The TJ Radio Relay System

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(Manuscript received February 19, 1960)

The TJ radio relay system is a broadband microwave facility that operates in the 10,700- to 11,700-mc common carrier frequency band. It has been specifically designed for short-haul transmission of either multichannel telephone or television circuits. Transmission performance and the over-all system description are presented, as well as some early field applications.

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I. INTRODUCTION

During the past decade, microwave radio in the Bell System has had a phenomenal growth. In terms of route mileage and number of circuits, this growth has been primarily in the long-haul field in the 4,000-mc common carrier band. The TD-2 system[1,2] now criss-crosses the continent several times and provides facilities for telephone and television to almost every part of the continental United States.* In many areas it is already loaded to capacity and, hence, its use for other than backbone service is becoming increasingly restricted. In the next decade it is expected that there will be a large demand for short-haul microwave facilities along backbone routes and remote rural areas. These will have to be supplied by systems operating in common carrier bands other than the 4,000-mc band. To allow for orderly growth of the Bell System radio plant, the 11,000-mc band has been selected for short-haul service needs where the maximum channel cross section might be only a few hundred telephone circuits.

In the past, the telephone companies have used 4,000-mc TE equipment,[3] secondary TD-2 arrangements or other currently available 6,000-mc common carrier equipment to fulfill their short-haul needs. Feasibility studies[4] by the radio research group at Bell Telephone Laboratories and systems engineering studies made in cooperation with the telephone companies indicated the possibility of and need for a new economical short-haul system that would permit the dropping and adding of circuits at each repeater or alternatively, be capable of transmitting monochrome or NTSC color television. Because of the potential interference problems with the 4,000-mc TD-2 system, and the 6,000-mc TH system[5] now being installed in some sections of the country, the new TJ system has been developed for the 10,700–11,700-mc common carrier band.

II. OBJECTIVES

2.1 *Area of Application*

There are a great number of uses for a flexible, economical short-haul radio system such as TJ. A partial list of these applications includes:

(a) relief on open-wire or cable routes now at full capacity;

(b) added facilities along open-wire and secondary cable routes for improved reliability;

(c) television side-legs and short-haul message facilities branching off backbone routes;

(d) short-haul message facilities on existing backbone TD-2 or TH radio routes;

* At present, more than 15 million (27 per cent) of the long distance telephone circuit miles and more than 60,000 (78 per cent) of the intercity television circuit miles of the Bell System are provided by microwave radio relay.

(e) new facilities to locations where wire construction is difficult;
(f) alarm, control and order-wire facilities on backbone radio routes;
(g) general purpose local television service;
(h) bypass service in large city areas where the TD-2 system is at capacity.

2.2 *Development Objectives and Performance Characteristics*

Prior to the beginning of the development program, a set of objectives was specified reflecting the best judgment at that time as to the features and capabilities necessary for the new system. These objectives have been reviewed and modified from time to time as the development of the new system progressed and, in most instances, the original requirements for the TJ system have been met.

2.2.1 *Frequency Band and Allocation Plan*

The TJ system operates in the 11,000-mc common carrier frequency band and provides either message or television service for end-link or short-haul applications. A frequency allocation plan has been devised to permit operation of six two-way TJ channels on the same route with common antennas for transmitting and receiving. One-for-one frequency diversity, with a simple automatic switch has been provided on an optional basis, and little or no cost penalty has been incurred by systems not having such switches.

2.2.2 *Telephone and Television Capacity*

The TJ system has been engineered to transmit 96 channels of ON-2 multiplex[6] or 240 channels of L multiplex through nine repeaters for a total distance of 200 to 300 miles. The system is also being engineered to transmit one monochrome or NTSC color television signal, meeting end-link and short-haul objectives over distances of approximately 100 miles on each radio channel. Sufficient video bandwidth has been provided to transmit the audio portion of the television program along with the video signal on a multiplex basis in the vicinity of 6 mc.

2.2.3 *Order Wire and Alarm*

An order-wire and alarm facility has been provided which will work over the radio for TJ telephone systems or over a wire facility for one-way television routes.

2.2.4 *Stand-by Power*

The stand-by power equipment provides the minimum discontinuity consistent with system cost objective and with other sources of system failure.

2.2.5 *Economics*

One of the primary objectives of this development has been to provide system arrangements and operating features at the lowest first cost and annual charge consistent with meeting Bell System requirements. Equipment arrangements have been designed to minimize job engineering and installation expense. Proper packaging has received careful consideration. Ease of maintenance is of prime importance in its relation to annual charges, and equipment arrangements have been devised with this in view.

2.3 *Transmission Objectives*

2.3.1 *General*

The TJ hops should be engineered to have a 50-db rms carrier-to-noise ratio during periods of free space transmission. The 50-db ratio is necessary to provide adequate margin over first circuit noise during periods of signal attenuation caused by rainfall. Propagation tests[7] conducted at 11,000 mc indicated that during periods of heavy rainfall the attenuation may be in the order of 40 db or more, depending upon the length and location of the radio path. Reliable protection against selective fades and equipment failure outages can be obtained with frequency diversity. Protection against rain attenuation, however, can only be assured by engineering sufficient fading margin into the system and by using path lengths appropriate to the particular area of the country.

2.3.2 *Telephone*

The TJ telephone end-link objective for cross-modulation and noise has been set at 32 dba at the 0 db transmission level point. This figure was arrived at by assuming that the random addition (power addition) of four such links to a backbone system should not degrade by more than 3 db the long-haul, heavy-route system objective of 38 dba. In practice, the degradation is not expected to exceed more than about 1 db in most cases because of shorter end-links and switching losses.

Due to the large carrier-to-noise ratios expected in TJ systems, all of the 32 dba objective may be allocated to FM intermodulation and noise in the baseband circuits. Single-section performance can be derived from the knowledge of how fluctuation and intermodulation noise add as the number of repeaters is increased. For typical values of deviation used in the TJ system, the total noise power increase is approximately proportional to the numbers of repeaters.

2.3.3 *Television*

The television signal-to-noise* objective for a single-section TJ system is 54 db unweighted. Differential phase and gain objectives for a single section are ±1.0 degree and ±0.5 db, respectively.

2.3.4 *Stability*

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

III. TRANSMISSION PLAN

The TJ radio system offers a maximum of six two-way broadband channels, each of which provides for either multichannel telephone or television transmission. To provide a high degree of reliability, only three channels are ordinarily used as working channels, the remaining three being used for protection on a one-for-one basis, with automatic switching at each repeater.

The radio signals are transmitted to a dual polarized antenna by RF channelizing and duplexing arrangements. It is expected that most systems will use a "periscope" type of antenna arrangement to minimize the loss associated with long waveguide runs. Such a system uses a 5-foot paraboloidal antenna at the base of the tower directed at a plane 6- × 8-foot or a "dished" 8- × 12-foot reflector at the top of the tower. A 10-foot paraboloidal antenna is available as a direct radiator for those applications using short towers on natural elevations. In addition, an 11,000-mc systems-combining network is available so that the TJ system may utilize the horn-reflector antennas installed on TD-2 and TH backbone routes.

A block schematic of a two-section TJ system is shown in Fig. 1.

* Peak-to-peak signal to rms noise.

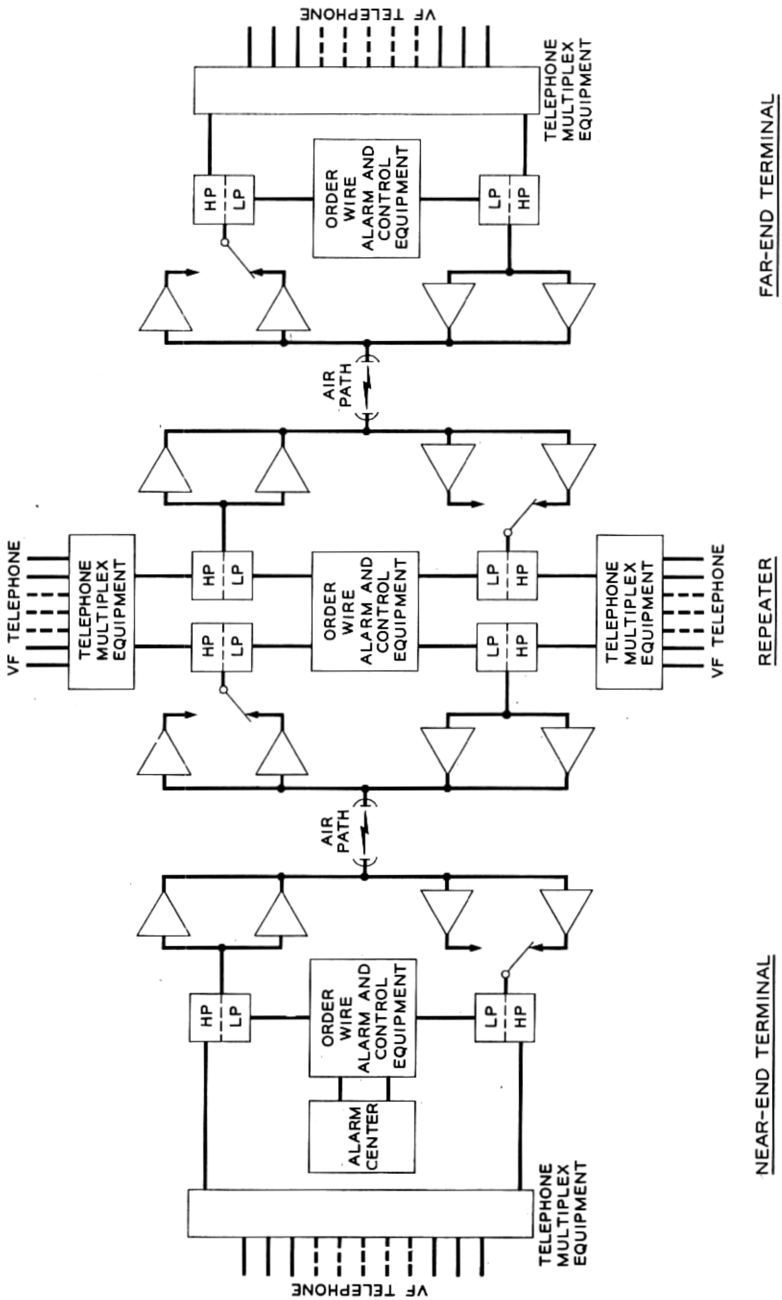
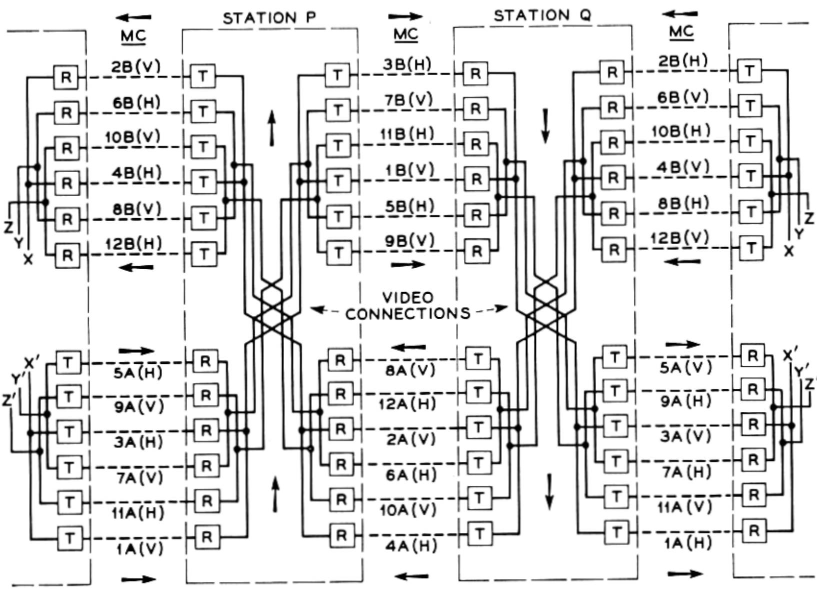


Fig. 1 — Block schematic of a two-section TJ system.

The multiplex and control signals are combined by the high-pass–low-pass filter and feed the transmitters of the working and spare radio channel. At the receiving end, the selected radio receiver feeds into a similar filter combination, which separates the multiplex from the control signals. A 2600-cps pilot is transmitted over the system and is used to send alarms and orders between the various radio locations.

The TJ frequency plan is shown in Fig. 2. Because of the expected use of the "periscope" antenna system, the plan is based on the use of four frequencies for each two-way radio channel. The 10,700- to



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

Fig. 2 — TJ frequency assignment plan.

11,700-mc common carrier band is divided into 24 channels, each about 40 mc wide. In a given repeater section, only 12 of these are used, resulting in 80-mc spacing between midchannel frequencies. These channels are further divided into two groups of six for transmission in each direction. The polarization of the channels alternates between vertical and horizontal to provide 160-mc separation between signals having the same polarization, thereby substantially easing requirements on the channel-separation networks. The remaining 12 channel assignments are used in adjacent repeater sections. These frequencies are repeated in alternate hops. Potential "overreach" interference is reduced by reversing the polarization of the third section with respect to the first section. Cochannel interference from adjacent repeater stations, a necessary consideration in the TD-2 and TH systems because of their use of the two-frequency plan, is eliminated in this system by the use of the four-frequency plan. At a given repeater, adequate frequency separation between transmitters and receivers is achieved by using the upper half of the band for transmitting and the lower half for receiving. This arrangement is inverted at alternate stations.

The TJ frequency plan and channelizing arrangements permit efficient use of the entire 11,000-mc common carrier band and establish an orderly growth pattern. Additional radio channels may be added in the future to a system whose initial requirements are less than its maximum capabilities without disrupting service on the working channels. Actual route cross sections may vary from a single one-way television system, without protection, up to a full system of three protected two-way channels carrying either telephone or television circuits.

IV. DESCRIPTION OF SYSTEM

4.1 *General Description*

A basic building block in the TJ system is the transmitter-receiver bay. It consists of a frequency-modulated transmitter, a heterodyne-type receiver and regulated rectifiers operating from standard ac line voltages. A block schematic of the bay is shown in Fig. 3. An incoming microwave signal from the antenna system is selected by a channel-separation network of the type shown in Fig. 4. This network drops the desired channel and permits the remaining channels to pass through essentially unattenuated for selection in similar networks on adjacent bays. The selected channel is fed to the receiving modulator, which is preceded by a bandpass filter providing additional preselection. In the

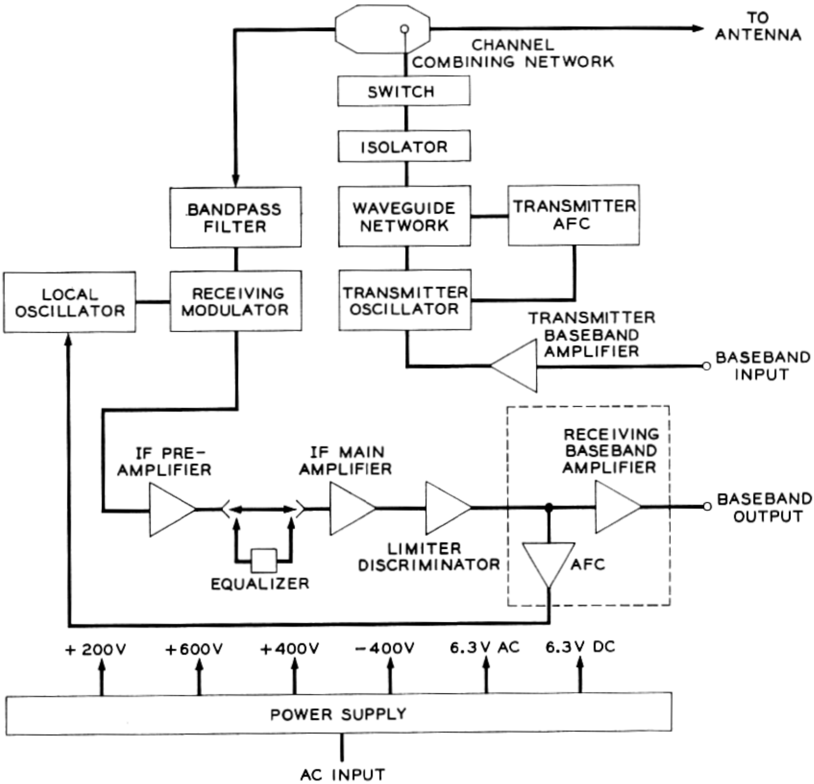


Fig. 3 — Block schematic of the TJ transmitter-receiver bay.

receiving modulator the signal is heterodyned with the output of a local oscillator to produce a difference or intermediate frequency (IF) of 70 mc. The IF signal is amplified and detected in the receiver to provide the original baseband intelligence, which may be applied either to the next transmitter or delivered to appropriate terminal equipment. In the transmitter, the baseband signal is amplified and applied to the repeller electrode of the transmitting klystron. The frequency-modulated output of the klystron is combined with outputs from adjacent transmitters in a channel-combining network similar to the receiver separation network. The transmitter outputs are then connected to the antenna system which in general will be simultaneously receiving from

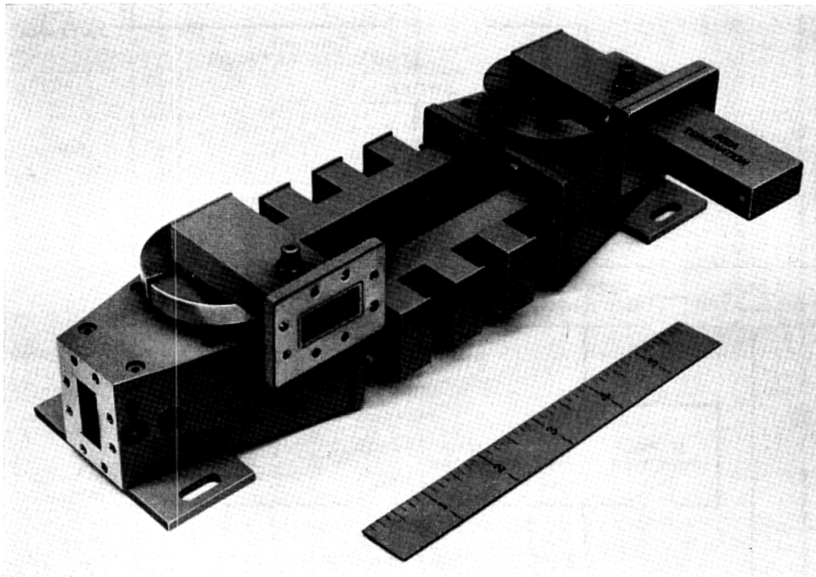


Fig. 4 — Channel separation-combining network.

the same direction. Electronic automatic frequency control (AFC) is provided on the receiver local oscillator to maintain the average intermediate frequency at 70 mc. On the transmitter, an electromechanical AFC system keeps the average transmitter frequency at the resonant frequency of a highly stable reference cavity.

The baseband type of repeater distinguishes the TJ system from the more common situation in long-haul microwave systems such as TD-2 and TH. In these, the signal remains in the frequency-modulated form throughout the amplification process at repeaters, and the baseband signal is only recovered through the use of special terminal equipment.

4.1.1 *Transmitter Radio Frequency Units*

The radio frequency output from the transmitter is provided by a Western Electric 445A klystron developed specifically for the TJ system. The same tube, illustrated in Fig. 5, is used as the receiver local oscillator. Typical operating characteristics in both applications are summarized in Table I.

Although the nominal output of the transmitter klystron is 0.5 watt when operated in the $2\frac{3}{4}$ mode, the actual output is dependent to

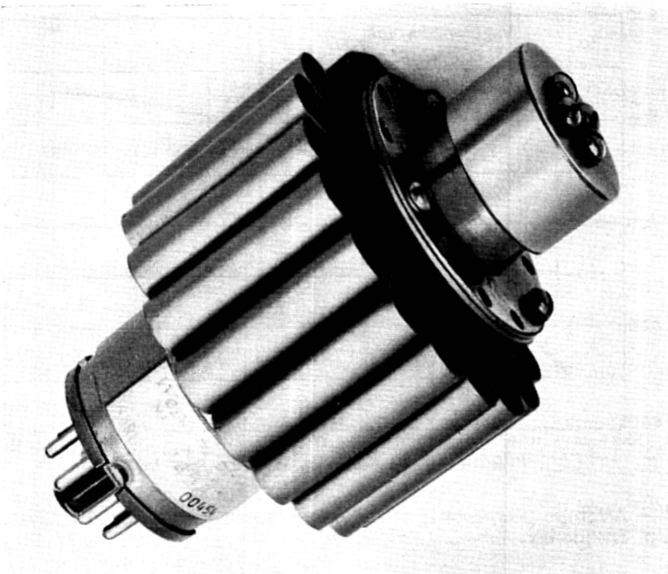


Fig. 5 — Western Electric 445A klystron.

TABLE I — TYPICAL OPERATING CONDITIONS OF WE 445A KLYSTRON

	Transmitter	Beat Oscillator
Resonator voltage	+600 volts	+400 volts
Resonator current	65 milliamperes	40 milliamperes
Repeller voltage	−250 volts	−125 volts
RF power output	400 milliwatts (minimum)	50 milliwatts (minimum)
Oscillating mode	$2\frac{3}{4}$	$3\frac{3}{4}$
Electronic tuning range	50 mc (minimum)	50 mc (minimum)
Repeller modulation sensitivity	0.8 mc/volt (minimum)	1.5 mc/volt (minimum)
Cooling	forced air	natural convection
Heater voltage	6.3 volts	
Heater current	0.9 ampere	
Repeller capacity	6 mmf (maximum)	
Mechanical tuning sensitivity	0.5 mc/angular degree	
Output	matched to WR90 waveguide	

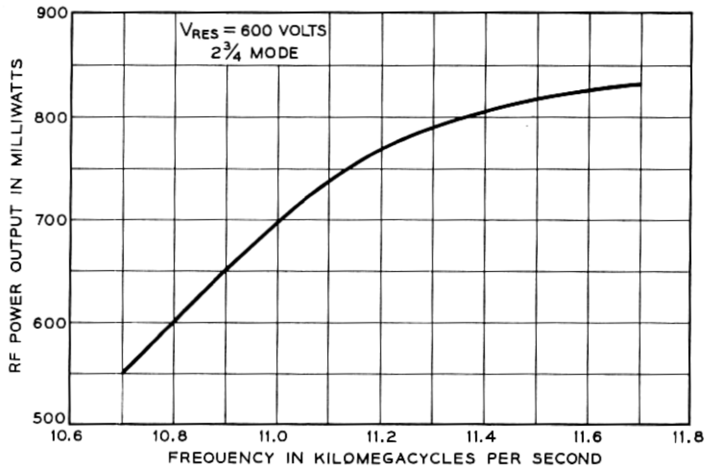


Fig. 6 — Average power output of the Western Electric 445A klystron as a function of frequency.

some extent on frequency. This dependence is demonstrated in Fig. 6, in which the average output of a number of production tubes is plotted against frequency.

Precautions against tube damage by positive repeller voltage have been included in both the transmitter and local oscillator circuits in the form of a clamping diode between repeller and cathode.

To reduce the maximum dc voltages on the bay and, hence, to simplify protective arrangements, the klystron body (resonator) operates at 600 volts above ground. An insulator between the tube output and its mating flange keeps this dc potential off the connecting waveguide.

The output from the transmitting klystron feeds a waveguide network, which serves the dual purpose of an AFC discriminator and power monitor. A schematic of the network is shown in Fig. 7. The first directional coupler feeds a waveguide hybrid, which, in conjunction with an invar reference cavity and a pair of silicon diodes, forms an RF discriminator. The operating principles of the discriminator have been described by Pound,[8] and a typical output characteristic is shown on the schematic. Zero output at the "tails" of the discriminator characteristic is controlled by the balance control, while the crossover point can be set to any frequency in the TJ band by tuning the reference cavity. The slope of the discriminator characteristic is determined by the loaded Q of the reference cavity, which is nominally 900. The second directional coupler in the waveguide network monitors transmitter power output,

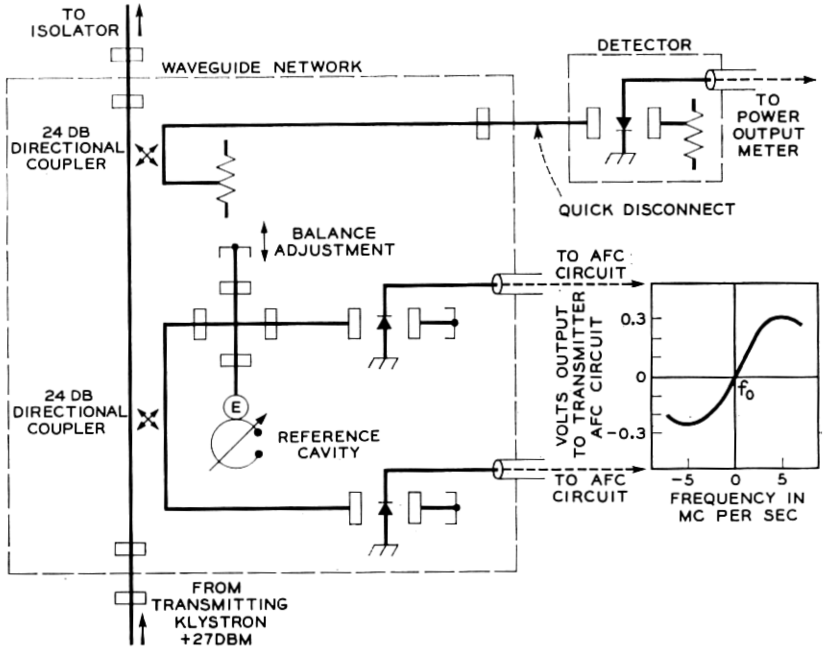


Fig. 7 — Schematic of the transmitter AFC discriminator and power-monitoring network.

and, with a nominal +27 dbm signal from the klystron, the coupler output is +3 dbm. Normally, this signal is fed to a detector and meter circuit that is calibrated in decibels referred to the +27 dbm level. For test purposes, the detector can be rapidly removed, permitting frequency and other transmitter characteristics to be checked.

To minimize the nonlinear effects produced by reflections in the antenna feed, a high-performance ferrite isolator is required between the klystron output and the antenna system. The field displacement isolator[9] shown in Fig. 8 connects to the output port of the AFC waveguide network, and typical forward and reverse loss characteristics are shown in Fig. 9.

The transmitter output is fed to the channel-combining networks through a waveguide switch, which normally allows the RF energy to pass through unattenuated. When a klystron is replaced, the initial oscillating frequency may be considerably different from nominal. To prevent interference with adjacent channels, the switch can be temporarily closed, thereby attenuating the output signal by more than 80 db.

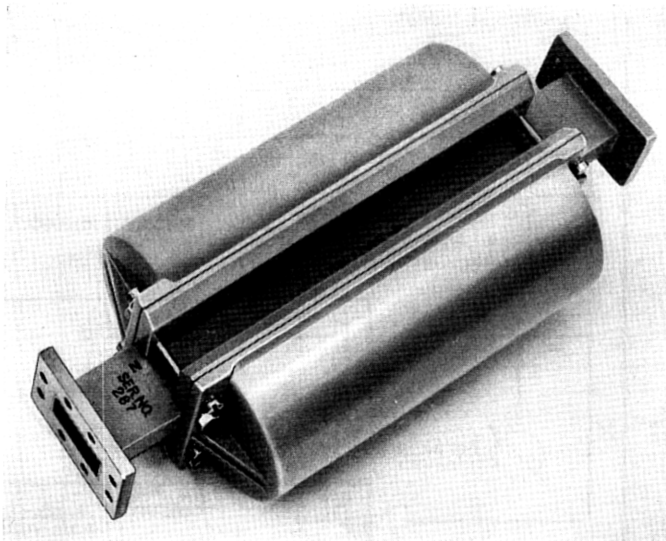


Fig. 8 — Field displacement isolator.

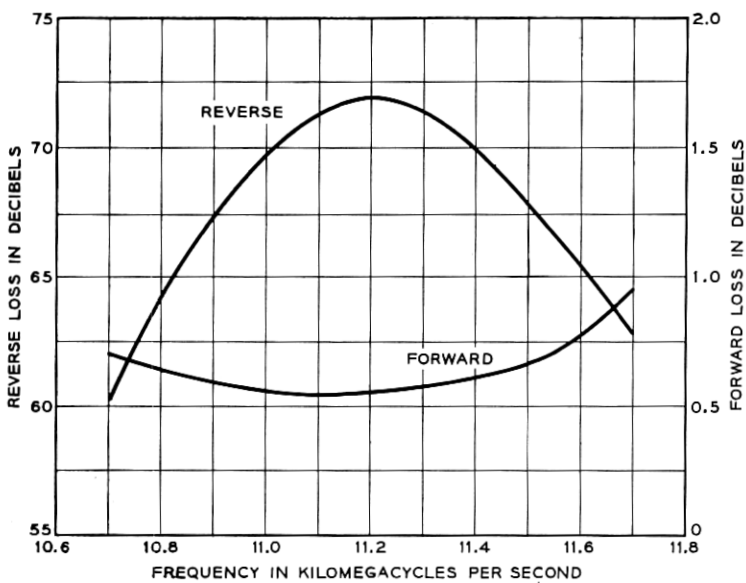


Fig. 9 — Forward and reverse loss characteristics of the TJ isolator.

The channel-combining networks are identical with the channel-separation networks on the receiver (Fig. 4). The principle of operation has been described elsewhere,[10] and representative transmission characteristics are given in Fig. 10.

4.1.2 *Receiver Radio Frequency Units*

Incoming RF channels from the antenna are selected by channel-separation networks identical with the combining networks mentioned in the previous section. In the case of the last receiver in a line-up, the separating network is not required, since at this point the number of RF channels has been reduced to one.

The selected channel is fed to the receiver modulator through a band-pass filter, a waveguide tuner and a critically dimensioned waveguide spacer. The filter serves the two-fold purpose of providing suppression against interfering image signals and enhancing the efficiency of the modulator by reflecting out-of-band modulation products back into the

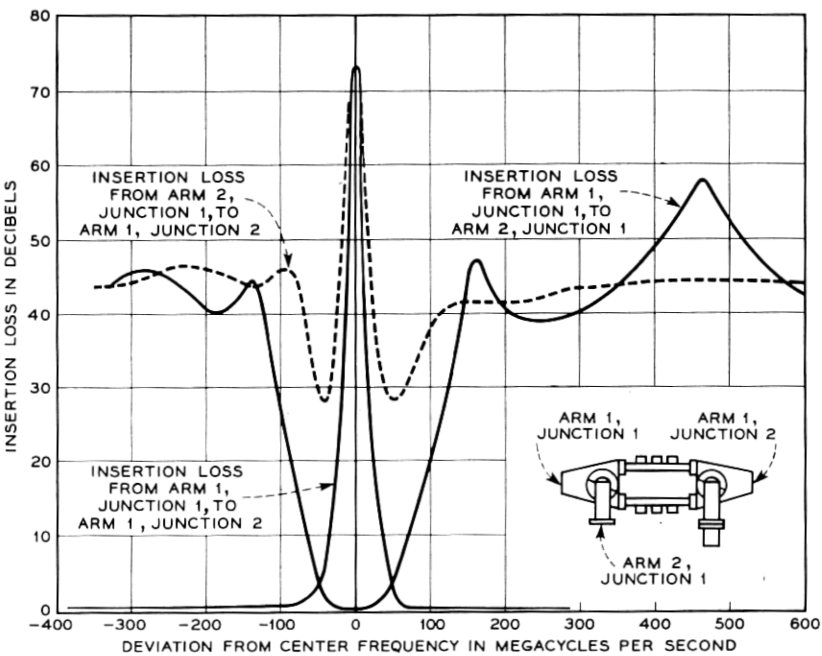


Fig. 10 — Representative transmission characteristics of the RF channel separation-combining networks.

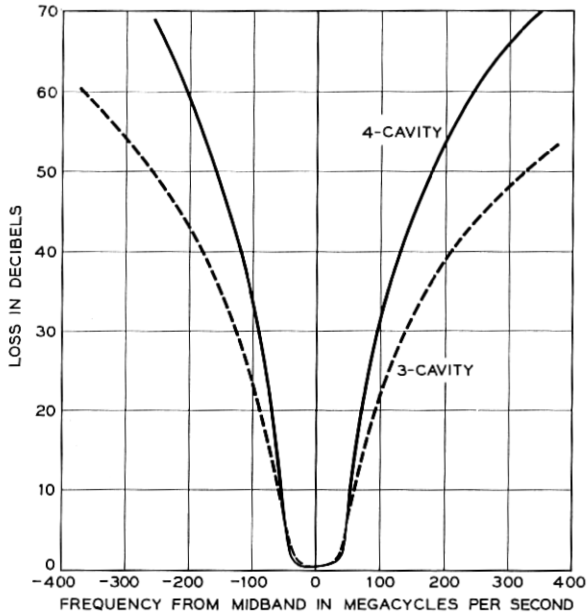
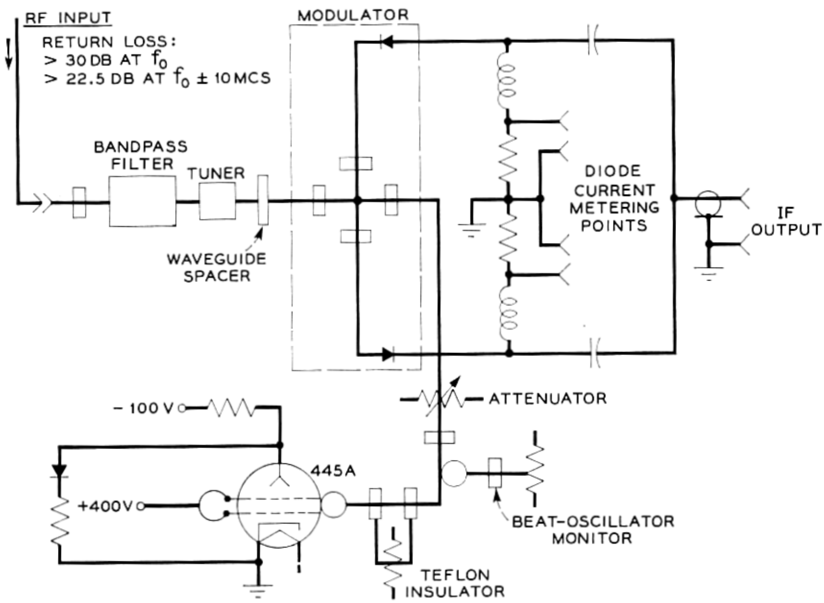


Fig. 11 — Representative transmission characteristics of the RF receiver bandpass filters.

converter in the proper phase. Correct phasing is achieved by choosing a suitably dimensioned waveguide spacer, which determines the electrical path length traversed by the modulation product. To minimize reflections in the waveguide run between the antenna and the modulator input, the modulator input impedance must be closely matched to the waveguide impedance. This match is optimized by the adjustment of a two-stub tuner located between the bandpass filter and the modulator.

The bandpass filters are of two types, having either three or four resonant cavities. The additional selectivity of the four-cavity filter is required when a receiver is not provided with a channel-separation network. Typical transmission characteristics for both filter types are shown in Fig. 11.

The balanced receiving modulator is shown schematically in Fig. 12. Waveguide inputs are provided for both the incoming and local oscillator signals, while a coaxial output connection is provided for the 70-mc IF signal. The unbalanced output is obtained by reversing the polarity of one diode relative to the other in the hybrid junction assembly, thus permitting paralleled unbalanced output connections.



OVER-ALL LOSS (MAX) RF INPUT TO IF OUTPUT = 9.0 DB
MAXIMUM NF AT TUNER INPUT = 15.0 DB

Fig. 12 — Schematic of the balanced receiving modulator.

The local oscillator is a Western Electric 445A klystron identical with that used in the transmitter. It feeds the modulator through a monitoring coupler and an attenuator, which can be adjusted to give a power input to the modulator of approximately 0 dbm.

4.1.3 *Intermediate Frequency Units*

The IF output from the receiver modulator is amplified in a preamplifier followed by the IF main amplifier. These units have a passband centered at 70 mc with typical gain and delay characteristics illustrated in Fig. 13. Input and output impedances are 75 ohms unbalanced with a minimum return loss of 20 db. Table II summarizes the gain and tube complement for both units.

The main amplifier has a nominal power output of +5 dbm, and internal automatic gain control on the first six stages maintains the output within 4 db of nominal for a 40-db change in input level. Matched double-tuned coupling circuits are used in all IF units, with nonadjustable auto transformers in the interstage networks. The only adjustable

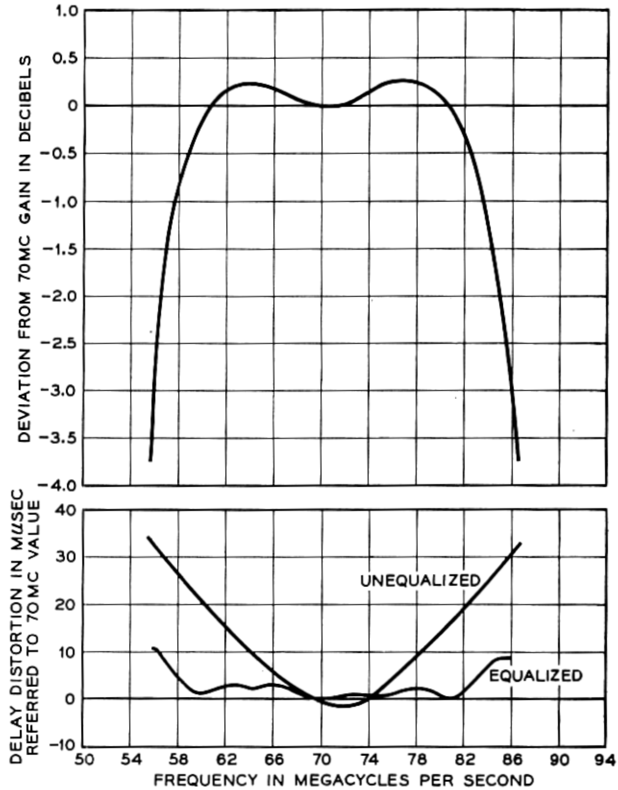


Fig. 13 — IF gain and delay characteristics.

elements are in the input and output coupling networks, which are adjusted for maximum return loss. The marked reduction in the number of tuning adjustments simplifies testing and maintenance, while reducing the possibility of maladjustment. Alternative coupling networks providing higher gains per stage were considered in the initial design

TABLE II

Unit	Gain	Tube Complement
Preamplifier	32 db	two 417A triodes two 435A tetrodes
Main amplifier	75 db	seven 435A tetrodes

but were discarded in favor of the matched circuit, which is much less sensitive to tube changes.

In the interests of minimizing maintenance and reducing the number of tube types, the Western Electric 435A is used wherever possible. This tube is a tetrode of proven integrity with a life expectancy based on field experience of 50,000 hours.

The plate supply for the preamplifier and main amplifier is +200 volts. The total plate current for all tubes in the main IF amplifier is fed through a common resistor located in the power supply. Since the amplifier gain, and hence the total plate current, is automatically adjusted to compensate for changes in received signal level, the voltage across the common resistor is a measure of the received signal strength. This voltage is used to actuate the comparator circuit in a diversity system.

The 75-ohm unbalanced output from the main amplifier feeds the limiter-discriminator circuit. Plate limiting is employed in a three-stage circuit, using 435A tetrodes. Low-forward-impedance gold-bonded diodes provide the clipping action and give a total dynamic limiting of approximately 40 db. The discriminator uses two separately driven antiresonant circuits tuned to approximately 52 and 87 mc. When these circuits are driven by the frequency-modulated signal, amplitude modulation results, which is detected by a double diode and fed through video coupling circuits to the balanced receiving baseband amplifier.

4.1.4 *Baseband Units*

A maximum peak-to-peak signal of 10 volts is required to modulate the repeller of the transmitting klystron, to provide ±4 megacycles deviation. This is provided by a two-stage, balanced video amplifier with an optional input impedance of 75 ohms unbalanced or 124 ohms balanced. The transmitting amplifier utilizes four Western Electric 437A triodes and has a nominal voltage gain of 37 db, adjustable over a range of ±3.5 db. A peaking circuit in the amplifier input provides low-frequency phase correction for a complete repeater when it is used for television transmission. The peaking circuit is provided as a wiring option and is not used in telephone applications.

The receiver baseband amplifier is a single stage balanced circuit utilizing Western Electric 417A triodes. Its principal function is to convert from the relatively high output impedance of the discriminator to the line impedance. This may be 124 ohms balanced or 75 ohms unbalanced in accordance with the wiring option chosen within the unit. With an FM deviation of 8 mc peak-to-peak, the discriminator-balanced amplifier combination gives a minimum balanced output of −1 dbm (−1 dbv).

4.1.5 *Automatic Frequency Control*

Automatic frequency control is used on both the transmitting klystron and the receiver local oscillator. In the former case the control is electromechanical; in the latter, it is electronic.

The transmitter frequency-error signal is derived from the RF discriminator network described in Section 4.1.1. This error signal is applied to the AFC circuit shown in functional schematic form in Fig. 14. When the frequency error exceeds 300 kc, the meter-type relay operates one of the mercury relays, causing the drive motor to mechanically tune the klystron cavity in a direction to reduce the error. The drive motor then continues to operate until the meter relay is reset. If the frequency error still exceeds 300 kc, the same sequence of events will be repeated until the error is less than 300 kc. The accuracy of the AFC system is controlled by the stability of the reference cavity in the RF discriminator circuit. Over the ambient temperature range from −20 to +120°F the transmitter frequency is maintained within ±0.03 per cent of its nominal value.

Electromechanical control of the transmitter frequency is preferred to electronic control, since most of the frequency error results from changes in ambient temperature. Mechanical tuning corrections for this type of frequency error have much less effect on modulation linearity than does a corresponding correction produced electronically.

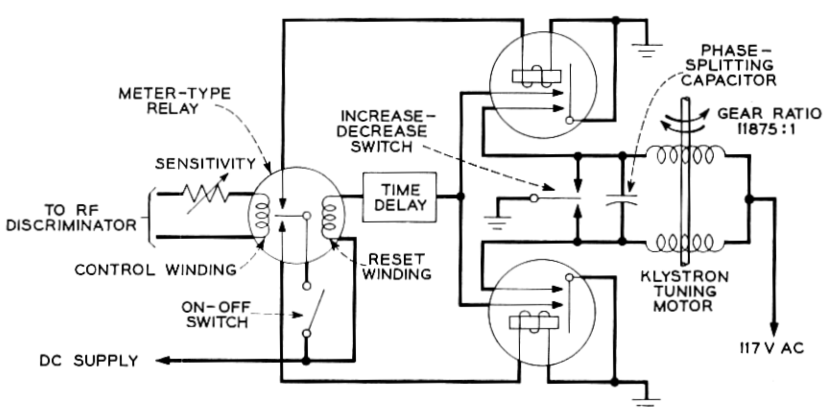


Fig. 14 — Functional schematic of the transmitter AFC circuit.

Automatic frequency control on the receiver is performed electronically since, in this case, the beat oscillator operates at a fixed frequency and modulation linearity is not of importance. The IF error voltage is derived from the signal discriminator, as illustrated in Fig. 15. The error signal is amplified and applied in series with the beat oscillator klystron repeller voltage with the appropriate sign to reduce the error. This automatically maintains the intermediate frequency at the cross-over frequency of the discriminator. If the cross-over point is not exactly at 70 mc, an adjustable bias is provided at the input of the AFC amplifier, which permits adjusting the intermediate frequency to exactly 70 mc. To limit the frequency excursions of the beat oscillator and prevent the receiver's locking onto unwanted signals, a clamp circuit is included in the AFC loop. An additional clamp circuit for the protection of the klystron beat oscillator ensures that the magnitude of the negative repeller voltage never drops below 40 volts.

The frequency of the receiver beat oscillator may be above or below the incoming signal frequency, depending on the channel number. These two conditions correspond to a phase reversal at the discriminator output, and must be compensated for to ensure stability in the AFC feedback loop. The phase correction is obtained by reversing the balanced connections between the limiter-discriminator chassis and the receiver baseband–AFC unit.

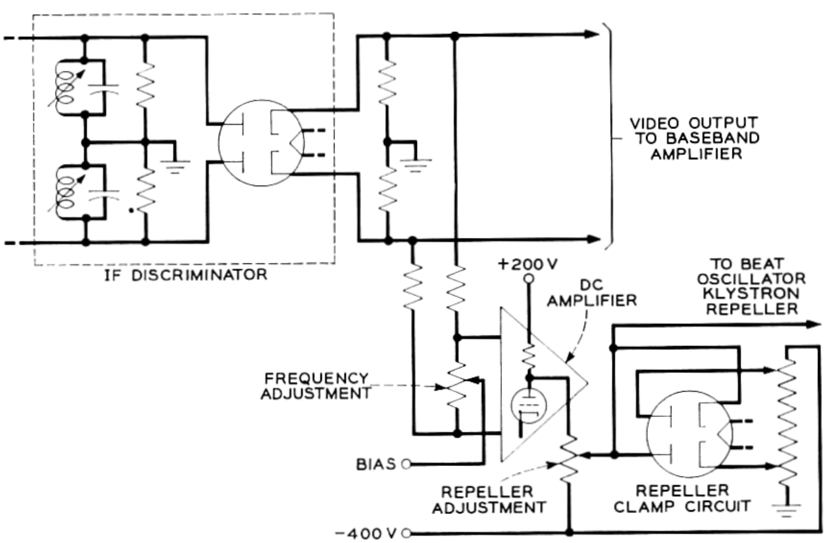


Fig. 15 — Functional schematic of the receiver AFC circuit.

4.1.6 *Power Supplies*[11]

All dc voltages and ac filament supplies are derived from an ac-operated power supply in the lower third of the transmitter-receiver bay.

The principle of operation is illustrated in the block schematic of Fig. 16. Only the −400 volt output is directly controlled by the feedback loop; regulation on the other outputs is dependent on their tracking the −400 volt output. This is achieved by suitable design of the filter networks and the rectifier regulation characteristics. A sensing relay on the −400 volt output ensures that negative repeller voltage is applied to the klystrons before the positive resonator voltages.

Silicon diodes are used throughout as the rectifying elements, so that the only active devices in the circuit are two Western Electric 310A dc amplifier tubes and two voltage reference tubes (423A and 427A) in the feedback control loop. Compared with the more usual series tube regulation, it is expected that the combination of solid state rectifiers and long-life control tubes of proven integrity will greatly reduce power consumption and the annual charges associated with the maintenance of the series tube type of regulated power supply.

The stability of the dc output voltages over the ambient temperature

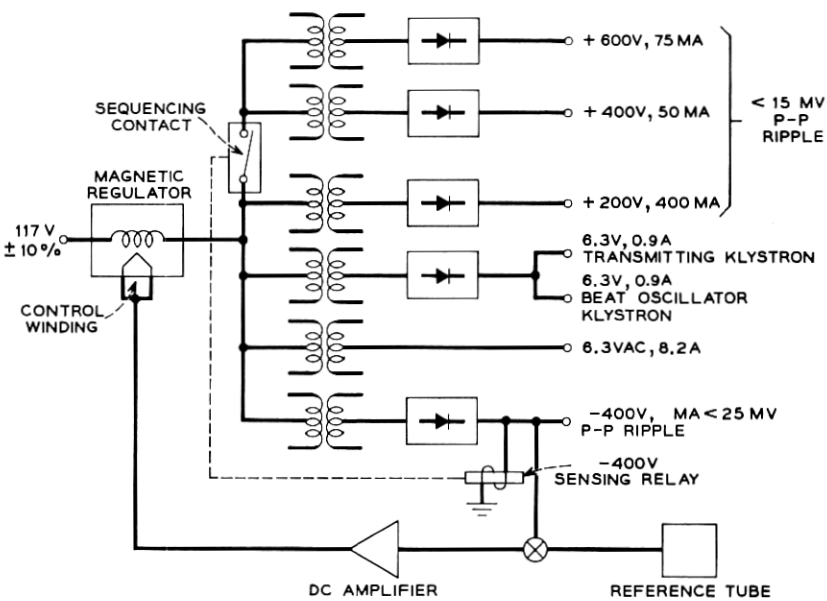


Fig. 16 — Power supply block schematic.

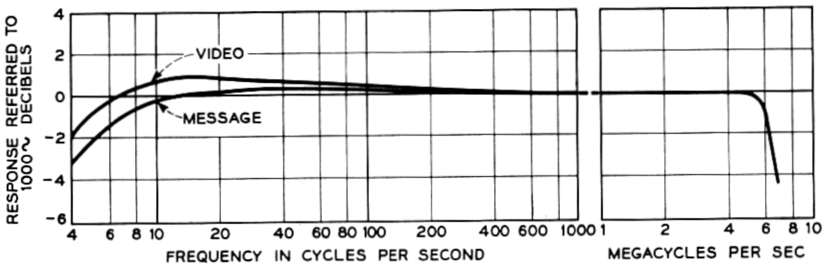


Fig. 17 — Gain-frequency characteristic of a TJ repeater.

range 32° to 120°F and with line voltage variations of ±10 per cent is better than ±0.5 per cent.

4.1.7 *Over-All Performance Characteristics*

The gain-frequency characteristic of a single TJ repeater relative to 1 kc is shown in Fig. 17. The absolute gain of a repeater is nominally 16 db measured from transmitter input to receiver output between 124-ohm balanced impedances. In diversity applications, 6 db of this gain is lost when two transmitters are fed simultaneously resulting in a net gain of 10 db between HP FL IN and HP FL OUT on the diversity switch unit.

To illustrate the linearity of the TJ equipment, Fig. 18 gives the re-

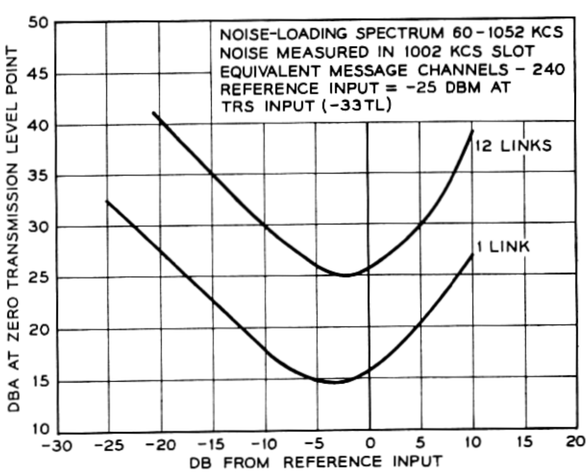


Fig. 18 — Typical noise loading performance of a TJ system.

sults of noise loading tests on a system between Mt. Clemens and Port Austin, Michigan. The system was measured with different numbers of links in tandem, and the results are presented for one and 12 links. The single-link data are the average performance on six individual links; the data on 12 tandem links include these six links in the over-all measurement. For test purposes, 240 channels of single-sideband suppressed-carrier multiplex were simulated by a band of white noise, and the fluctuation and intermodulation noise was measured in a slot at the top end of the transmitted band. The 0 db reference level corresponds to a total input noise power of −25 dbm at HP FL IN on the diversity switch and transmission unit, which is a −33 db transmission level point.

The contribution of fluctuation-type noise to total noise at the receiver output will depend on the received RF carrier level. This relationship is illustrated in Fig. 19, where the noise is given in dba for the top channel in a system carrying 240 channels of suppressed-carrier type-L multiplex. The dba readings are based on a peak-to-peak frequency deviation of 8 mc and a load capacity rating for 240 channels of 21 db.

In television transmission, the linearity characteristics of interest are differential gain and phase. Without pre-emphasis or delay equalization, the differential gain and phase on a single link are respectively 0.5 db and 4.5°. With 13.2 db of pre-emphasis and IF delay equalization, the corresponding figures are 0.1 db and 0.5°.

Low-frequency noise objectives at the output of a TJ receiver require

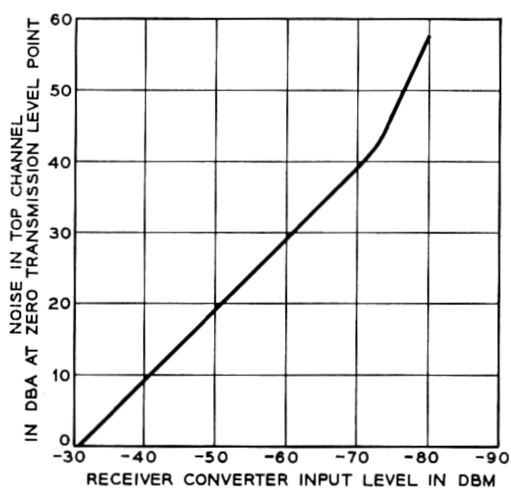


Fig. 19 — Fluctuation noise output as a function of received signal level.

the use of dc heaters on the transmitter and local oscillator klystrons. The ratio of peak-to-peak signal to low-frequency unweighted rms noise at the receiver output on one TJ link is 67 db.

4.2 *Diversity Switching Arrangements*

4.2.1 *General*

Most applications of the TJ system will use one-for-one frequency diversity. This provides protection against multipath fading and equipment failures, and provides alternate facilities during maintenance and equipment additions. At each repeater the diversity equipment selects one baseband output from two receivers and applies this signal simultaneously to two transmitters. The selection of a receiver is controlled by a logic circuit, which, along with the switch, is contained in the diversity switch and transmission unit.

4.2.2 *Diversity Switch and Transmission Unit*

Fig. 20 is a block schematic of the diversity switch and transmission unit as used at a telephone repeater. The audio and high-frequency components of the baseband signal are separated and subsequently recombined by high-pass–low-pass filters. This permits connection to the D-type alarm and order-wire equipment without affecting through trans-

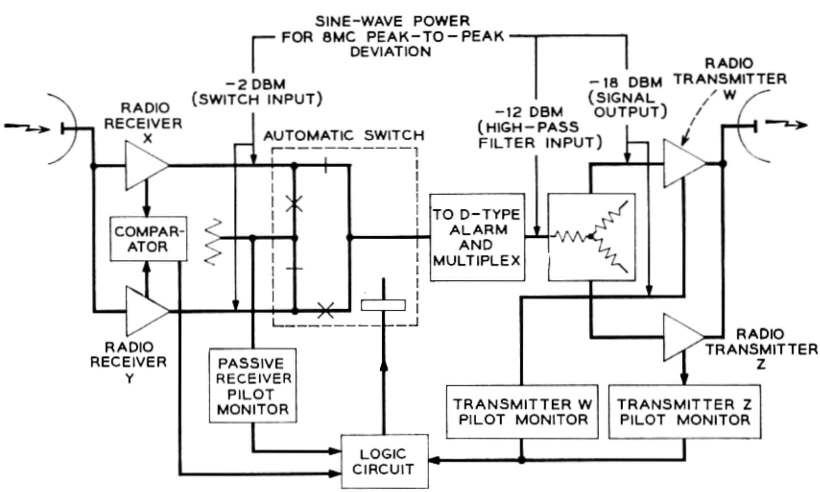


Fig. 20 — Block schematic of the diversity switch and transmission unit

mission of the higher frequency multiplex signals. Furthermore, if the multiplex signals are connected through dropping equipment that does not normally pass low frequencies, the separation filters enable the audio portion of the band to be bypassed without undue attenuation. Typical loss-frequency characteristics for the split-apart filters are given in Fig. 21. Adjustable attenuators and pads provide for equalizing receiver levels and setting frequency deviations on the transmitters.

On a fully developed TJ route the order-wire and alarm information will be carried on only one of the three diversity pairs. In general, therefore, split-apart filters are not required on switch units associated with the second and third systems. In these cases, the switch output can be connected directly to the Y-pad input through a 10-db pad. An exception to this rule occurs with multiplex dropping facilities, as described previously.

The signal switch is controlled by a logic circuit operating under instructions from transmitting and receiving pilot monitors and an RF signal comparator. In general, three monitors are utilized to sense the presence of a 2600-cps pilot tone at the two transmitter AFC discriminators and at the output of the idle receiver. The pilot tone is applied

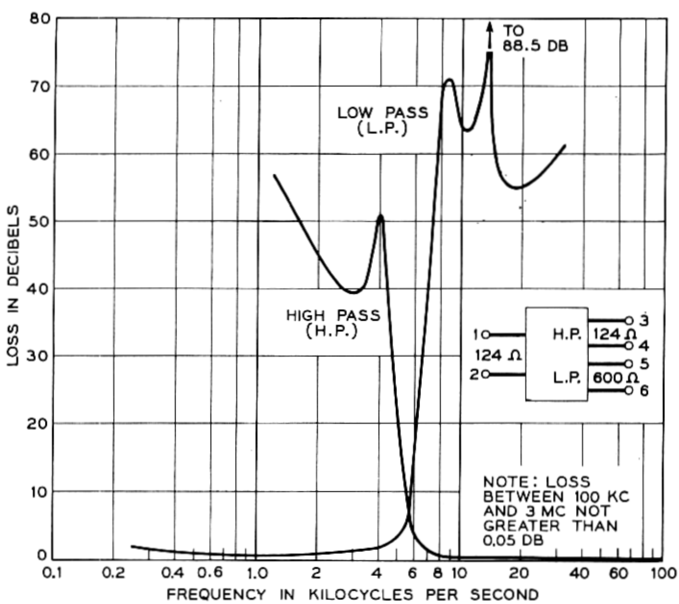


Fig. 21 — Typical loss-frequency characteristics of baseband split-apart filters.

continuously from one end of the system and is looped around at the far end terminal to provide pilot tone on the return path. The 2600-cps tone is also used for signaling purposes, and alarm functions are performed by interrupting the tone temporarily. This arrangement provides a fail-safe alarm system, which will be described in more detail in Section 4.4.

The functional schematic of a pilot monitor and its selectivity characteristic are shown in Fig. 22. During signaling, the pilot tone is applied to the line intermittently, and enough time delay must be built into the monitors so that the absence of tone between pulses may be ignored.

The RF signal comparator is actuated by voltages proportional to the IF plate currents in the X and Y receivers. As described previously, these voltages are an indirect indication of the received RF signal strength. Fig. 23 shows a simplified schematic of the comparator, which provides an output to the logic circuit in the form of high and low contacts on the comparator relay C. Diodes CR1 and CR2 act as clamps on the comparator tube grid voltages, so that the circuit is inactive until one or other of the received RF signals reaches a level of approximately −40 dbm. The operational characteristic of the comparator as a function of input signal

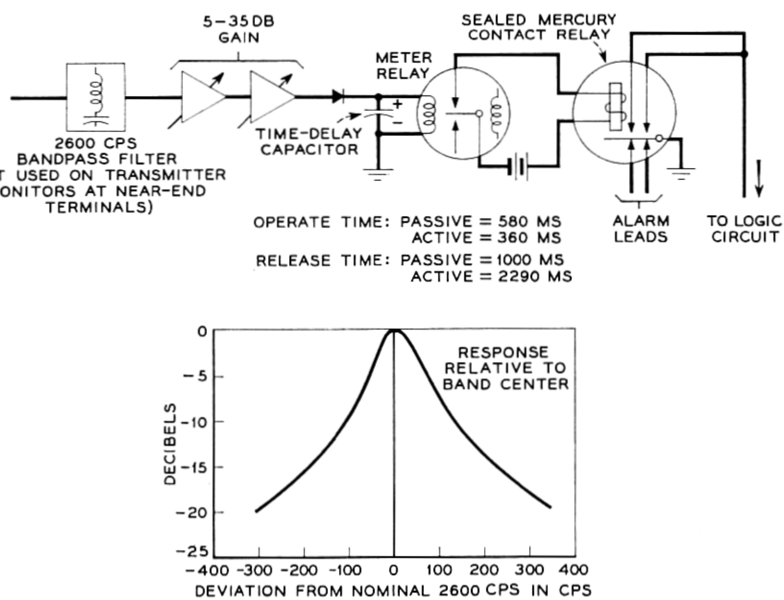


Fig. 22 — Functional schematic and selectivity characteristic of the 2600-cps pilot monitor.

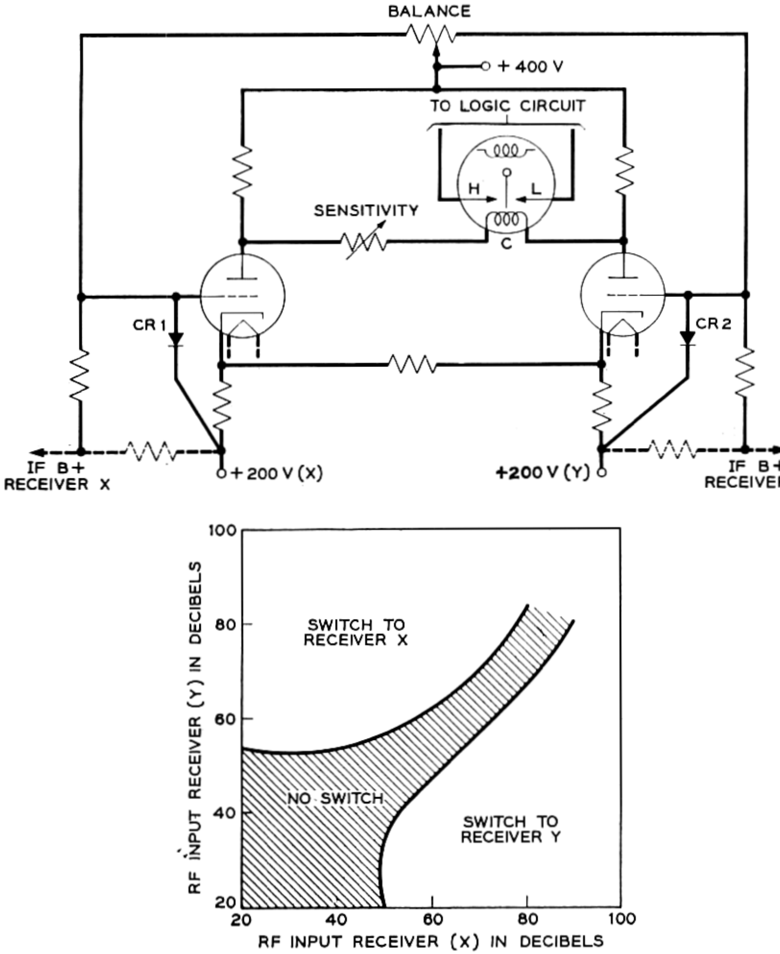


Fig. 23 — Schematic and operating characteristic of received signal comparator.

levels to the two receivers is also indicated in Fig. 23. Both the pilot monitor circuits and comparator are designed to fail-safe in the sense that a failure will bring in an alarm or at least prevent a switch to a bad channel.

When the diversity switch is used with a television system, the 2600-cps pilot tone cannot be used, since it lies within the video band. Likewise, the band-separation filters cannot be used. As a result, the diversity switch is controlled entirely by the comparator relay, protecting the system against selective fading but not against all equipment failures.

4.2.3 *Diversity Switch and Logic Circuit*

The signal-switching function is performed by a wire-spring relay with make-before-break contacts. During switchover, the relay contacts are momentarily bunched (for approximately one millisecond) paralleling the outputs of the two receivers. If the receiver outputs are equal in magnitude and phase, connecting them in parallel produces no level change, since they are at the same potential. With selective fading the condition of equal baseband levels during a switch is generally met, since the fade must be quite deep before it affects the receiver output. Thus, with proper adjustment, switches due to selective fading are hitless and will not result in data transmission errors. Likewise, manual switches made during system maintenance will also be hitless.

In the case of switches resulting from an equipment failure, the situation is different. Due to the time delay built into the pilot monitors, 2.3 seconds are required to recognize the trouble and make the switch. During this period there will be no transmission and errors in data systems will result. This is not an extremely serious situation, since equipment failures will be much less frequent than atmospheric disturbances.

Each diversity switch can be operated from the control center by means of an order from the D-type order-wire and alarm equipment. This feature is extremely useful for maintenance purposes and permits the rapid location of any level changes that might occur on a system in service.

4.2.4 *Squelch Circuit*

If a complete power failure should occur at a TJ repeater station, the loss of transmitted carrier will cause an increase in noise output from receivers at adjacent stations. This could result in the alarm equipment being unable to interrogate the system to locate the station in trouble and might require a visit to every repeater on the route. Furthermore, if the system connects to a long-haul system carrying other circuits, the excessive noise could make the other circuits unusable. To eliminate this possibility, a squelch circuit is available that cuts off the receiver baseband amplifier when the received RF signal drops below a prescribed value. The circuit is actuated by the IF plate current in the same manner as the comparator. When the plate current exceeds a certain value, plate voltage is removed from the receiving amplifier tubes. The depth of fade at which the squelch circuit operates is adjustable, but is generally set to actuate at a received RF level of −80 dbm.

4.3 *Nondiversity Applications*

Situations will arise where diversity operation is not required, most commonly in television applications. To facilitate interconnection between transmitters and receivers when the diversity switch and transmission unit is not required, a special connecting panel is available to provide the necessary attenuators, equalizer, cable terminations and access jacks.

4.4 *Order-Wire, Alarm and Control System**

The TJ repeater stations are usually unattended. For this mode of operation to be feasible, attended points responsible for the maintenance of the system must have information promptly as to equipment failures and other abnormal conditions occurring in the unattended radio stations. The type-D alarm, control and order-wire system was developed for this purpose. As the name implies, this system also provides the voice-communication facility between stations and remote control from an attended point of certain functions at the unattended stations.

The principal features of the D2 system may be summarized as follows:

i. It transmits up to 18 distinct alarm functions and six other indications from each unattended station to its associated alarm center. The indications are generally used to determine which receiver of a diversity pair is in use.

ii. It transmits 11 remote control orders from the alarm center to each unattended station under its control.

iii. It allows a maximum of 14 unattended stations to be associated with one alarm center "main station."

iv. It provides order-wire talking and monitoring facilities at each radio station and at the alarm center, with extensions to other points as required. The order-wire channel between radio stations is transmitted in the baseband below 4 kc. All points having access to the circuit are linked together on a multistation or "party line" basis.

v. It provides alarm and control signaling by means of a single frequency tone of 2600 cps within the same four-wire circuit used for the order wire, so that no line facilities other than the voice-frequency chan-

* This section prepared by H. H. Haas.

nel of the radio system are required, except for extensions to points off the radio system.

4.4.1 *Alarms*

The alarm center (main station) signals the remote points (substations) by pulsing the 2600-cps tone. Signal receivers, bridged on the outgoing line at each substation as shown in Fig. 24, transform these tone pulses into dc pulses to operate decoding relays. Each substation is capable of recognizing pulse codes directed to it and translating these codes into orders or, alternatively, answering codes that are essentially queries by reverting certain received pulses.

The main station transmits a continuous tone in the idle condition through each intermediate substation. The normally closed pulse-reverting path of a terminal substation sends the tone back to a signal receiver at the main station. This closed loop is self-alarming in the event of failure of the alarm line and, in addition, provides the means of alerting the main station when a trouble occurs at any substation.

When an alarm condition occurs, substations initiate automatic interrogation from the main station by inserting a 2600-cps stop filter in the return line until this process is completed. A relay sending director circuit at the main station reacts to the interruption of the tone loop by sending out a train of pulses to successively identify the substation at which the alarm occurred and the nature of the trouble — that is, which of the 18 alarms exist at that station. The substation provides automatic identification and scanning by reverting a unique combination of the received pulses, and momentarily closes the pulse-reverting path from outgoing to return line at appropriate times, under control of the relay circuit that counts and decodes the received pulses. The information derived from reverted pulses received at the main station is displayed on lamps. An attendant at the alarm center can also scan the alarms at any time by sending out an order.

4.4.2 *Remote Controls*

Basically, remote control techniques of the D2 system are similar to those involved in reporting alarms. Typical orders to a radio station may be for remote manual control of the emergency engine alternator or for protection switching. Other orders are provided to request a scan of alarms and other indications. In the first example, one-way selective signaling is employed; in the second, revertive pulsing conveys the response to the interrogation.

The sending director sends out the station-selection and order code

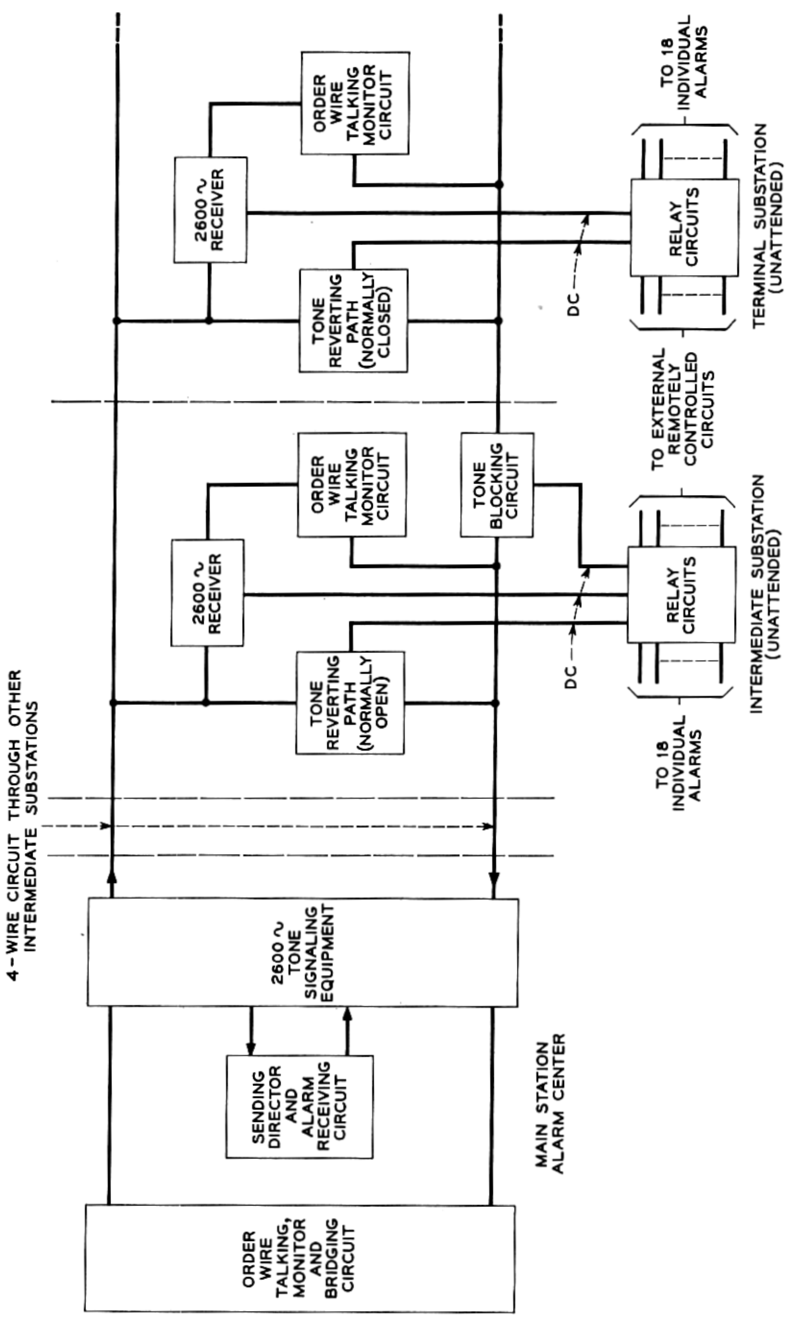


Fig. 24 — Block diagram of D2 alarm and control system.

pulses in response to the operation of keys. To send an order the alarm center, an attendant first operates one of 14 station keys, then one of 11 order keys. The relays at the substations count and decode the pulses. The wanted substation recognizes from the initial pulses that the order applies to it, and proceeds to translate the remaining pulses into one of 11 orders at that particular station.

The 2600-cps tone-signaling equipment of the D2 system is a transistor version of the standard in-band type used on telephone trunks.[12] In the idle "tone-on" state, when no alarm or control pulsing is taking place, the tone level is low and is filtered out of the monitoring circuits of the order wire. The pulsing sequence, although at a higher level, is of such short duration that it can be transmitted over the order wire without objectionable interference with voice communication. Conversely, interference between the voice and signaling equipment is prevented by guard circuits built into the signaling equipment.

Main stations may be located at the focal point of up to four converging radio routes or at an intermediate point along a route as well as at the end of the route as shown in Fig. 24. In addition, a main station can be used to alarm radio routes that converge at unattended substations (junction substations).

4.4.3 *Order Wire*

Way stations on the order wire talk on one side of the four-wire line and monitor on the other. To complete the circuit, the two sides are bridged at the main station so that all intersubstation communication is via the main station.

4.5 *Antenna Systems*

Some of the factors affecting the choice of antennas are; antenna height required, gain, return loss, location and cost. Generally speaking, there are five standard antenna arrangements suitable for use with the TJ system.

4.5.1 *5-Foot Paraboloid*

The antenna shown in Fig. 25, is a rear-feed, ring-focus, dual-polarized paraboloidal antenna. It comprises a 5-foot-diameter paraboloid, a primary feed system, a radome and a ball-swivel base with adjustable support rods. It is primarily intended for use in "periscope" antenna systems, but may be used as a direct radiator.

The feed is made of a straight section of circular waveguide, which

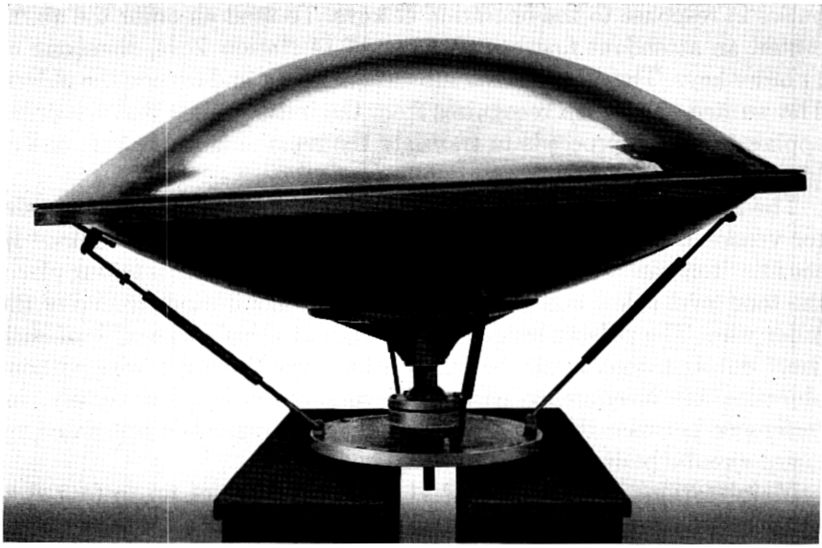


Fig. 25 — TJ 5-foot dual-polarized paraboloidal antenna.

passes through the apex of the paraboloid and along its axis. A specially shaped 3-inch disc reflector is located at the waveguide aperture and serves to direct the energy back on the surface of the paraboloid.

The gain of this antenna is 42.1 db over an isotropic radiator at a frequency of 11,200 mc and varies less than 1 db over the 10,700- to 11,700-mc common carrier band, as shown in Fig. 26. The return loss and cross-polarization discrimination are in excess of 20 db. Fig. 27 shows

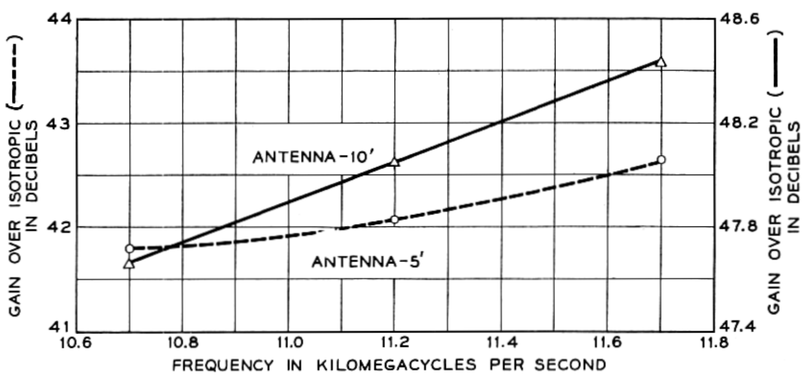


Fig. 26 — Gain-frequency characteristic of the TJ radio 5- and 10-foot antennas.

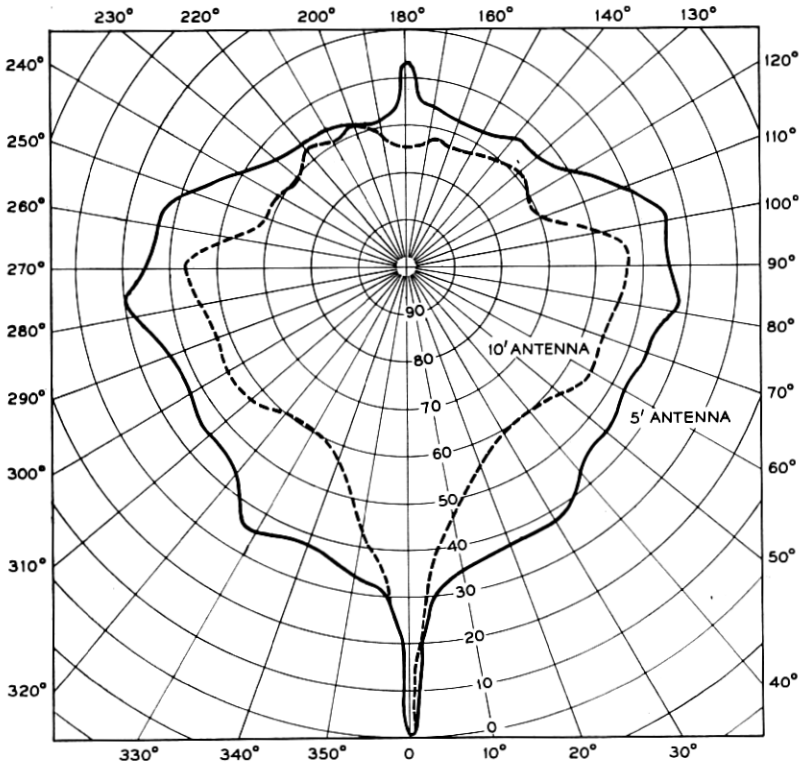


Fig. 27 — Typical 360° radiation pattern for the TJ 5- and 10-foot antennas.

a typical 360° radiation pattern of the 5-foot paraboloidal antenna, and Fig. 28 shows an enlargement of the ±15 degree direct and cross-polarized patterns.

4.5.2 *10-Foot Paraboloid*

Natural elevations are often available in mountainous country for repeater sites. In these cases, path clearance is not usually a problem and the antennas are mounted on short towers whose height is just sufficient to provide foreground clearance. The antenna is composed of a 10-foot paraboloidal reflector, a primary feed system and an A-type mounting frame that provides azimuth and elevation angle aiming adjustments. The feed arrangement is similar to the 5-foot paraboloidal antenna. The 10-foot paraboloid does not have a radome, but heaters are available for both the feed and the paraboloidal reflecting surface.

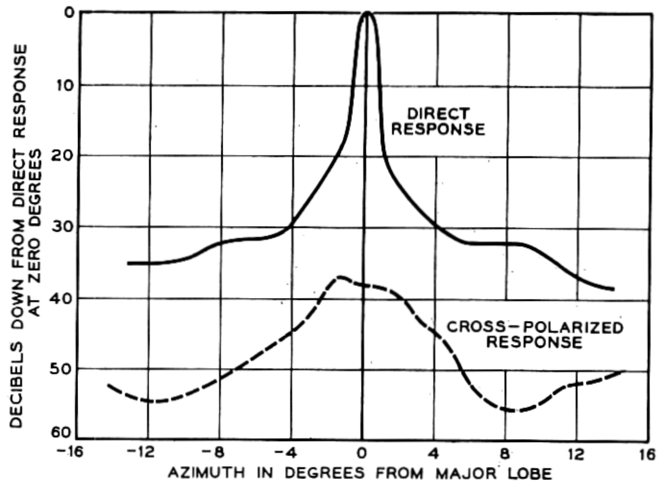


Fig. 28 — ±15° radiation pattern of the TJ 5-foot antenna.

The gain of the antenna is approximately 48 db for the two polarizations as shown in Fig. 26. The return loss and cross-polarization discrimination are in excess of 20 db. Fig. 27 shows a typical 360° radiation pattern of the 10-foot paraboloidal antenna, and Fig. 29 shows an enlargement of the ±15 degree direct and cross-polarized patterns.

4.5.3 *Periscope Antennas*

In many areas of the country the terrain is relatively flat and paths 25 to 30 miles in length require antenna heights in the order of 250 feet. The use of paraboloidal antennas as direct radiators is not desirable, because of the long rectangular waveguide runs and their associated high loss. The horn-reflector antenna, with its 3-inch circular waveguide and combining network performs well at 11,000 mc, but it is too expensive The "periscope" antenna system, which satisfactorily fills this need, consists of a paraboloidal antenna mounted at or near ground level, usually on the roof of the repeater station, illuminating a reflector at the top of the tower. It has the advantages of requiring a minimum length of waveguide and providing an over-all antenna system gain that is equal to or greater than the gain of the paraboloidal antenna alone.

Some of the factors determining the gain[13] of a "periscope" antenna are the frequency, the relative size of the apertures of the paraboloid and the reflector, and the separation between them. Standard arrangements for the TJ system consist of the 5-foot paraboloidal antenna

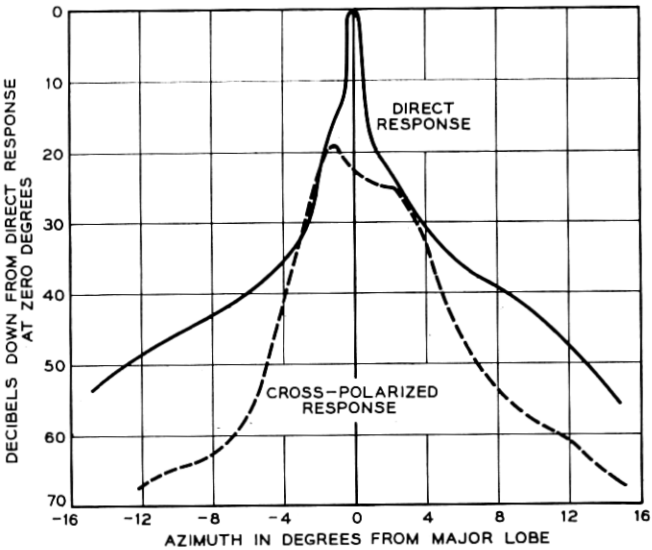


Fig. 29 — ±15° radiation patten of the TJ 10-foot antenna.

and either a 6- × 8-foot plane reflector or an 8- × 12-foot reflector, which may be plane or curved. Fig. 30 shows the approximate gains to be expected for these TJ "periscope" antennas. Estimated radiation patterns of the 6- × 8-foot plane and the 8- × 12-foot curved reflector are shown in Fig. 31.

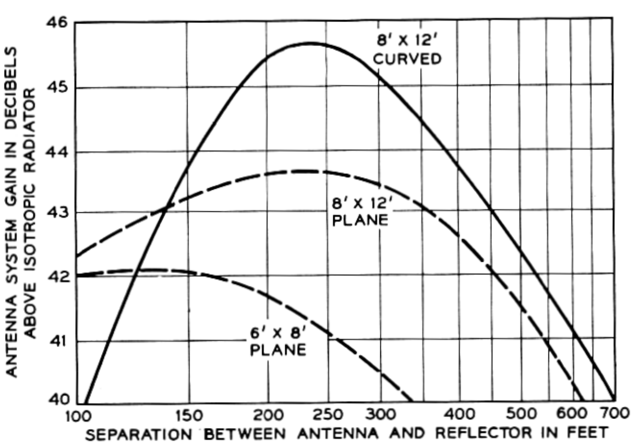


Fig. 30 — Gain of periscopic antenna system.

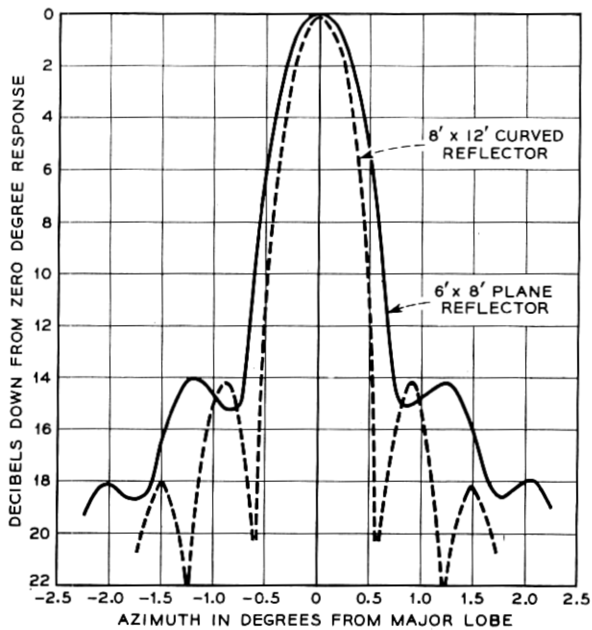


Fig. 31 — Estimated radiation pattern of 6- × 8-foot plane and 8- × 12-foot curved reflectors.

The gains of a "periscope" system for spacings between 25 and 100 feet are not shown in Fig. 30. It suffices to say that the combination of the 5-foot paraboloid and the 6- × 8-foot plane reflector with these separations will yield a gain approximately 42 db.

4.5.4 *Towers*

Both guyed and self-supporting towers are available for the TJ system. The guyed tower is made of galvanized structural steel, triangular in cross section, 4 feet on a side, and is available in heights of 80 to 300 feet in increments of 20 feet. The structure is guyed in three directions with guy directions spaced at 120°. Mounting facilities for three passive reflectors of either the 6- × 8-foot or 8- × 12-foot type, or combinations of the two, are provided. The center positions of the three reflectors are separated by 120° and, with the flexibility inherent in the mounting and in the reflector itself, each reflector may be adjusted in azimuth through ±40 degrees from its center position.

The self-supporting tower is made of galvanized structural steel, square in cross section, with a straight top section and below this a uniformly tapering body. It is available in heights of 40 to 300 feet in increments of 20 feet and provides mounting rings at the top of the tower to which may be attached any combination of up to four 6- × 8-foot reflectors, 8- × 12-foot reflectors and 10-foot paraboloidal antennas. The antennas may be attached to the mounting rings in any position irrespective of the tower orientation and, with the adjustability inherent in the antennas, two adjacent antennas may be oriented to a minimum angular separation of 25°.

Both of these towers have been designed to tilt no more than $\pm\frac{1}{4}$ degree and to twist no more than $\pm\frac{1}{2}$ degree under wind loading of 20 lbs per square foot (approximately 70 mph), and to withstand winds of 100 mph with the maximum number of antennas attached. Ground wires and rods to protect foundations and anchors from lightning are supplied with both types of towers.

4.6 *Connecting Circuits*

4.6.1 *Type A and Type B Entrance Links*

When L-carrier multiplex signals are connected to a TJ radio system, amplification is required in both directions of transmission. To protect against amplifier failures and facilitate maintenance, protection or standby circuits can be provided on either a manual or automatic basis. The complete ensemble of amplifiers, switches and control circuits is referred to as an *entrance link*. Fig. 32 is a block schematic showing the basic features of an L-carrier–TJ radio interconnection. When fully equipped, three-wire lines with a common protection circuit will supply up to three TJ radio channels. Essentially, the only difference between the type A and type B links is the maximum permissible circuit length. Each circuit on the type A link uses one 40-db flat-gain amplifier and, in the type B link, this is augmented by a second amplifier having a gain shape complementing the cable loss.

4.6.2 *ON-2 Multiplex*

ON-2 multiplex equipment basically provides 48 channels in the 36- to 268-kc band, with a transmitted carrier between each pair of voice channels. For radio applications, modulating equipment is available to stack a second group of 48 channels on top of the basic group to provide a 96-channel system. The frequency band of the upper group is 316 to 548 kc.

The levels out of the multiplex equipment are adequate to drive the

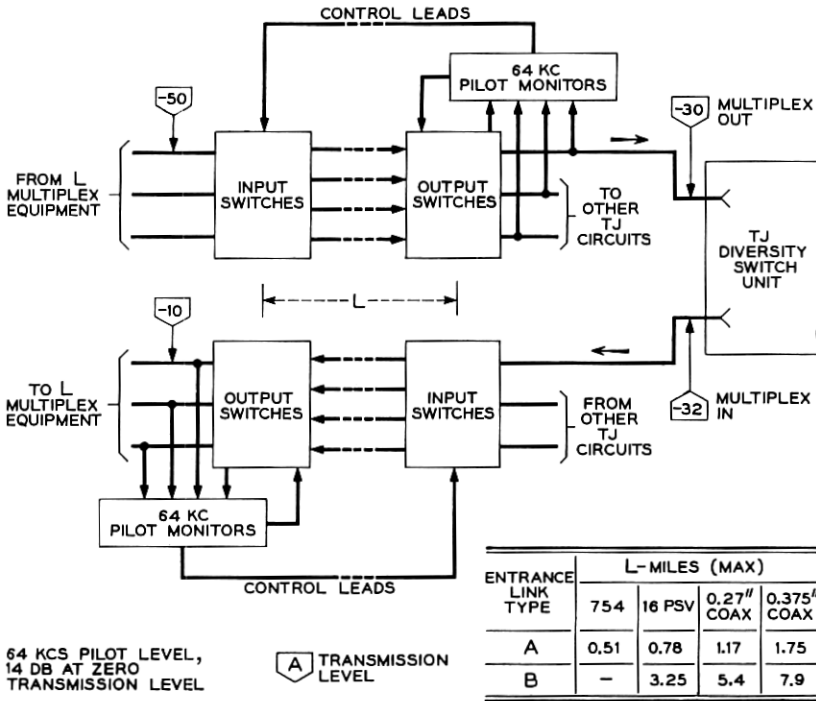


Fig. 32 — L-carrier to TJ radio entrance link.

TJ equipment directly, so that no special entrance link facilities are needed. In Table III the channel levels at the point of connection with the TJ equipment are summarized and expressed in terms of the transmitted carrier level at the point in question.

4.6.3 *Television Terminals*

When a television signal is transmitted over radio, it will generally be supplied from a customer or television operating center (TOC) at a

TABLE III

Location	Test Point	
	MX IN	MX OUT
Terminal	−40 dbm	−15 dbm
Dropping point	−34 dbm	−35 dbm

level of 1 volt peak-to-peak (0 dbv). Likewise, at the receiving end of the radio system it must be presented to the customer or TOC at the same level. In most instances, the television terminal equipment and the radio equipment will be physically separated, so that connecting facilities must allow for cable loss and cable equalization. Fig. 33 shows typical connecting circuits when the TJ system is used as an intermediate link between two television operating centers.

Before being applied to the radio equipment, the low-frequency components in the TV signal are reduced in level relative to the high-frequency components by a pre-emphasis network. At the receiving end, a complementary de-emphasis network restores the high- and low-frequency components to their original relative magnitudes. The purpose of the pre-emphasis network is to reduce the modulation index at low frequencies to reduce differential phase and gain distortion.

Alternative connecting circuit arrangements will be used when the television signal is transmitted or received over unbalanced cables. Functionally, they are the same as the balanced arrangements and differ only in the types of networks used for equalization and pre-emphasis.

4.7 *Stand-by Power*

A 5-kw gasoline engine alternator and a 10-kw diesel engine alternator with automatic controls have been made available for use with the

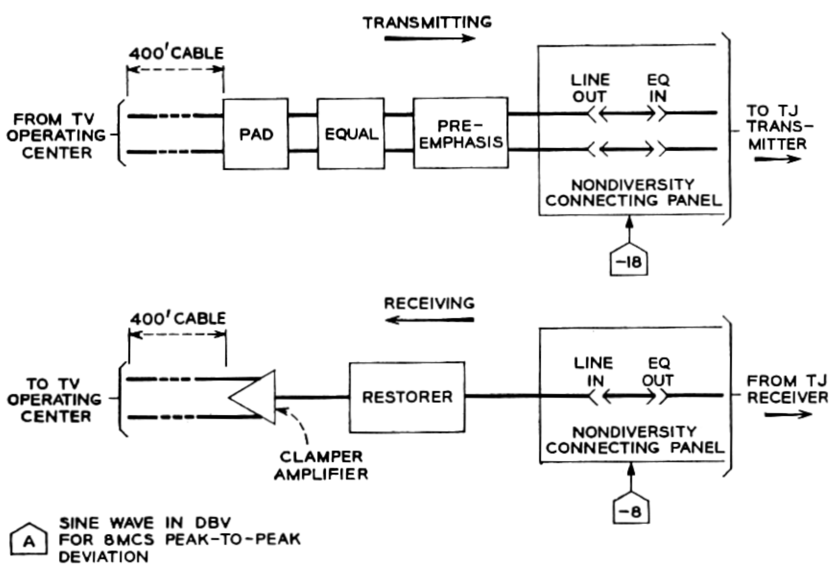


Fig. 33 — Video terminal connecting circuit.

TJ system. When commercial power fails, these units take approximately 30 seconds to reach operating speed and voltage. A further 20 seconds is required for the radio equipment to resume transmission.

For those applications where a 50-second interruption in transmission cannot be tolerated, other types of reserve power plants have been used, which provide essentially no-break operation. This is accomplished by the use of a motor-generator-flywheel combination coupled to a gasoline engine through a magnetic clutch. When commercial power fails, the clutch engages and the flywheel supplies sufficient energy to carry the load and start the gasoline engine.

V. EQUIPMENT FEATURES

5.1 *Transmitter-Receiver Bay*

5.1.1 *General*

The TJ radio transmitter-receiver bay is illustrated in Fig. 34. It consists of a 6-foot floor-supported duct-type framework built to accept standard 19-inch panels. The backplate support for the RF channelizing networks extends above the bay framework, giving an over-all height of 6 feet 8 inches and a total width of $20\frac{1}{2}$ inches.

The upper third of the bay houses the transmitter, while the middle and lower third contain the receiver and power supply, respectively. All units and controls are accessible from the front of the bay, thus permitting back-to-back or back-to-wall floor plan arrangements. To simplify maintenance and reduce out-of-service time from equipment failures, all units except the receiver modulator are of the plug-in type. The removal of any unit automatically shuts down the bay as a protection against exposure to hazardous voltages.

External connections to the bay consist of the ac power conduit, the transmitter and receiver waveguide runs and a control lead plug, which provides alarm and comparator information for the auxiliary bay.

5.1.2 *Radio Frequency Components*

From an RF equipment standpoint, of special interest are the receiving modulator and transmitter AFC networks. Instead of using standard cross-guide fabrication techniques, the waveguide network configurations are milled from sectionalized aluminum blocks. The blocks are then assembled to form a relatively compact, composite structure typified by the AFC network illustrated in Fig. 35.

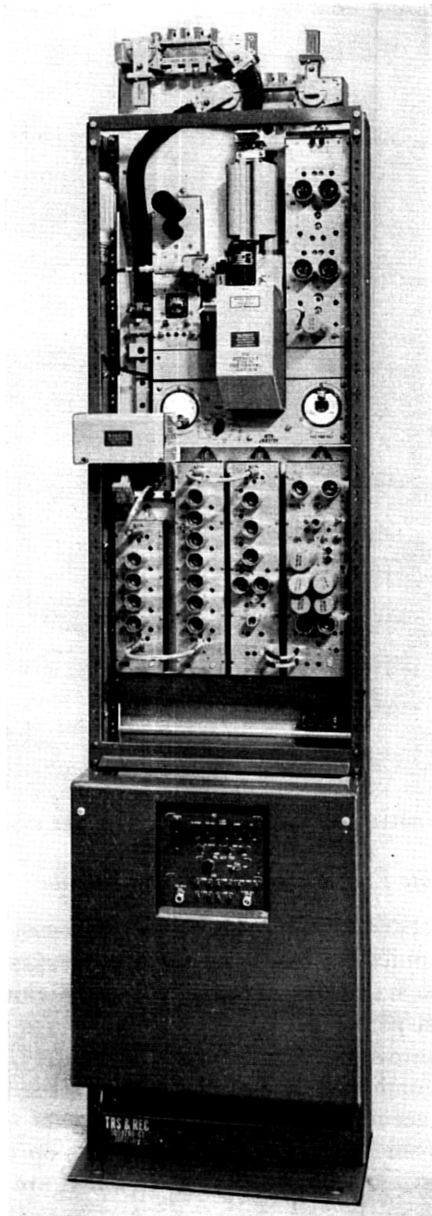


Fig. 34 — TJ transmitter-receiver bay.

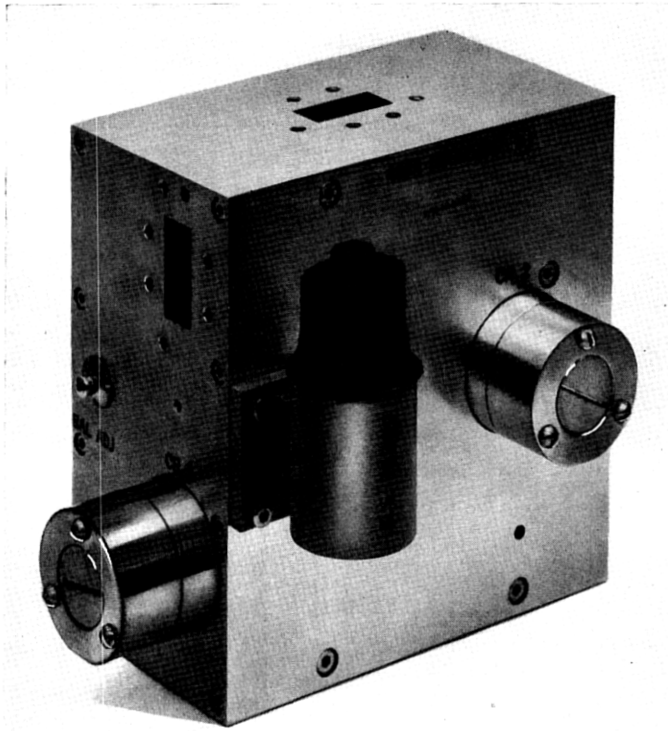


Fig. 35 — Transmitter AFC discriminator and power monitoring network.

5.1.3 *Intermediate Frequency and Baseband Units*

Each IF or baseband unit is assembled in a die-cast aluminum chassis. Typical of the IF units is the main IF amplifier illustrated in Fig. 36. The components for each stage are mounted on an individual plate assembly, which is attached perpendicularly to the tube base of that stage. The individual plates are assembled and wired separately, and then mounted on the die-cast aluminum chassis prior to interstage wiring. In addition to mounting and accurately positioning components, the plate assemblies act as interstage shields. The only adjustments on the IF units are on the input and output coupling networks, which are adjusted for optimum return loss.

The baseband amplifiers use standard assembly techniques, with special precautions being taken to accurately position components. This

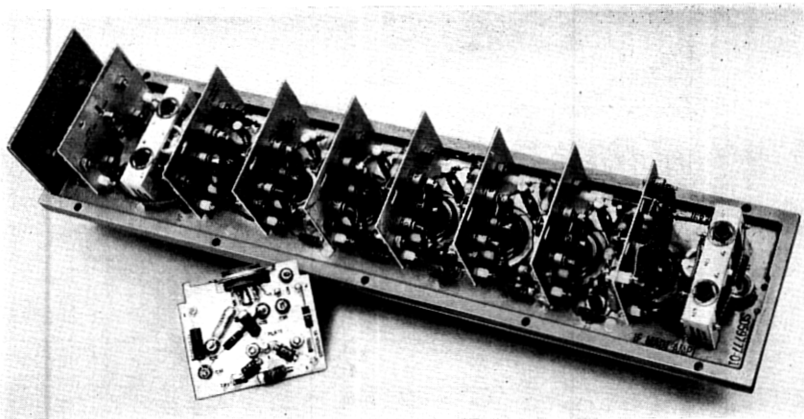


Fig. 36 — Photograph of main IF amplifier.

minimizes variations in parasitic capacities to obtain reproducible high frequency gain characteristics.

All units are equipped with test points for measuring plate and heater voltages. Test points are also provided to measure tube biases for cathode activity tests.

5.1.4 *Power Supply*

An internal view of the TJ power supply is shown in Fig. 37. The hinged front cover provides access to all components and an interlock switch protects against exposure to hazardous voltages. Components mounted in the rear of the unit, can be reached by lowering the back-plate, which is hinged near the lower end.

When the radio bay is equipped with a transmitter only or receiver only, the appropriate outputs on the power supply are equipped with bleeder resistors to maintain a constant load on the unit. These loads are located within the power supply and consist of resistors mounted in fuse-clip holders. The power supply also contains all voltage and current metering resistors.

Connections between the power supply and the rest of the radio bay are made through plug-in connectors in the rear of the unit.

5.2 *Auxiliary Bay*

The auxiliary order-wire, alarm and control bay is a 7-foot duct-type framework built to accept standard 23-inch panels. The over-all

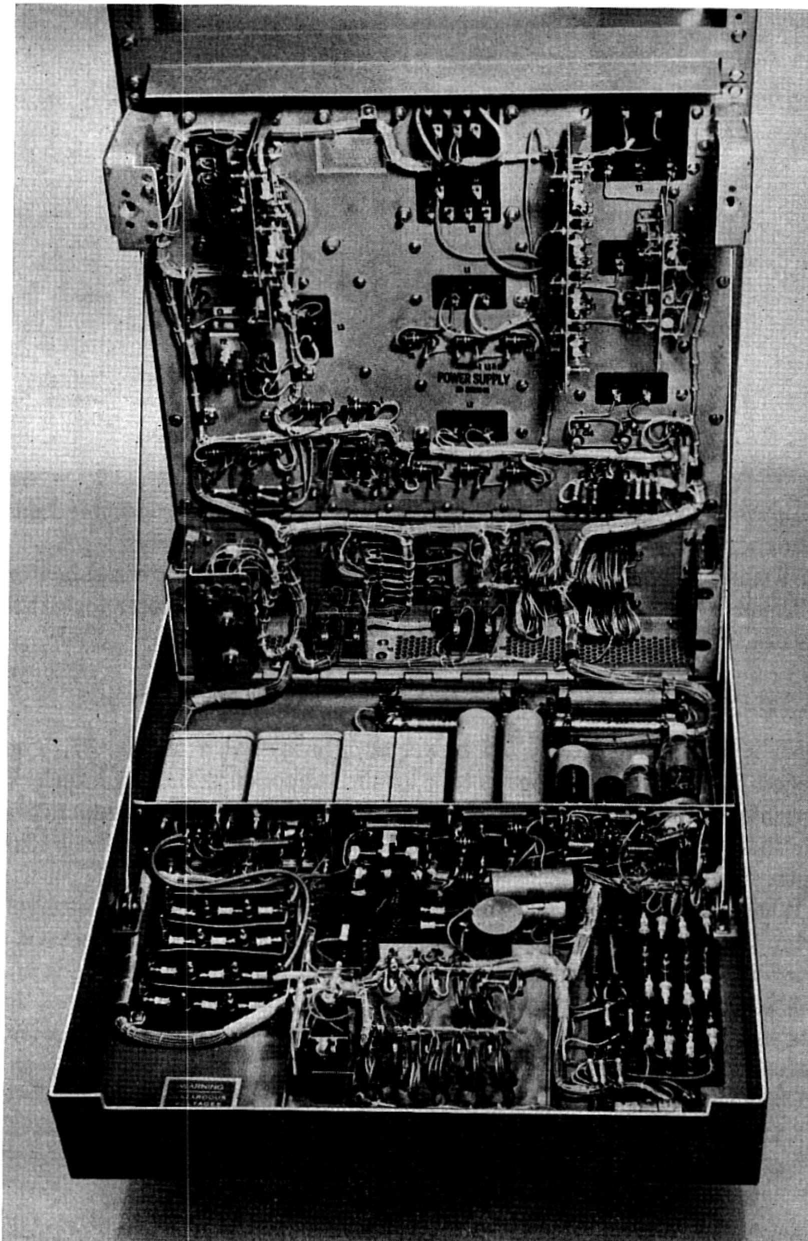


Fig. 37 — Internal view of TJ radio power supply.

height, width and depth dimensions are, respectively, 7 feet, $26\frac{1}{2}$ inches and $16\frac{1}{4}$ inches.

The bay, which is illustrated in Fig. 38, contains a maximum of six diversity switch units, the D-type alarm equipment and associated power supplies. Like the radio bay, it can be maintained from the front of the bay.

Control lead connections from the radio bays and all external alarm leads are brought to a terminal strip at the top of the auxiliary bay. Connections from the diversity switches are brought to the same panel, permitting cross connections to be made as required in particular applications.

The diversity switch units are built in the form of drawers which can be pulled forward on slides for maintenance purposes. Power and signal connections are made through a flexible cable detail which plugs into sockets in the bay cabling. Switch units can, therefore, be provided or added as needed.

Power rectifiers providing −48 and +130 volts are located below the switch drawers. If these voltages are available from the office supplies, the rectifiers can be omitted and replaced by an optional power-connecting panel.

5.3 *Interconnecting Arrangements*

5.3.1 *Antenna Feed*

The dual-polarized signal received by a TJ antenna is separated into its two components by a polarizer[14] network, which is illustrated in Fig. 39. The network is located directly behind the antenna and is connected to the radio equipment through two rectangular waveguides. The polarizer network has a cross-polarization discrimination over the TJ band in excess of 40 db, although only 20 db of isolation is realized in practice, due to coupling between polarizations within the antenna.

In a diversity system, the working and protection RF channels are connected to opposite polarizations. This permits maintenance and system additions to be carried out while service is maintained on the opposite polarization. If only one transmitter and receiver are connected to the antenna, the normal channel-dropping network can be omitted by connecting the receiver to one polarization and the transmitter to the other.

The rectangular waveguide connections from the polarizer are connected to the radio bays through a pressure window. Air line connections

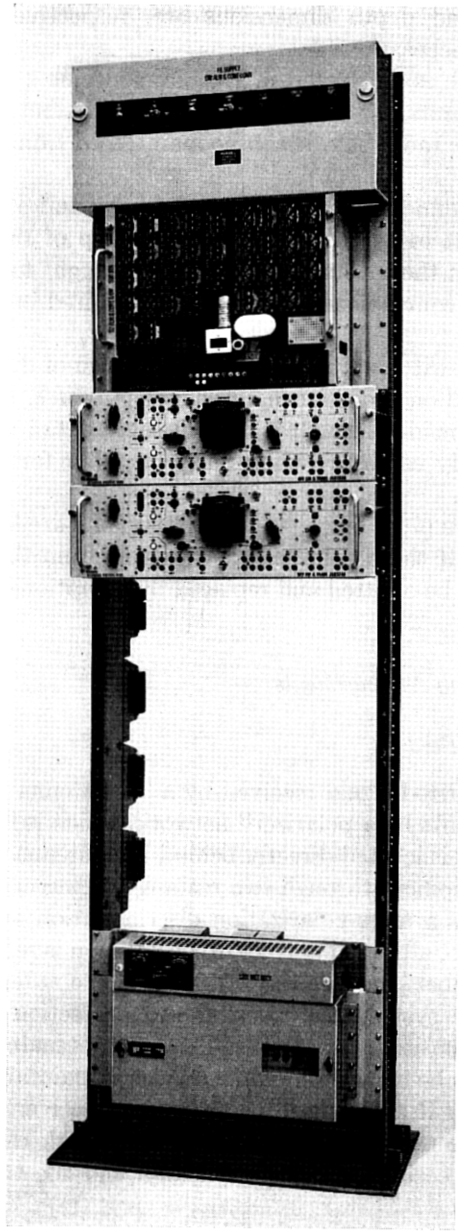


Fig. 38 — TJ radio auxiliary bay.

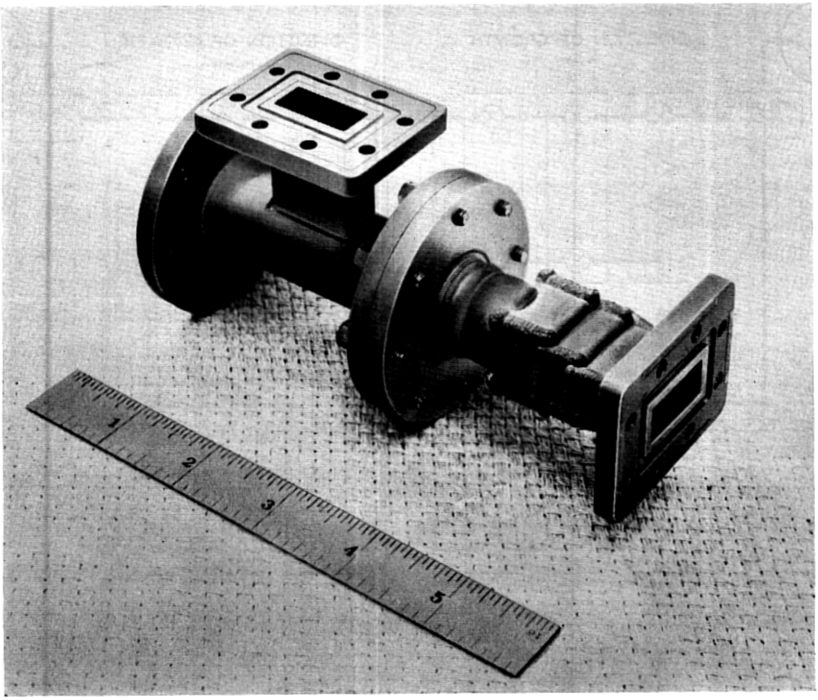


Fig. 39 — Polarization separation network.

to the pressure window from a dehydrator keep the entire waveguide run filled with dry air at a pressure of five inches of water.

5.3.2 *Radio Bay Interconnections*

A typical arrangement for connecting the radio equipment to the antenna system is illustrated in Fig. 40 for a fully equipped diversity system.

When the system has expanded to four two-way radio channels, an isolator is provided between transmitters and receivers, as illustrated for the six-channel case in Fig. 40. The purpose of the isolator is to prevent beat oscillator leakage from a receiver on one polarization going back through the polarizer network and being picked up by a receiver on the opposite polarization. With fewer than four channels the receivers are protected from this type of interference by adequate frequency separation.

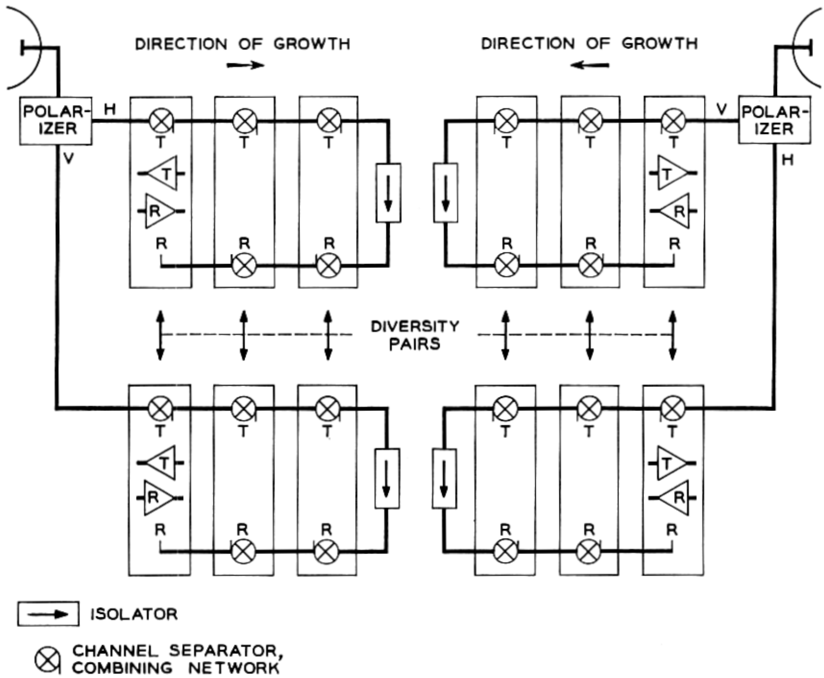


Fig. 40 — Waveguide interconnecting arrangements for a three-channel diversity system.

VI. SYSTEM MAINTENANCE AND TEST EQUIPMENT

Wherever possible, test procedures have been based on the use of commercially available test equipment. The only specialized test sets are:

(a) an impedance matching test set to enable commercial oscillators and voltmeters to be used with TJ circuit impedances;

(b) an IF test set for measuring intermediate frequencies and power output;

(c) an RF test set for generating and measuring 11,000-mc microwave signals;

(d) a transmitter disconnect unit, used to remove one transmitter of a diversity pair from service without introducing sudden level changes in the other which might affect data circuits.

The IF test set is illustrated in Fig. 41. It contains an IF frequency meter and attenuator, together with a calibrated detector for measuring IF signal level.

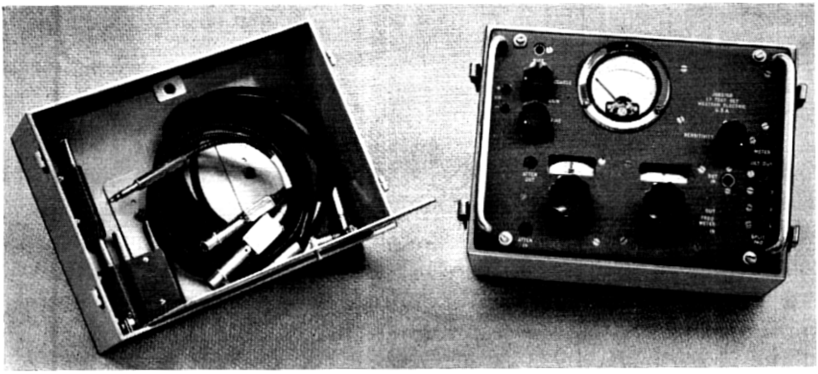


Fig. 41 — IF test set.

VII. APPLICATIONS OF TJ RADIO SYSTEMS

7.1 *Path Selection*

7.1.1 *General*

A number of factors must be carefully considered in engineering any microwave relay system. Before getting down to actual site selection it is necessary to consider all information known about propagation conditions in the general area. For instance, experience has shown that the inverse bending ($k<1$) type of fading is more prevalent in the moist coastal regions, and that some additional tower height should be considered for improved reliability in these areas (k is the radius of a fictitious sphere relative to that of the earth and, under normal propagation conditions, is equal to 4/3). This type of fading is not frequency-selective, and propagation at 4,000, 6,000 and 11,000 mc will be affected similarly.

On the other hand, multipath fading at 11,000 mc is dissimilar to that at 4,000 mc in certain aspects. Multipath fading is due to reflections from stratifications set up in the atmosphere that provide two or more paths of different electrical length for the radio signal. While the time of occurrence and duration of this type of fading at 11,000 mc is approximately the same as it is at 4,000 mc, the received signal levels vary more rapidly at 11,000 mc. Multipath activity is more prevalent at night than during the day; it is greater in warm and humid seasons than in cool and dry seasons; it is greater over water or smooth terrain than over rough ground and is more severe on longer paths. This type of fading is frequency-selective.

7.1.2 *Path Clearances*

Recommended path clearances for the TJ system are shown in Fig. 42. These clearances are for light-route systems in general and should be applied over true earth. For over-water paths it is recommended that they be increased by $D^2/24$ feet, where D is the path length in miles, in order to provide adequate mid-path clearance for protection against inverse bending type of fades. This suggested increase is based on values of k of approximately 2/3.

7.1.3 *Received Signal Objective*

Based on a 40-db fading margin and a suitable FM breaking allowance, the received signal level objective is −35 dbm to −40 dbm, depending upon the message load. A received signal level of −35 dbm can normally be met for path lengths in the order of 25 miles. Practical

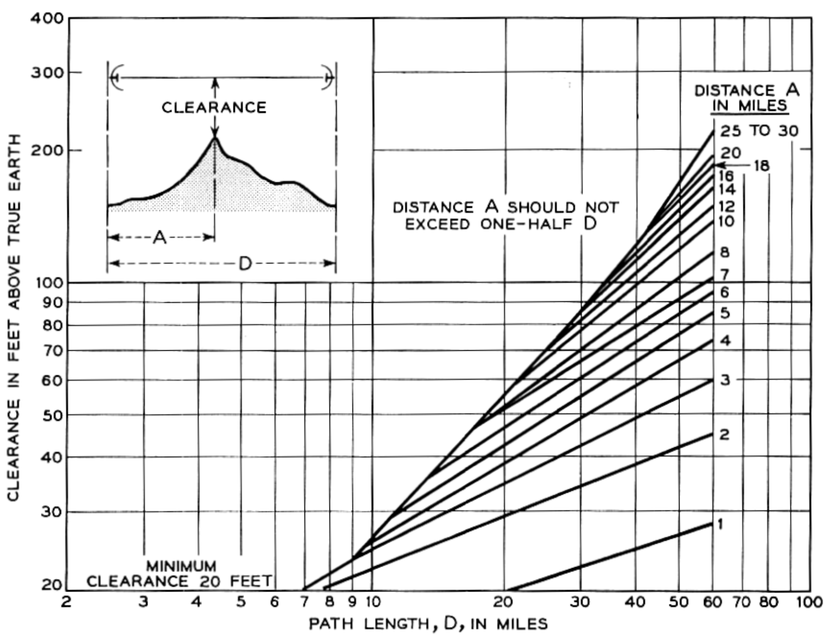


Fig. 42 — TJ radio path clearance requirements.

path lengths will vary from about 10 miles in regions of very severe rain to 40 miles or more in the drier climates.

7.1.4 *Overreach*

Since alternate repeaters use the same "nominal" carrier frequencies for a given direction of transmission, there will be the possibility of a receiver three hops away being subject to interference. The carrier frequencies may differ by as much as a megacycle or more, and the effect of the interference will be to phase-modulate the wanted carrier to produce a tone in the baseband at a frequency equal to the "nominal" frequency difference. Normally, this type of interference is avoided by zig-zagging. In laying out microwave routes, path bearings should be selected so that a total of 50 db discrimination against overreach interference will be provided by the two antennas involved.

7.1.5 *Branching*

The TJ system is designed for a maximum capability of 12 two-way radio frequency channels. For a through repeater and no branching radio routes, six transmitters will normally be used in each direction to provide three working and three protection channels.

Because no frequency is reused at a given repeater, any branching route configuration desired may be used, provided the total number of two-way radio channels does not exceed the system capability of 12. Fig. 43 shows a typical branching or spur route.

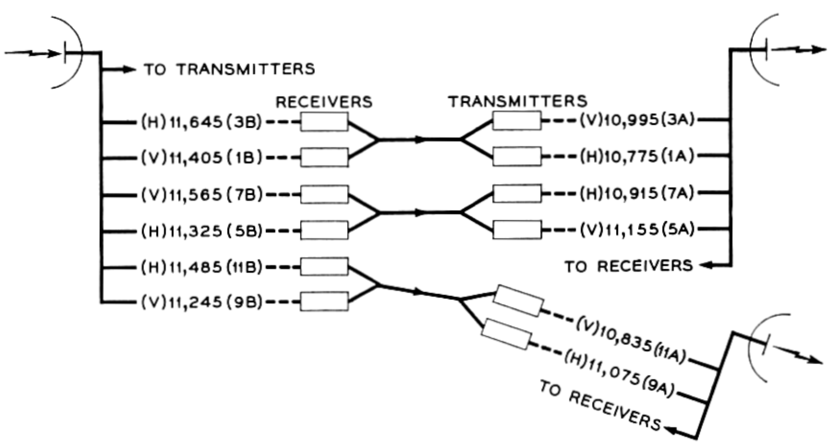


Fig. 43 — Typical frequency assignments at TJ branching point.

There will be instances where it will become desirable to add a branching route to a fully loaded route. To do this, some radio channel frequencies must be reused at the branching point. In these cases, careful consideration must be given to near-end and far-end crosstalk. A requirement of 50 db must be placed on the reduction of any undesired signal arising from these exposures. This precludes the use of periscope antennas. In order to meet this requirement, paraboloidal antennas will have to be used at the branching point on those channels having the same frequency. In addition, frequencies should be selected so that the channels common to both routes have the largest angular separation possible.

7.2 *Typical TJ Installations*

7.2.1 *Phoenix-Flagstaff System*

Prior to the installation of the TJ radio system between Phoenix and Flagstaff, Arizona, the facilities along this route consisted of an open-wire line equipped with various types of carrier. By 1956 these facilities had been developed to nearly their maximum capacity. New circuit requirements for northern Arizona would necessitate either an expansion of the old route or construction of a new route. The age and condition of the open-wire route made it uneconomical to rebuild this facility. Cost studies indicated that construction of a new wire-line facility would cost less initially, but that for a cross section greater than 60 two-way circuits, radio multiplexed with L-carrier would be more economical. Since the estimated requirements for the 20-year engineering period were in excess of 400 circuits, it was decided to develop a new route employing radio.

The Phoenix-Flagstaff TJ radio route, shown in Fig. 44, extends northward from Phoenix 133 miles, and elevations vary from a little over 1000 feet at Phoenix to more than 9000 feet at Mt. Elden. Short self-supporting towers, 60 to 120 feet high, and 10-foot paraboloidal antennas are employed on all paths with the exception of the Mt. Elden-Flagstaff path, a distance under four miles. Five-foot paraboloidal antennas were adequate for this short path and no tower was required at the Flag staff main office. Mingus Mt.-Mt. Elden is the longest path, in excess of 47 miles. Adequate clearance is provided by the mountainous terrain and attenuation due to rainfall is not expected to be serious in the dry Arizona climate.

It is interesting to note that freight-type containers, 28½ feet long by

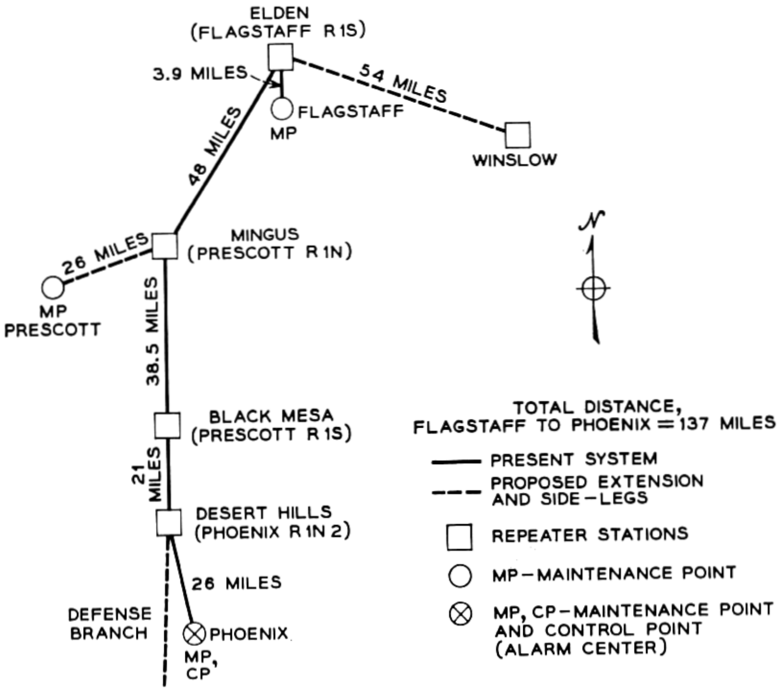


Fig. 44 — Route plan of the Phoenix-Flagstaff TJ system.

8 feet wide, were used for repeater buildings on this route. These buildings were temporarily located in Phoenix, where the radio equipment was installed and a large portion of the equipment tests were made. In this way, most of the time normally consumed in travelling to and from repeater sites for initial equipment line up and tests was saved. The buildings were then transported to the repeater sites as a complete package with the exception of the stand-by power sets. Commercially available "no-break" power sets were installed on this system at all locations except the Phoenix main office, where there was sufficient capacity in the existing L-3 motor alternator to power the additional load.

7.2.2 *Kiptopeke-Hampton System*

This TJ system, shown in Fig. 45, extends northward from Hampton, Virginia, 22.5 miles across Chesapeake Bay to Kiptopeke on the Eastern Shore of Virginia. Estimates of rain attenuation for this section of the country indicate that reliable transmission can be achieved over these

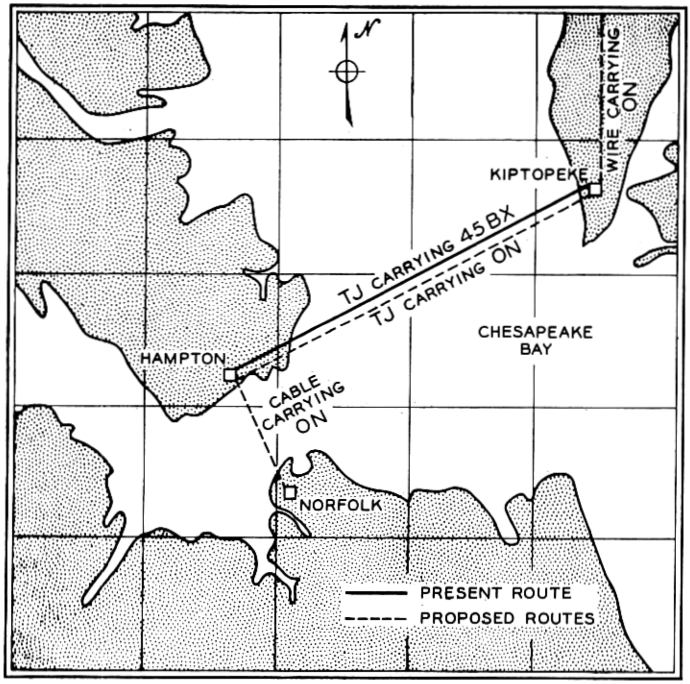


Fig. 45 — Hampton-Kiptopeke TJ system with proposed additions.

distances provided the system has a fading margin of 40 db. However, in engineering a microwave system to operate on a long over-water path, two propagation phenomena besides rain attenuation deserve careful consideration. These are (a) fading due to inverse bending, and (b) reflections from the surface of the water. In the former case, additional tower height is usually provided to assure reliability. In the latter case, some arrangement, such as a high tower at one end and a low tower at the other end of the path, is employed to place the reflection point advantageously so that cancellation will not occur. As can be seen, the remedy for inverse bending is not the remedy for reflective paths.

The Kiptopeke-Hampton TJ system employs periscope antenna systems at both ends of the path. The reflective antenna height at Kiptopeke is 266 feet, and at the Hampton end it is 260 feet. The received signal level is -32 dbm and, with 36 channels of single-sideband suppressed-carrier multiplex, 48 dba at 0 TLP occur at a receiver input of -75 dbm resulting in a fading margin of 43 db. The antenna heights provide grazing clearance when $k = 1/2$. Under normal propagation conditions, $k = 4/3$, the mid-path clearance is in the order of 15 fresnel zones. Frequency diversity, with 240-mc channel separation, provides reliable transmission during periods when reflection is taking place from the water.

VIII. ACKNOWLEDGMENT

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

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