna is illustrated in Fig. 1. The dual-frequency antennas are always furnished with radomes. Two 11-gc connections (WR90) and one 6-gc connection (WR159) are required for both sizes of antennas. A horn-reflector antenna may also be used in the TM-1/TL-2 systems.[4] In this case, WC281 circular waveguide is used from the antenna to the associated waveguide networks near the base of the tower. The minimum midband gain for these antennas compared to an isotropic radiator is as follows:

Antenna	*Minimum midband gain over isotropic antenna* 6175 mc	11,200 mc
6 ft dual-frequency antenna including radome	37.9 db	42.5 db
10 ft dual-frequency antenna including radome	42.3 db	46.7 db
Horn-reflector antenna	43.1 db	47.7 db

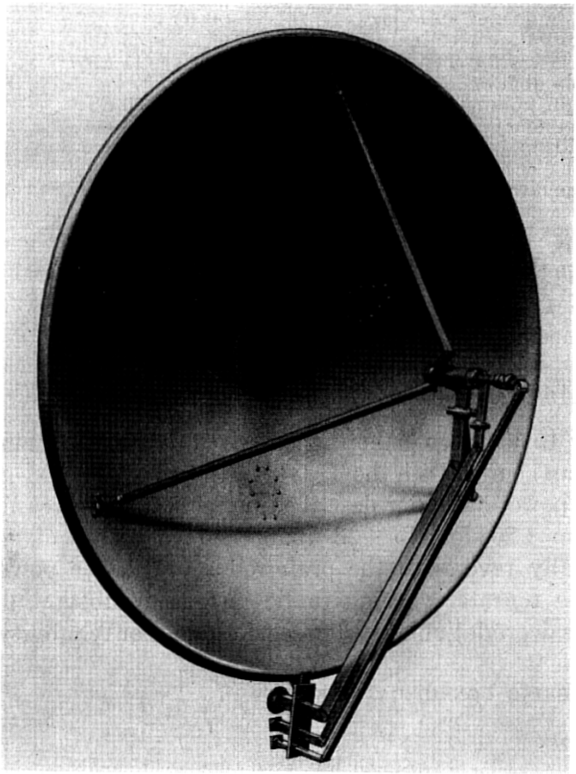

Fig. 1 — Dual-frequency antenna with radome removed.

The gain of the parabolic antennas used in conjunction with flat reflectors is shown in Fig. 2 where the effect of antenna-reflector separation is included.

The parabolic antennas and reflectors may be mounted on a wide variety of towers. The type of tower is dependent upon the wind loading for the area used as well as the size of the antenna or passive reflector. A somewhat more limited selection of tower designs is available for the horn-reflector antenna.

3.2 *The Design of a Typical Hop*

The expected performance of a hop may be computed for TL-2 and TM-1 based on the following assumptions:

	TM-1	*TL-2*
Path loss for 25 miles	140.4 db	145.6 db
Loss of waveguide components in radio equipment	3.4 db	5.5 db
Waveguide losses (40 ft) for a periscope system	1.0 db	1.6 db
Total losses	144.8 db	152.7 db
Minimum transmitter power	+20 dbm	+20 dbm
Gain of two 10-ft dual-frequency antennas	84.6 db	93.4 db
Gain of two 10-ft × 15-ft reflectors 180 ft away from antennas	−0.8 db	−0.8 db
Sum	103.8 db	112.6 db
Received carrier power	−41.0 dbm	−40.1 dbm
Assumed maintenance margin*	3 db	3 db
Received carrier power	−44.0 dbm	−43.1 dbm

* This factor is introduced to allow for some misalignment of the antenna system, etc.

The above calculation illustrates that in a typical hop, the received power for TM-1 and TL-2 are nearly the same. The increased path loss and waveguide component losses at 11 gc are balanced by an increased antenna gain.

In a low-index FM system, the thermal noise power in the highest frequency telephone circuit at the 0 TL point may be expressed by[5]

$$P_n = P_s + 20 \log \frac{f_1}{\Delta F} + 10 \log \frac{2\,\Delta f\, N}{P_c}$$

where

P_s is the power of a baseband sine wave at the O TL point that will produce a peak deviation of ΔF megacycles. This is taken as the Dixon-Holbrook multiload factor and is +23.5 dbm for a 600-circuit load.

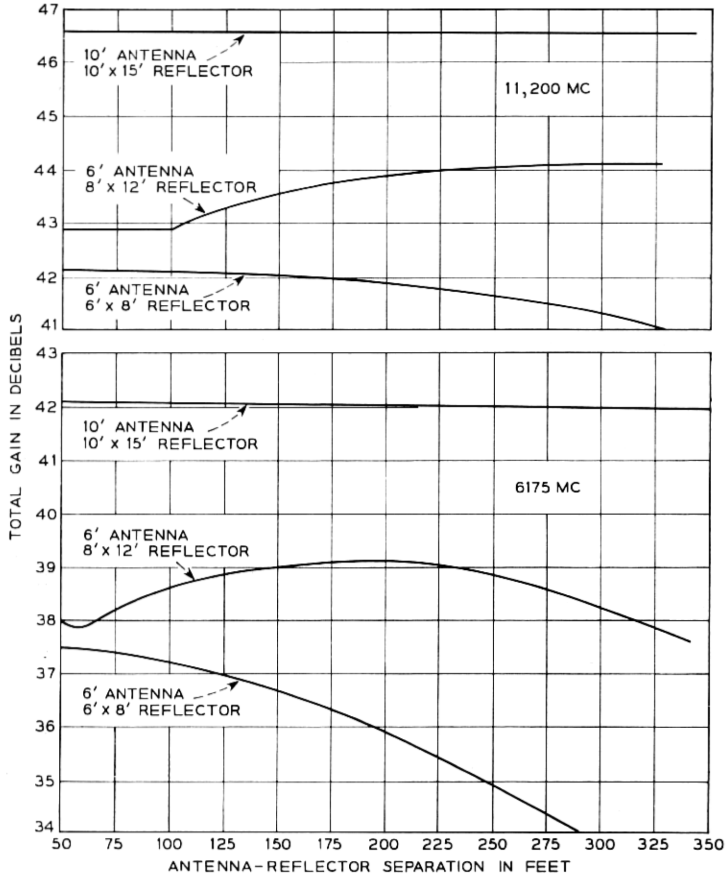

Fig. 2 — Periscope antenna gain vs separation for 6- and 10-foot dual-frequency antennas.

ΔF the peak deviation, is set to achieve an approximate balance between thermal and modulation noise. In TL-2 and TM-1, $\Delta F =$ 5 mc.

f_1 is the location of the highest frequency multiplexed telephone circuit. For a 600-circuit load this is 2788 kc.

Δf is the nominal bandwidth of a telephone circuit, 3 kc.

N is the noise power per cycle, $(-174 + NF$ dbm)/cycle. In these systems $N = -174 + NF = -163$ dbm.

P_c is the received carrier power. For TM-1, $P_c = -44.0$ dbm and for TL-2, $P_c = -43.1$ dbm.

The values of P_n for TM-1 and TL-2 are, therefore, −62.8 dbm and −63.7 dbm, respectively.

In the Bell System, noise measurements are made using a 3A noise measuring set with C-message weighting and the values of P_n just computed will read as 25.2 dbrn for TM-1 and 24.3 dbrn for TL-2.*

Other noise contributions, based on factory measurements of transmitter receiver units, must be included as follows:

	TM-1	*TL-2*
FM thermal noise	25.2 dbrnc0	24.3 dbrnc0
Klystron noise	18.0	16.0
Modulation noise	22.0	23.0
Total noise	27.4	27.1
Pre-emphasis advantage†	3.5	3.5
Expected per hop noise performance	23.9 dbrnc0	23.6 dbrnc0

† The pre-emphasis characteristic specified for TM-1/TL-2 is shown in Fig. 3.

The noise performance of the 0.1-watt TM-1 and TL-2 systems in a typical 25-mile hop is expected to be nearly alike and, in the general case, there is no advantage in assigning a preferred status to one system over the other. Geographical situations do occur, however, where a higher transmitted power is required to transmit a greater distance.

The TM-A1 amplifier is available as a hop stretcher. A traveling-wave tube amplifier, providing at least 13-db gain is capable of raising the transmitted power of TM-1 to 2 watts. The power of the TL-2 system is not increased, but a revertive diversity switch is used at the receiver to take advantage of the better signal-to-noise ratio on the TM-1 channel when the power amplifier is used.

Carrying through the calculations for a 75-mile hop, but retaining all the earlier assumptions, we have:

	TM-1	*TL-2*
Received carrier power		
TM-1 @ +33 dbm	−40.6 dbm	
TL-2 @ +20 dbm		−52.7 dbm
Expected per hop noise performance of the highest frequency telephone circuit	22.2 dbrnc0	30.6 dbnrc0

Under these conditions, TM-1 is the preferred channel, and a diversity switch that reverts to TM-1 would be used. The TL-2 channel provides protection against TM-1 fades and equipment failures. The combination of a 2-watt TM-1 system and a 0.1-watt TL-2 system is capable of meeting over-all system reliability objectives.

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* For the reasons given in the appendix, these readings will be referred as dbrnc0.

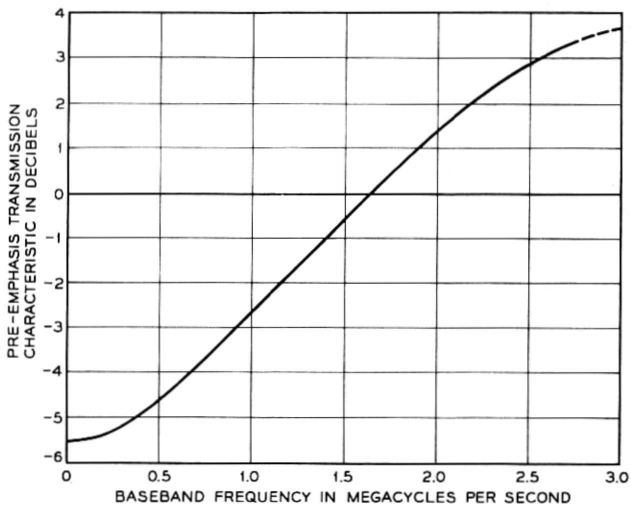


Fig. 3 — Message pre-emphasis characteristic.

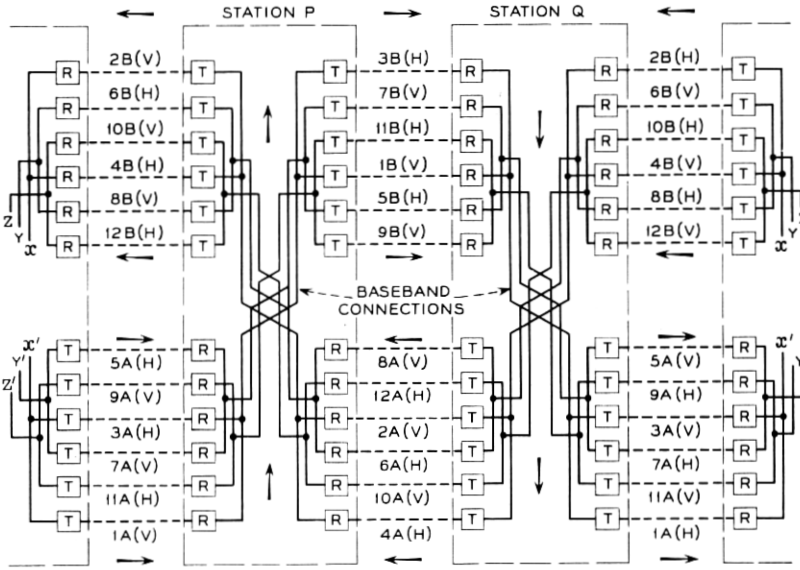
IV. TRANSMISSION PLAN

4.1 *Frequency Plans*

The number of two-way diversity channels which may be provided by TM-1/TL-2 combinations depends upon several factors. Where the normal TM-1 and TL-2 allocations are employed, the antenna system becomes the deciding factor. With the dual-frequency parabolic antennas, limited to a single polarization at 6 gc while providing two polarizations at 11 gc, a maximum of four two-way crossband channels may be provided. When two polarizations in both bands are available, as with the horn-reflector antenna, six two-way crossband diversity channels are possible.

Basically, the normal TL-2 frequencies are the same as those of the TJ and TL plans (Fig. 4). The staggered plan shifts all the A frequencies 20 mc higher and the B frequencies 20 mc lower. In the case of TM-1, several frequency allocations exist as shown in Fig. 5. The normal or split channel plan provides two TM-1 channels in the frequency space set aside for each TH channel.[7] The staggered allocation provides a more limited number of TM channels which are located between TH channel assignments. This allocation is used to minimize interference in cases where a TM-1 route crosses a TH route. A third allocation, the co-channel plan, is the TH frequency plan which is used where TM and TH will share the same route. In this instance, the normal or staggered plans would not be suitable. It should be pointed out that in all cases, the preferred order of channel growth in TM-1 is the reverse of the preferred use order in TH to minimize interference possibilities.

Although TM-1 and TL-2 Radio Systems may be operated on a non-



Channel number	Transmitter frequency, gc	Beat oscillator frequency, gc	Channel number	Transmitter frequency, gc	Beat oscillator frequency, gc
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	11.255
11A	10.835	10.905	8B	11.365	11.295
6A	10.875	10.805	1B	11.405	11.335
7A	10.915	10.845	4B	11.445	11.375
2A	10.955	11.025	11B	11.485	11.555
3A	10.995	11.065	10B	11.525	11.595
12A	11.035	11.105	7B	11.565	11.495
9A	11.075	11.145	6B	11.605	11.535
8A	11.115	11.045	3B	11.645	11.575
5A	11.155	11.085	2B	11.685	11.615

Fig. 4 — TL-2 frequency allocation plan.

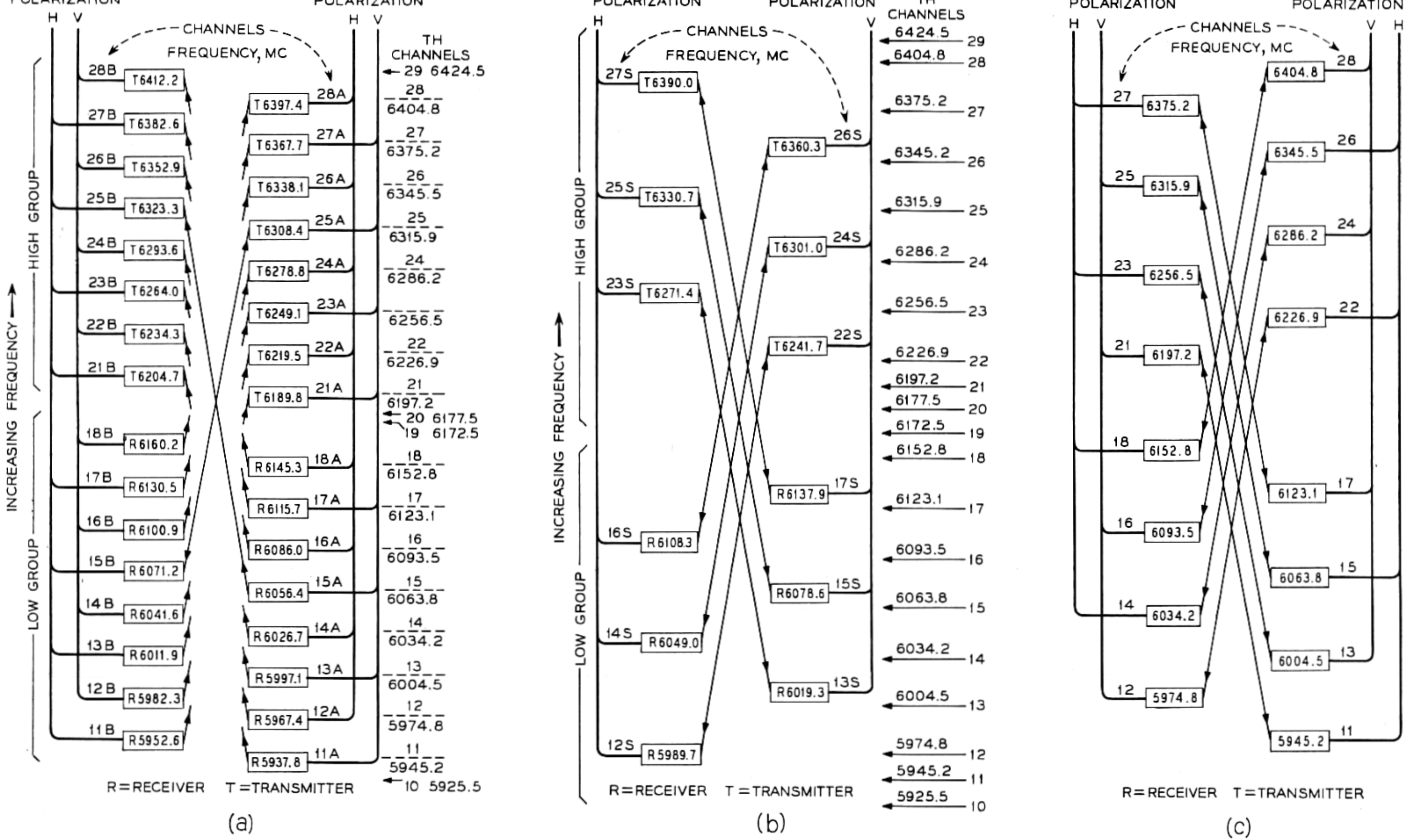


Fig. 5 — Frequency plans—TM-1 microwave high-group transmitting repeater: (a) normal channel frequency plan, (b) staggered channel frequency plan,

diversity basis, or in diversity with other channels within their individual bands, these cases will not be discussed here. Generally speaking, in message service, the increasing size of circuit groups and the more severe reliability objectives makes nondiversity operation undesirable. For educational TV, industrial or closed circuit video, however, nondiversity operation is usually acceptable.

Fig. 6 shows a possible growth plan for a TM-1/TL-2 crossband diversity system. Both the TM-1 and TL-2 systems normally employ a four-frequency plan using each RF frequency only once at a repeater which is required when periscope antenna systems are employed. These frequency plans achieve the following results:

(*i*) There is adequate separation between transmitters and receivers by using the upper (or lower) half of the band for transmitting and the lower (or upper) half for receiving. This arrangement is inverted at alternate stations.

(*ii*) Polarization of adjacent channels alternates between vertical and horizontal to provide maximum frequency separation between channels of the same polarity.

(*iii*) "Over-reach" interference is reduced by alternating horizontal and vertical polarization of a given frequency. A frequency having a horizontal polarization in one hop will occur again two hops away but will be vertically polarized.

4.2 *Diversity Operation*

The beat frequency oscillator is always kept within the assigned common carrier band, but its frequency may be above or below the frequency of the incoming RF carrier. Hence, since all other phase relationships are identical, the two halves of a diversity pair could have baseband outputs of opposite polarity. A polarity inverter is therefore included in the TM-1 transmitter baseband amplifier to insure in-phase signals at the baseband switch points to provide hitless diversity switching.

Two forms of diversity switch may be employed with the TM-1/TL-2 combination. The simple bistable switch has been described in detail in an earlier paper.[2] Where the performance of the two systems of a diversity pair is comparable, this type of switch is fully adequate, but where the performance of one of the systems is better than the other, a revertive switch, described in Section VII, is normally used. A typical two-hop system is illustrated in Fig. 7.

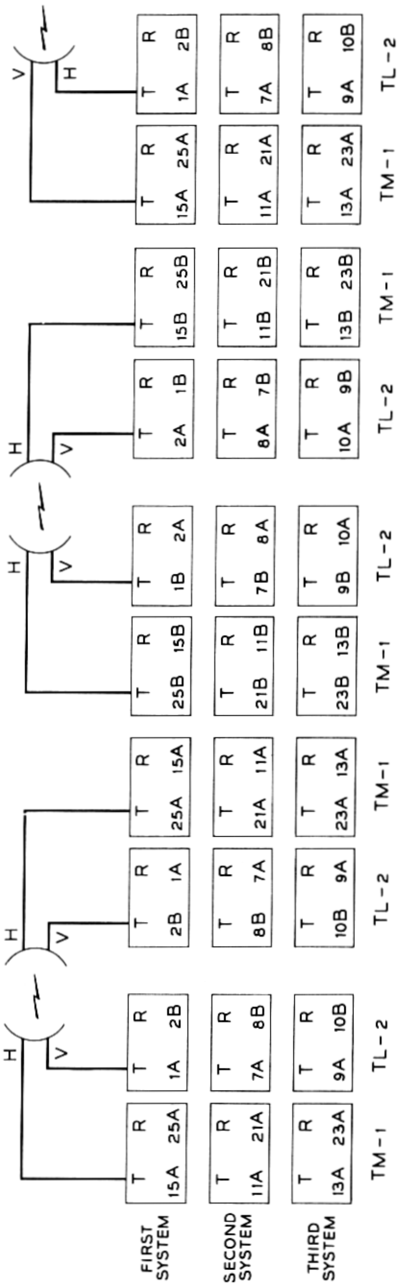


Fig. 6 — A growth plan for a TM-1/TL-2 crossband diversity system.

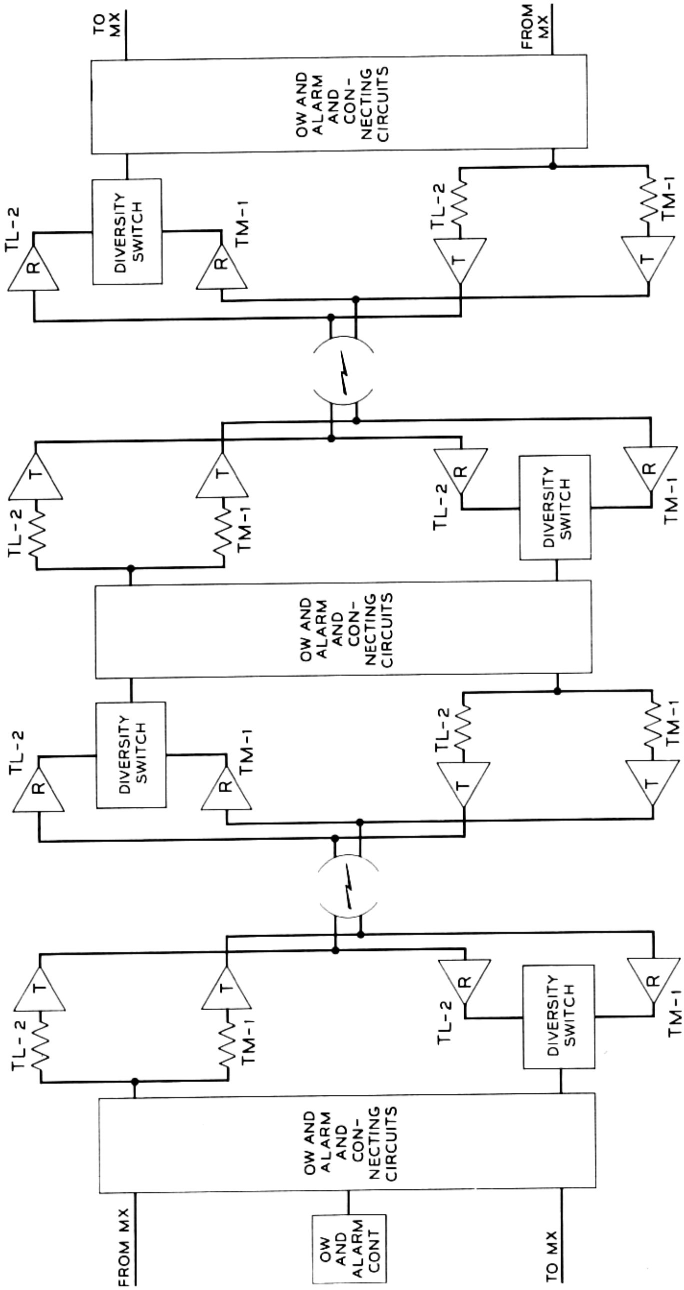


Fig. 7 — A typical two-hop TM-1/TL-2 diversity system.

V. MICROWAVE MULTIPLEXNG NETWORKS

5.1 *Antenna Multiplexing Networks*

The dual-frequency antennas mentioned in the previous section accept two polarizations at 11 gc and one polarization at 6 gc for a total of six 11-gc radio channels and four 6-gc radio channels. For crossband diversity usage this is limited to four diversity radio channels. Where load requirements are greater, the horn-reflector antenna may be used and here a microwave multiplexing network is required which will permit the multiplexing of more radio channels.

The block schematic of Fig. 8 illustrates how six two-way radio channels may be operated in crossband diversity. The two groups of TL-2 channels are combined in a 1405A polarizer network. The three TM-1 channels to be polarized horizontally and the three TM-1 chan-

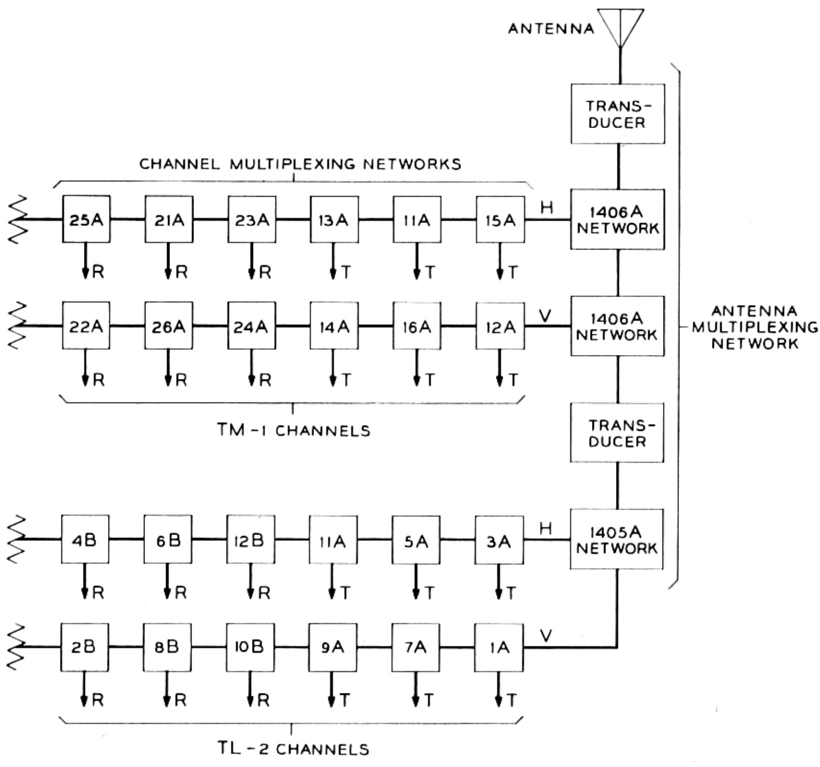


Fig. 8 — Use of microwave multiplexing networks in a TM-1/TL-2 installation.

nels to be polarized vertically are connected to separate 1406A networks which are multihole directional couplers having square through arms that support 6- and 11-gc orthogonally polarized waves. One 1406A network is rotated 90° with respect to the other. A transducer is required between the 1405A network and the 1406A networks, and another between the 1406A networks and the antenna. The networks are, of course, bilateral and have been described fully in previous literature.[8]

5.2 *Channel Multiplexing Networks*

The use of channel multiplexing networks is also illustrated in Fig. 8. Transmission through a network is nearly lossless for all channels except for the assigned channel where the through loss is very high but the loss to the drop is low. Fig. 9 illustrates a TM-1 channel multiplexing network. It consists of two channel rejection filters inserted between two short-slot directional couplers. The directional couplers are terminated in end pieces that provide the desired access for 3 ports and a termination for the fourth port. The manner in which a channel multiplexing network operates may be described by referring to the schematic shown in Fig. 10. A signal incident to port 1 is divided into two equal signals that differ in phase by 90° appearing at ports 5 and 6. These signals then pass into the filters and if the filters are tuned to the frequency of the signals, they are reflected back into the coupler. Each reflected signal is then divided into equal components with an additional 90° phase difference at ports 1 and 2. The components at port 1 are 180° out-of-phase and cancel while the components at port 2 are in-phase and add to give the original signal for the dropped channel. If the filters are not tuned to the signal frequency, the two signals pass freely through the filters and emerge in phase at port 3, and out-of-phase at port 4. Port 4 is terminated to present a good impedance looking into the other ports.

The performance of a representative network is shown by the transmission characteristics in Fig. 11. The in-band loss between ports 1 and 2 is less than 0.5 db for a 20-mc band while the loss between ports 1 and 3 is less than 0.1 for frequencies in the 5925 – 6425-mc band outside of the $f_m \pm 59.3$-mc region. In the standard frequency plan, the center frequencies of the other channels are at least 59.3 mc removed from f_m. The return loss of any port with the other two ports terminated is greater than 35 db from 5925 to 6425 mc.

The filters used in the channel multiplexing networks are constant-k.

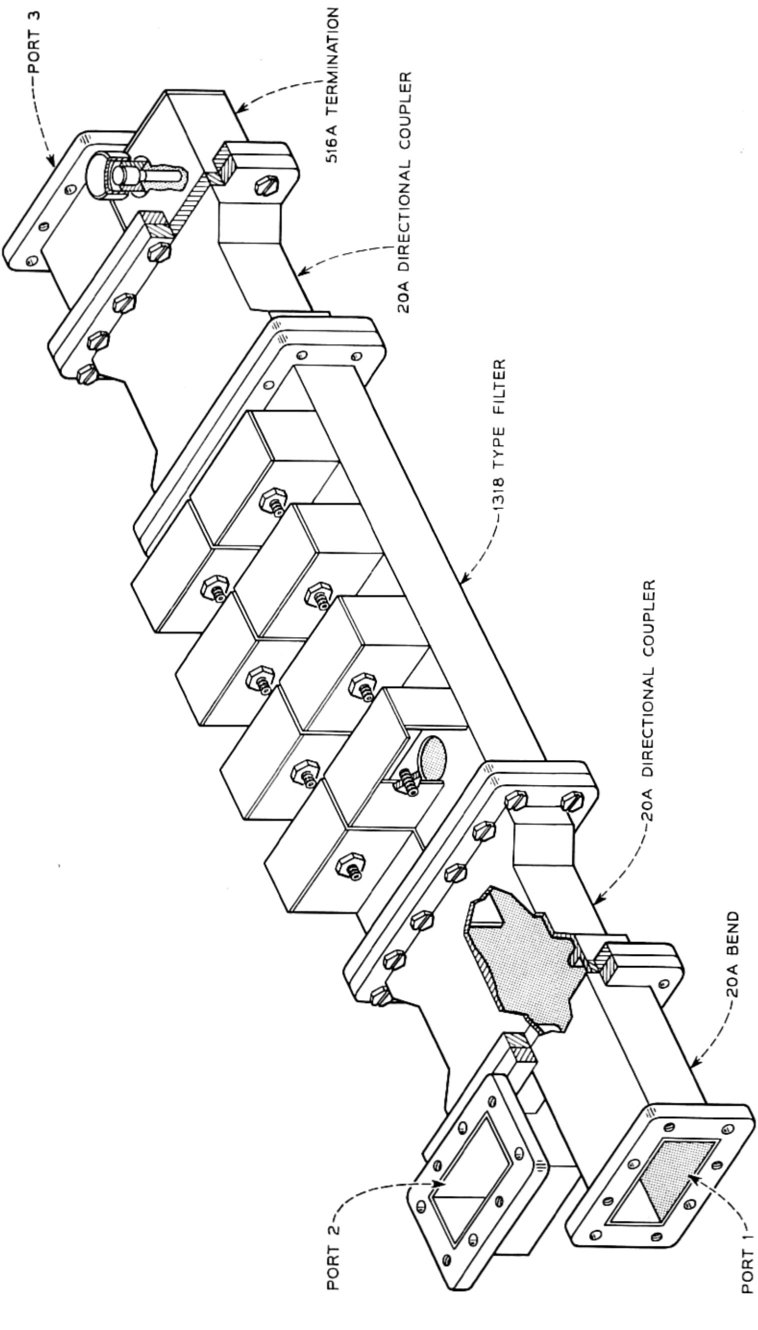


Fig. 9 — TM-1 channel multiplexing network.

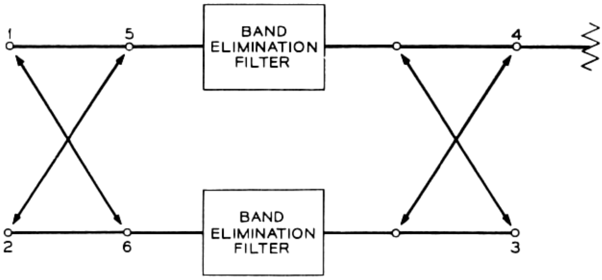


Fig. 10 — Channel multiplexing network schematic.

Each filter consists of four aperture-coupled cavities spaced $\frac{3}{4}\ \lambda$ along a section of waveguide. This type of cavity can be closely approximated by a series parallel-tuned circuit over a narrow band of frequencies.

The channel separating networks for TL-2 have been described previously.[1] Typical performance characteristics are given in Fig. 12.

VI. RADIO TRANSMITTERS

6.1 *General*

The block diagram of Fig. 13 describes both the TM-1 and the TL-2 radio transmitters. The baseband signal is amplified by the transmitter

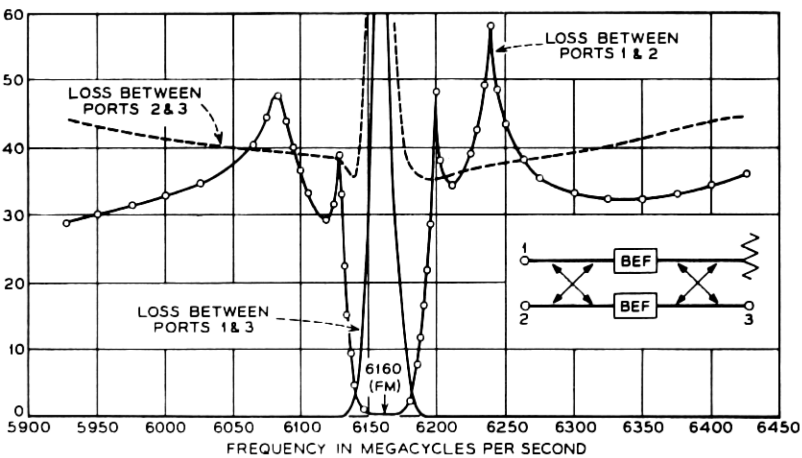


Fig. 11 — Insertion loss characteristic of TM-1 channel multiplexing network.

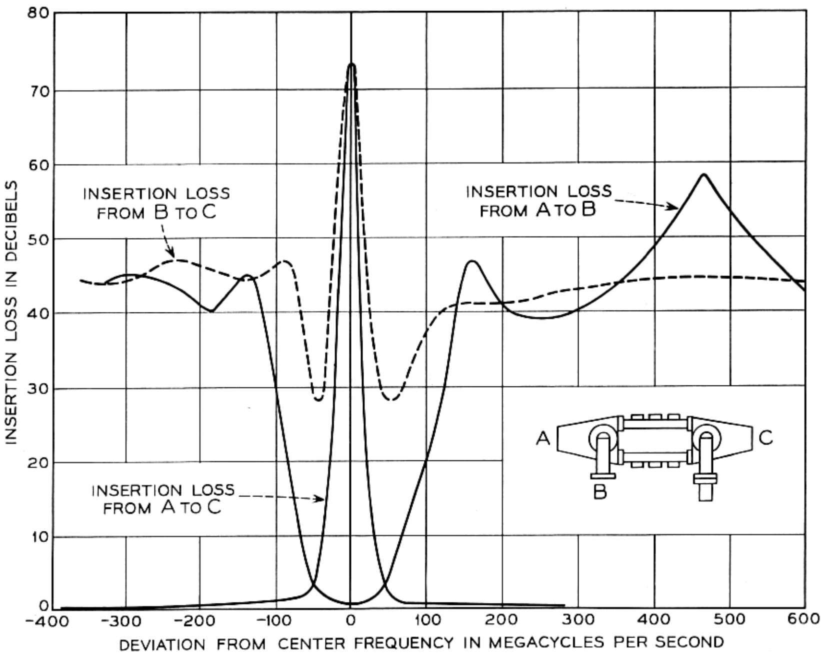


Fig. 12 — Transmission characteristic of channel multiplexing networks for TL-2.

baseband amplifier and is applied to the repeller of the klystron oscillator causing the frequency of oscillation to be deviated about the assigned channel frequency. The resulting band of RF frequencies is fed to the antenna networks through an isolator, directional couplers to permit frequency and power monitoring, a waveguide switch, and a channel separation network. Photographs of the transmitter portions of TM-1 and TL-2 are shown in Figs. 14(a) and (b). The klystrons and the isolators are not visible in these photographs.

6.2 *Transmitter Baseband Amplifiers*

The transmitter baseband amplifier for TL-2 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 8 volts peak-to-peak. A gain control of ± 4 db is provided to accommodate the modulation sensitivity of all klystrons. The amplifier has a frequency characteristic that is nomismall frequency errors due to this effect are unacceptable. The basic time constant is still approximately C_1R_1, but in the circuit of Fig. 16 leakage currents in C_1 flow in R_2 rather than R_1. Both C_2 and R_2 are large compared to C_1 and R_1. The voltage across C_2 is essentially zero.

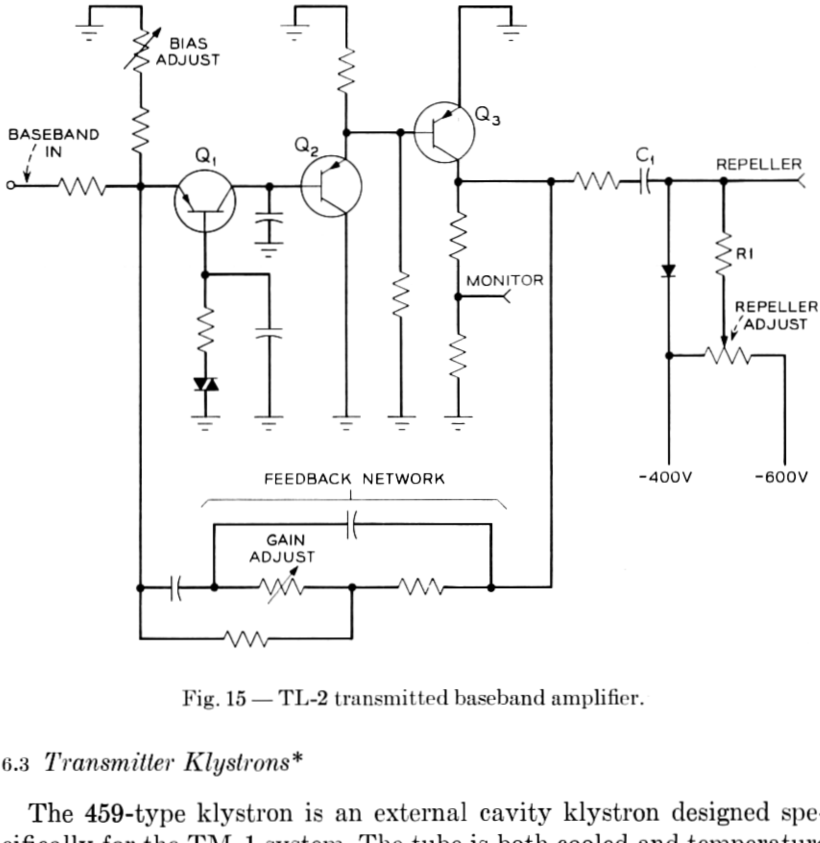


Fig. 15 — TL-2 transmitted baseband amplifier.

6.3 *Transmitter Klystrons**

The 459-type klystron is an external cavity klystron designed specifically for the TM-1 system. The tube is both cooled and temperature stabilized by clamping it to a vapor phase cooling boiler by means of the output flange. It has a specially designed temperature compensator which provides a frequency temperature coefficient of less than ±0.1 megacycle per degree Fahrenheit.

The external cavity design was chosen in order to achieve a relatively high modulation sensitivity comparable to that of the 457A 11-gc klystron. Even though the efficiency of an external cavity structure

* This section was written by Mr. E. J. Panner.

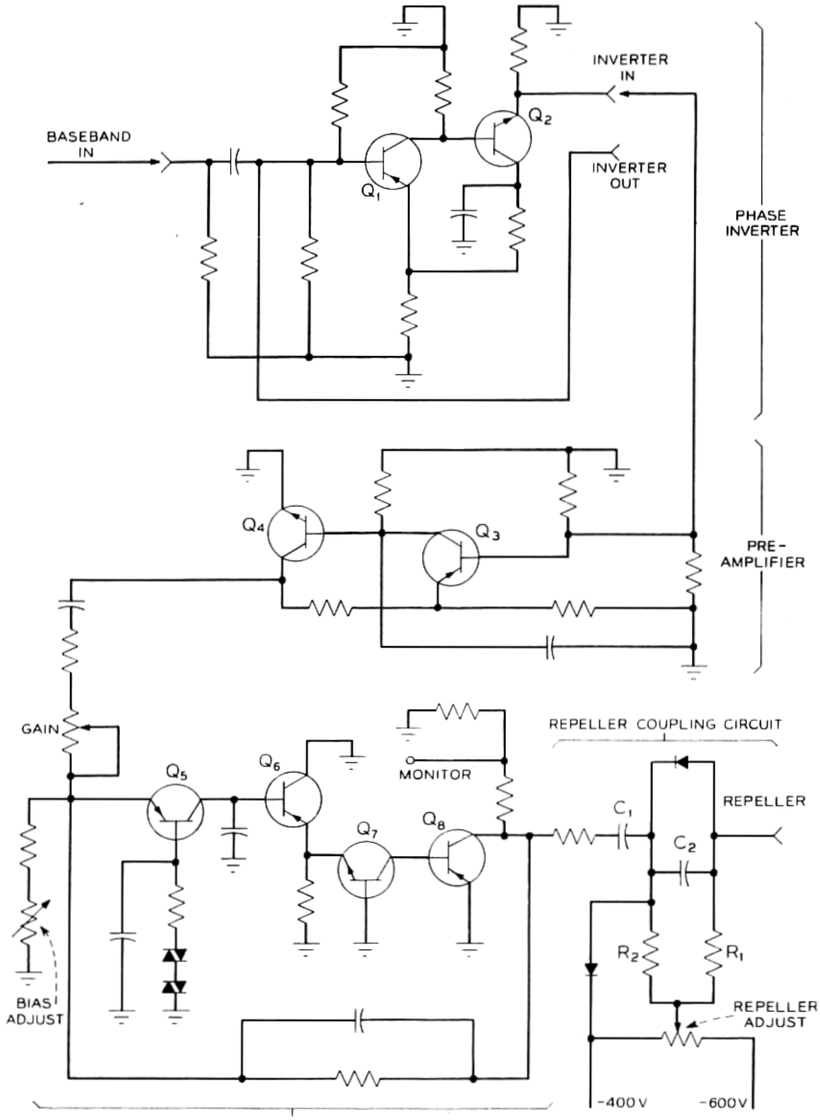


Fig. 16 — TM-1 transmitter baseband amplifier.

is somewhat lower than that of an internal cavity tube, some of this loss of efficiency is regained by operating the tube in the $2\frac{3}{4}$ mode. In addition, the higher output power tubes are coded 459A for use in transmitters while the lower end of the distribution is coded 459B for use as local oscillators in receivers.

Tuning is accomplished through the use of a contacting tuning plunger which is coupled to a frequency indicator and is driven by a slotted tuning nut. Mechanical tuning is possible without removing the insulating cover in the TM-1 bay. The entire tube is gold plated to raise the Q of the cavity and reduce the effects of oxidation.

The WE457A klystron, used in TL-2, has been described in connection with the TL Radio System.[9]

Fig. 17 is a photograph showing both the 459A and the 457A klystrons while typical output power versus frequency characteristics of both tubes are shown in Fig. 18. Typical operating characteristics of both tubes are summarized in Table I.

6.4 *Isolators**

New high reverse loss isolators were designed for these systems to be used at the outputs of the transmitter klystrons to prevent frequency pulling that would give rise to intermodulation distortion.[10] Fig. 19 shows the dielectric loaded full-height E-plane structures used and typical performance characteristics for both isolators. This structure was chosen to maximize the reverse loss per unit length to obtain a minimum length isolator.

The isolators consist of a thin ferrite slab (nickel aluminum ferrite) bonded to a ceramic loading of aluminum oxide which is approximately ten times thicker than the ferrite. The ferrite-ceramic loading is positioned in the waveguide at a nearly circular point of polarization of the microwave magnetic field. In addition to supporting the ferrite, the ceramic increases the microwave energy in the ferrite and decreases the frequency dispersion of the point of circular magnetic field polarization by lowering the cut-off frequency of the waveguide. The ferrite is biased to ferri-magnetic resonance with and external "C" magnet which is potted in glass filled nylon and bonded to the waveguide. The magnet length is critically determined to realize a variation in applied magnetic field along the ferrite, increasing the bandwidths of the reverse loss (isolation) characteristic. Matching is accomplished with linear tapers ground in both ends of the ceramic loading. The TM-1

* This section was written by Mr. J. J. Degan.

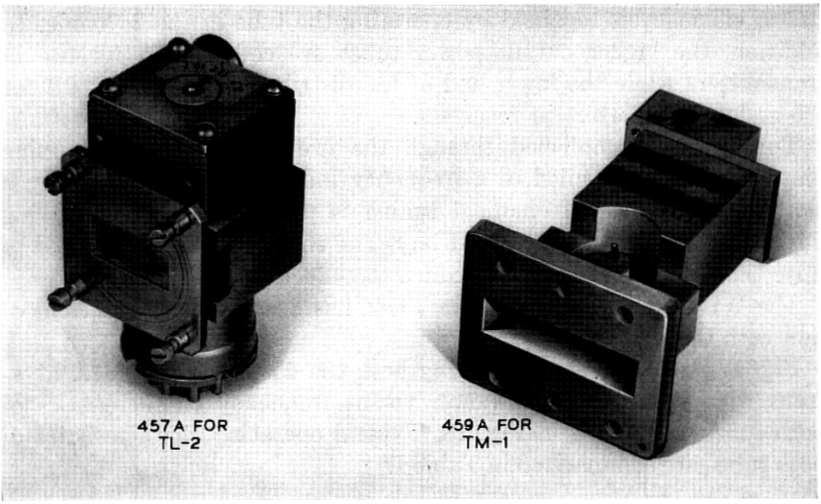


Fig. 17 — Klystrons.

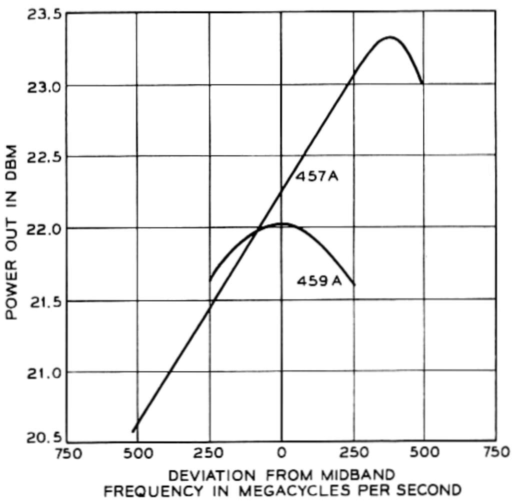


Fig. 18 — Typical power output vs frequency for 457A and 459A klystrons.

Table I — Typical Operating Characteristics

	459A Klystron	457A Klystron
RF power output	0.1w (min)	0.1w (min)
Resonator voltage	400v	400v
Repeller voltage	−120v	−115v
Repeller modulation sensitivity	1.7 mc/volt	2.3 mc/volt
Electronic tuning range	75 mcs	100 mcs
Heater current	0.88 amp	0.90 amp
Cathode current	43 ma	43 ma
Frequency-temperature coefficient	<0.1 mcs/°F	<0.15 mcs/°F
Oscillating mode	$2\frac{3}{4}$	$3\frac{3}{4}$

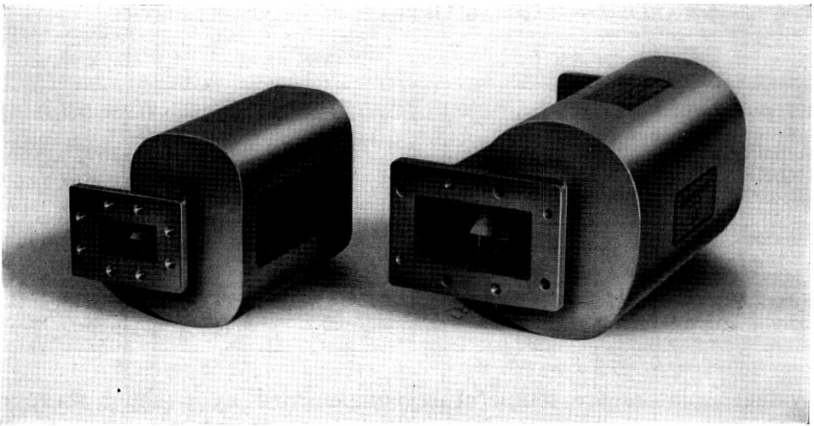
system isolators are temperature compensated by a shunt strap of magnetic material whose permeability changes rapidly with temperature.

An additional feature of the high reverse loss isolator in the TM-1 system is its built-in harmonic absorption. Harmonic outputs from the klystron tend to pull the klystron frequency, causing modulation distortion unless these harmonics are properly terminated. The ceramic-ferrite loading of the isolator preferentially mode converts the harmonic energy into the TE_{30} mode. On the other hand, energy at the fundamental frequency remains in the dominant mode (TE_{10}) in the desired signal band and is concentrated into the high dielectric loading. The resulting distribution of fundamental and harmonic electric field intensities is shown in Fig. 20. The result is a large differential in the value of electric field intensity near the side walls of the waveguide. Resistive vanes are placed in a position to provide several db of loss at the harmonic frequencies with less than 0.2 db of additional loss at the desired signal frequency. The vanes are bonded to a dielectric slab which in turn is bonded to the waveguide wall. Fig. 21 is a cut-away view of the isolator showing details of construction.

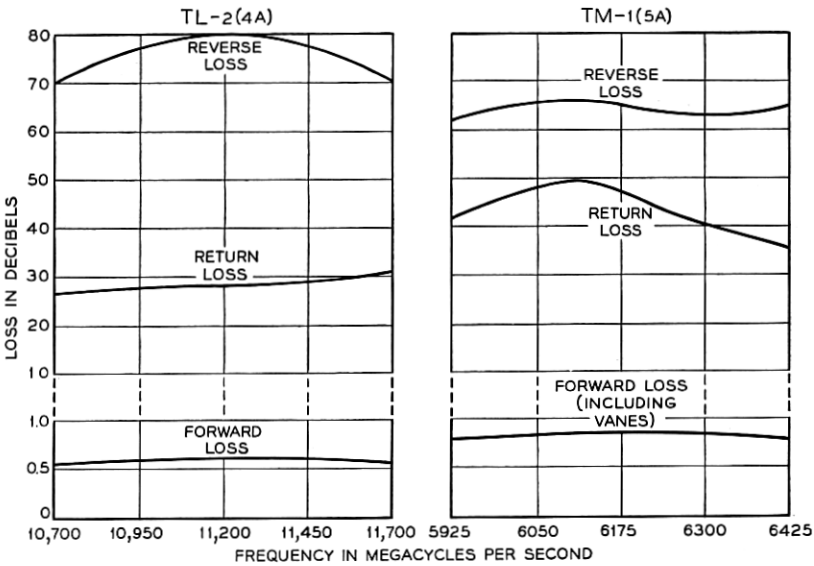
6.5 *Vapor Phase Cooling System Designs**

The frequency stability of the TM-1 and TL-2 transmitters is obtained in part by carefully controlling the temperature of the klystrons. This method was successfully used for TL-1 and the technique was improved for TM-1 and TL-2. Also, since TM-1 and TL-2 are designed to fit in the same panel space and to operate in diversity ar-

* This section was prepared by Mr. W. G. Stieritz.



(a)



(b)

Fig. 19 — (a) Transmitter isolators. (b) Typical isolator characteristics.

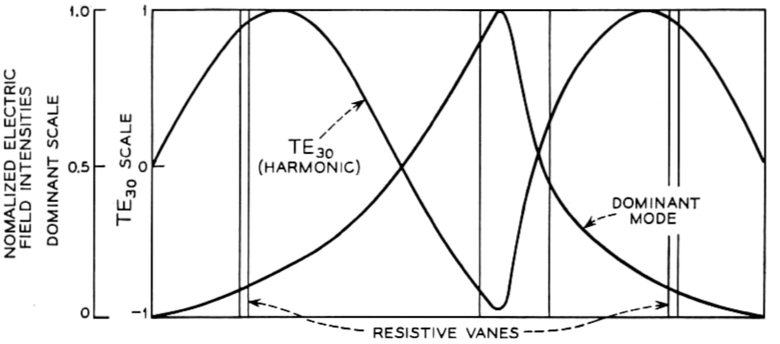


Fig. 20 — Comparison of dominant mode and TE_{30} transverse E fields in dielectric loaded guide.

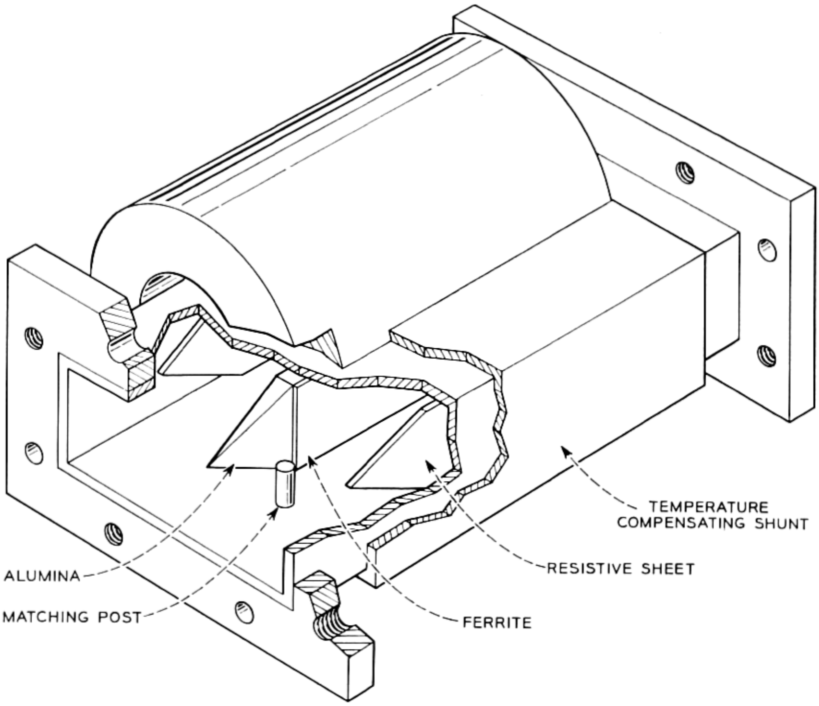


Fig. 21 — 5A isolator, cut-away view.

rangements with each other in the same shelters, it was advantageous to use a common equipment design.

The radio equipment is designed to be mounted in unattended shelters or in pole-mounted cabinets. The power dissipated in these enclosures will produce a temperature rise of about 20°F at low temperatures. The radio equipment must therefore operate in an environment of −20°F to +120°F corresponding to an outside ambient ranging from −40°F to +120°F. (At high ambient temperatures an exhaust fan is used.) Over a nominal 3-month maintenance interval the range of ambient temperature variation is not likely to exceed 100°F, however. To meet the ±0.05 percent frequency accuracy for TL-2 and the ±0.02 percent requirement for TM-1, the klystron temperature must be held to ±3°F. Klystron voltages must also be closely regulated, as described in Section VIII.

The major elements of the TL-2 vapor phase cooling system are shown disassembled in Fig. 22. The heat source is a pair of klystrons clamped to each side of a copper boiler. The boiler and klystrons are enclosed in a fiberglass insulated chamber to reduce the effect of ambient temperature variation. The boiler is filled with a heat transfer fluid, FC-75 fluorochemical which is a liquid that has a boiling point of 214°F at standard atmospheric pressure of 29.98 inches of mercury. The vapor from the boiling liquid which has absorbed the klystron heat is led by an inclined stainless steel pipe to the copper condenser block. Here the vapors are condensed back to the liquid phase, and returned to the boiler. This condenser is in turn bolted to the equipment mounting panel which serves as a heat sink to ambient. A rubber bladder connects to the condenser outlet and allows for expansion of the gases inside the system without allowing their escape. The flexible bag permits substantial changes in volume of the enclosed system without appreciable changes in pressure. This is required since otherwise changes in heat input to the boiler caused by ambient temperature changes would result in pressure changes inside the system, hence changes in the boiling temperature of the liquid. This equipment is capable of holding temperature changes of the klystrons of about 5°F over an ambient temperature change from −20°F to +140°F.

While the design of the TM-1 vapor phase cooling system is based on the earlier TL-2 design, the two systems differ considerably in detail. The differences may be attributed to physical and thermal differences between the 11- and 6-gc components.

The TM-1 solution, which was achieved by heat flow analysis and

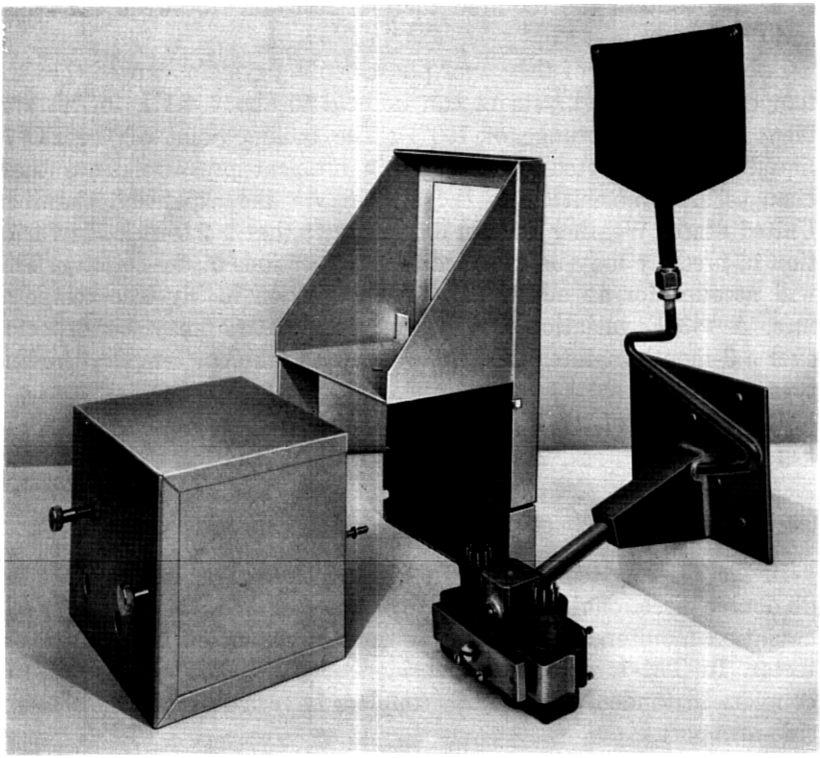


Fig. 22 — TL-2 vapor phase cooling system.

experimental verification, includes the following refinements over TL-2:

(*i*) The boiler, in the shape of a double waveguide flange, was thermally isolated from each waveguide by a section of internally plated plastic guide to eliminate heat flow through the large mass of the waveguide.

(*ii*) Foamed plastic blocks about ¼-inch thick are inserted in the plastic waveguides, and cemented to the narrow dimension of the guides. These blocks isolated the klystrons from air currents in the waveguides.

(*iii*) The cover assembly for the klystron chamber is insulated with polyurethane foam, rather than fiberglass as used in TL-2. A thermostatically controlled heater was also added to hold the temperature in the klystron chamber to about 110°F ±5° at lower ambient temperatures.

(*iv*) Synthetic rubber tubing between the boiler and the condenser is used to obtain the required thermal resistance between the boiler and the frame.

Laboratory tests of the vapor phase cooling system showed that the temperature of the klystrons can be held to about ±1°F for an ambient temperature range of 100°F. The boiling point of the FC-75 liquid is also affected by changes in ambient pressure, since these changes are transmitted to the system via the expansion chamber. United States Weather Bureau data suggest that a 2.0-inch Hg variation in pressure may be expected in some sections of the country. This will account for an additional ±2°F variation in klystron temperature. A ±3°F variation in klystron temperature may be expected over a 3-month maintenance interval due to ambient temperature and pressure chages.

The elements of the TM-1 vapor phase cooling system are shown in Fig. 23.

6.6 *Frequency and Deviation Monitor*

In the TL-2 system the output of the isolator is connected to a 20-db double directional coupler where one output feeds the frequency and deviation monitor and the other output is connected to a power detector. In TM-1, equipment considerations dictated the use of two couplers in tandem where both couplers have a loss of 17 db to the side-arm port.

The frequency accuracy of the transmitter is dependent upon the accuracy of the microwave reference cavity. The frequency stability requirement for TM-1 particularly, resulted in the following design:

(*i*) The cavity was constructed from specially heat treated and machined invar.

(*ii*) Provision was made to annul the small but finite expansion of invar using a brass detail compensator.

(*iii*) The cavity was filled with dry argon and sealed to minimize any variation of the dielectric constant with humidity.

(*iv*) Individual cavities were designed for each channel because it was felt that tuning mechanisms covering a wider frequency range might not be sufficiently stable.

Fig. 24 shows a cut-away view of the TM-1 reference cavity. It is a TE_{011} cavity aperture-coupled to rectangular guide. The dimensions of the cavity are proportioned to provide single mode operation and the apertures are proportional to achieve the narrow-band insertion loss characteristic shown in Fig. 25. The aperture tolerances are held

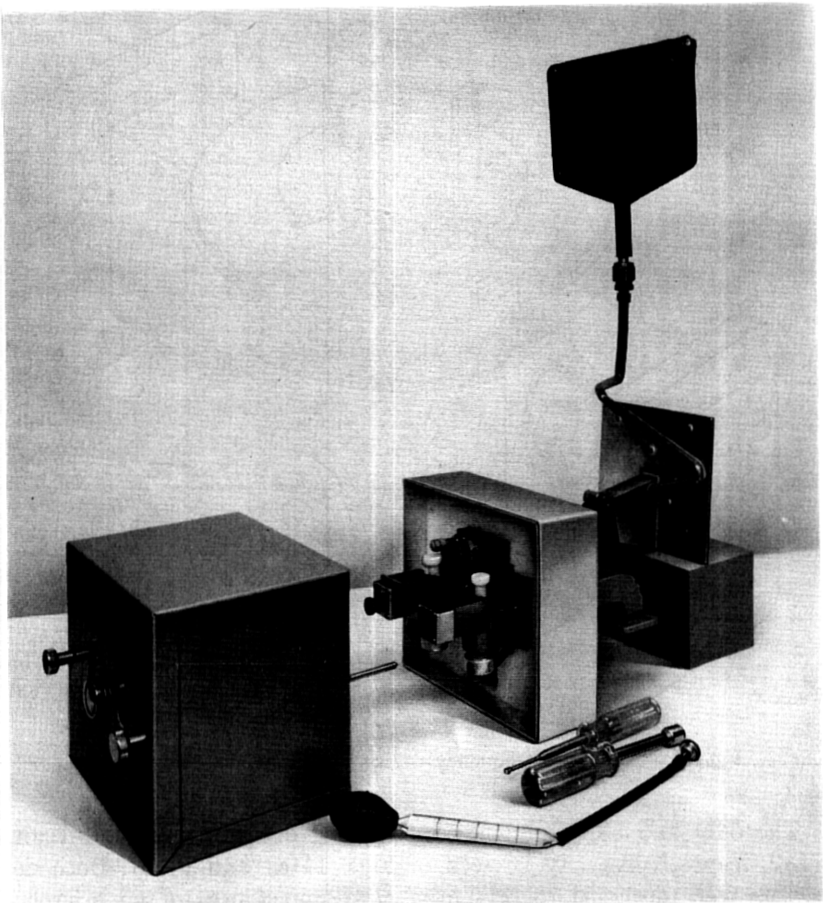


Fig. 23 — TM-1 vapor phase cooling system.

tightly to give accurate bandwidth control. The details of construction are shown in Fig. 24 including the brass temperature compensator. A typical cavity is stable to ±300 kc over the temperature range of −40°F to +140°F.

The frequency stability requirements for the TL-2 reference cavity are more lenient than those for TM-1, hence the compensation for the expansion of the invar was omitted. The tuning mechanism, consisting of a screw that is solder-sealed after cavity adjustment, is simpler than that used in TM-1. The transmission characteristic of the TL-2 reference cavity is shown in Fig. 26.

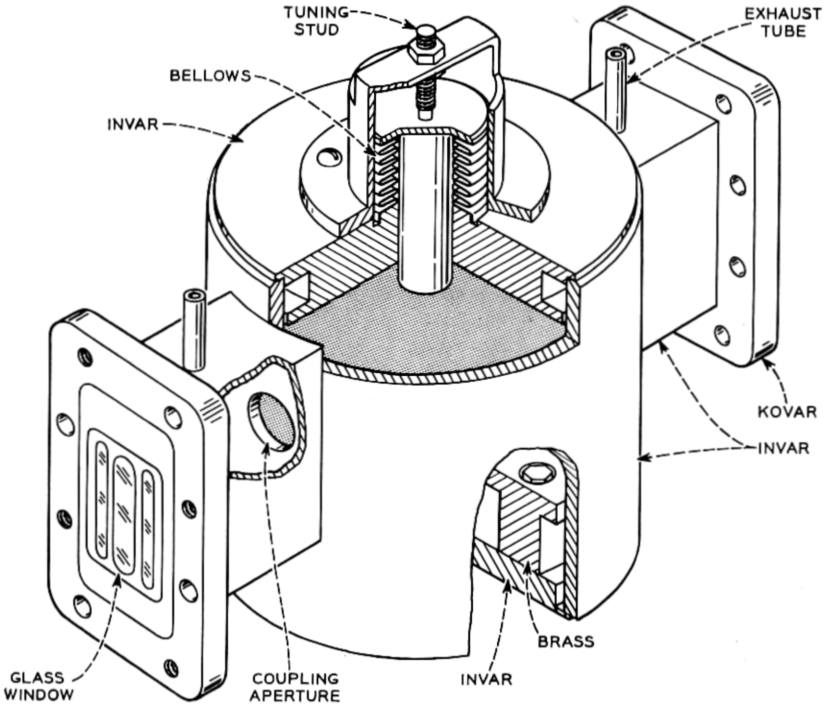


Fig. 24 — Reference frequency cavity for TM-1, cut-away view.

The 54D and 53A frequency monitoring detectors, for TM-1 and TL-2, respectively, may be seen in Figs. 14(a) and 14(b). Both detectors were designed to present a good impedance to the reference cavities as well as a flat transmission characteristic over a wide band.

In both TM-1 and TL-2, the waveguide attenuator is an integral part of the coupler and can be set to either of two positions. One position is virtually no loss while the loss for the other position (ranging from 2.5 to 3.5 db) is carefully set at the time of manufacture to permit a simple field adjustment of deviation. When the unmodulated transmitter is "on frequency", the detector meter readings will be maximum. When the transmitted RF carrier is frequency modulated, the detected output through the cavity filter will decrease because the filter selectivity attenuates the sidebands that are generated. 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 say 100 kc at a given level, the transmitter baseband gain control can be adjusted to give the same output from the cavity filter as is obtained when the attenuator is in its loss position and the carrier is unmodulated.

6.7 *Power Monitors and Waveguide Switches*

The power monitor detectors may be seen in the left-hand side of Fig. 14(a) for TM-1 and in the upper right-hand corner of Fig. 14(b) for TL-2. While the 53A detector used in TL-2 is identical to the frequency monitor, the power detector for TM-1 is built integrally with a 17-db directional coupler to better fit the TM-1 equipment design.

The waveguide switches may also be seen in Figs. 14(a) and 14(b). These switches are required in tests, such as the initial tuning of klystrons, where the transmitters must be effectively disconnected from the antenna. Each switch consists of a short section of waveguide with a narrow slot to accept a double-ended vane. The vane is properly positioned in the slot by means of detents and leakage from the slot is minimized by choke rings. The switch provides more than 60-db attenuation in the "off" position and a return loss of more than 40 db in its "on" position.

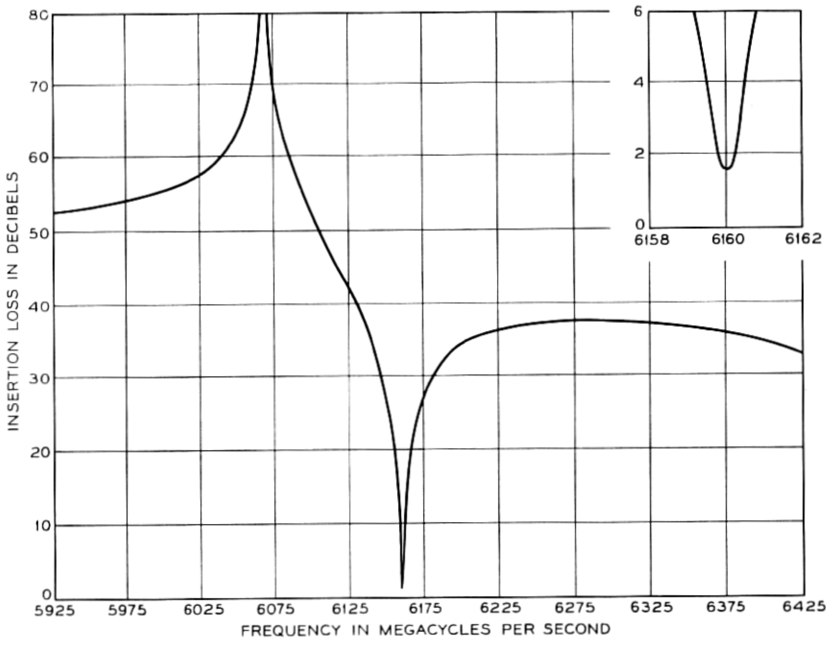


Fig. 25 — Transmission characteristic of reference cavity for TM-1.

6.8 *Stability of the TM-1 Transmitted Frequency*

The maintenance objectives for these systems are that a quarterly adjustment of frequency will be made using the built-in frequency and deviation monitor. A 100°F variation in temperature may be encountered over this interval. Laboratory measurements on a number of

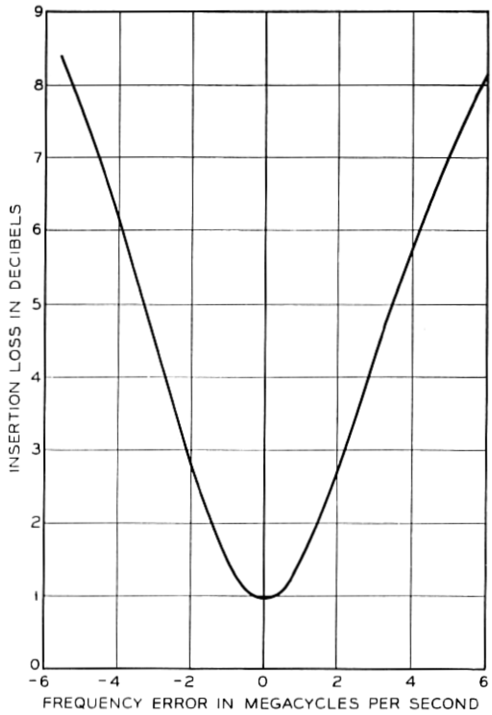


Fig. 26 — Transmission characteristic of reference cavity for TL-2.

transmitters (see Fig. 27) indicate that the TM-1 frequency is within ±0.02 percent of the assigned channel frequency for temperatures varying between −20°F and +120°F and the expected pressure variations that will be encountered during the maintenance interval.

6.9 *The TM-A1 Power Amplifier**

Fig. 28 shows a block schematic of the power amplifier and how it is used with a TM-1 transmitter to achieve an RF output of 2 watts.

* This section was written by Mr. L. K. S. Haas.

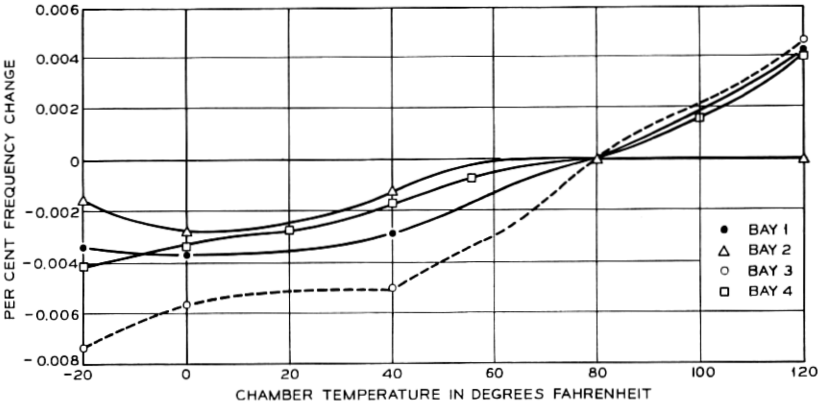


Fig. 27 — Transmitter frequency stability vs temperature for TM-1 transmitters.

The concept followed in the development of the 462A traveling-wave tube is that of a tube and circuit package in which all adjustments of electron beam focus and helix-to-waveguide match are made at the factory. To minimize the effects of defocusing, the helix diameter of the traveling-wave tube (TWT) is slightly larger than optimum for band flatness, and as a result, the gain characteristic has a slope of about 2 db over the 500-mc TM band. In the event of a tube failure, the package is returned to the factory for a new tube. Provision is made for an interlocking circuit so that the power supply cannot be turned on unless connection is made to the 462A package.

Focus of the TWT is accomplished by means of a repeating magnetic field pattern along the length of the tube provided by a stack of alternating Alnico VIII magnets and iron pole pieces. Magnets of this material were chosen because of its stability with changes in temperature.

RF input and output to the amplifier are made through reduced height waveguides which require waveguide transformers to match the standard WR-159 waveguide used elsewhere in the TM bay. The smaller waveguide inside dimensions are 0.318 by 1.590 inches for the input and 0.100 by 1.590 for the output.

The important parameters of the traveling-wave tube package are given in Table II. Nominal values are shown.

Cooling of the collector is accomplished by thermal contact between a cooling block on the 462A package and a heat sink which is part of the TM bay. A photograph of the 462A package is shown in Fig. 29.

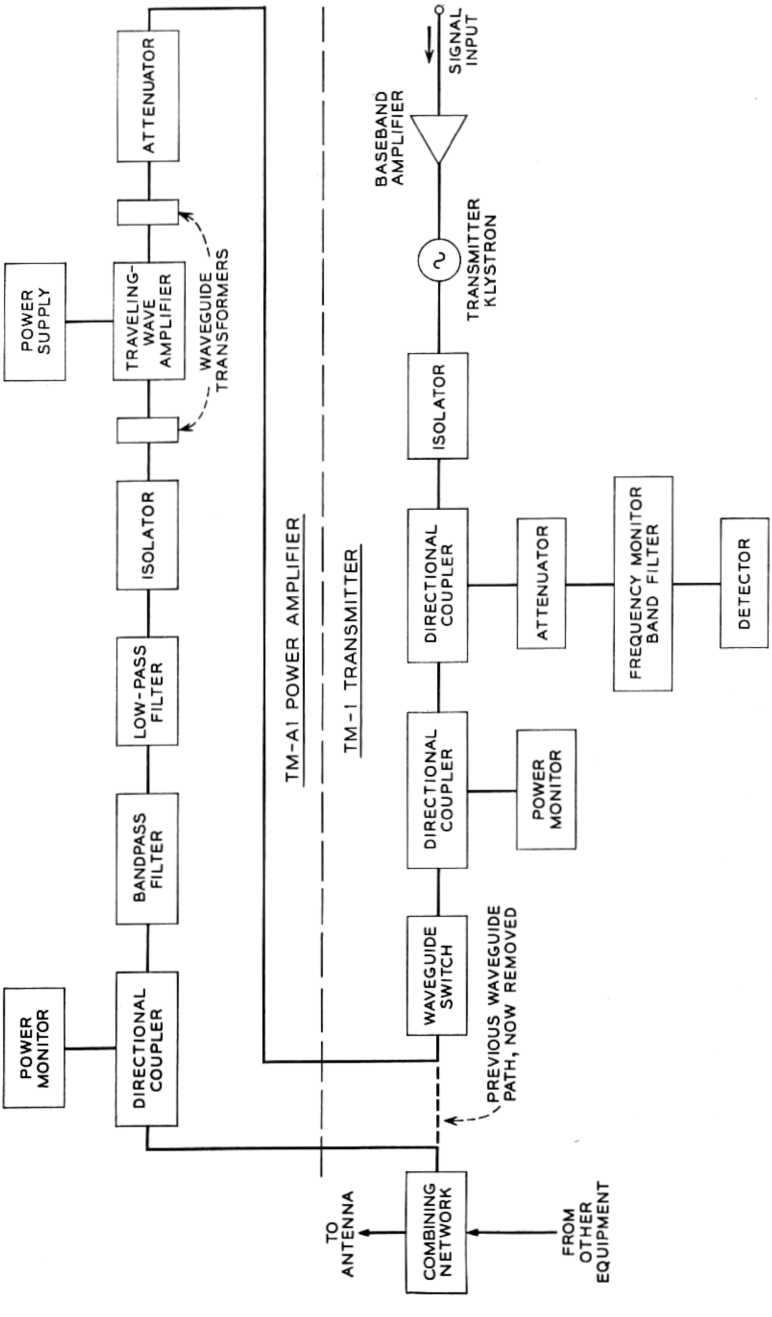


Fig. 28 — TM-A1 amplifier block schematic showing how amplifier may be added to a TM-1 transmitter.

TABLE II

Heater voltage	6.5v
Anode voltage	+2500 with respect to cathode
	+400 with respect to helix
Helix voltage	+2100 with respect to cathode
Cathode voltage	−1200v with respect to ground
Collector voltage	ground
Beam current	32 milliamperes
Collector dissipation	38 watts
Hot input return loss	17 db over entire TM band
Gain	21 db
Noise figure	25 db
Saturation power	+36 dbm
AM-PM conversion at +33 dbm output	2.5°/db
Spurious noise	20 db above background (max)

Provision is made in the TM-A1 amplifier to measure output power as shown in Fig. 28. The low-pass filter is provided to attenuate second harmonics generated in the traveling-wave tube while the purpose of the bandpass filter is to prevent wideband noise produced by the TWT from reaching receivers on the same waveguide run.

Performance tests made of a TM-1 system with a TM-A1 amplifier show that the amplifier introduces negligible transmission impairments in raising the outpuut power to 2 watts.

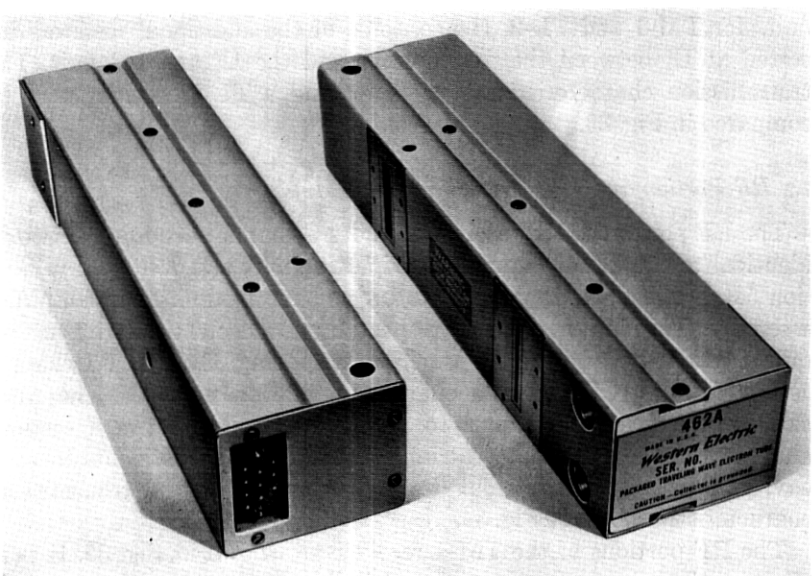


Fig. 29 — 462A packaged traveling-wave tube.

VII. RADIO RECEIVERS

7.1 *General*

The receiver portion is generally located on the right-hand portion of the RF panel as shown on the TM-1 photograph of Fig. 30. All the non-microwave circuits of the receiver except the preamplifier are contained in the IF and baseband plug-in unit that is the same for both TM-1 and TL-2, the general construction of which may be seen in Fig. 31. The box is divided into four shielded compartments with all the IF and baseband circuitry being divided among four printed wiring boards.

Fig. 32 shows the block diagram of either system. The functions served by the IF and BB unit and the receiver control unit are indicated. The IF bandpass filter and delay equalizer, used in TM-1 only, is the unit to the far right in Fig. 30.

With TM-1 channels spaced more closely than TL-2 channels, it was necessary to provide more discrimination against adjacent channels in TM-1 than in TL-2. Adding sufficient discrimination to the TM-1 RF bandpass filter would have been costly in terms of meeting stability requirements with temperature and the use of a narrower IF filter following the input IF amplifier would have meant separate IF and BB units for TM-1 and TL-2. Hence, some of the additional loss was inserted at IF between the preamplifier and the IF and BB unit. The transmission characteristics of a TM-1 and a TL-2 receiver may be compared in Fig. 33.

7.2 *RF Portion and IF Preamplifier for TM-1*

The RF portion of the receiver includes a channel-dropping network, identical to the TM-1 channel multiplexing network described in Section 5.3, a bandpass filter, an isolator, and the modulator preamplifier assembly. The design of the bandpass filter reflects the stringent requirements imposed by the close channel spacing. Each TM-1 channel uses a 5-cavity filter plus a channel separation network. The filter cavities are spaced $\frac{3}{4}\ \lambda$ apart to minimize coupling between sections and the filter is aligned by variable capacitance adjustments in each cavity. It is a maximally flat design having the typical transmission characteristic shown in Fig. 34.

The RF portions of the TM-1 receiver are shown in Fig. 35. It is in effect, a three-layer arrangement with the channel-dropping network mounted against the back plate of the RF panel. In a tandem ar-

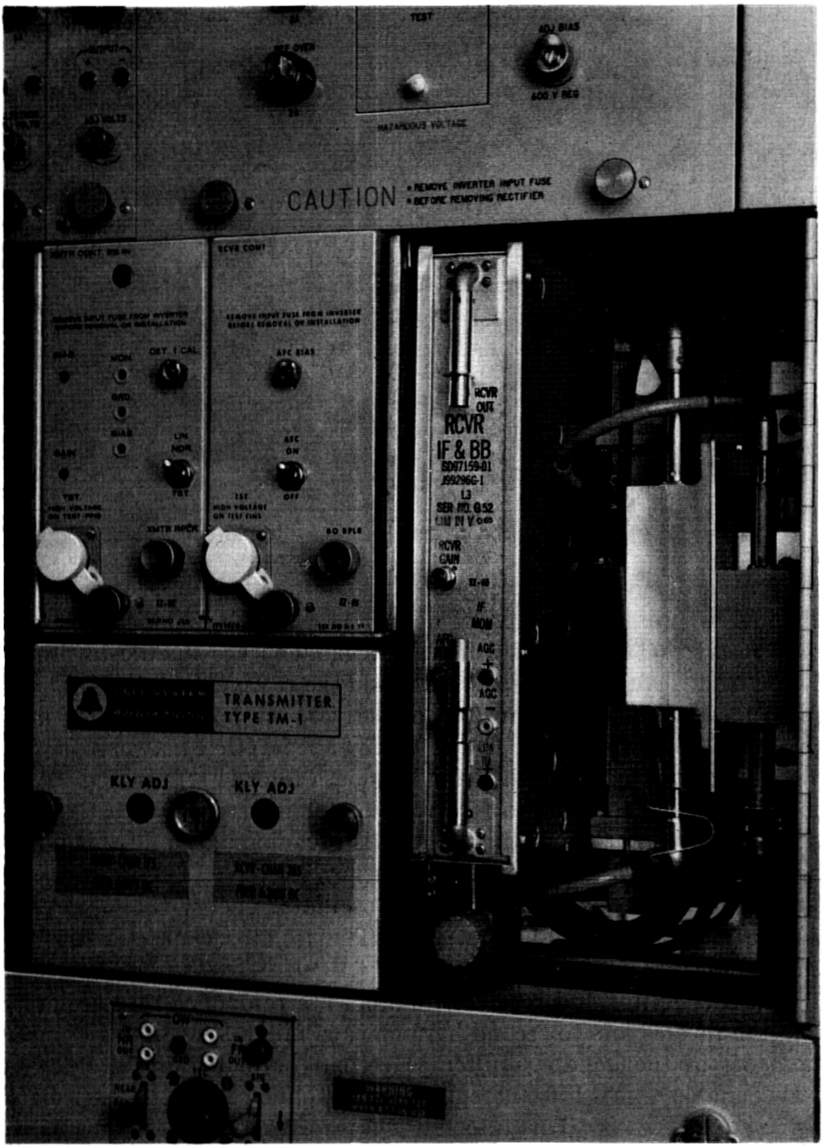


Fig. 30 — Receiver portion for TM-1.

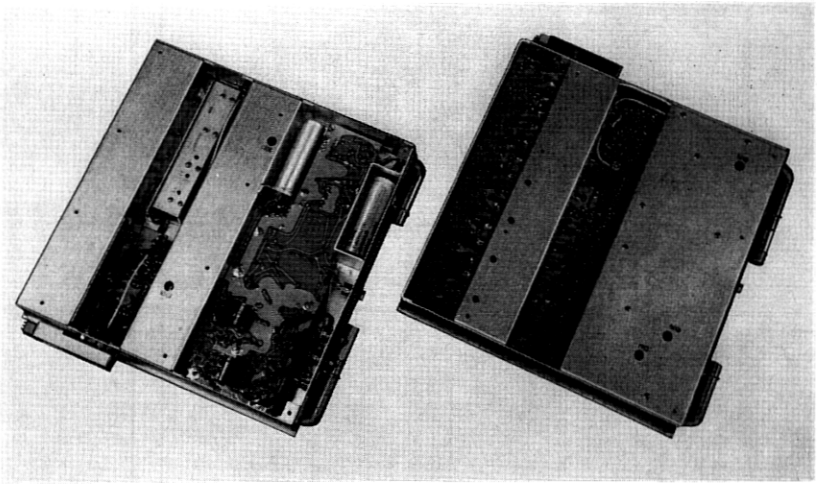


Fig. 31 — IF and baseband unit showing internal construction.

rangement of several receivers, the termination at the upper port of the channel-dropping network is replaced by a waveguide connection to the next receiver. The bandpass filter is located in the middle layer followed by a waveguide low-pass filter and the receiver isolator.

To meet over-all transmission objectives, the bandpass filter must present a good impedance to the channel separation network. This is very difficult to accomplish if the bandpass filter is terminated by the modulator, and therefore a receiver isolator is used between the filter and the modulator. Since this isolator is broadband, the filter is terminated by a network that is not frequency selective. The isolator also protects other receivers against beat oscillator energy that is present at the modulator signal input port. The isolator characteristics are shown on Fig. 36.

The transmitter and receiver isolators are resonance-type isolators, and the reverse loss to second harmonics is fairly low. Since the insertion loss of the bandpass filter to second harmonics is also low, a waveguide low-pass filter is required immediately ahead of the isolator as shown in Fig. 35. This filter attenuates the second harmonic of the beat oscillator (generated in the modulator) and prevents this energy from entering the modulator of another receiver and generating in-band interference products.

A 459-type klystron, operated in the same mode as the transmitter klystron, serves as the local oscillator. It is held at thermal equilibrium

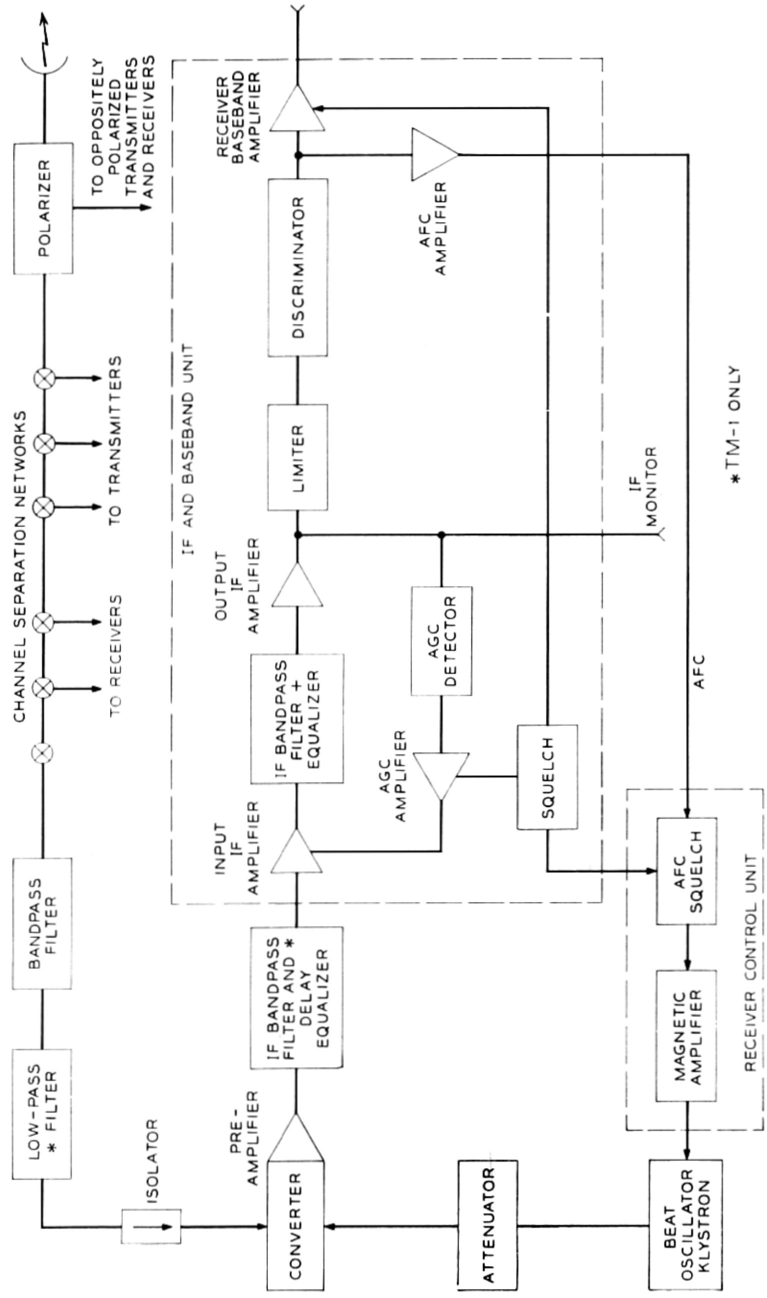


Fig. 32 — Receiver block diagram.

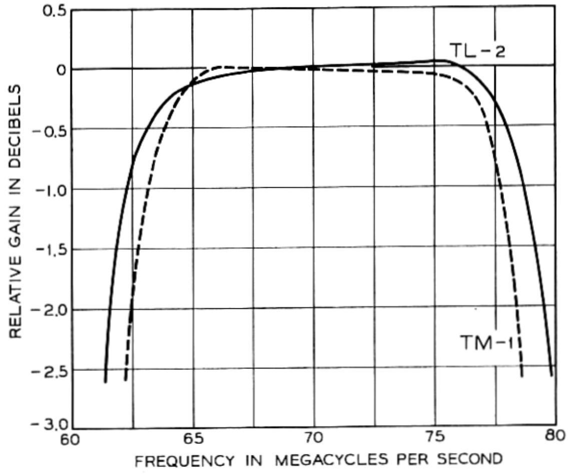


Fig. 33 — Relative receiver gain from RF input to IF output for TM-1 and TL-2.

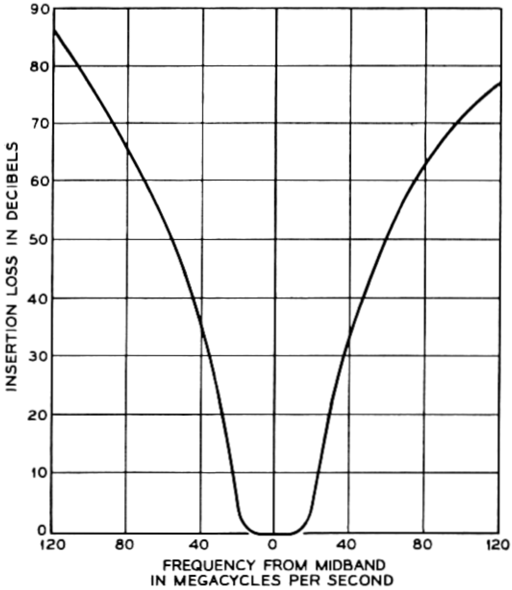


Fig. 34 — Transmission characteristic of TM-1 bandpass filter.

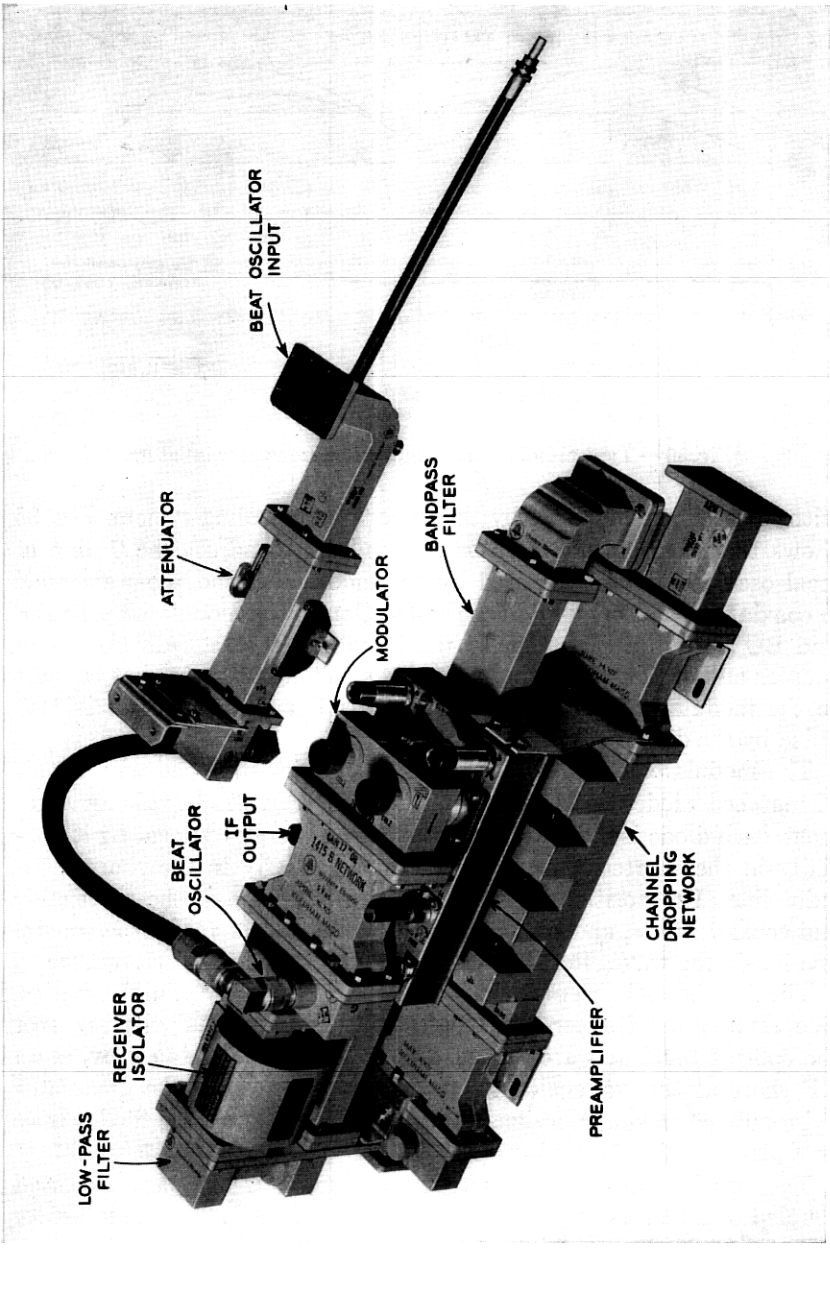


Fig. 35 — RF portions of a TM-1 receiver.

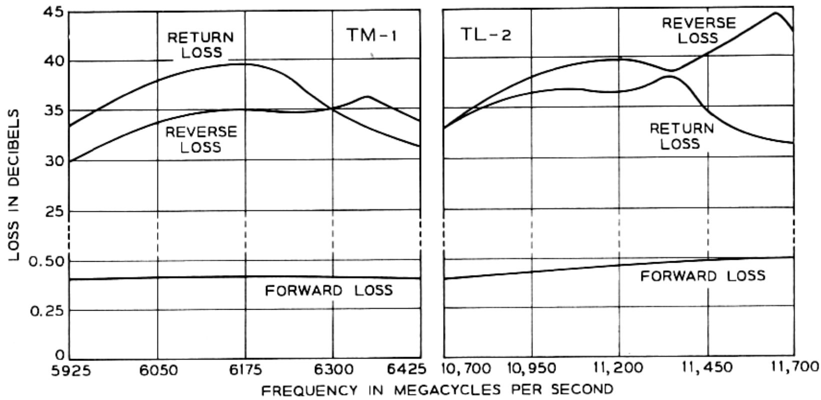


Fig. 36 — Typical isolator characteristics for receiver isolators.

with its transmitting mate by the vapor phase cooling system. Fig. 35 shows the waveguide attenuator that is used to adjust the 0 dbm of local oscillator power required by the modulator, and the waveguide to coaxial transducers used in the connection to the modulator. The RF and BO powers are applied to the input ports of a 3-db short slot coupler and are divided equally between the output ports that connect to the modulator. Isolation between the RF and BO sources is provided by the directivity of the coupler.

The modulator consists of two parallel guides equipped with a pair of matched diodes in the manner shown by Fig. 37. In this arrangement, each diode is coupled to the waveguide energy by locating it partially in the shorted waveguide line and partially in the shorted coaxial line. The position of the diode and locations of the waveguide and coaxial shorts, and the shape of the outer conductor of the coaxial line inside the waveguide are selected to give optimum performance.

The IF signal is separated from the RF signal by radial cavities. The cavities are stagger-tuned to provide optimum RF filtering over the 500-mc band and are spaced along the coaxial line to provide an RF short at the waveguide-to-coaxial interface. Since the modulator is broadband, a single design covers all channels, and the diodes may be replaced without retuning.

The two IF output signals from the modulator are paralleled and coupled to a transistor preamplifier as shown in Fig. 38. The interface or coupling network consists of a shunt tunable inductor paralleled by parasitic capacitance. The inductor is factory tuned to give a maximally flat transmission for channel 28B, and may be used for any other channel without retuning.

The preamplifier consists of two low-noise grounded-emitter stages plus a grounded-base stage. It has a noise figure of about 4 db. The nominal performance characteristics from the RF input to the microwave bandpass filter to the IF output of the preamplifier are:

RF to IF conversion gain	18 db
Noise figure	10.5 db
Transmission flatness over the 64–76 mc band	0.2 db

7.3 *RF Portion and IF Preamplifier for TL-2*

The channel-dropping networks and bandpass filters used in TL-2 were designed originally for the TJ Radio System, and the filters are of two types. Three cavity bandpass filters are used in all cases except for the last receiver in a lineup if the standard frequency plan is followed. Here a 4-cavity filter is specified and the channel-dropping net-

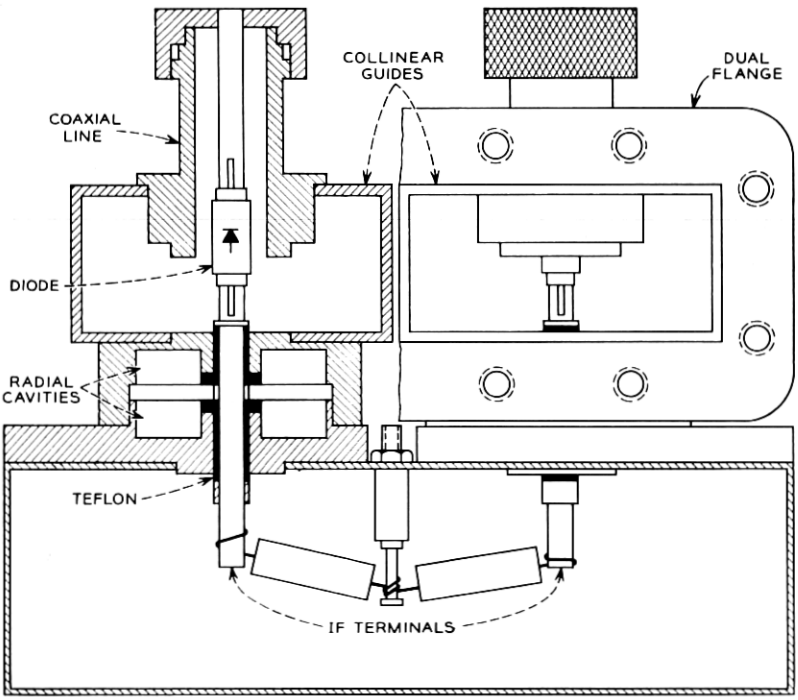


Fig. 37 — Internal configuration of modulator.

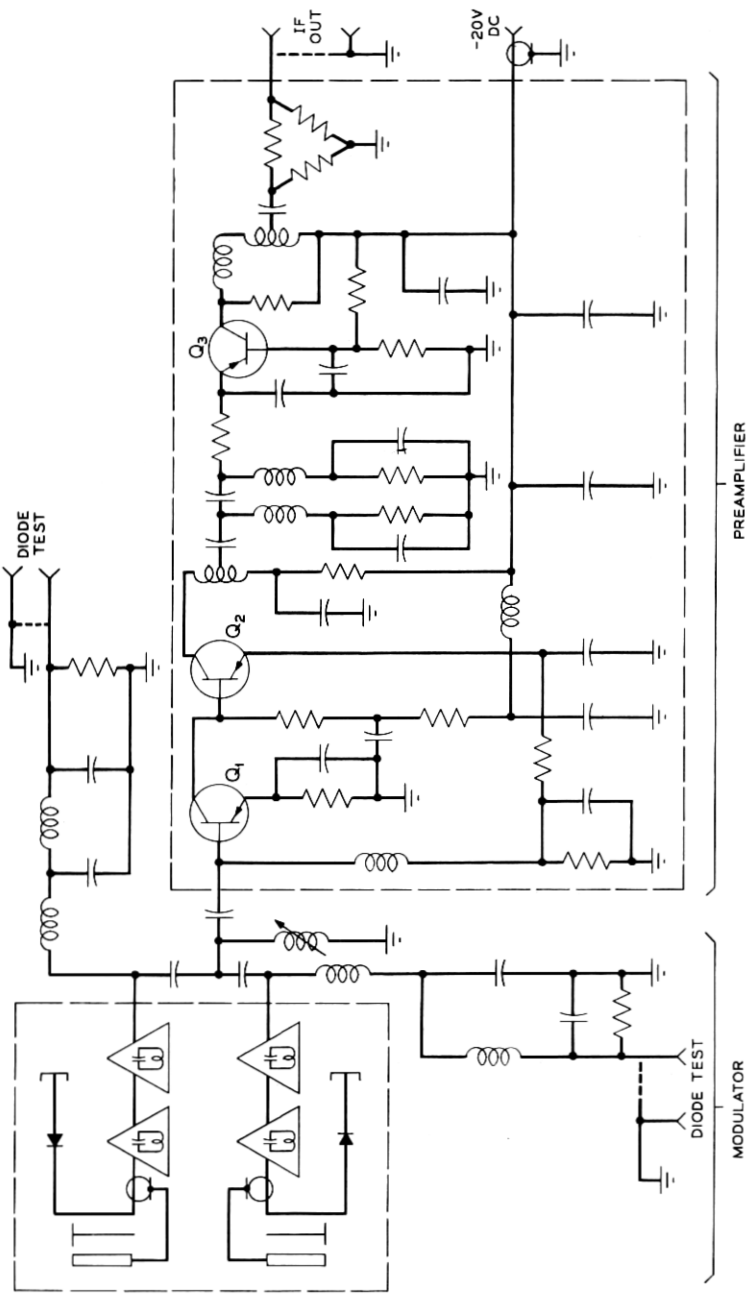


Fig. 38 — TM-1 modulator-preamplifier schematic.

work may be omitted. The transmission characteristics for the two types of filters are shown in Fig. 39; the characteristics of the channel-dropping network are given on Fig. 12.

The modulator-preamplifier assembly for TL-2 is shown in Fig. 40 where the 4-cavity filter, the receiver isolator and the modulator block may be identified readily. The preamplifier is housed in the section to the rear of the modulator block. The isolator serves the same purpose as the isolator in TM-1 and its performance characteristics are also

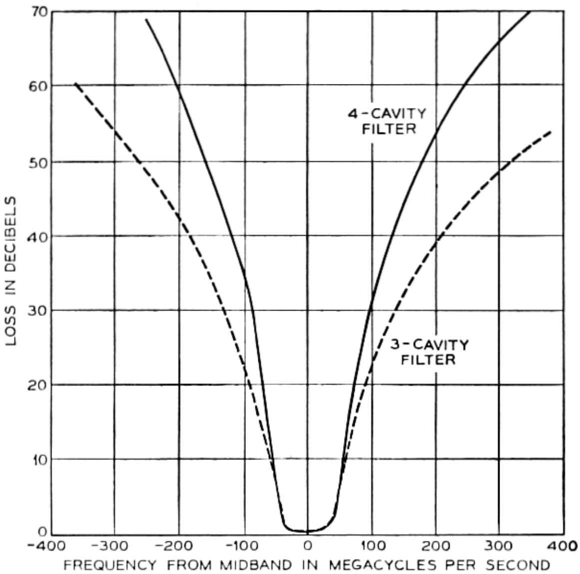


Fig. 39 — Representative transmission characteristic of TL-2 bandpass filters.

shown in Fig. 36.* Here again, the use of the isolator makes the modulator-preamplifier a broadband device, and a bandpass filter, an isolator, and a modulator-preamplifier may be assembled and used without making any over-all adjustments.

Beat oscillator power at about 0 dbm is applied to the modulator at the waveguide port that is visible at the front of the block. A low-pass filter in the signal waveguide path has not been found necessary since

* In early TL-2 production a tuner was used rather than an isolator. The tuner was adjusted for an optimum impedance into the bandpass filter. Thus, in the earlier design, the modulator-preamplifier assembly was a frequency sensitive entity.

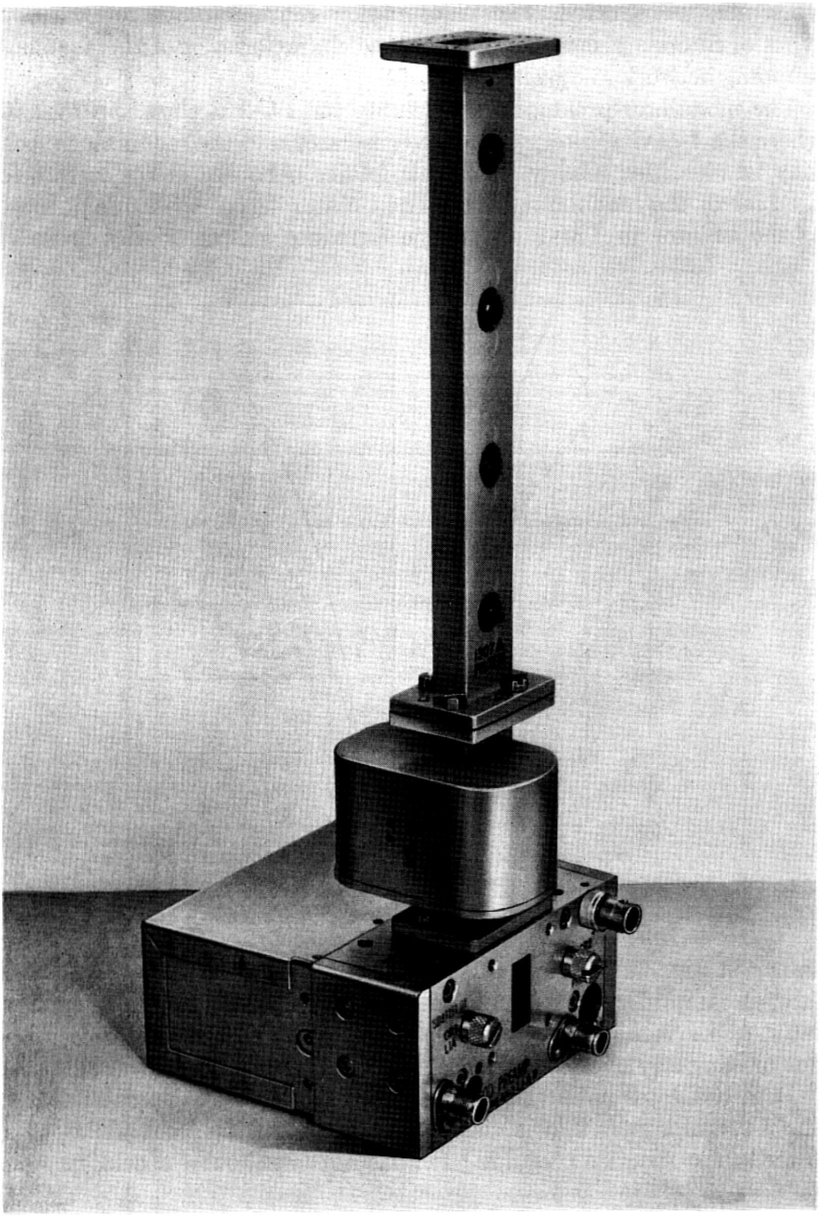


Fig. 40 — TL-2 receiver-modulator preamplifier.

nally flat from less than 10 cycles to over 6 mc. A schematic of the amplifier is shown in Fig. 15. The amplifier is packaged in the transmitter control unit.

The nominal deviation sensitivity of the TM-1 klystron is less than that of the TL-2 klystron, hence the TM-1 input amplifier requires additional gain. The schematic for TM-1 is shown in Fig. 16 where the output amplifier is similar to the TL-2 amplifier and the preamplifier provides the added gain. The maximum gain of the amplifier is 34 db, and it is capable of supplying a maximum voltage of 12 volts peak-to-peak. The transmission characteristic is essentially flat from less than 10 cycles to over 6 mc.

As described previously, the phase inverter is required to obtain hitless switching. By providing for reversal of the baseband signal in the inverter of the TM-1 amplifier, the proper polarity of the diversity switch in the next receiver can be obtained.

The repeller coupling circuits for the two systems are also shown in Figs. 15 and 16. In TL-2, the time constant R_1C_1 is sufficiently long to insure good low frequency performance and the breakdown diode protects the repeller against voltages that are positive with respect to the klystron cathode. The voltage across C_1 is about 500 volts however, and changes in leakage current will result in frequency errors. In TM-1, with the more stringent requirements on frequency stability, the

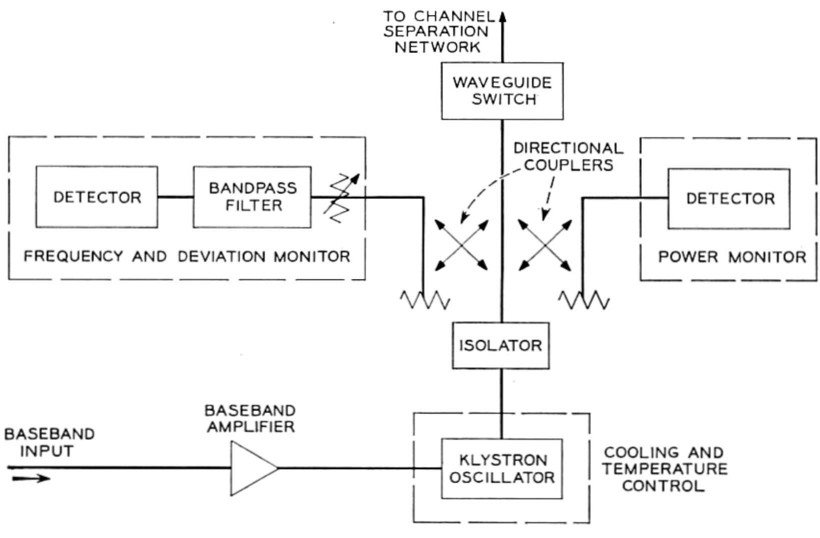


Fig. 13 — Transmitter block schematic.

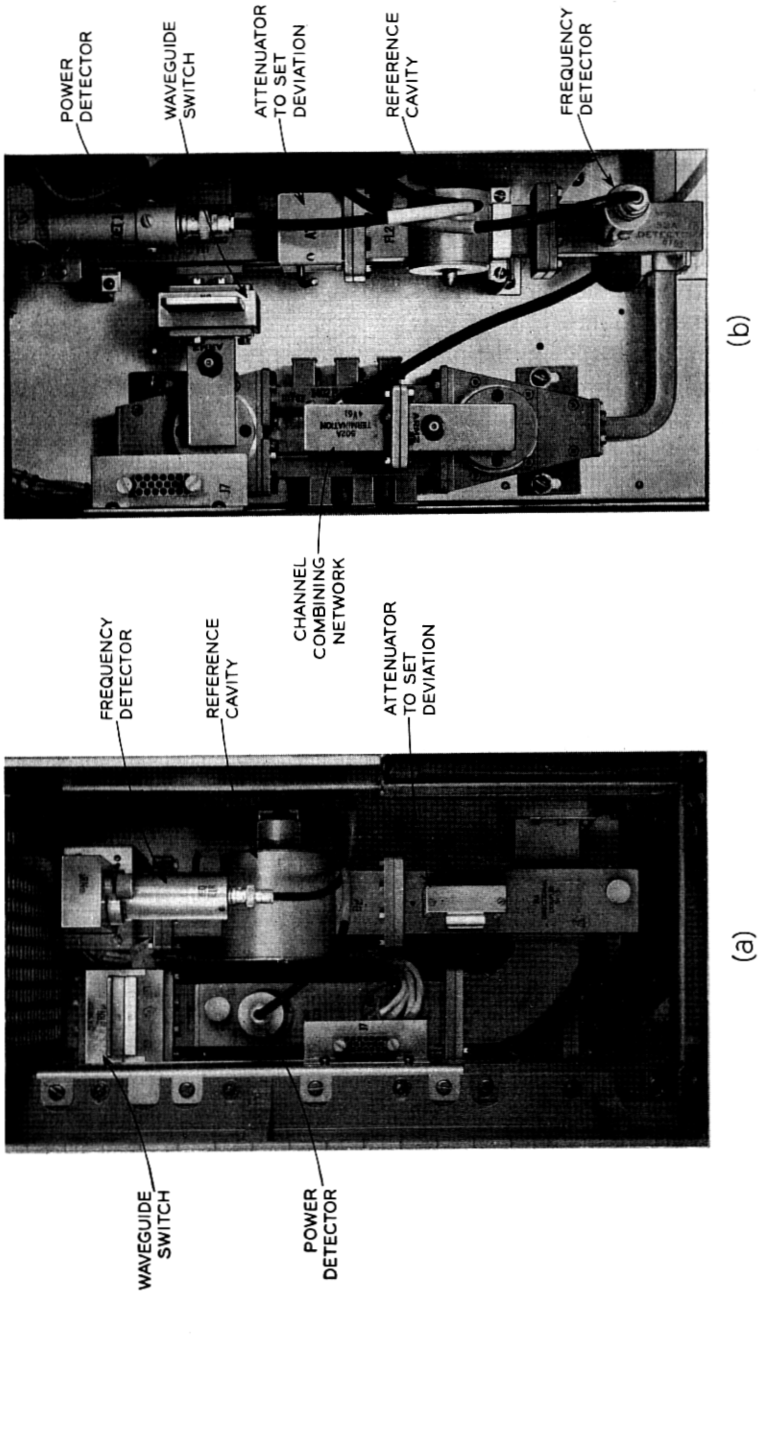


Fig. 14 — (a) TM-1 transmitter. (b) TL-2 transmitter.

the TL-2 receiver modulator design provides sufficient balance against the second harmonic of the local oscillator.

The circuit of the TL-2 preamplifier is shown in Fig. 41. The important difference between this preamplifier and the one for TM-1 obtains at the modulator-preamplifier interface. Where TM-1 is tuned, TL-2 is broadband; the output capacitance of the TL-2 modulator is too high to accommodate the TM-1 circuit. While the untuned circuit provides less gain, it was possible to optimize the noise performance of the circuit with the input transformer and to make up the gain by using additional grounded-base stages. The nominal conversion gain of

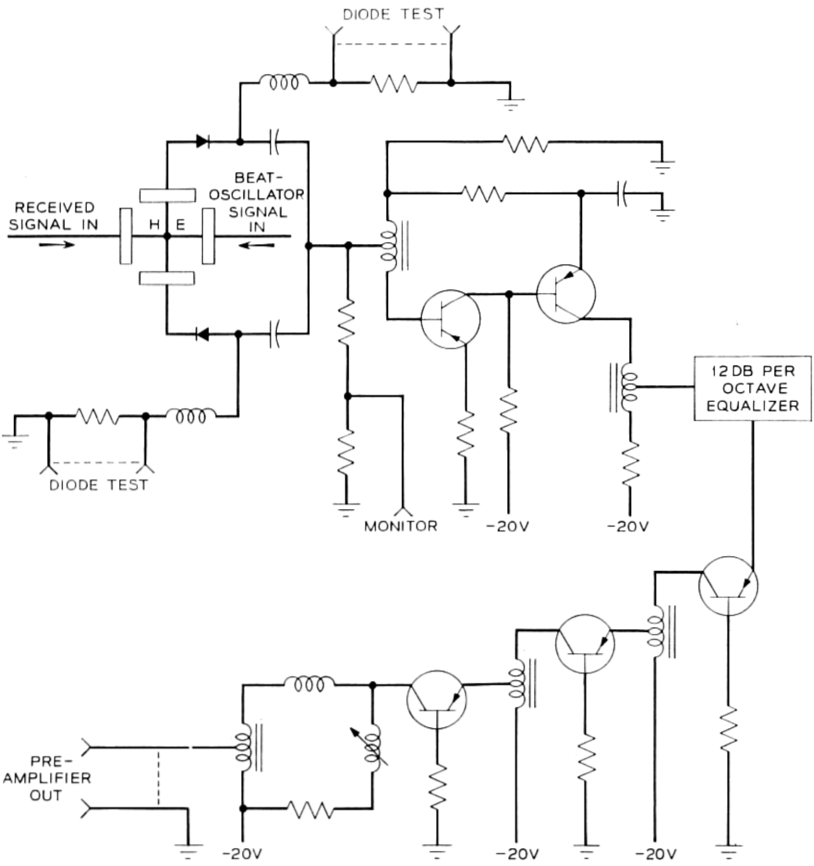


Fig. 41 — TL-2 preamplifier simplified schematic.

this modulator-preamplifier is also 18 db and its nominal noise figure, referred to the input of the mixer, is 10.5 db.

7.4 *The IF Amplifier*

Nearly all the IF stages in the IF input and output amplifiers are grounded base stages as shown in Fig. 42(a).[11] Using 2:1 interstage transformers as shown, the theoretical current gain per stage is 6.0 db but due to transformer losses, the practical current gain is about 5.5 db. To a first approximation, and neglecting the transformer step-up, the equivalent circuit is as given in Fig. 42(b), where L is the sum of the transformer leakage and emitter inductance, R is a damping resistor and the capacitors are the collector and transformer shunt ca-

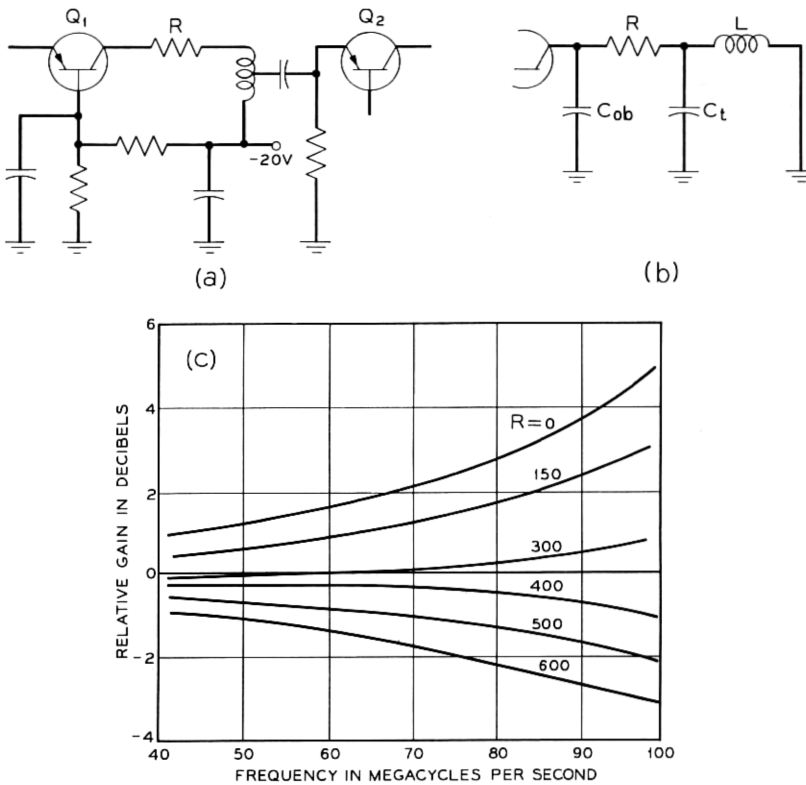


Fig. 42 — IF interstage; (a) typical IF stage, (b) equivalent circuit, (c) relative transmission characteristic for several values of damping resistance.

pacitances. Without damping, such an interstage peaks at about 135 mc for the transistors, transformers, and printed board design used. The damping resistance is selected for a maximally flat transmission, and Fig. 42(c) illustrates the relationship between damping and transmission. By designing the active circuits for a wide transmission band, it is possible to use a passive network to limit the band to the desired 64–76 mc. This is the purpose of the IF bandpass filter and equalizer shown in Fig. 32.

The input IF amplifier shown in Fig. 32 includes three variolossers controlled by an AGC circuit to hold constant the IF power delivered to the limiter over a fade range of at least 35 db. Each variolosser is of the form shown in Fig. 43. The losser element is a point contact germanium diode shunted across the circuit. Control current from the AGC detector is made to flow through this diode; a high value of control current, corresponding to a high RF input to the receiver, produces a low impedance path to ground, and hence, a high loss in the variolosser section. The series resistance, $R_1 + R_2$, serves again to damp the transmission characteristic. The relative transmission characteristic of the stage can be held very nearly fixed over a wide range

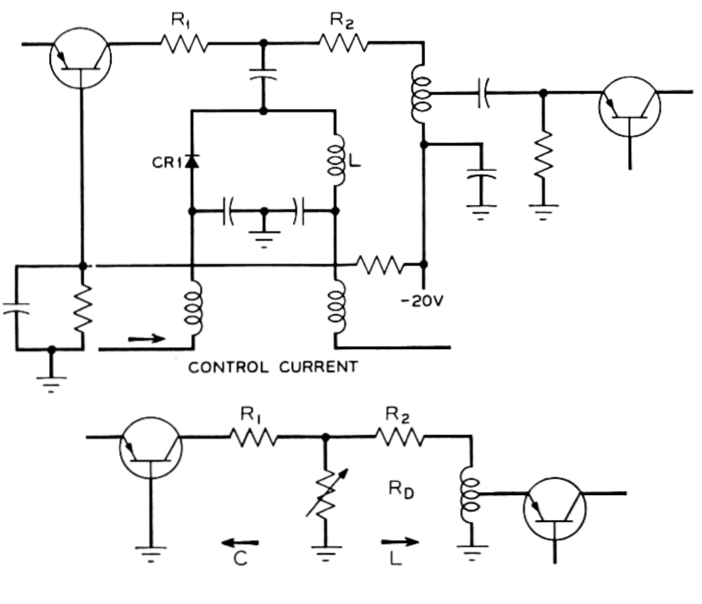


Fig. 43 — A variolosser stage.

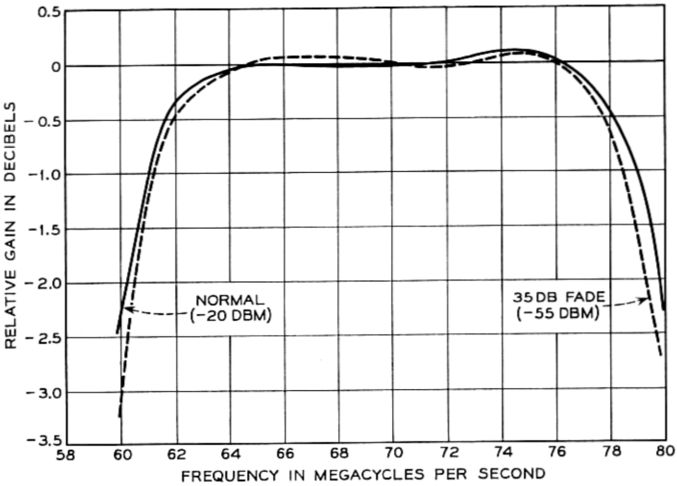


Fig. 44 — Transmission characteristic of the IF amplifier for normal and faded inputs.

of loss, if the variolosser diode is located at a constant resistance point. This is achieved if

$$R_1 = R_2 = \sqrt{\frac{L}{C}},$$

where C is the parasitic collector capacitance and L is the parasitic inductance contributed by the transformer, the wiring, and the following transistor. The maximum flat design is obtained when

$$R_1 + R_2 = \sqrt{\frac{2L}{C}} \sqrt{1 - \left(\frac{f_c}{f_p}\right)^2}$$

where f_p is the peak frequency of the interstage and f_c is the center of the band. The variolossers therefore, contribute a small negative transmission slope that is overcome by slightly peaking the other IF stages. Fig. 44 shows transmission characteristics of a typical IF amplifier for a normal input and for an input corresponding to a 35-db fade.

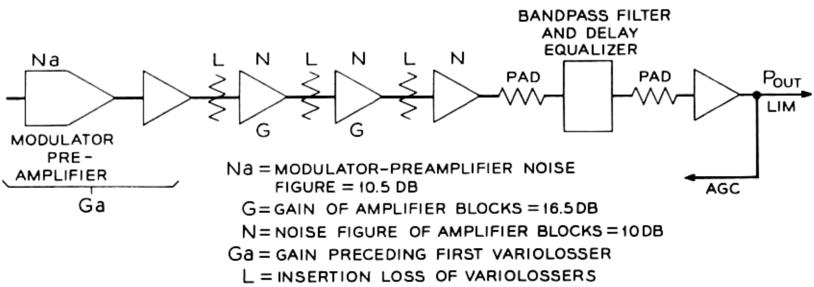
The location of variolossers in the circuit is critical. They are preferably used at low-level points to minimize AM-to-PM conversion in the receiver but if located too near the input of the receiver, the signal power level at the stage following the variolosser could be lower than the signal power level at the input for normal operating conditions.

Under these conditions the later stages could contribute significantly to the noise figure of the receiver.

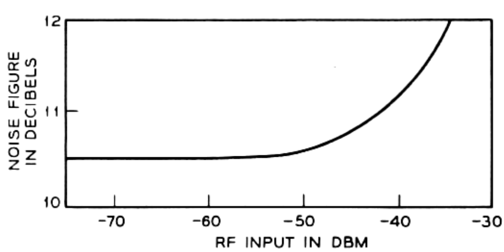
The variolosser line-up in the receiver is shown in Fig. 45(a). Since the AGC circuit holds P_{out} to a fixed value, and the maximum gain is known, the loss L of each variolosser is fixed for a given value of input power. Fig. 45(b) shows a measurement of noise figure of a TL-2 receiver versus input power.

The complete IF amplifier (apart from the preamplifier) includes 12 stages ahead of the bandpass filter and 7 stages following the filter. The nominal maximum IF gain is 92 db, but some 19 db of padding is provided nominally as shown in Fig. 45(a) to insure good impedance terminations for the filter and equalizer. The exact value of padding is adjusted as part of the manufacturing testing routine. A minor adjustment of the delay equalizer is also made after the other adjustments of the IF and baseband unit are completed.

An IF output is available from the receiver at the IF monitor jack as shown in Fig. 32 to permit an IF connection at 70 mc to other microwave systems. The power output at this point is 0 dbm.



(a)



(b)

Fig. 45 — Thermal noise performance; (a) gain allocation in the receiver, (b) receiver noise figure vs RF input.

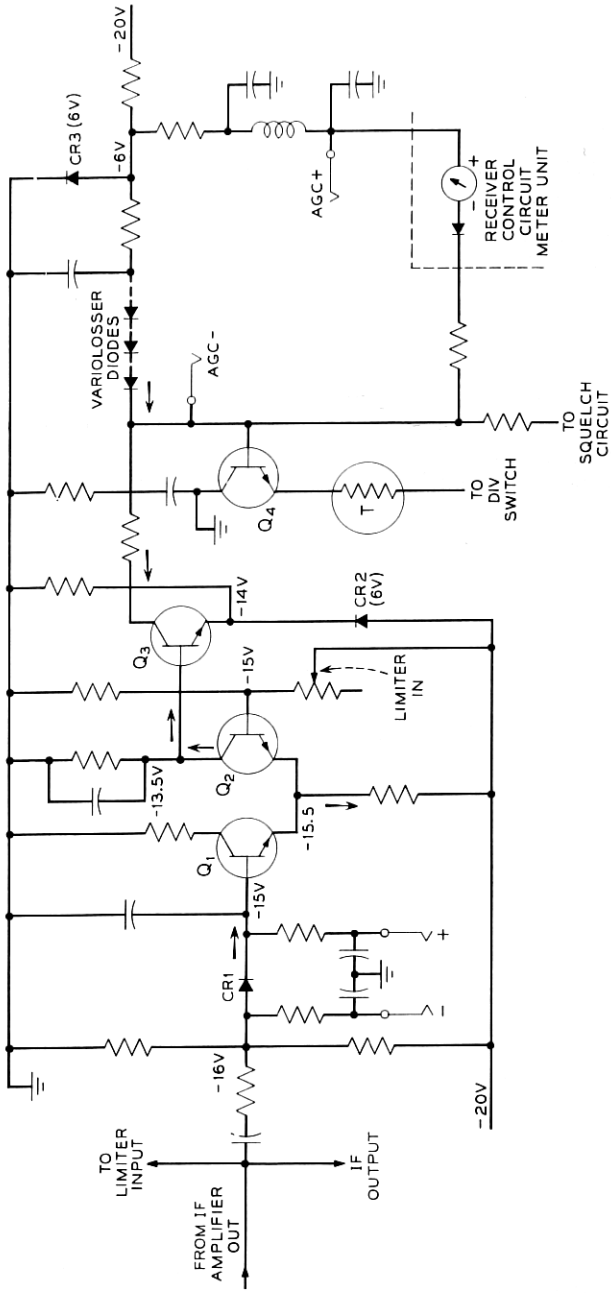


Fig. 46 — Automatic gain control circuit.

7.5 *AGC Circuit, Squelch Operation and Diversity Drive*

The elements of the AGC circuit are shown in Fig. 46. The output from the final IF stage is divided among three loads; the limiter (+11.5 dbm), the IF output (0 dbm), and the AGC detector.

The AGC rectifier, CR_1, is followed by a three-stage dc amplifier. Since the variolossers are shunted across the transmission path, a high loss corresponds to a high-control current. When the IF output power increases, additional dc currents flow in the amplifier in the directions shown in Fig. 46. The gain of the circuit is such that when the feedback loop is open, a change in the IF power of 0.1 db is sufficient to swing the dc amplifier over its entire operating range. The LIM IN potentiometer is used to adjust the operating range of the AGC amplifier, hence the desired IF output power.

When the input to the receiver is reduced, the collector current of Q_3 decreases and the voltage at the base of Q_4 decreases linearly with input power in db. At the end of the regulating range when the current through the variolosser diodes is zero, the voltage at the base of Q_4 is -6 volts. A slight further reduction in IF power will result in zero collector current for Q_3 with the Q_4 base voltage going to zero. Typical operating characteristics of the circuit are shown in Fig. 47. The abrupt change in the squelch voltage from -6 to 0 results in a positive trigger for the squelch circuit. The IF power to the limiter is held essentially constant up to the end of the regulating range beyond which the output decreases db for db with the input. In this circuit, the squelch point is determined by the available IF gain. There are no adjustments in the control circuit to set the point at which the receiver squelches. The total IF gain of the IF and baseband unit is, therefore, adjusted at the time of manufacture.

The above description is simplified in that noise was not considered. Practically, as the gain of the receiver is increased, the noise will also increase and the AGC circuit operates to hold the output of signal plus noise constant. In a practical case then, the operating characteristic conforms to the carrier plus noise curve. It is apparent that if the maximum gain of the receiver is too high, the resulting high noise will prevent receiver squelch. For this reason, the gain of the preamplifier is restricted. Any IF and baseband unit can work with any modulator-preamplifier.

In the receivers for the TM-1 and TL-2 systems, the maximum gain from the input of the RF band filter to the monitor jack, shown in Fig. 32, is about 80 db. This allows approximately 35-db fade margin for a

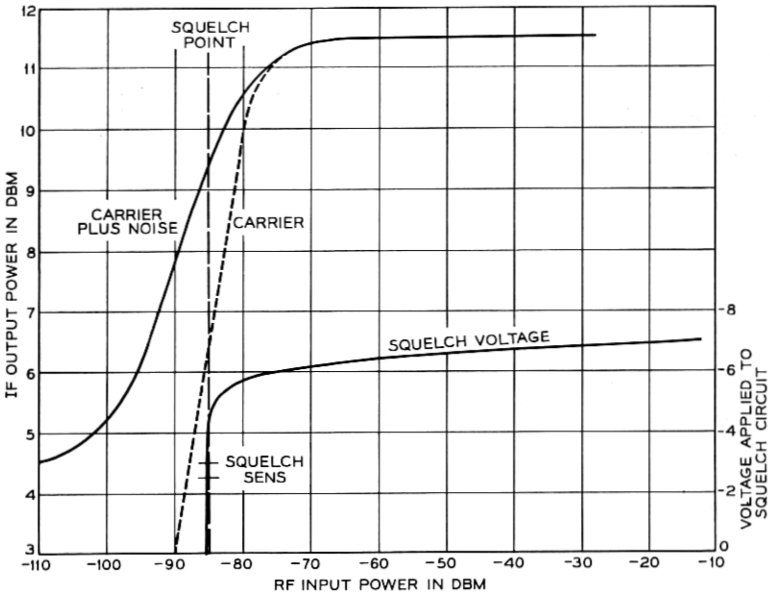


Fig. 47 — Operation of the automatic gain control and squelch circuits vs RF input power.

normal input of −45 dbm, and provides approximately 6-db margin against squelch malfunction due to excessive noise.

It is important that the receiver be squelched when the input signal drops below a given power. Unbalances in the discriminator characteristic can result in the AFC circuit being biased off when the receiver goes to full noise. Under these conditions, there is a danger that the circuit will not restore when the RF signal becomes normal again. Full noise in a radio channel could also cause interference in other facilities since groups of voice circuits from the radio facility in question are frequently combined with other groups of voice circuits transmitted by other radio or cable facilities.

The squelch relay has two transfers. One circuit is used to open the AFC loop when the receiver goes to full noise, while the other transfer is used to place a short circuit across the output of the receiver baseband amplifier under these conditions.

The linear portion of the squelch voltage characteristic shown in Fig. 47 between 6 and 7 volts provides information regarding RF input power. It serves as the control characteristic for the diversity switch. The circuit has been designed so that the slope of the control characteristic is essentially the same in all receivers and is nearly independent of temperature. The temperature correction is provided by the temperature sensitive resistor following the emitter of Q_4 (Fig. 46).

The operation of the bistable diversity switch is not affected by temperature-sensitive control circuits so long as the control characteristics of the two receivers are alike. For the revertive switch, however, where the control voltage is compared with a fixed voltage, the control voltage must be independent of temperature.

7.6 *Discriminator and Receiver Baseband Amplifier*

The receiver baseband amplifier for the TL-2 and TM-1 systems is designed to provide television and telephone service. This required extending the low frequency cut-off to below one cycle and, in the case of the receiver amplifier, providing adequate linearity so that the amplifier contributes negligible intermodulation noise, differential phase and differential gain.

The receiver baseband amplifier, shown in Fig. 48, consists of two feedback amplifiers in tandem. The input amplifier is a three-stage amplifier with a loop feedback connection between the emitters of the first and third stages. A minimum feedback of 20 db is maintained at 4 mc, with feedback increasing to about 30 db at low frequencies. The input coupling circuit was designed for minimum loss between the discriminator and the amplifier which is also the condition for minimum thermal noise.

The receiver gain control is located between the two baseband amplifiers and has a range of 6 db. The output amplifier is a two-stage feedback amplifier with the second stage employing two transistors in a compound connection. Its output capability exceeds +10 dbm. For a 4-mc deviation of the RF signal, the normal sine wave output is +6.5 dbm. The inductor in the output collector insures that virtually all the signal current flows into the load and the feedback circuit includes compensation for the low-frequency transmission characteristic caused by the inductor. The feedback trimmer capacitor is adjusted at the time of manufacture to set the transmission characteristic of the overall video amplifier.

7.7 *Receiver AFC*

Except for time constants, the receiver AFC circuits are essentially the same as for the TL-1 design.[11] A system having a transmission

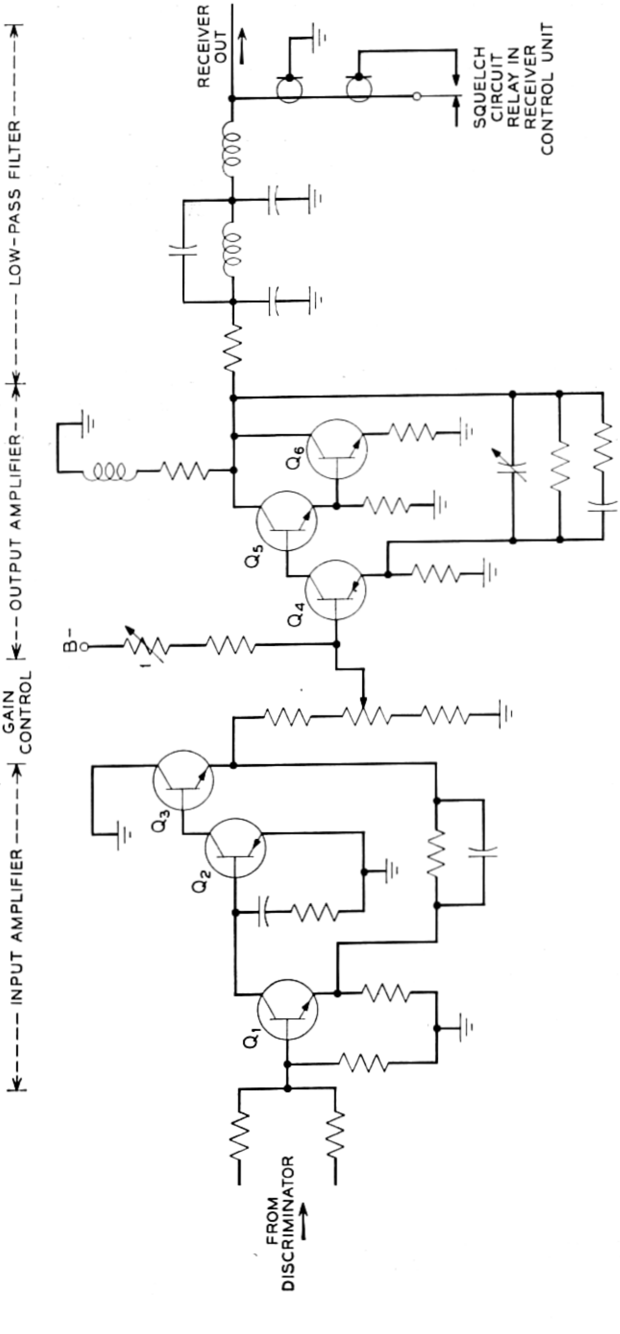


Fig. 48 — Receiver baseband amplifier.

characteristic that extends to the order of 1 cycle per second requires a slowacting AFC circuit. The cut-offs in the AFC feedback characteristic must be well separated in frequency to avoid gain enhancement and the lowest frequency cut-off must be well below the band of interest to avoid erasing signal information. The first two cut-off frequencies in the AFC circuit for the TM-1 and TL-2 receivers occur at 0.03 cycle per second and about 0.5 cycle per second.

7.8 *Revertive Diversity Switch*

Two forms of diversity switches may be employed with the TM-1/TL-2 combination. The simple bistable switch furnished with the TL-1 system has previously been described in detail.[2] In the bistable switch, the AGC signals of the diversity pair are compared; the difference signal is fed to a Schmitt trigger circuit which activates the switch when the input of the working receiver drops below the input to the standby receiver by a predetermined amount. If the nominal received RF power for one system is appreciably stronger than the nominal received power for the other system, it is desirable to have the switch revert to the system having the stronger received signal. This is accomplished in the revertive switch by using switching logic which orders that transmission be via the preferred channel unless and until its incoming radio signal power drops below a predetermined absolute value. At this predetermined level, the logic block is removed and the switch functions in the bistable manner, causing a switch if the received power of the preferred channel compares unfavorably with the incoming received power of the other system. The block schematic of Fig. 49 illustrates how the revertive comparator may be associated with either receiver, or not used at all for bistable operation. It is recommended that the switch be set up on a revertive basis only if the normal incoming level of the two systems is appreciably different (say 5–6 db), or if the performance of one of the two systems is appreciably superior to the other.

The operation of the revertive switch may be illustrated by means of Fig. 50. If a point whose coordinates are given by the received power of channel A (preferred) and channel B (protection) falls in the shaded area, the switch will select channel A. If that point falls in the crosshatched area, it will switch to channel B. If the point falls in the clear area, the switch will not operate — it will hold whatever position it has. The width of both corridors in Fig. 50 are adjustable.

The bistable switch operates similarly except that the bistable cor-

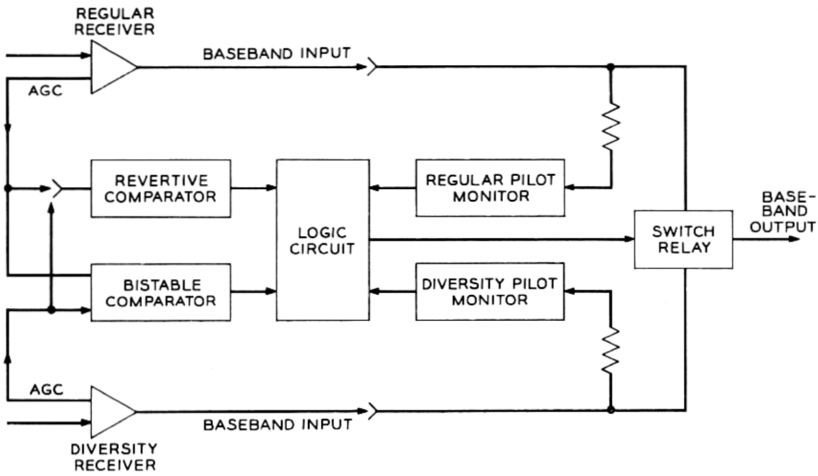


Fig. 49 — Block schematic showing use of a revertive diversity switch at a receiver location.

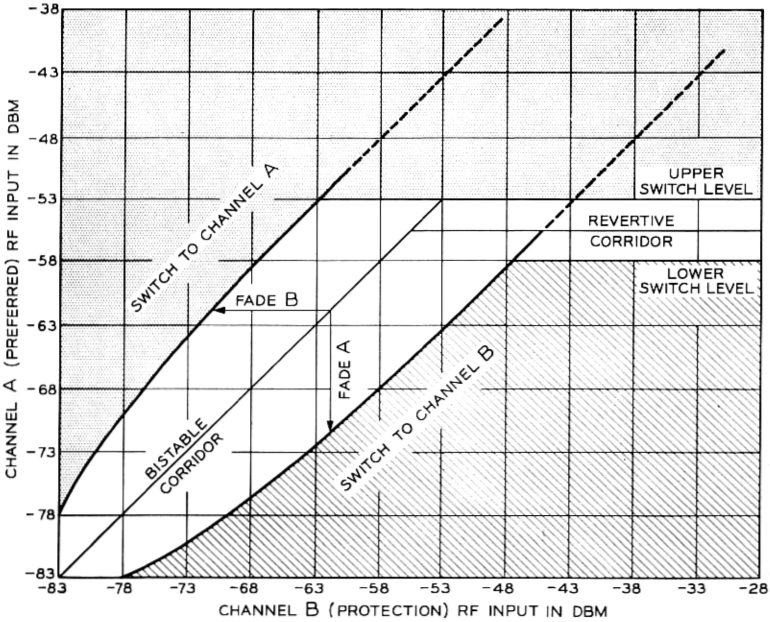


Fig. 50 — Typical TM-1/TL-2 revertive switch characteristic based on RF inputs.

ridor is extended as indicated by the broken lines and all the area below the corridor is assigned to channel B.

7.9 *Other Features*

Order wire and alarm arrangements, and all other circuits not mentioned specifically above, are very similar to the designs for the TL receiver. The reader is referred to the earlier article for details.[2,11]

VIII. POWER SYSTEM*

8.1 *General*

Power to the TM-1/TL-2 system is maintained during commercial ac power outages through the use of batteries which are an integral part of the power plant. The batteries are charged to float voltage and act as a filter for the output of the ac rectifier unit when ac power is present. Continuous power is provided to the radio bays since the batteries are always in the circuit and no transfer of power source is required when ac fails.

The block diagram of Fig. 51 shows the power design for TM-1/TL-2 radio. The battery charger, fed from 117-volt commercial ac power, supplies the stabilized dc voltage to float-charge 6-volt batteries in series-parallel combinations whose number depends upon the desired reserve capacity. Power for the transistor circuits of each RF panel is supplied through a voltage regulator, while a second regulator powers a dc-to-dc converter and related circuits to provide the required klystron voltages. Provision is also made to power the traveling-wave tubes in those stations where TM-A1 amplifiers are employed. Each TM-1 or TL-2 RF panel (typically one transmitter and one receiver) requires up to about 8 amperes maximum, hence the 48-ampere charger can service 6 RF panels. An allowance of 8 amperes should also be made for a TM-A1 power amplifier. A 16-ampere charger is available for small installations.

The batteries are housed in a separate cabinet with the large charger, or on shelves on the radio bay where the small charger is used. There is often a preference for connecting fewer than the maximum number of RF panels to a charger and battery unit in order to increase the reserve capacity.

The −24-volt office battery may be used to power the radio equipment in central office installations.

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* This section was prepared by Mr. P. W. Ussery.

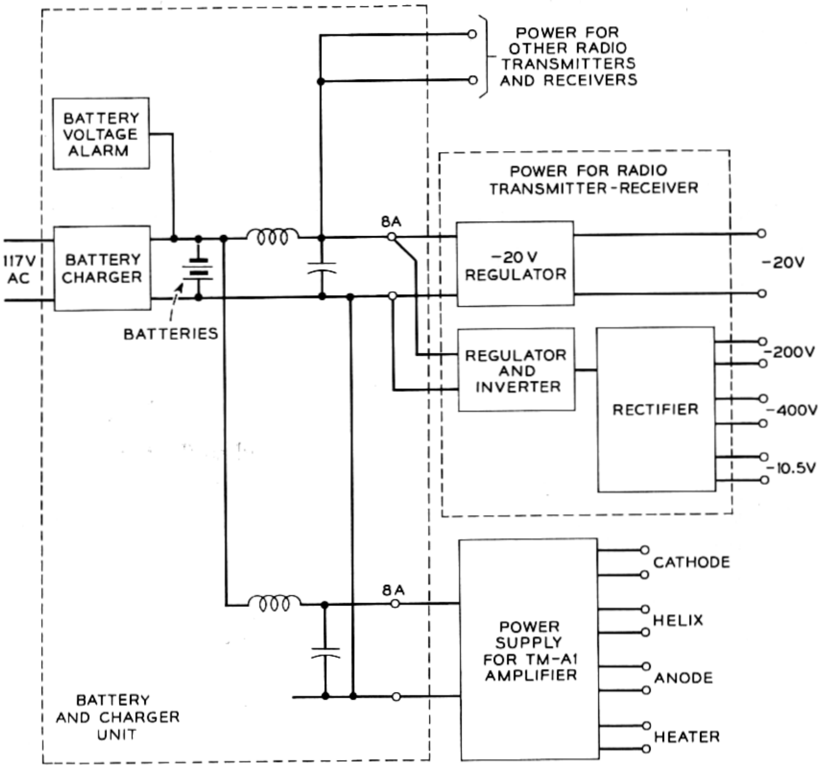


Fig. 51 — Power system block schematic.

8.2 *The Charger Unit*

A simplified schematic of the 48-ampere charger is shown in Fig. 52. The ferroresonant transformer in the battery charger regulates the ac voltage applied to the rectifier of the battery charger. Silicon diodes in a full-wave bridge arrangement give a dc output which is applied to the batteries for floating or charging.

The 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 minimum cost for severe environments involving wide temperature swings from −20°F to +120°F. Most of the time the batteries are being float-charged and this condition contributes to very low battery maintenance. The high specific gravity aids both in protecting

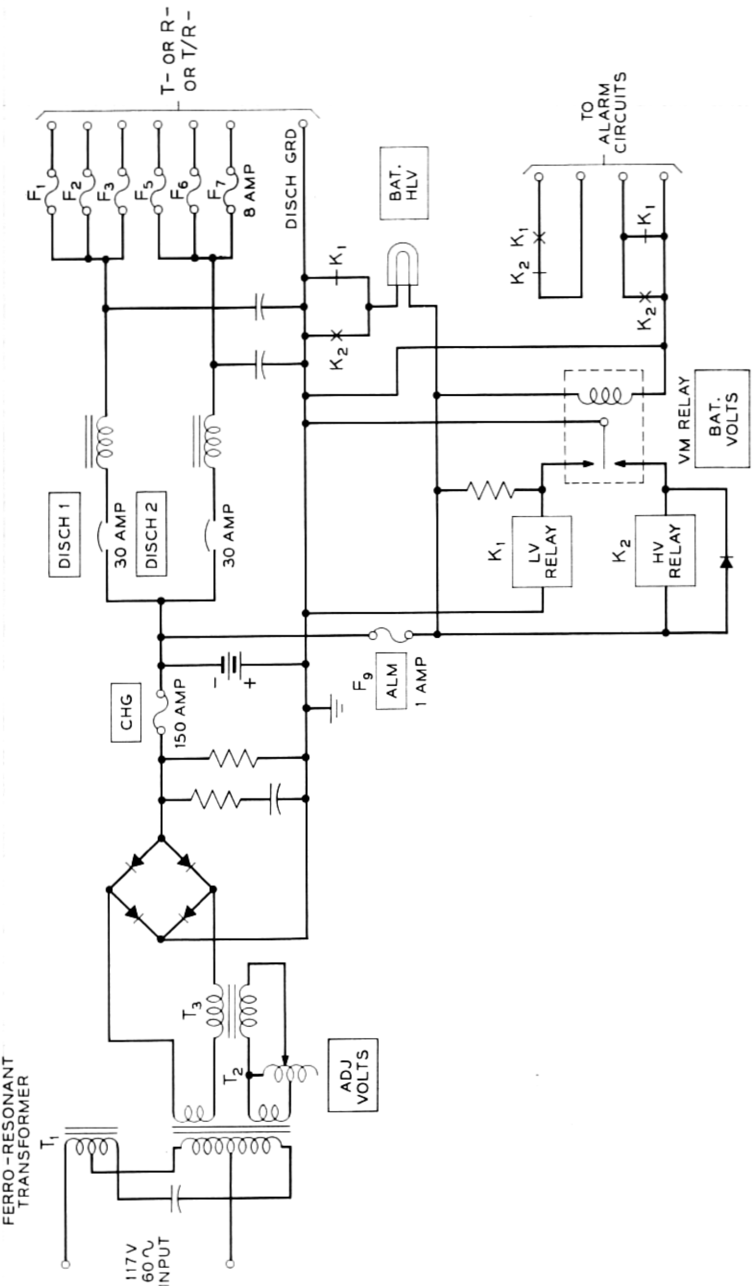


Fig. 52 — 48-ampere battery charger and power supply, simplified schematic.

the batteries and increasing their hours of reserve at low temperatures. At −40°F they do not freeze, even if fully discharged.

The battery chargers incorporate a battery voltage alarm to operate an alarm lamp on the front panel of the charger when the battery voltage falls outside the normal limits and to send an alarm to the central office when the battery voltage is below normal. The power cabinet containing the 48-ampere charger is shown in Fig. 53.

8.3 *Power for the Radio Equipment*

The radio equipment requires −20 volts for the transistor circuits, −400 volts for the klystron cathode, 10.5 volts as a klystron heater supply voltage, and a voltage that can be varied between −400 volts and −600 volts for the klystron repeller. The latter requirement is satisfied by a −200-volt supply that is connected in series with the −400-volt supply. An 1800-cycle square wave is used to operate the magnetic amplifier in the receiver AFC circuit. The klystron voltages must be very precisely regulated in order to achieve the required stability of the average transmitted frequency. Also, the noise on the output voltages of the power supply must be very low to obtain the signal-to-noise ratio required to meet the message and television transmission limits for the system. These factors contribute to very demanding requirements on the stability of the power supply.

Voltage stability requirements were derived based on an allocation of permissible frequency errors and the known sensitivities of the 457A and 459A klystrons. The stability requirements are given below:

Voltage	*TL-2*	*TM-1*	*Currents for 2 Tubes*
−400V	±0.45%	±0.10%	100 ma
−200V	±0.45%	±0.05%	10 ma
10.5V	±0.75%	±0.75%	1800 ma

These objectives should be met over a three months maintenance interval that may include temperature changes up to 100°F and ac line voltage changes from 105 to 129 volts. In order to meet the more stringent TM-1 requirements, several refinements of the initial TL-2 design were required. Regulators were added to both the −200-volt and −400-volt supplies and these regulating circuits are located in temperature-controlled ovens.

The other power supply requirements, common to the two systems, are as follows:

Voltage	*Stability*	*Currents*
−20V	±1%	1.1 amp (max)
43V ac(1800 cps)	±0.45%	10 ma
27.6V	battery	750 ma (max)

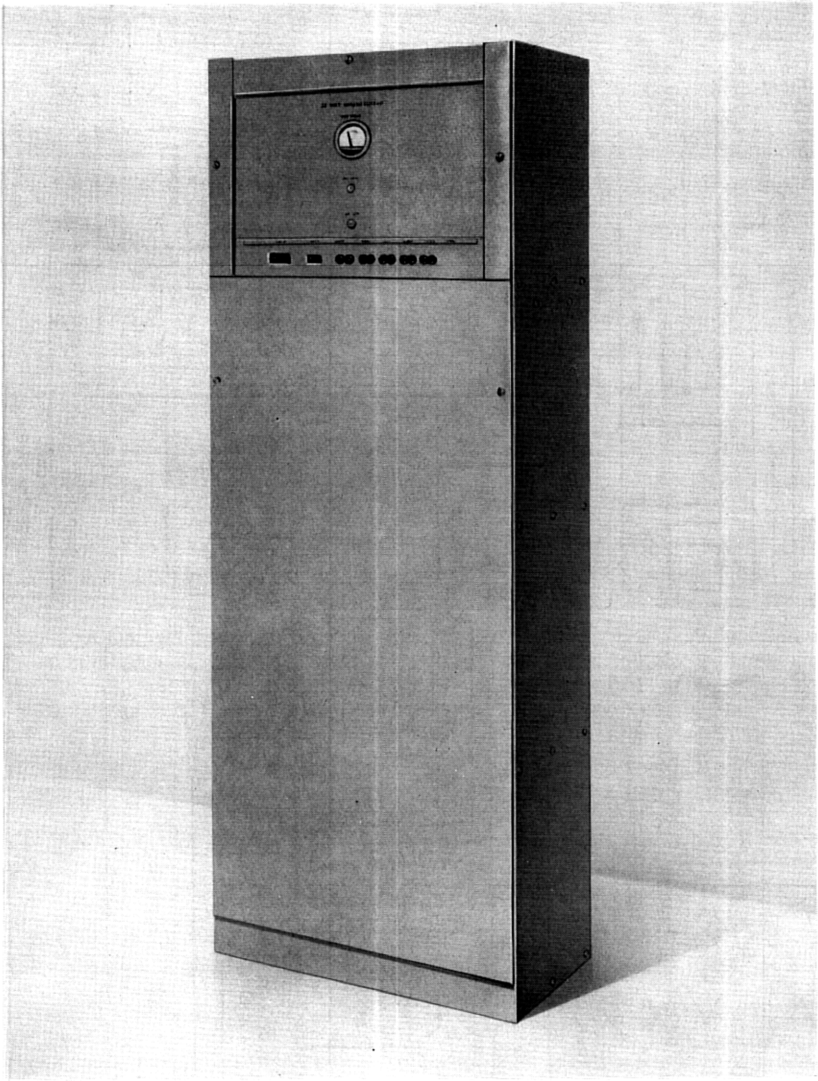
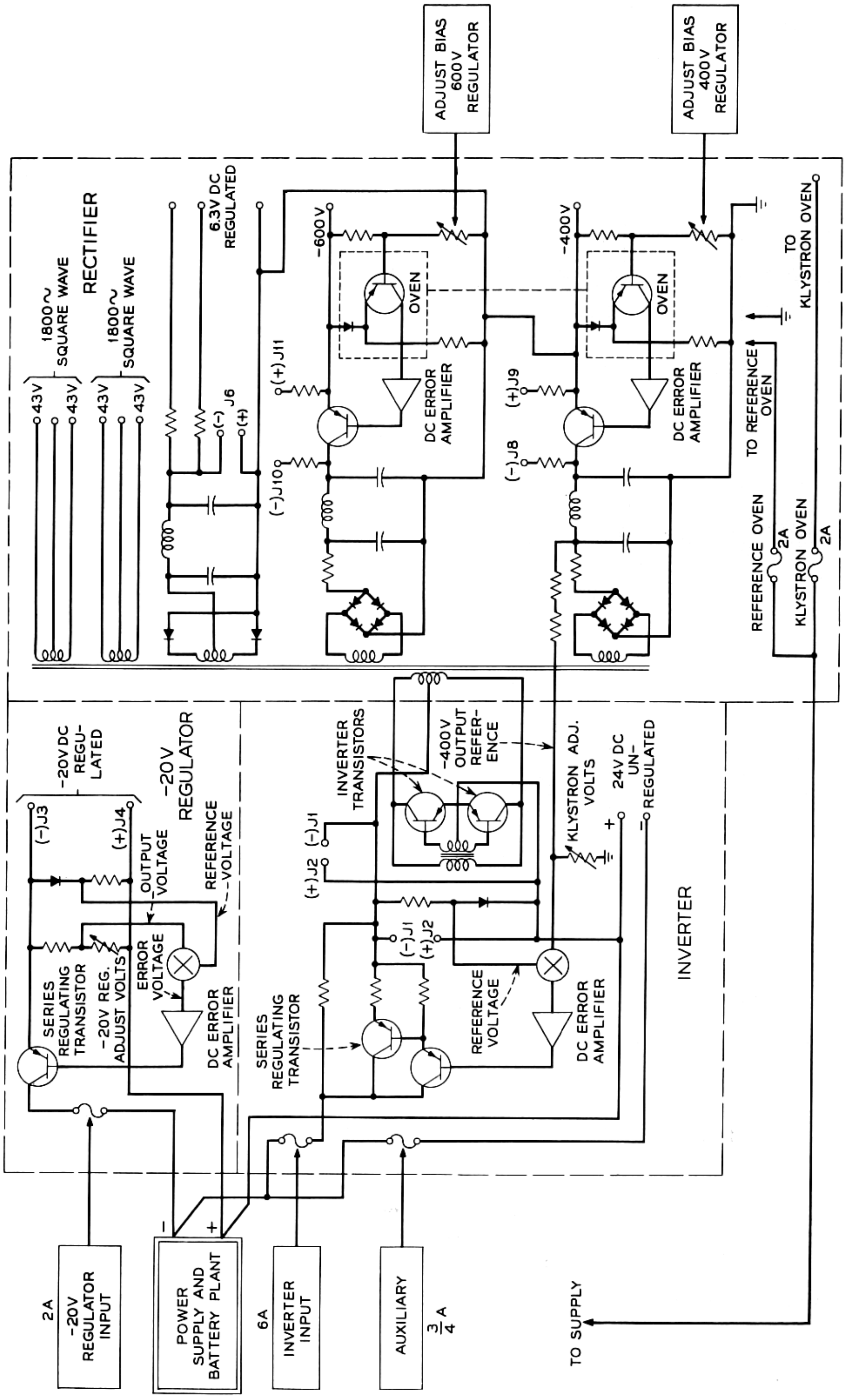


Fig. 53 — Cabinet containing 48-ampere charger and batteries.

Circuit-wise, the power supply is divided conveniently into three parts: a −20-volt regulator, an inverter operating at about 1800 cycles, and a rectifier to supply the klystron voltages. The same regulator and inverter are used for both TL-2 and TM-1. Fig. 54 gives a simplified schematic of the TM-1 power supply. TL-2 is substantially the


ADJUST BIAS 600V REGULATOR
ADJUST BIAS 400V REGULATOR
RECTIFIER
43V
43V
43V
1800~ SQUARE WAVE
43V
43V
43V
1800~ SQUARE WAVE
6.3V DC REGULATED
(−) J6
(+)
−600V
(+)J11
(−)J10
OVEN
DC ERROR AMPLIFIER
−400V
(+)J9
(−)J8
OVEN
DC ERROR AMPLIFIER
TO KLYSTRON OVEN
TO REFERENCE OVEN
REFERENCE OVEN
2A
KLYSTRON OVEN
2A
−20V DC REGU-LATED
(−)J3
(+)J4
−20V REGULATOR
OUTPUT VOLTAGE
REFERENCE VOLTAGE
ERROR VOLTAGE
SERIES REGULATING TRANSISTOR
−20V REG. ADJUST VOLTS
DC ERROR AMPLIFIER
INVERTER TRANSISTORS
−400V OUTPUT REFER-ENCE
KLYSTRON ADJ. VOLTS
24V DC UN-REGULATED
(−)J1
(+)J2
(−)J1
(+)J2
REFERENCE VOLTAGE
DC ERROR AMPLIFIER
SERIES REGULATING TRANSISTOR
INVERTER
2A
−20V REGULATOR INPUT
POWER SUPPLY AND BATTERY PLANT
6A
INVERTER INPUT
AUXILIARY
3/4 A
TO SUPPLY

same except that the regulators shown in the −400-volt and −200-volt supplies are not present.

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

The dc-to-ac inverter consists of two transistors and a saturable transformer switching at a frequency of 1800 cps. The square wave output is stepped up in a power transformer and rectified to provide the klystron voltages. The klystron cathode voltage is −400 volts with respect to the cavity resonator which is grounded. Since the repeller operates between 100 and 200 volts more negative than the cathode, its voltage is obtained by connecting the output of another rectifier in series with the −400-volt supply. Other windings on the power transformer provide a 43-volt center-tapped square wave voltage for the receiver AFC magnetic amplifier. Another winding is used for the 10.5-volt dc klystron heater supply which is fed to ballast resistors in series with the heater of each klystron which drop the voltage to 6.3 volts. The heater supply is operated essentially on a constant power basis to gain longer life and greater frequency stability from the klystron. The output of the −400-volt rectifier is also used to control the regulator preceding the inverter. This provides regulation for the −200, 10.5, and the square wave voltages since these will all track the −400-volt output. In the TM-1, the −400 and −200-volt supplies are regulated independently as shown.

Photographs of the TM-1 and TL-2 power supply units are given in Fig. 55.

8.4 *Power for the TM-A1 Amplifier*

An electronically regulated power supply is used for the TM-A1 amplifier to obtain the required voltages for the traveling-wave tube. It also draws its input power from the battery-charger combination described above.

Fig. 56 gives a block schematic of the supply. The inverter delivers a 48-volt, 2000-cycle square wave to four separate circuits from which are derived the anode, the helix, the cathode, and the heater potentials. The anode and the helix voltages are jointly regulated with respect to the cathode, and the heater is regulated separately.

The helix supply is regulated to $\pm\frac{1}{2}$ percent of the nominal helix to cathode voltage. A sample of the helix-to-cathode output voltage is

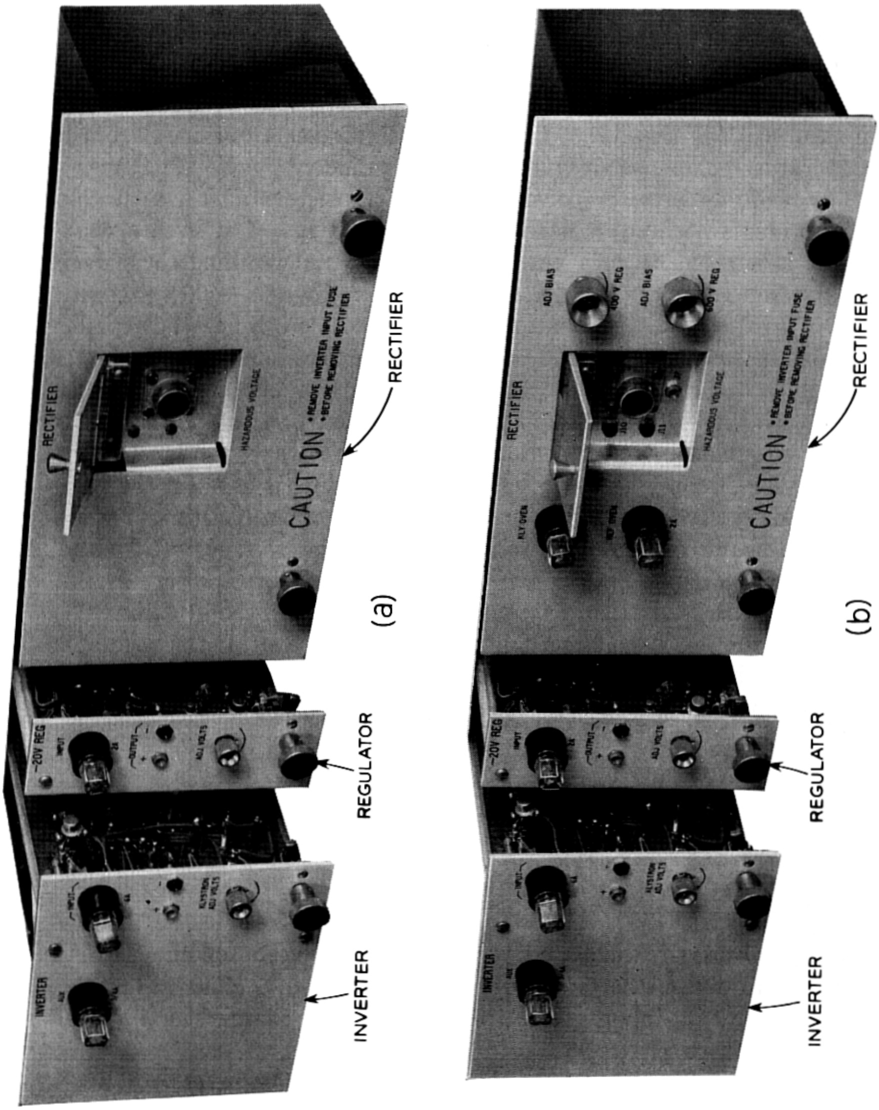


Fig. 55 — Power supply for (a) TL-2 and (b) TM-1.

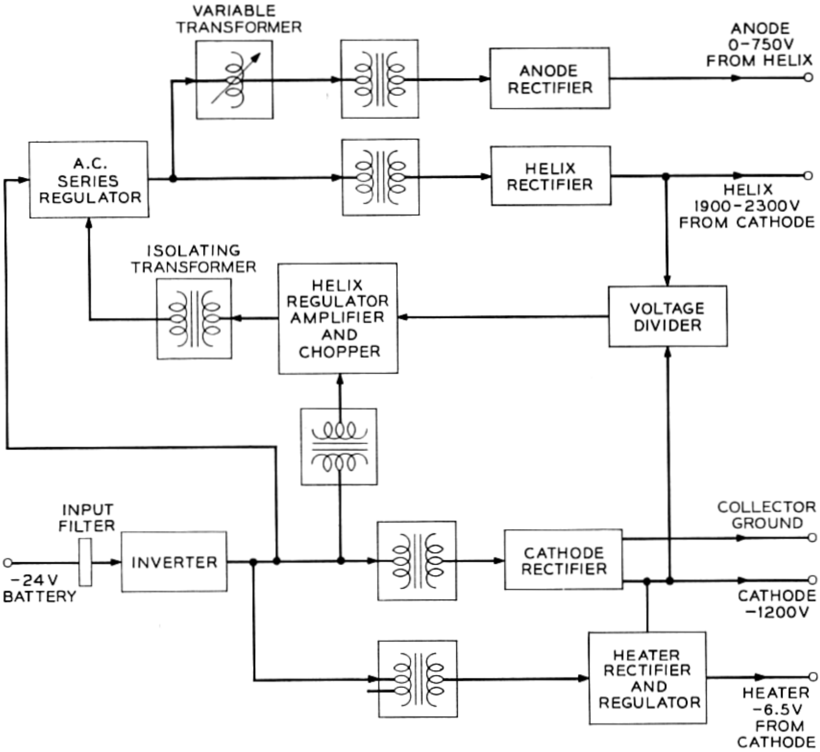


Fig. 56 — TWT power supply, block schematic.

compared with a reference voltage and the difference voltage (the error) is amplified by a dc amplifier. The amplified error signal is then "chopped" and the resulting square wave applied to a rectifier and applied to the ac series regulator. The isolating transformer in the control path isolates the regulator from the high helix voltage. The anode voltage will track the helix voltage as shown in Fig. 56.

A series transistor regulator is used to regulate the heater voltage, the positive side of which is connected directly to the cathode, nominally held at −1200 volts.

The power supply includes four meters to read collector current, helix current, anode-to-cathode voltage and heater voltage. Adjustments for cathode and heater voltages are provided; the heater voltage is set precisely in the factory. The power supply may be seen in the photograph of Fig. 57. The following table summarizes the performance of the power supply.

Fig. 57 — Power supply for traveling-wave tube amplifier.

	Nominal Operation (−27V @ 4.5A)	*Regulation (−21.5V to −29V)*
Anode-cathode	2500 volts 0–1 ma	±45 volts
Helix-to-cathode	2100 volts 0–4 ma	±12 volts
Cathode	−1200 volts 30 ma	−900 to −1300 volts
Heater-to-cathode	−6.5 volts 0.8 to 0.95 ampere	±0.13 volts

IX. EQUIPMENT DESIGN FEATURES

9.1 *Radio Equipment*

Fig. 58 illustrates a typical TM-1/TL-2 single channel bay intended for installations with very limited or no growth potential. The 7-foot high by 23-inch wide bay houses a single TM-1 or TL-2 RF panel (transmitter-receiver plus plug-in power units), four 6-volt high spe-

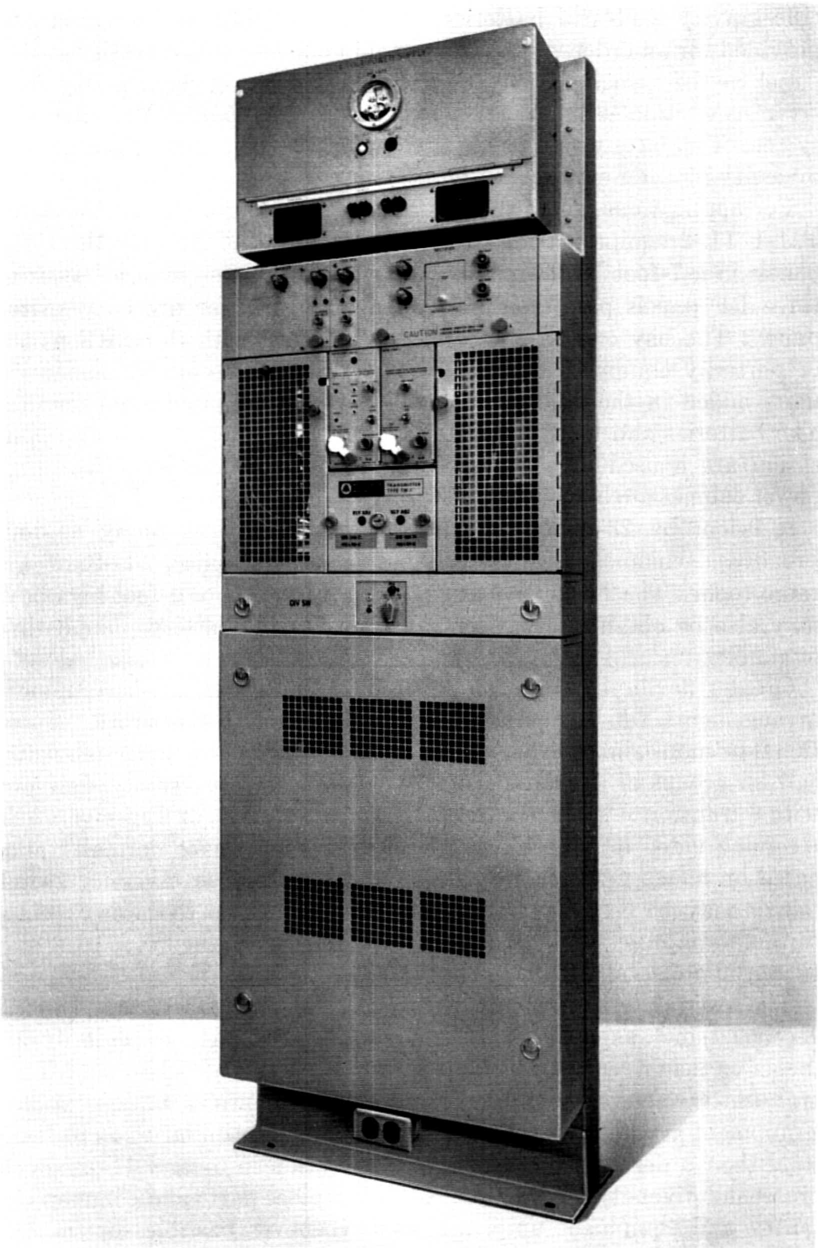


Fig. 58 — Single channel transmitter-receiver bay complete with batteries and charger.

cific gravity lead-acid batteries, and the charging rectifier. Space is provided for an order wire alarm panel in one bay or a diversity switch panel in the associated bay of a diversity system. Such a bay may serve as a radio terminal for a two-way single channel non-diversity system. Two bays would be required at a two-way, single channel non-diversity repeater station.

For applications where there is an appreciable growth potential, the TM-1/TL-2 equipment may be obtained with one, two, or three RF panels in a 7-foot by 23-inch bay. Fig. 59 illustrates such a bay with three RF panels plus their associated order wire or diversity switch panels. The bay can be ordered fully equipped with three RF panels or partially equipped with one or two RF panels and the remaining units added in the field as the need develops for additional circuits. The batteries and their associated charging rectifier in such an application are housed in a separate 30-inch by 16-inch by 7-foot high power cabinet as shown in Fig. 53.

A 9-foot by 23-inch bay arrangement housing as many as four broadband channels is also available for central office, TD-2, or TH radio rooms. The 24-volt battery power for these 7- or 9-foot high bays may also be obtained from central office 24-volt battery plants when available.

Greater flexibility has been realized in the TM-1/TL-2 equipment arrangements which facilitate their application for network, educational or industrial television system. Since ETV needs may frequently call for groups of six channels, a 7-foot bay may be readily equipped with 6 transmitters as a transmitting video terminal, or 6 receivers as a receiving video terminal. The 4-inch by 23-inch space normally allocated on message systems to the order wire alarm or diversity switch panels may be used in television systems for video repeater or video terminal amplifiers and equalizers depending upon the needs of a particular application.

The frontal dimensions of a typical TM-1 or TL-2 transmitter-receiver panel, as shown on Fig. 58 or 59, are 23-inches wide by 21-inches in height, inclusive of the power supply. The TM-1 and TL-2 transmitter-receiver panels are essentially identical in appearance. Equipment arrangements for the two systems are similar so as to facilitate their ordering, installation, and operation in 6- and 11-gigacycle crossband diversity applications. Common piece parts and common circuitry and equipment units are used whenever possible for the two systems to reduce costs and ease field maintenance problems.

Fig. 60 illustrates a 7-foot bay housing two RF panels with their

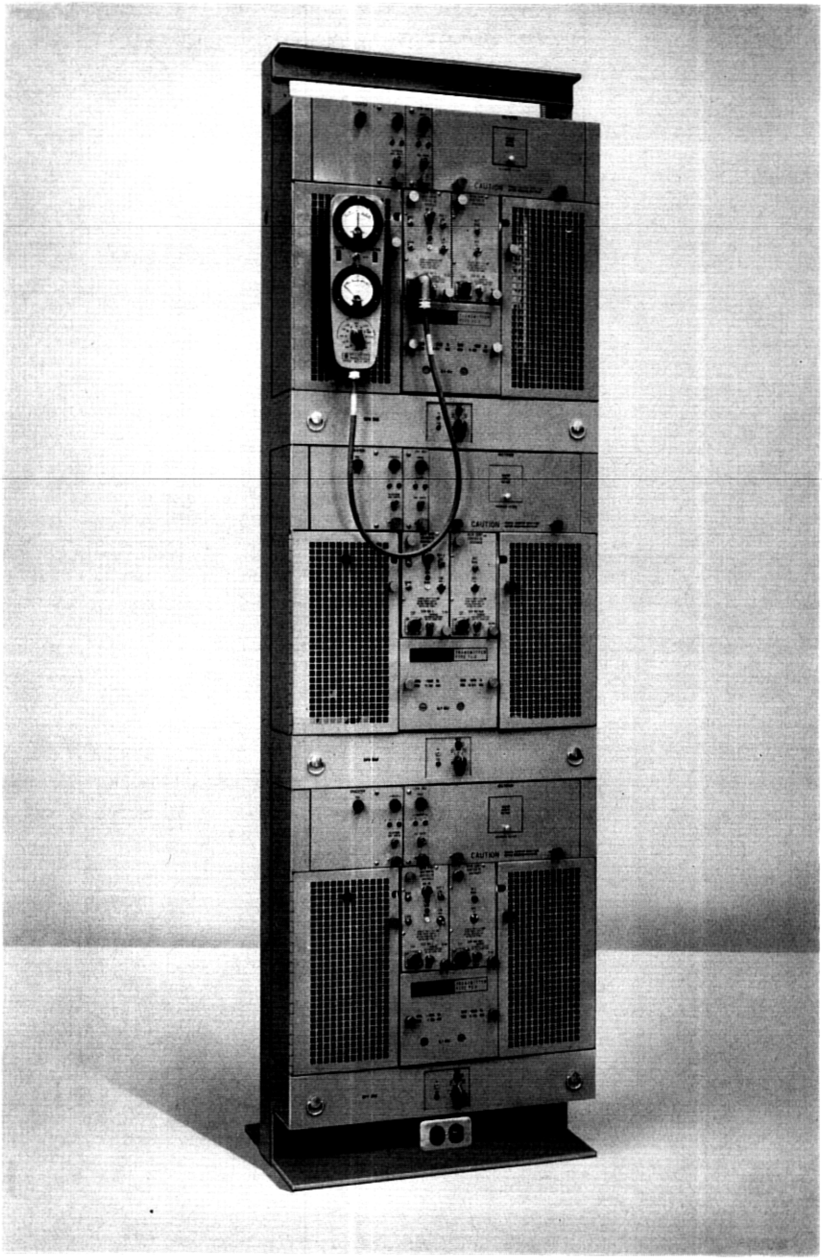


Fig. 59 — A 7-foot bay equipped with three transmitter-receiver units, power supplies, and diversity switches.

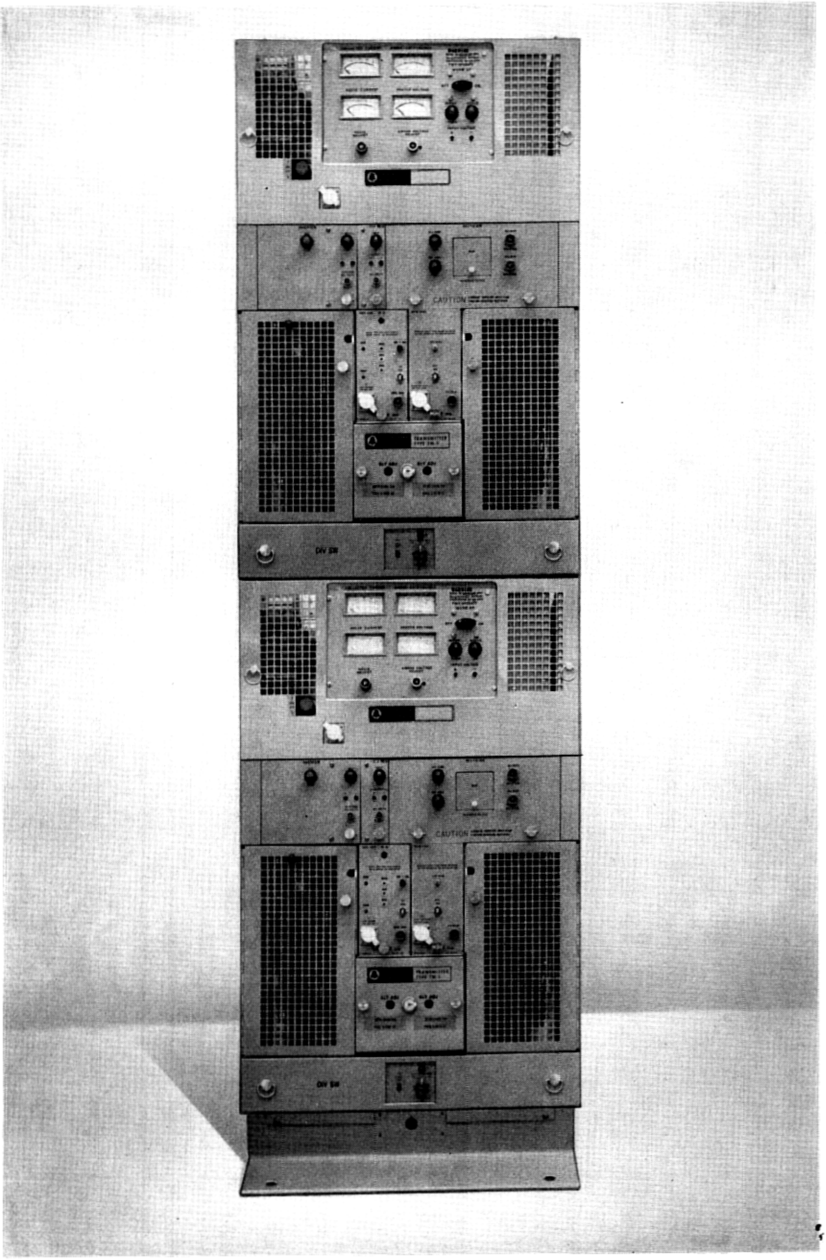


Fig. 60 — A 7-foot bay equipped with two transmitter-receiver units and their associated TM-A1 amplifiers.

associated TM-A1 amplifiers. The plug-in traveling-wave tube amplifier power supply is mounted on the TM-A1 amplifier panel and furnishes all required voltages for the amplifier. The power supply operates from the same battery source as the TM-1 transmitter-receiver.

9.2 *Equipment Shelters*

One of the earlier concepts of short-haul, light-route microwave radio relay systems[2] eliminated the need for a building or shelter to house the equipment and substituted a relatively small and less expensive weatherproof cabinet. The type of equipment cabinet developed for TL-1 was continued for TL-2 and TM-1, but the smaller TM-1/TL-2 package permitted the design of the equipment cabinet illustrated in Fig. 61 which houses twice as many RF panels as the earlier cabinet. This thermally insulated cabinet houses either a TL-2 and a TM-1

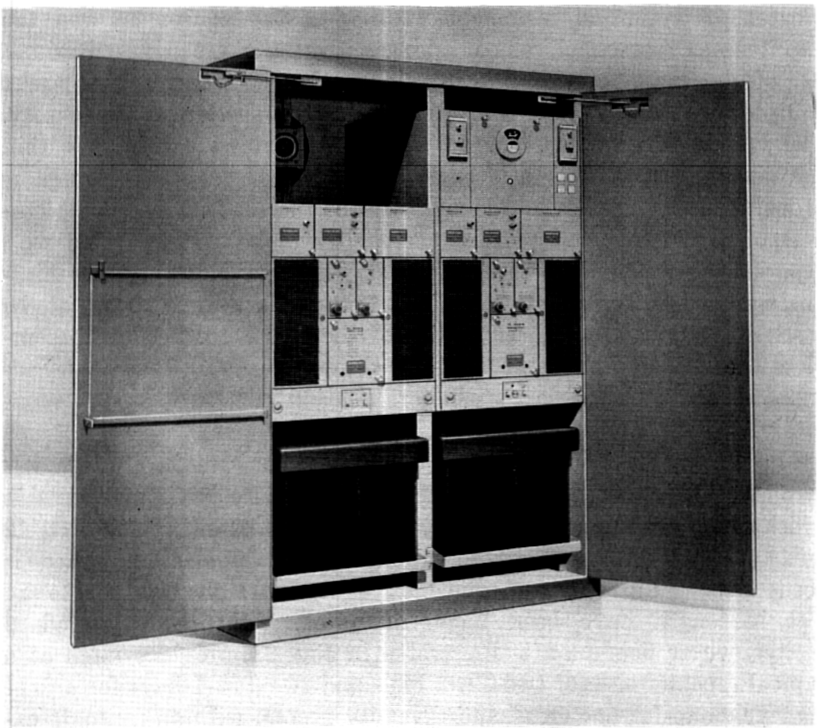


Fig. 61 — Equipment cabinet for two transmitter-receiver panels plus batteries and charger.

RF panel, or two TL-2 or two TM-1 panels with their associated power supplies, batteries, and order wire and alarm, diversity switch, or video panels. The cabinet is 57-inches wide by $76\frac{1}{2}$-inches high by 21-inches deep. Only one cabinet is now required for a diversity terminal or at a repeater point for a non-diversity system. Two cabinets are required at a diversity two-way repeater station. However, the use of cabinets is limited to single broadband channel message systems with no growth potential beyond the initial 600-message circuit capacity or for video service limited to two two-way or four one-way channels. While these solid-state TL-2 and TM-1 systems have demonstrated excellent reliability, and are designed to facilitate maintenance with the quick replacement of plug-in units, the above growth limitations and the problems of the maintenance personnel during possible difficult winter operating conditions has limited the use of such cabinets.

Like TL-1 radio, TL-2 and TM-1 radio systems make use of the equipment shelter illustrated in Fig. 62. This shelter not only provides greater protection in inclement weather to the equipment and the maintenance personnel, but it also removes the growth limitations. All of the radio, carrier line interconnecting equipment, and power equipment, less batteries, can be installed in a shelter at the factory. The installation includes the ac, dc, and transmission cabling within the shelter, as well as all the interconnecting waveguide which is brought out to hatches in the side wall of the shelter. The completeness of the installation permits the shelter to be system tested with experienced personnel before shipment from the factory, thus minimizing job engineering and installation time, effort, and expense at the repeater station sites. The majority of the few items needed to complete the installation in the field are shipped properly crated and secured to the floor within the shelter. The batteries are shipped separately.

The TM-1/TL-2 shelter is standardized at present in a thermally insulated truck body type of aluminum structure having an outside width of 7 feet, a height of 8 feet, and a length of either 7½ feet, 12 feet, or 16 feet. For special applications where more space is needed for radio spur or multiplex equipment, shelters up to 24 feet in length have been made available. The 12-foot standard shelter, whose floor plan is illustrated in Fig. 63, provides room at a typical repeater site for two TL-2 bays and two TM-1 bays for a 6/11 gigacycle one-for-one crossband diversity system with an ultimate capacity of 3-broadband channels or 1800-message circuits. Space is provided for three power cabinets with their self-contained 24-volt bat-

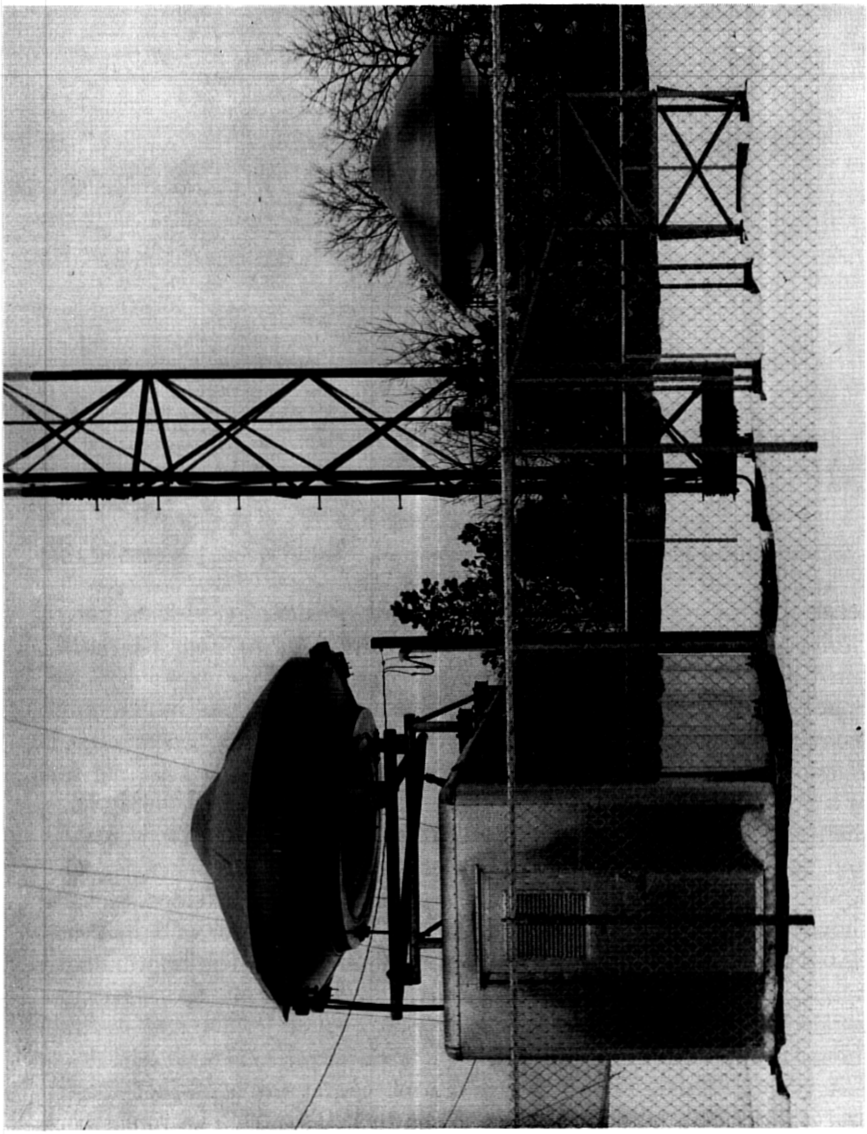


Fig. 62 — TM-1/TL-2 repeater station showing equipment shelter, antennas, and guyed tower.

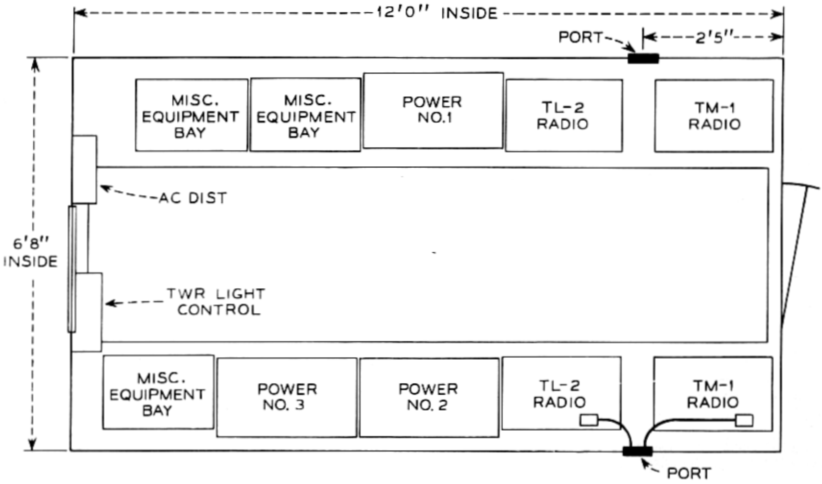


Fig. 63 — Floor plan for a TM-1/TL-2 equipment shelter showing growth plan.

teries and chargers. The single 30-inch by 16-inch by 84-inch power cabinet, provides about 24 hours battery reserve for the four RF panels illustrated in Fig. 64 in the event of commercial ac power failure. Space is also provided for a miscellaneous bay for multiplex equipment at stations where message circuits are to be dropped or added. Windows are omitted for security reasons, but either a ventilating fan or a $\frac{1}{2}$ or $\frac{3}{4}$ HP room air conditioner can be installed at one end of the shelter. The air outlet in the door and the intake port are screened and provided with dust filters. Interior lighting, ac wiring for test equipment and a power distribution cabinet are all provided. Fig. 64 shows the ac distribution box at the end of the shelter and its associated tower lighting panel underneath the air filter. The approximate weight of an unequipped 12-foot shelter is 2000 pounds, the maximum weight fully equipped for shipment by rail or truck is 4300 pounds; and the maximum in-place installed weight with batteries is 6900 pounds.

A typical TM-1/TL-2 repeater station employing a 16-foot shelter and a periscopic antenna system is shown in Fig. 65. The roof structure of the shelter supports a ten-foot diameter dual-frequency 6/11 gc paraboloidal dish antenna that illuminates the 12- by 15-foot plane reflector. A second 10-foot dish supported by a triangular pylon illuminates the reflector facing the rear. The guyed tower is 120 feet in height with a triangular base four feet on a side.

9.3 *Maintenance*

The maintenance philosophy for the TM-1/TL-2 short-haul systems is to minimize testing and to use relatively simple test equipment that will enable the craftsman to locate troubles quickly and eliminate them by the substitution of spare plug-in units. He is not expected to make field repairs on any plug-in unit.

A portable meter unit, shown plugged into the top RF panel in Fig.

Fig. 64 — Interior view of an equipment shelter at a repeater station equipped for a diversity message system (ultimate capacity is 3 diversity systems).

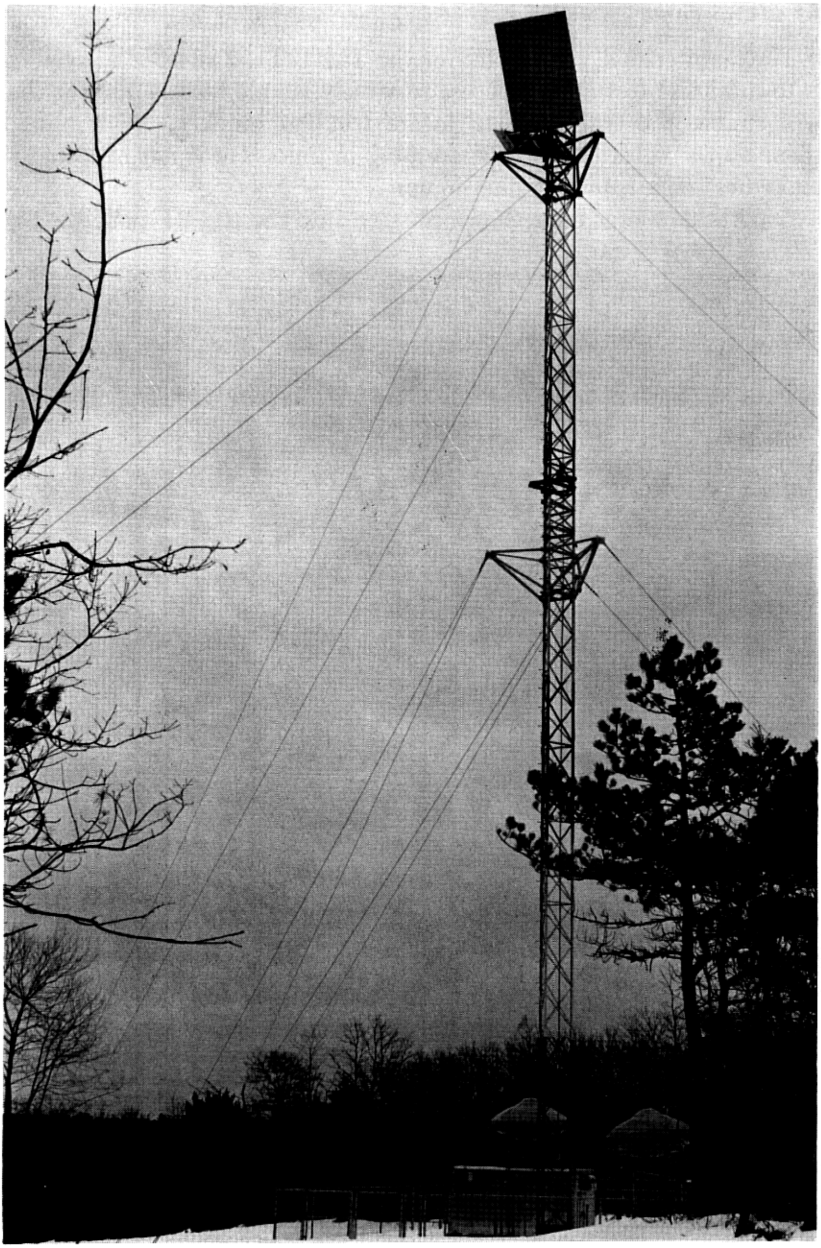


Fig. 65 — Typical TM-1/TL-2 repeater station.

59, provides the means of making certain maintenance tests and adjustments and for monitoring various currents and voltages within the transmitter-receiver panel. A light, portable, solid-state test set[2] which can be carried from station to station provides the test facilities for maintenance and trouble location at terminal or repeater stations. The test set provides oscillators for all required baseband and intermediate frequency testing and a solid-state voltmeter for measuring transmission levels and baseband response up to 4.5 mc. The test set is 16-inches long, 10-inches wide, and 10-inches deep and weighs 35 pounds.

While this test equipment is adequate for making all tests and adjustments on lightly loaded systems, more specialized and more precise instruments are available for tests to ensure high performance on systems carrying 600 message channels or broadcast quality television.

Two fiberglass cases, each limited in weight to about 40 pounds provide the recommended spare parts and tools that may be required by a craftsman in the on-site maintenance of a TL-2/TM-1 radio system. Each of the cases shown in Fig. 66 is 20 by 16 by 10 inches. The spare parts are protected in transit by encasement in cavities moulded into the soft polyurethane foam liner. The No. 1 case contains the volt-ohmmeter, fluorochemical for the boiler, spare TM-1 and TL-2 klystrons, a receiver IF/baseband amplifier and those other tools and spares having a higher probability of use in the routine maintenance of a remote station. The No. 2 case contains TM and TL receiver modulators and preamplifiers, transmitter baseband amplifiers, and a plug-in diversity switch comparator and pilot monitor.

X. THE INITIAL INSTALLATION

10.1 *Description of the System and Test Results*

The first TM-1/TL-2 crossband diversity system was installed between Charlottesville and Richmond, Virginia. The layout and description of the route is given in Fig. 67. The table indicates what antennas were used, whether direct radiators or periscope systems, the length of the waveguide runs, and the measured received signal powers.

Several weeks were devoted to making performance tests of this system before it was placed in service. Noise loading tests and transmission tests were made on the individual hops as well as on several combinations of hops in tandem. The single-hop noise loading results of a nominal length section, the Carter Mountain-Shannon Hill hop, are given in Fig. 68(a). The 4 hops (two TL-2 and two TM-1) were connected in tandem and the results are given in Fig. 68(b).

Fig. 66 — Spare parts cases for TM-1/TL-2.

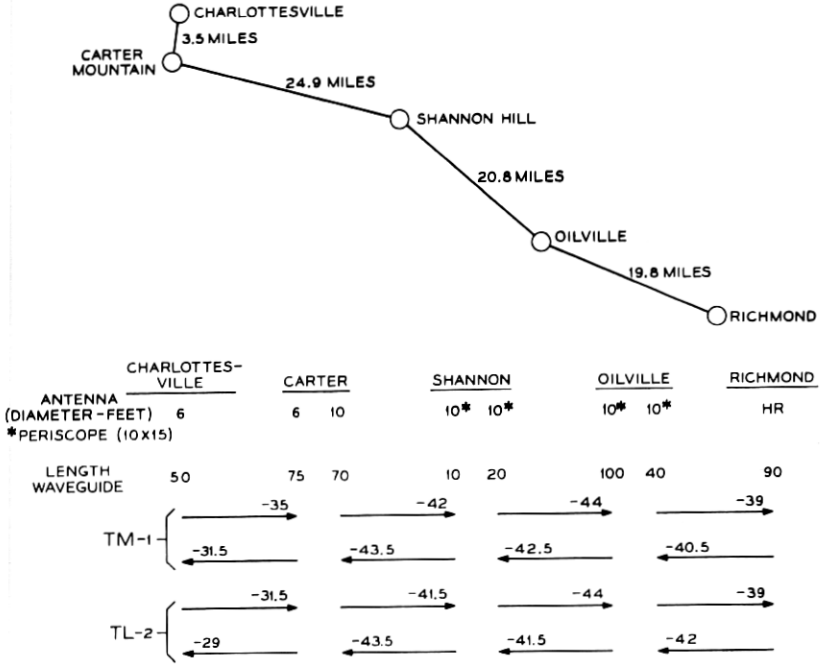


Fig. 67 — Charlottesville-Richmond diversity system.

Also shown are the results for a 10-hop system that included a loop from Carter Mountain to Richmond in tandem with a loop from Carter Mountain to Oilville. The 10-hop system included six TL-2 hops and four TM-1 hops, a combination that could occur easily if a system were equipped with bistable diversity switches. In all of the noise loading results the test signal was a 60–2540-kc band of noise and the noise power applied to the transmitter baseband input corresponding to 0 db in the figures gave 5-mc peak deviation. The pre-emphasis network, used in some of the tests, had a transmission characteristic as shown in Fig. 3. The transmission characteristic of the 10-hop system is given in Fig. 69 while a thermal noise characteristic of 8 of these hops is given in Fig. 70. (The two Oilville-Richmond hops were not available for this test.) A de-emphasis network was not used in the noise measurement.

10.2 *Some Factors that Influence Performance*

The linearity and the delay characteristics of the receivers in the TM-1 and TL-2 systems are determined mainly by factory adjust-

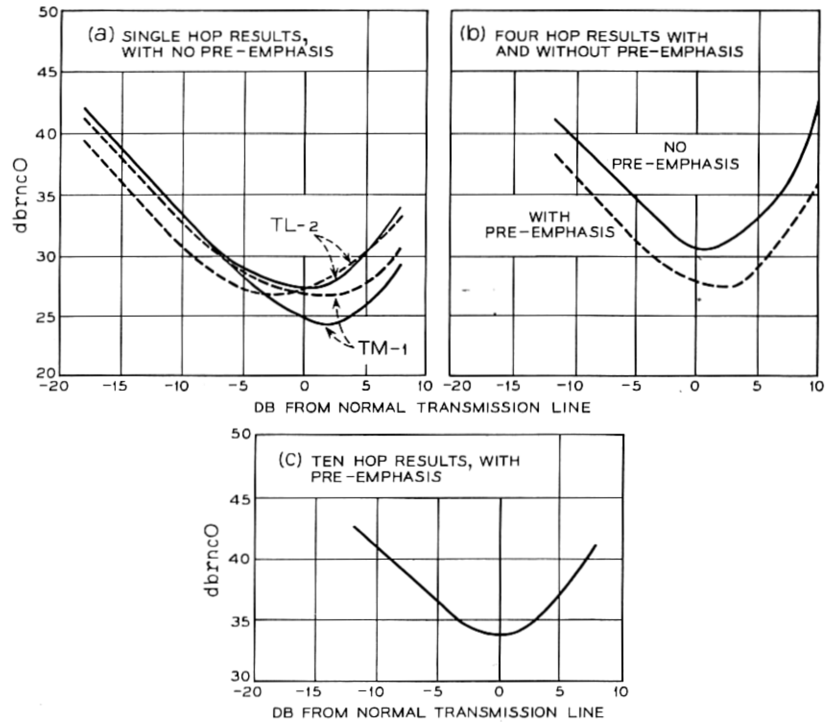


Fig. 68 — 600 circuit noise loading results (slot at 2438 kc).

ments. These are expected to hold essentially for the life of the equipment. The linearity of the transmitter klystron is adjustable, however. It has been found that optimum linearity of a reflex klystron obtains at the repeller voltage for which the deviation sensitivity is minimum and so the repeller bias may be adjusted to minimize the small signal FM deviation produced by a small voltage variation.[12] The minimum is very shallow, however.

The repeller voltage may also be adjusted to optimize the noise loading performance of a hop. This may be done by adjusting for minimum modulation noise in the 70-kc slot and is the technique that was employed in these tests.

Echoes in the RF paths can result in substantial performance degradations. The return loss of the parabolic dish antenna and the radio equipment are such that echoes should be down from the main signal by 50 db or more. A significantly larger echo will degrade the performance severely if the two impedance mismatches are separated by sufficient waveguide (75 feet or more).

This kind of trouble was encountered in the Carter Mountain-Charlottesville section. Initially, the noise loading result corresponded to the "Before" curve of Fig. 71. Investigation showed that the sum of the return losses at Carter Mountain was only 42 db and that the waveguide was noticeably dented close to the antenna. Replacing this section of guide improved the return loss by 6 db and the noise loading characteristic to the "after" curve of Fig. 71.

Another factor, encountered in crossband systems, was insufficient isolation in dual-frequency dish antennas. Energy at 11 gc can couple into the 6-gc port of the antenna from whence it propagates down the 6-gc waveguide, is reflected by the TM-1 radio equipment and radiates from the antenna as an echo. Since the echo delay will cause a changing phase across a given channel bandwidth, the resulting phase distortion produces higher than normal cross modulation. This problem was solved by adding a low-pass filter in the 6-gc waveguide as close to the antenna as possible in all such installations.

XI. TELEVISION TRANSMISSION

11.1 *General*

The objectives for television transmission in TM-1/TL-2 included meeting NTSC color transmission requirements for six hops and educational television requirements for 10 hops. All input and output

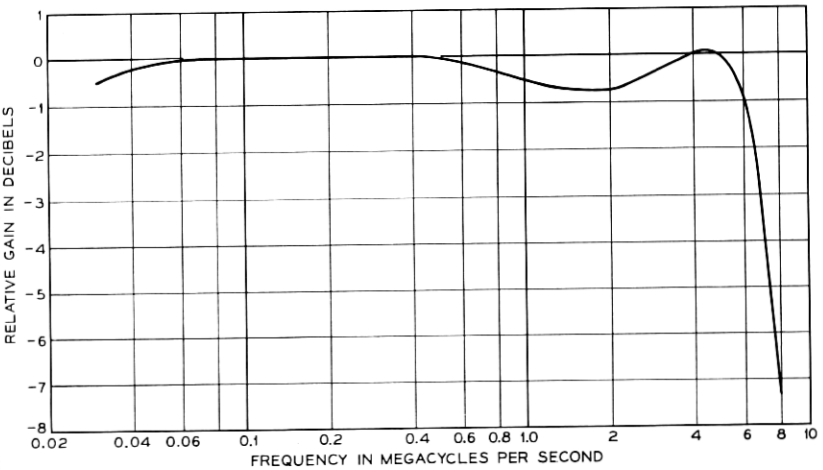


Fig. 69 — Transmission characteristic of 10 hops in tandem.

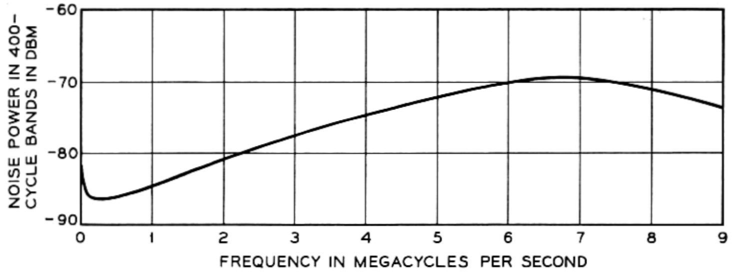


Fig. 70 — Thermal noise characteristic of eight hops.

impedances are 75 ohms and the system delivers a 1 volt peak-to-peak output signal. The plan for television transmission that was adopted originally is given in Fig. 72 showing arrangements at a transmitting terminal, at a repeater, and at a receiving terminal.

A pre-emphasis network and an adjustable attenuator to set deviation are included at the transmitting terminal. Fixed attenuators are used at repeaters, while a receiving terminal includes a de-emphasis network and a television terminal amplifier. The final amplifier insures a 1-volt peak-to-peak output, it provides some $\sqrt{f}$ adjustable equalization, and includes a signal inverter that may be used to obtain the desired signal polarity at the output of the system. The very low frequency transmission of the system was extended by adding large capacitors in the shunt legs of attenuators.

Extensive tests were made on the TL-2 installation at the New York World's Fair involving ten television channels in each direction be-

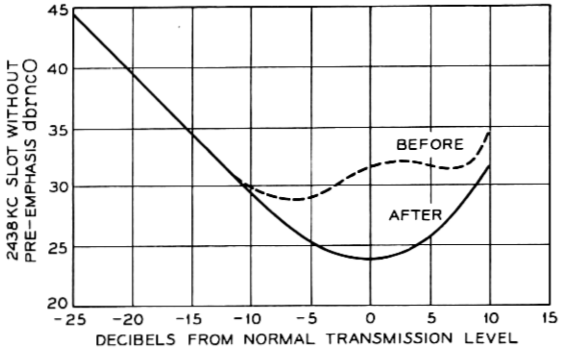


Fig. 71 — Effect of reducing amplitude of echo in waveguide in the TM-1 system between Charlottesville and Carter Mountain.

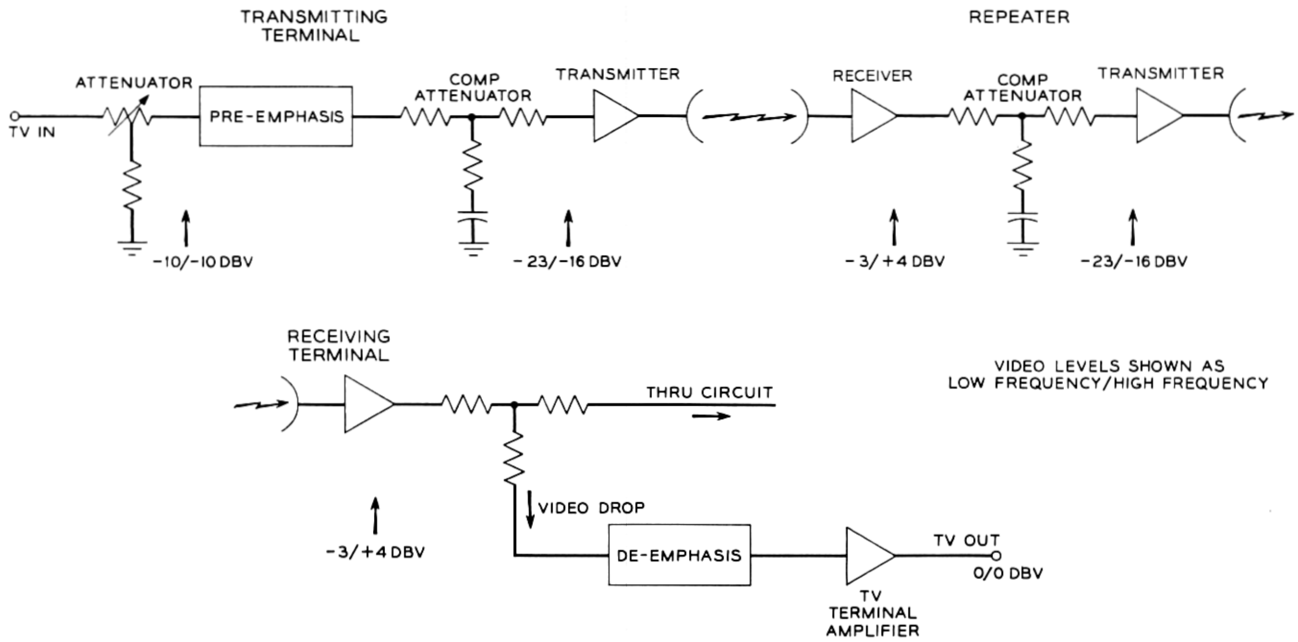


Fig. 72 — Basic television transmission plan.

tween Manhattan and the Fair. As a result of these tests, a number of refinements of the basic plan are being introduced into production.

The performance data and the further description of the system given below, are based on the revised block schematic shown in Fig. 73. All the equalizers, networks, attenuators, and the terminal video amplifier will be mounted on the video panels as described in Section X.

11.2 *Low-Frequency Equalization*

Even though individual baseband amplifiers in TM-1/TL-2 were designed to have a low-frequency cut-off under one cycle per second, the tandem combination of many amplifiers does result in the systematic addition of many very small deviations. For example, a 10-hop TM-1 system includes at least 40 baseband amplifiers since each receiver baseband amplifier and each transmitter baseband amplifier includes two feedback amplifiers in tandem.

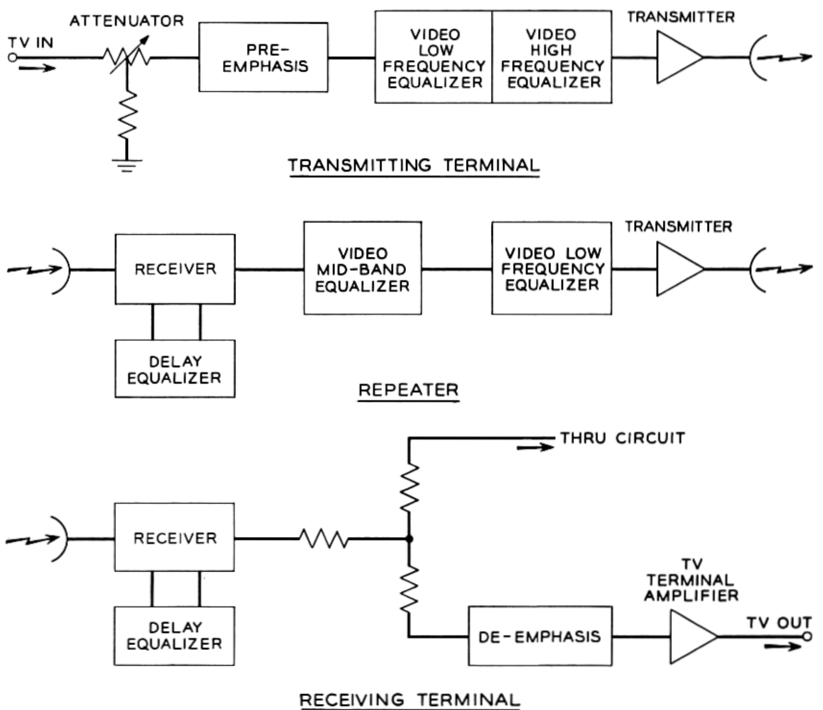


Fig. 73 — Television transmission.

The very low end of the characteristic is controlled by taking advantage of loss pads at the transmitter and at repeaters. The low-frequency equalizers, shown in Fig. 73 are similar to the compensated attenuators of Fig. 72 except that provision is made for selecting the shunt-leg capacitors. The adjustment is made to obtain minimum slope across a 60-cycle square wave at the time of installation or as part of a maintenance routine. Fig. 74 illustrates the performance that has been measured for a six-hop system.

Equalization is also required to mop-up small systematic effects between about 500 cycles and 50 kc that would produce some horizontal smearing of the picture. These equalizers, called video mid-band equalizers, are fixed equalizers and are to be applied at every third repeater.

11.3 *High-Frequency Equalization*

Equalization at the upper end of the band is to be provided by a video high-frequency equalizer located at the transmitting terminal. It provides a $\sqrt{f}$ characteristic having a range of about ± 4 db at 6 mc. To conserve loss, the high-frequency equalizer and the low-frequency equalizers for the transmitter terminal will be combined in

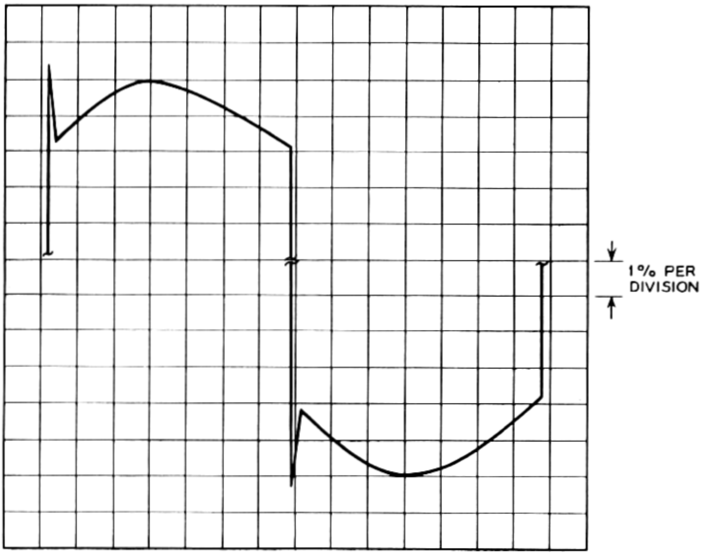


Fig. 74 — Expanded presentation of a 60-cycle square wave transmitted over 6 hops.

a single design. The video terminal amplifier for the Fig. 73 plan will not have a $\sqrt{f}$ adjustment.

11.4 *Differential Phase and Gain*

For television transmission, the transmitter klystrons are adjusted to minimize differential gain. Not only is the procedure different, but optimum klystron tuning for television transmission is not the same as the klystron tuning that minimizes cross-modulation in message systems.

Differential phase is minimized by a factory adjustment of the IF equalizer in the IF and baseband unit, and by the use of additional delay equalizers. These equalizers are selected from a family of equalizers, at the time a system is installed, based on differential phase measurements. They are inserted between the output of the pre-amplifier and input to the IF and baseband unit at some repeater locations.

Differential phase and gain performance can be improved by the use of pre-emphasis. Television systems in TM-1/TL-2 are operated at a peak deviation of 4 mc with 7 db of pre-emphasis such that a high-frequency sine wave deviates the carrier ±4 mc while a low-frequency sine wave deviates it ±1.8 mc. The emphasis characteristics are shown in Fig. 75. While the use of more pre-emphasis would be helpful as far as differential phase and gain are concerned, it would penalize low-frequency noise performance.

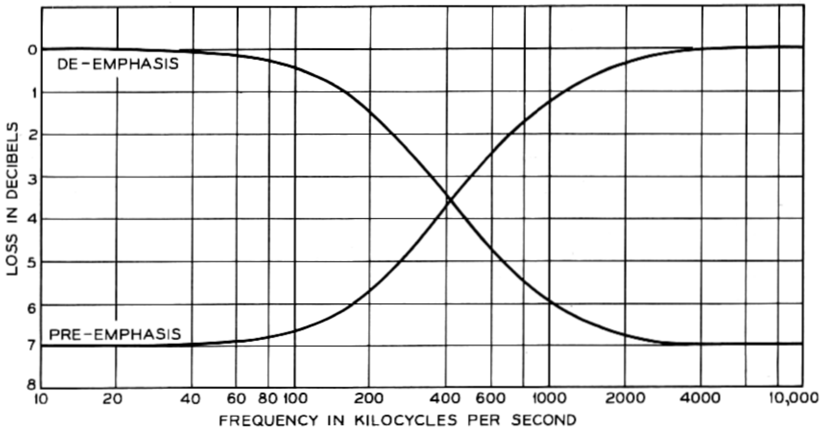


Fig. 75 — Loss of pre-emphasis and de-emphasis networks for television transmission.

By adjusting the transmitter klystrons and by the use of auxiliary delay equalizers, it is possible to obtain differential gain and phase performance of 1 db and 2 degrees for 6 hops with proportionate increases for 10 hops.

Fig. 76 shows the transmission of two common television test signals over a 6-hop TL-2 system at the Fair. The video mid-band equalizers, designed to be applied on every third hop, were not available for these tests and this accounts for the window signal tilt that may be seen. There was no difficulty in meeting thermal noise objectives.

XII. ACKNOWLEDGMENT

The systems described here are the result of the efforts of many members of the Bell Telephone Laboratories in the research, systems development, device development, outside plant, and systems engineering departments. The cooperation of the American Telephone and

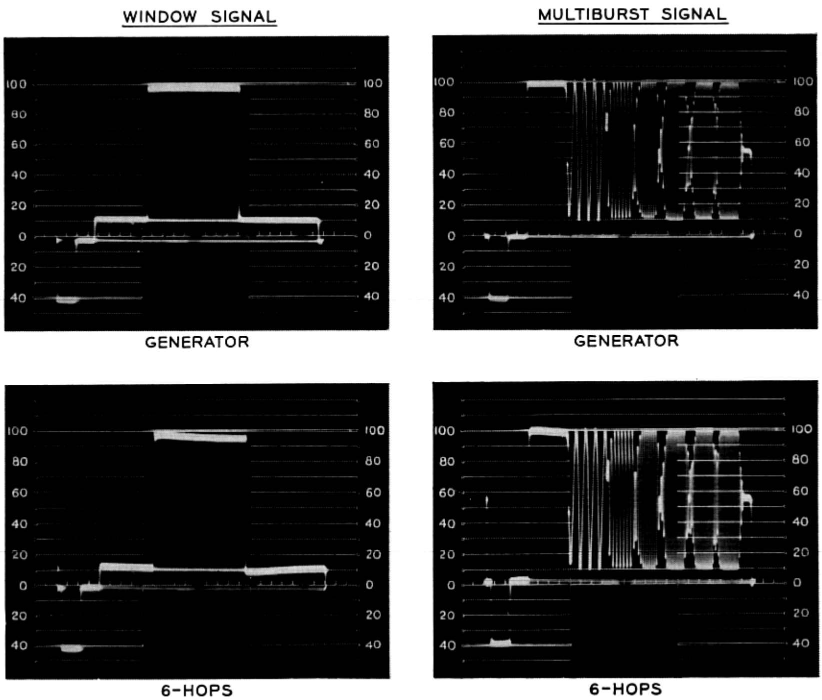


Fig. 76 — Television test signals transmitted over a 6-hop TL-2 system.

Telegraph Company and of the Western Electric Company was important to the success of this undertaking.

APPENDIX

The performance of transmission systems is rated in terms of the interfering noise power that may be measured in a telephone circuit at the reference transmission level point — the 0TL point. As the technology has advanced, the methods of measurement have changed with the result that several units of measurement are found in the literature. The purpose of this note is to relate these units.

A 3A noise measuring set is currently used in the Bell System. Readings are generally made using C-message weighting and the set is calibrated in dbrn or db above reference noise. The 2B noise measuring set was used prior to the advent of the 3A instrument. Its weighting curve was dbrn adjusted (adjusted with respect to an earlier value of reference noise) and generally called dba.

When measurements are made at the 0 TL point, the readings are frequently given in dba0 or dbrn0. Since the 3A noise set can be used with flat weighting as well as C-message weighting, it has become common to state the reading as dbrnc0 when C-message weighting is used.

Noise readings on the 2B and 3A sets may be summarized as follows:

Set	*Readings due to 0dbm of* *1000 Cycles*	*0–3kc White Noise*
2B	85 dba	82 dba
3A	90 dbrn	88 dbrn

The international standard weighting characteristic is the CCIF psophometric curve. It is similar to the FIA weighting curve, but a reference frequency of 800 cycles rather than 1000 cycles is used. A 300 – 3400-cycle band of uniform noise is attenuated 2.5 db by the CCIF weighting network. In CCIF terms, a picowatt (pw) is −90 dbm, and a psophometrically weighted picowatt (pwp) is −87.5 dbm for a band of flat noise (300 – 3400 cycles). Hence

$$0 \text{ dba} = 3.55 \text{ pwp}$$

and

$$0 \text{ dbrnc} = 0.89 \text{ pwp}.$$

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