

**TL-1 MICROWAVE RADIO
OVERALL SYSTEM
DESCRIPTION**

CONTENTS	PAGE
1. GENERAL	1
2. EQUIPMENT	1
A. Transmitter-Receiver	1
B. Order-Wire and Alarm System	3
C. Antennas and Waveguide	5
D. Towers	8
3. FREQUENCY PLAN	9
4. RADIO TRANSMISSION CONSIDERATIONS	10
A. Fading	10
B. Rain Attenuation	10
C. Noise	15
D. Interference	19
E. Frequency Diversity	19
5. MULTIPLEX LOADING OF RADIO CIRCUIT	19
6. EQUIPMENT MAINTENANCE	20

1. GENERAL

1.01 This section contains a description of the physical and functional characteristics of the TL-1 microwave radio system (Fig. 1 and 2). The description includes the frequency plan, transmission considerations, and connecting service requirements for the system.

1.02 This section is reissued to add information for TL-1 systems that may now be equipped with either of the following:

- (a) The J99296AA-2, List 3 modulator-preamplifier unit with the J99296G-2 receiver IF and baseband unit
- (b) The J99296AA-2, List 3 modulator-preamplifier unit with the J99351E-1 IF amplifier unit and the J99351J-1 FM receiver unit.

The equipment indicated in (a) or (b) is installed in the TL-1 system to increase the message circuit capacity from 240 to 600 circuits.

Since this is a general revision, change arrows ordinarily used have been omitted.

2. EQUIPMENT

A. Transmitter-Receiver

2.01 The transmitter-receiver contains equipment needed for receiving an FM microwave signal from an adjacent radio station and converting this signal to baseband, and for generating an FM microwave signal that is transmitted to an adjacent radio station. The transmitter-receiver is packaged for either outdoor or indoor installation. In outdoor installations, the transmitter-receiver equipment is rack mounted in an insulated steel cabinet, as illustrated in Fig. 1, and is approximately 3 feet 11 inches wide, 5 feet 3 inches high, and 1 foot 7 inches deep. Up to four cabinets may be installed at any one radio station, where they are mounted at the base of the tower. Single-side maintenance is provided by two doors which give access to all units of the equipment. The equipment is mounted on two vertical 19-inch racks contained within the cabinet. The transmitter-receiver uses solid-state components throughout except for a transmitting klystron and beat-oscillator (BO) klystron. One transmitter-receiver unit is required for each 2-way radio channel.

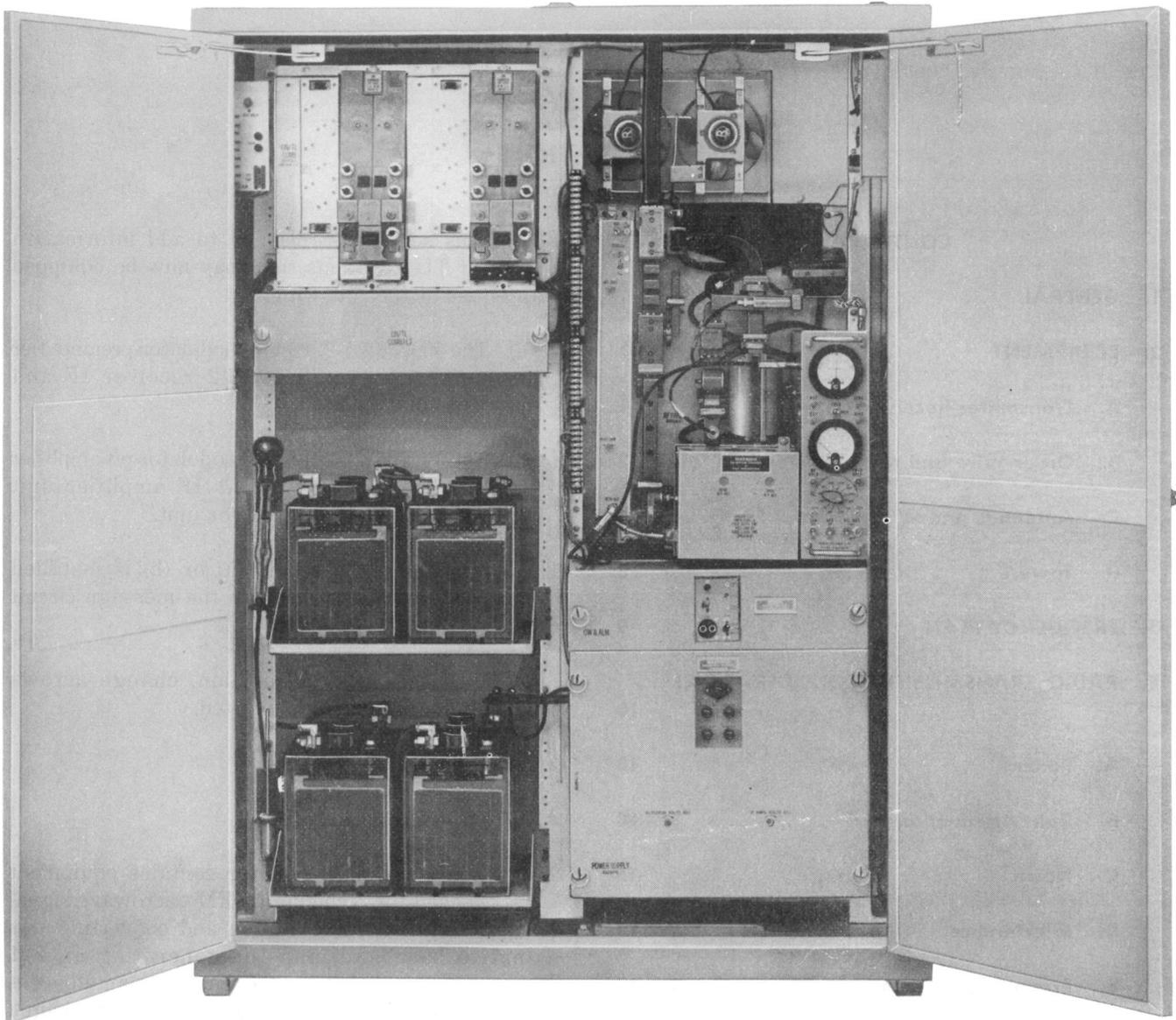


Fig. 1—J99262A Transmitter-Receiver Cabinet—Open View

2.02 A panel, located in the upper half of the right cabinet rack, mounts the microwave transmitter-receiver. This comprises a waveguide assembly, IF receiver and baseband amplifier unit, transmitting baseband amplifier, transmitter and BO klystrons, and a metering panel assembly (Fig. 1). Also included is a vapor-phase cooling system that maintains the two klystrons at a fixed temperature. Below the transmitter-receiver assembly is a panel containing the order-wire and alarm circuitry. In a diversity system, a diversity switch panel is installed in one of the two equipments in place of an order-wire and alarm panel. Operating

voltages for the transmitter-receiver assembly, alarm panel, and diversity switch unit are obtained from a dc-to-dc converter and power supply mounted at the bottom of the rack.

2.03 The left rack in the cabinet mounts four 6-volt storage batteries, and the upper half of this rack is reserved for multiplex terminal or dropping equipment. The battery supply powers the transmitter-receiver unit and is continuously charged from a 117-volt commercial ac line. Power connections between units are made by means of

a cable harness; IF and baseband signal connections are made via short coaxial cables.

2.04 In indoor installations, the transmitter-receiver unit is installed in 19-inch wide racks as illustrated in Fig. 2, 3, and 4. In a maximum system, the bays would most often be connected as a diversity system giving three 2-way diversity channels. The arrangement of units within the rack is essentially the same as in the cabinet, except that the batteries are located below the power supply and the multiplex equipment is not mounted within the rack but is external.

2.05 External emergency power equipment is not normally required in the TL system. In the event of an ac line failure, the storage batteries can provide up to 24 hours of service. The actual reserve time depends upon battery temperature and, in most cases, ac service should be restored within this interval. The actual reserve times are as follows: at 0°F, from 10 to 12 hours; at 60°F, 18 hours; below 0°F, somewhat less than 10 hours. This system has the advantage of providing hitless operation when the commercial power fails.

B. Order-Wire and Alarm Systems

2.06 An alarm system is needed to ensure reliability of service and meet Federal Communications Commission (FCC) requirements in communications systems where stations operate unattended. Various trouble conditions occurring in these stations are reported by the alarm system to an alarm center that is continuously attended. A telephone order-wire facility is also included to provide voice communications between stations and the alarm center. A maximum of eleven stations may be placed in one alarm system with spur routes included. A separate order-wire and alarm system is required for each nondiversity radio channel and each diversity pair or radio channels. The alarm system reports and identifies up to five trouble conditions that may exist at a radio station by interrogation from an attendant at the alarm center. These alarm conditions are:

- (a) Two tower light beacons out or ac power failure
- (b) Tower light flasher mechanism inoperative
- (c) One tower beacon or any side light out

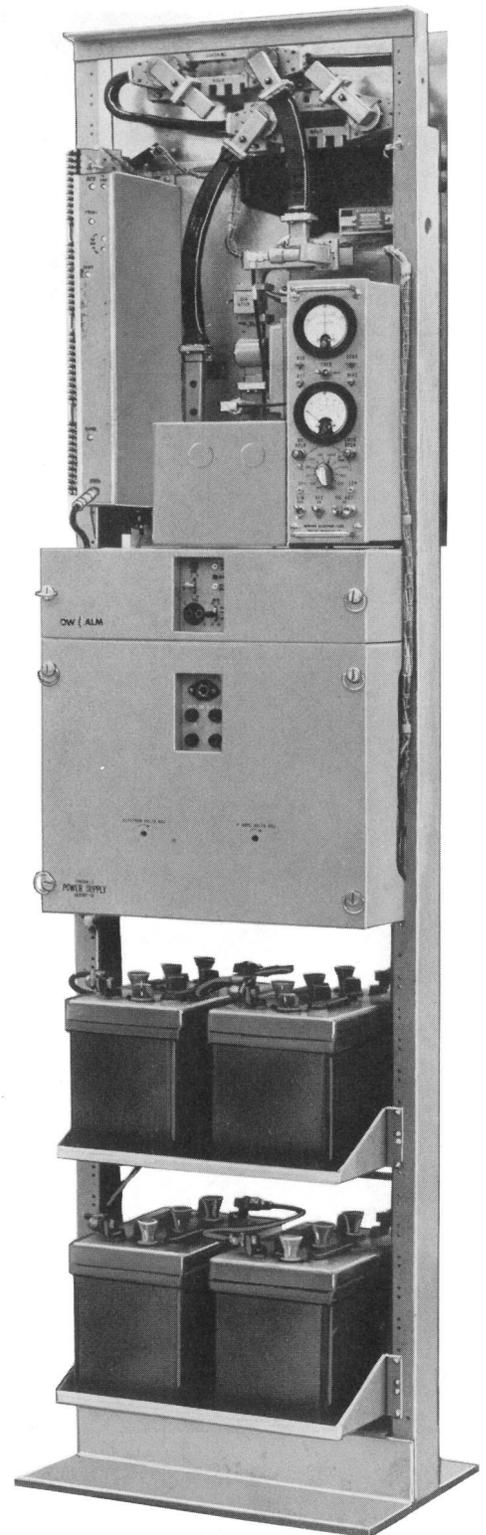


Fig. 2—J99262B Transmitter-Receiver Rack Mounted, 7-Foot Bay

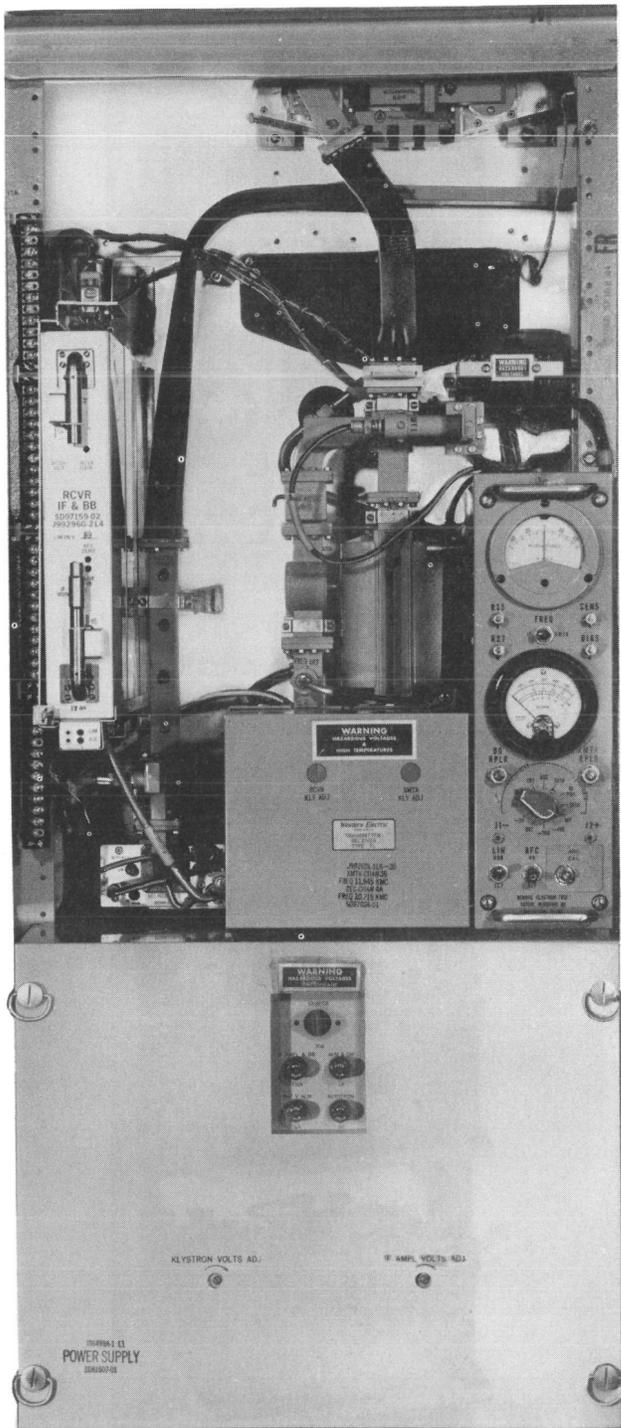


Fig. 3—J99296AA-2, List 3 Modulator-Preamplifier Unit With J99296G-2 Receiver IF and Baseband Unit

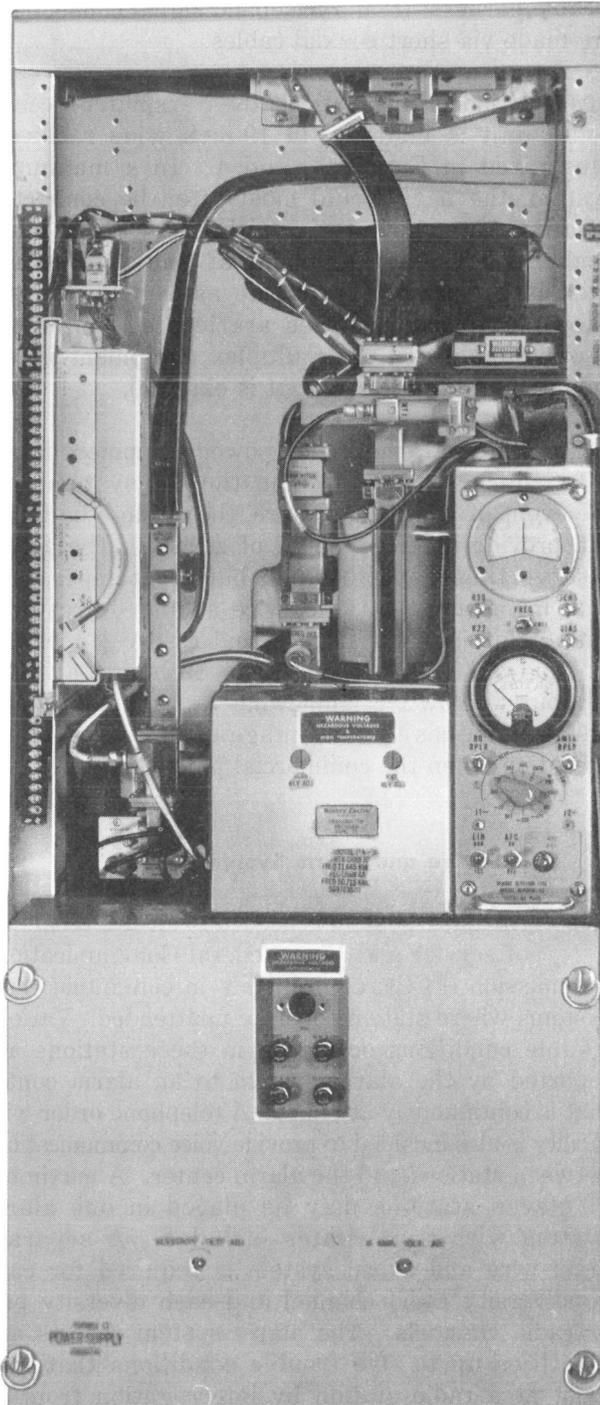


Fig. 4—J99296AA-2, List 3 Modulator-Preamplifier Unit With J99351E-1 IF Amplifier Unit and J99351J-1 FM Receiver Unit

- (d) Low battery voltage
- (e) Failure in transmission.

2.07 Order-wire facilities provide telephone access jacks at each radio station and alarm center. The far terminal radio station and the order-wire and alarm control station have provisions for connections of a 4-wire extension of the order wire. Operation of a "signaling in" key will create an alarm for calling in from a radio station to the alarm center.

2.08 The alarm system is made up of two types of equipment: the control circuit located at the alarm center, and the alarm panel located at the radio repeaters and terminals.

C. Antennas and Waveguide

2.09 The TL-1 system requires a line-of-sight path between transmitting and receiving antennas. This type path presents no obstructions to the beam of the RF energy. Because the effect of the surface of the earth influences the received signal, clearance is provided between the beam and the high point on the earth along the path. Generally, these factors result in the repeater sites being located at high elevations or in the use of towers to mount antenna systems. These antenna systems produce narrow beams that are aimed at one another resulting in high gains to overcome path loss. TL-1 radio normally uses 5-foot and 10-foot parabolic antennas in direct radiator systems and 6-foot by 8-foot, 8-foot by 12-foot, and 10-foot by 15-foot passive reflectors in periscope systems.

Parabolic Antennas

2.10 The KS-15970 antenna, Fig. 5, can be used in conjunction with the KS-16320 reflector, Fig. 6, or as a direct radiator. The antenna is a rear-feed, ring-focus antenna which consists essentially of a 5-foot spun-aluminum parabolic reflector and a simple primary feed system. This antenna has a gain of approximately 42 dB and is highly directional, having a beam width of approximately 1 degree at the half-power points. Adjustable supports provide for independent azimuth and elevation orientation of up to 55 degrees in azimuth and -5 to 43 degrees in elevation from the central position. The feed system is made of a straight section of round waveguide which passes through

the apex of the paraboloid and has a specially shaped reflecting disc on one end. The disc serves to reflect energy from the waveguide back into the paraboloid when transmitting and vice versa when receiving. The antenna is used simultaneously for transmitting and receiving. Both horizontal and vertical polarizations may be used, and the antenna characteristics in both planes are essentially the same. The antenna is not equipped with a heater, but it may be equipped with a radome.

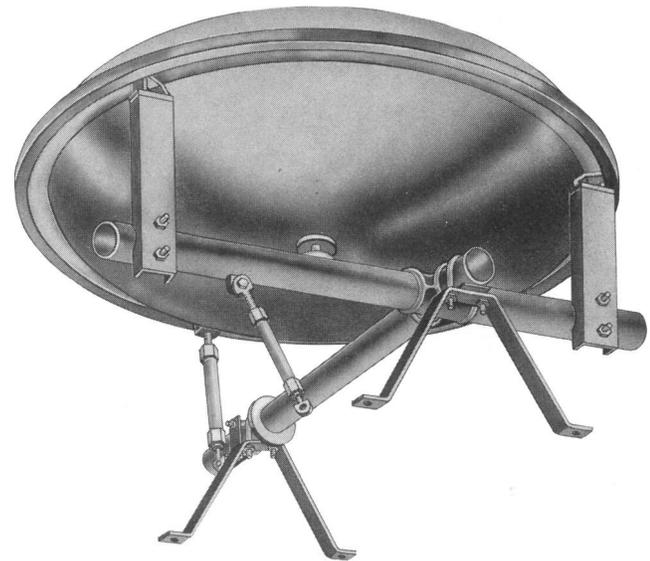


Fig. 5—KS-15970, 5-Foot Parabolic Antenna

2.11 Two dual-frequency (6 and 11 GHz) antennas are used in the 11- and 6-GHz crossband diversity application. Each antenna (KS-19529 and KS-19530), Fig. 7, consists of a parabolic reflector, a feed assembly, a radome, and a mounting frame. The dual-frequency feedhorn consists of two concentric cylindrical apertures. The inner aperture provides illumination for the dual-polarized 11-GHz frequencies and the outer cylinder provides illumination for the 6-GHz frequencies. A waveguide assembly consisting of three feeds, two 11 GHz and one 6 GHz, connects the feedhorn to two WR90 waveguides and one WR159 waveguide at the rim of the dish. The feedhorn and waveguide assembly are supported by three struts forming a tripod. The radome is attached to the rim of the dish. A radome should always be used because it covers and protects the feedhorn, waveguide assembly, struts, and the face

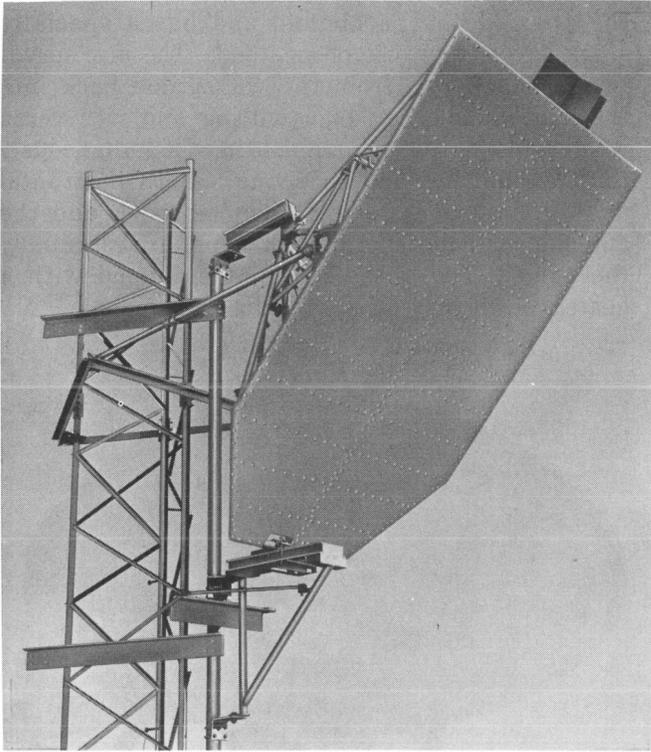


Fig. 6—KS-16320 Reflector

of the reflector. Table A gives the electrical characteristics of the 10-foot KS-19529 antenna and the 6-foot KS-19530 antenna.

2.12 The KS-15852 parabolic antenna is composed of a 10-foot parabolic reflector with a simple ring-focus primary feed system similar to that used in the 5-foot antenna. The focal length of the 10-foot dish is longer than that of the 5-foot dish; therefore, the waveguide feed is necessarily longer to provide correct dish illumination. This antenna has a higher gain than the 5-foot antenna, and is used in direct radiator installations or in conjunction with a 10-foot by 15-foot reflector in a periscope arrangement where higher gain is required for transmission considerations. The higher gain antenna is also used to compensate for the longer waveguide runs sometimes necessary in direct radiator systems. One of the major advantages of this antenna over the 5-foot dish or the periscope arrangement is its very good directivity. This feature is used at stations where potential RF interference presents a problem.

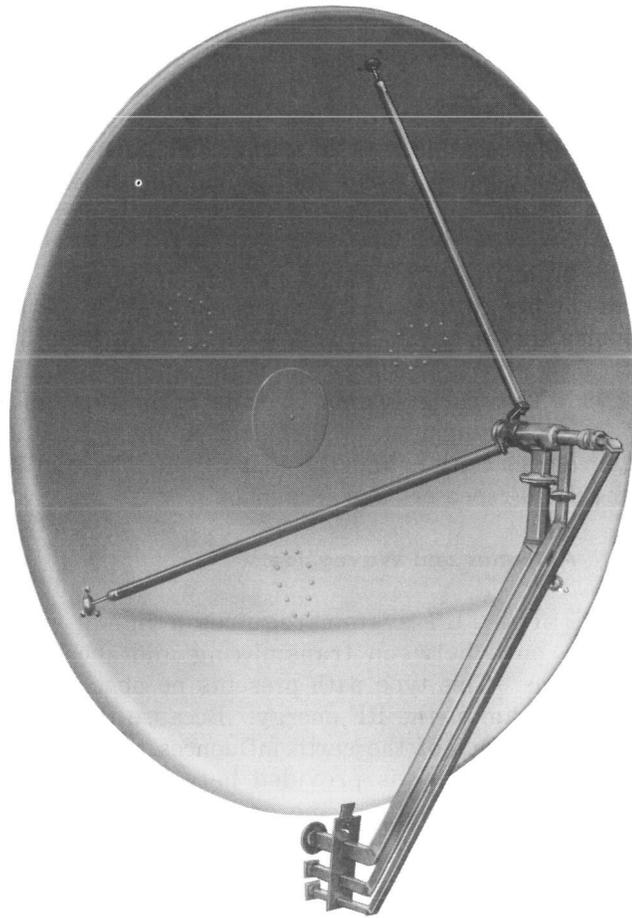


Fig. 7—KS-19529 or KS-19530 Dual-Frequency Antenna

Periscope Antenna System

2.13 A periscope system is used at TL radio installations where relatively high towers are required to give an optical path. The use of an elevated reflector, with an antenna at the base of the tower, minimizes the use of an extended waveguide run and resultant loss in signal strength due to waveguide losses. For the periscope installations, KS-16320 6-foot by 8-foot and 8-foot by 12-foot reflectors are used. Normally, the 5-foot dish would be installed horizontally near ground level with its beam directed upward toward the tower-mounted reflector. The reflector, Fig. 6, serves to redirect the beam over the path, and is adjustable in azimuth and elevation to facilitate aiming. In contrast to this, direct radiator installations on towers require that the parabolic be mounted

TABLE A
CHARACTERISTIC OF KS-19529 AND KS-19530

FUNCTION	KS-19529 10-FOOT ANTENNA (GAIN-dB)	KS-19530 6-FOOT ANTENNA (GAIN-dB)
5.925 GHz	41.54 Gain	37.04 Gain
6.175 GHz	41.90 Gain	37.40 Gain
6.425 GHz	42.25 Gain	37.75 Gain
10.7 GHz	45.40 Gain	41.40 Gain
11.2 GHz	45.80 Gain	41.80 Gain
11.7 GHz	46.19 Gain	42.19 Gain
Return Loss (dB)	23*	23*
Polarization Discrimination	18 MIN	18 MIN
Radome Loss (dB)		
6.175 GHz	0.6	0.9
11.2 GHz	1.2	1.2
Beam Width		
6 GHz	1°	2°
11 GHz	0.5°	1°

*Corresponds to a voltage standing wave ratio (VSWR) of approximately 1:1.15.

on the tower with its beam pointed to the next station. The periscope system offers a sharper beam width and, with an 8-foot by 12-foot reflector at the proper height, higher gain than a direct radiating 5-foot dish. However, the minor lobes are larger in a periscope system. The gain is a function of the parabolic reflector spacing, and by slightly curving or dishing the reflector so that it presents a concave reflecting surface, still higher gains may be attained. The characteristics of the various types of antennas are listed in Table B. The periscope system gains are the maximum attainable and vary considerably with different dish-reflector spacings.

Waveguide

2.14 Connections between the parabolic antennas and the transmitter-receiver units are made

with rectangular waveguide components. The arrangement of these components varies depending upon such factors as the type of transmitter-receiver installations, indoor or outdoor; the number of radio channels and therefore transmitter-receiver units at a station; and the antenna system used. Waveguide runs are formed with WR90 (0.9 by 0.4 inch) rigid rectangular waveguide. Straight sections are used and also E- and H-plane bends of 90, 60, 45, and 30 degrees. In addition, flexible, twistable waveguide is included to allow flexibility for orienting the antennas and to simplify the installation of the waveguide runs.

2.15 At radio stations where one polarization per antenna is used, a 4A transducer connects at the antenna to convert from the round WC75 (0.75 inch) antenna waveguide used in the antenna feed assembly to the rectangular WR90 waveguide.

TABLE B
TRANSMISSION CHARACTERISTICS (11.2 GHz)

TYPE	GAIN OVER ISOTROPIC	BEAM WIDTH AT 3-dB POINT
	dB	degrees
5-ft dish	42.1	1.2
5-ft dish plus plane reflector (6 ft by 8 ft)	42.1 MAX	0.8
5-ft dish plus plane reflector (8 ft by 12 ft)	43.6 MAX	0.6
5-ft dish plus curved reflector (8 ft by 12 ft)	45.6 MAX	0.6
10-ft dish	48.0	0.7
10-ft dish plus plane reflector (10 ft by 15 ft)	48.0	0.5

When cross-polarized transmitters and receivers are used at each station, 1405 polarizer networks, illustrated in Fig. 8, are connected to the round antenna waveguide. The polarizer enables two WR90 waveguides to be connected to a single circular waveguide so that the two signals from the rectangular waveguides will be polarized at 90 degrees to one another in the common circular waveguide. Conversely, signals polarized at 90 degrees in the circular waveguide will be separated in the polarizer and delivered separately in the two rectangular waveguides. At least 20 dB of cross-polarization discrimination on the major lobe is provided by the polarizer. A typical installation includes a run of flexible and rigid waveguide from the polarizer to a 1402 channel dropping and combining network contained within the transmitter-receiver unit. The 1402 networks are selective to a single-channel frequency band and permit frequencies outside this band to pass through them unaffected. They act as low-loss directional couplers in a designated frequency band and are, therefore, used to separate received channels in a multichannel system and to add transmitter signals together for application to the antenna.

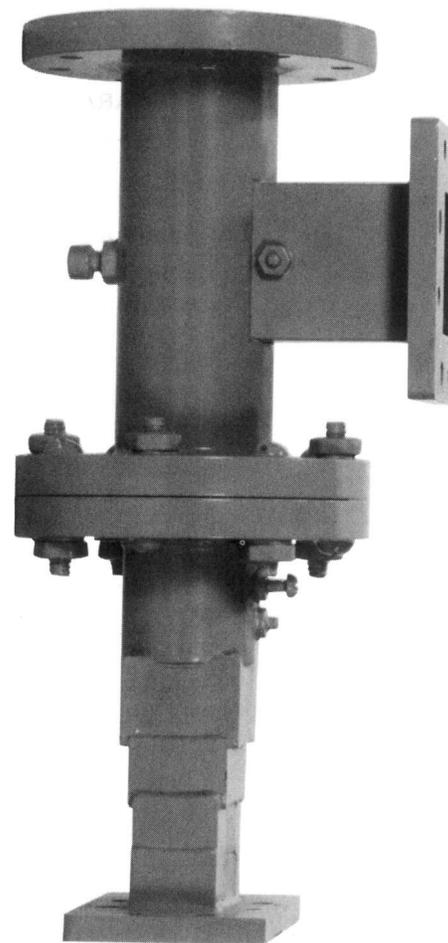


Fig. 8—1405A Dual Polarizer Network

2.16 In general (there are exceptions), when three or more transmitter-receiver units are connected to a single antenna using two polarizations, an isolator is required between transmitters and receivers in a waveguide run. The purpose of the isolator is to prevent beat-oscillator leakage from reaching receivers on opposite polarizations and causing beat tones.

D. Towers

2.17 Three types of towers will most often be used in TL-1 radio systems. The three types of TL-1 towers are listed in Table C.

2.18 A typical installation of a wooden H-frame tower is illustrated in Fig. 9.

TABLE C

TYPE OF TOWER	HEIGHTS	LOAD CAPACITY
Steel guyed	75 ft, 90 ft, and 105 ft	Two 6-ft by 8-ft reflectors
Steel self-supporting	30-ft to 105-ft increments of 15 ft	Two 6-ft by 8-ft reflectors; or for heights up to 60 ft, two 5-ft or 10-ft dishes
Wooden H-frame	Up to 60 ft	Two 5-ft or 10-ft dishes or two 6-ft by 8-ft reflectors

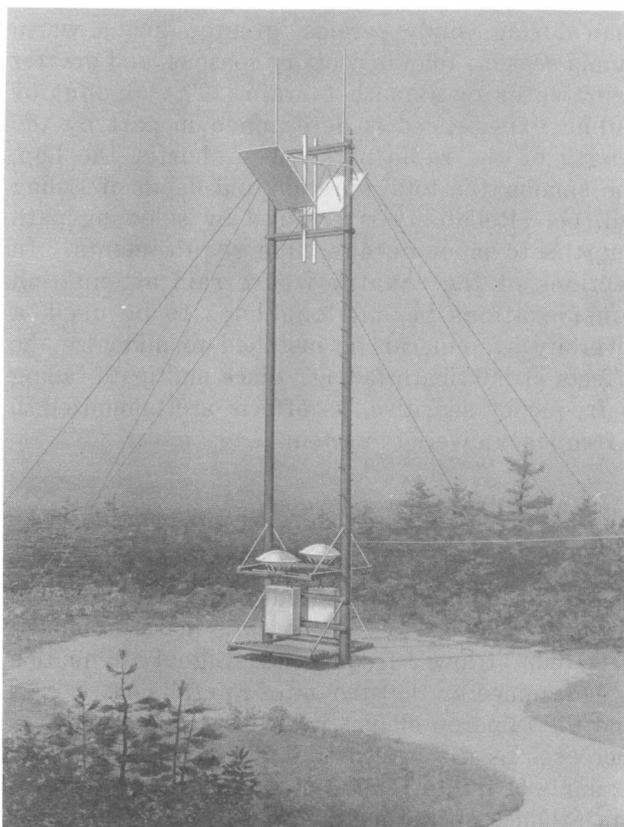


Fig. 9—H-Frame Installation

3. FREQUENCY PLAN

3.01 The TL-1 radio frequency plan is the same as the 4-frequency allocation plan used in the TJ radio system. The maximum number of channels in a radio system is determined by the width of the frequency band and the selectivity requirements of the radio equipment. By using 40-MHz channel separations in TL-1 radio, 24 radio channels are obtained from a 1000-MHz frequency spread between 10,700 and 11,700 megahertz.

3.02 On any 1-hop system, alternate channels (12 total) having an 80-MHz separation are used. The channels are polarized alternately giving a 160-MHz separation between adjacent channels of the same polarization. The adjacent radio paths use the alternate 12 channels resulting in a 40-MHz separation between channels on opposite sides of a repeater station. To provide adequate frequency separation between transmitting and receiving at any one station, the upper half of the frequency band is allocated to transmitting while the lower half is receiving. Since transmitters work into receivers of the same frequencies, alternate stations will necessarily be inverted with receiving in the upper half and transmitting in the lower half of the frequency band. In addition, the separation between the two channels adjacent to midband is 90 MHz rather than 40 MHz. This is done to meet a requirement for a minimum separation of 130 MHz between any transmitting and receiving channels combined at one antenna. Frequency diversity channels are paired to provide frequency separation of 240 MHz consistent with adding channels later without interrupting service. There are exceptions to the standard frequency plan depending upon the antenna system used and other radio path considerations.

3.03 At indoor installations the system has been planned to allow the equipment bays to grow from both ends toward the middle, giving the least filter and waveguide losses to the channels installed first. The growth patterns are shown schematically in Fig. 10. With this plan, the bays are arranged in what is known as a terminal-type arrangement. Waveguide interconnections are shown along with channel frequencies and numbers in Fig. 11. As indicated in Fig. 11, the 12 channels in the lower half of the total frequency band are designated group A. They are numbered 1A to 12A in accordance with a definite numerical plan which dictates the system growth. The 12 channels in

SECTION 409-300-101

the upper half of the total frequency band are designated B and are numbered 1B to 12B. The following explains the frequency allocation plan as shown here.

- (a) Channels (six minimum) transmitting north or east have odd numbers. Channels (six maximum) transmitting south or west have even numbers.
- (b) All channels transmitting in one direction on a specific hop are designated A, in the opposite direction B; on adjacent hops, this is reversed.
- (c) The 12 channels are divided into two groups designated regular and diversity. Channels 1 and 2, 7 and 8, and 9 and 10 are in the regular group. Channels 3 and 4, 5 and 6, and 11 and 12 are in the diversity group.
- (d) In dual-polarization systems, channels are assigned and installed in numerical order beginning with channel 1 or 2. In diversity systems, channels 1, 2, 3, and 4 are involved in the first diversity switching group; channel 5, 6, 7, and 8 in the second diversity switching group; and channels 9, 10, 11, and 12 in the last diversity switching group. In single-polarization systems, the regular group is installed in numerical order beginning with channels 1 and 2.
- (e) A single baseband signal (ignoring diversity switching) retains its basic number throughout the system but changes its letter designation on adjacent hops. In addition, the polarization of a specific channel is shifted every third hop.
- (f) The two channels comprising a diversity pair are on opposite polarizations. This permits maintenance and growth with minimum interruption to service.

3.04 Normal channel numbers, including transmitting and receiving frequencies, are listed in Table D.

3.05 The TL-1 radio system design has been coordinated with the 6-GHz TM-1 system assuring a convenient combination of the two in future crossband diversity systems. The combination of TM-1/TL-1 frequencies is illustrated in Fig. 12.

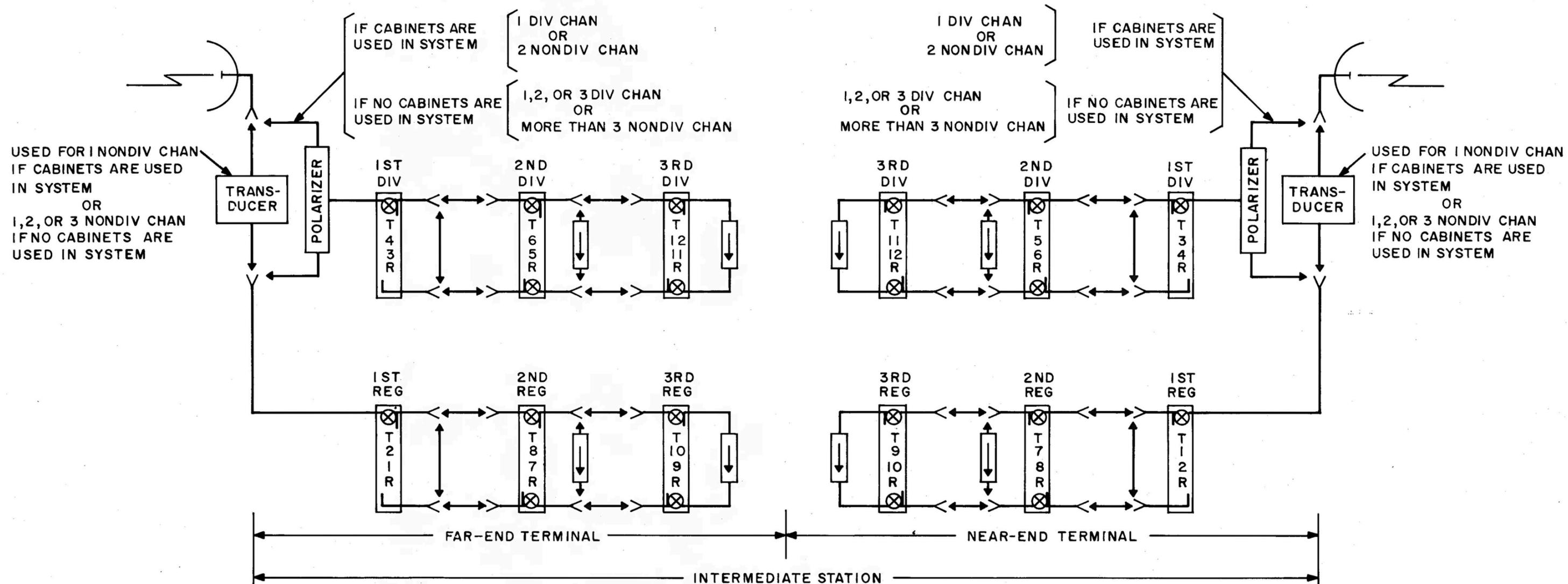
4. RADIO TRANSMISSION CONSIDERATIONS

A. Fading

4.01 Other than fading due to rain, which will be discussed in 4.02, there are two general types of fading encountered in microwave transmission. One of them, inverse bending, is the result of an abnormal change in the dielectric constant of the atmosphere which causes the radio beam to be directed toward the earth. The receiving antenna, therefore, is no longer in the incoming beam resulting in a drop in received signal power. The other more prevalent type of fading is caused by multiple path transmission. This creates wave interference at the receiving antenna that can result in deep fades of 30 to 40 dB or more. This type of fading is frequency selective, shorter in duration, and occurs more often than the inverse bending type. Fading is usually greater at night than during the day, greater under still conditions than during windy periods, greater during warm humid seasons than in cool dry seasons, and greater over water or smooth terrain. The amount of fading experienced is determined in part by the length of the radio path. The shorter the hop, the smaller the total duration and depth of fading will be. Reliability is ensured by selecting path lengths to meet outage time requirements. In sections of the country where rain attenuation considerations permit long hops to be used, a diversity system can be installed to minimize the effects of multipath fading. Since multipath fading is frequency sensitive, its effects are minimized in a frequency diversity system.

B. Rain Attenuation

4.02 Because the wavelength at 11 GHz approaches the diameter of raindrops, scattering and absorption of energy by rainfall is more prominent here than at lower frequencies. Signal attenuation is determined by the amount of rainfall encountered and the raindrop diameter. Attenuation, therefore, increases as the rate of rainfall increases. As an example of this, a rainfall of cloudburst proportions can produce an attenuation of several decibels per mile. System outage time due to rainfall increases as radio path length increases since a long path, over a period of time, will experience more rainfall than a shorter one. Repeater spacings, therefore, will vary as determined by the expected rates of rainfall which varies with geographical location. Figure 13 is a map of the United States with



LEGEND

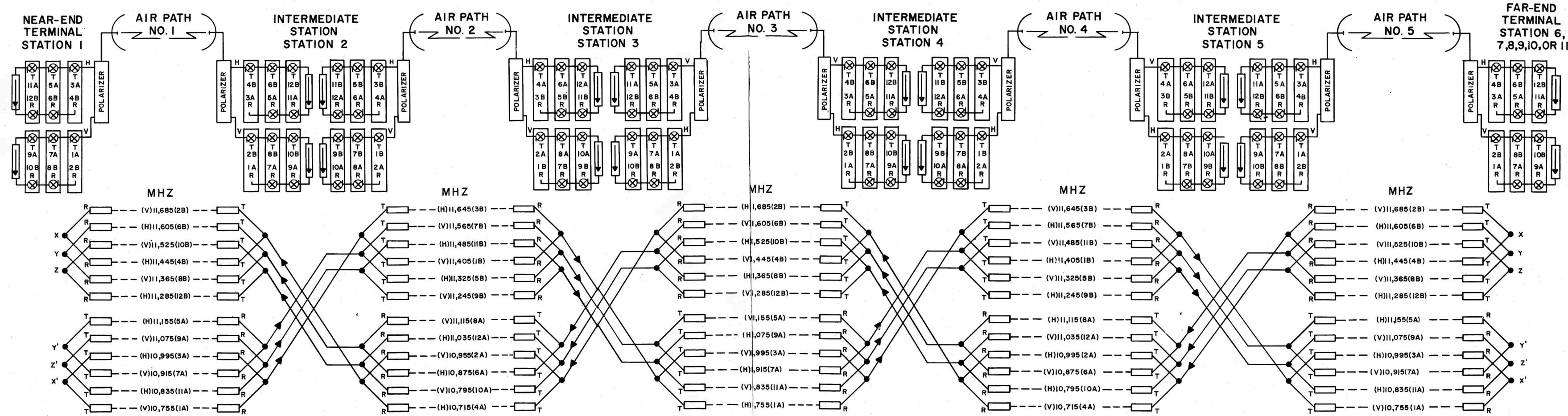
1. ⊗ IS A CHANNEL DROPPING/COMBINING NETWORK
2. → IS AN ISOLATOR
3. RECEIVERS PAIRED FOR PROTECTION ARE COMBINED AT A DIVERSITY SWITCH
4. TRANSMITTERS PAIRED FOR PROTECTION ARE COMBINED AT A SPLIT PAD
5. T- TRANSMITTER RADIO EQUIPMENT
6. R- RECEIVER RADIO EQUIPMENT

GROWTH PATTERN

FOR T/R BAYS 1 TO 6: TWO-WAY NONDIV CHANS AND 1 TO 3 TWO-WAY DIV CHANS

Fig. 10—Growth Pattern for Multichannel TL-1 Radio System—Block Diagram

- LEGEND**
- ⊗ IS A CHANNEL DROPPING/COMBINING NETWORK.
 - ⇨ IS AN ISOLATOR.
 - A BASIC LETTER AND ITS PRIME LETTER CONSTITUTE AN EQUIVALENT 4-WIRE CIRCUIT (XX', YY', B ZZ') WHICH MAY BE CONNECTED TO A 2-WIRE LINE CIRCUIT THROUGH THE USE OF A HYBRID.
 - RECEIVERS PAIRED FOR PROTECTION ARE COMBINED AT A DIVERSITY SWITCH.
 - TRANSMITTERS PAIRED FOR PROTECTION ARE COMBINED AT A SPLIT PAD.
 - H - HORIZONTAL SIGNAL POLARIZATION
 - V - VERTICAL SIGNAL POLARIZATION
 - T - TRANSMITTER RADIO EQUIPMENT
 - R - RECEIVER RADIO EQUIPMENT



T/R BAY ARRANGEMENT AND FREQUENCY PLAN
 FOR AS MANY AS $\begin{cases} 3 \text{ TWO-WAY DIVERSITY CHANNELS} \\ 6 \text{ TWC-WAY NONDIVERSITY CHANNELS} \end{cases}$

Fig. 11—Transmitter-Receiver Bay Arrangement and Frequency Plan

TABLE D
NORMAL FREQUENCY ADJUSTMENTS

CHANNEL	TRANSMITTING AND RECEIVING FREQUENCY
1A	10,755
1B	11,405
2A	10,955
2B (highest)	11,685
3A	10,995
3B	11,645
4A (lowest)	10,715
4B	11,445
5A	11,155
5B	11,325
6A	10,875
6B	11,605
7A	10,915
7B	11,565
8A	11,115
8B	11,365
9A	11,075
9B	11,245
10A	10,795
10B	11,525
11A	10,835
11B	11,485
12A	11,035
12B	11,285

contour lines superimposed that designate areas of equal expected occurrence of high rainfall rates (1 inch per hour or greater). In any one designated area, equal length paths should, over a period of time, experience the same rainfall rates for equal durations. Figure 14 contains a curve for each contour that shows the estimated outage time on a single hop with different length radio paths. Figures 13 and 14 are used in laying out a TL-1 system in any part of the country so that the requirements for reliability are met. The figures

show that shorter paths must be used in the southeastern section of the United States to obtain the same reliability as in the northern and western parts of the country.

C. Noise

4.03 Total noise power in the baseband spectrum is composed of fluctuation and intermodulation noise. Fluctuation noise originates in the receivers and transmitters of the various radio equipment in

SECTION 409-300-101

NOTE:
 TM-1 FREQUENCY IS 6 GC.
 TJ, TL-1, OR TL-2 FREQUENCY IS 11 GC.

LEGEND:

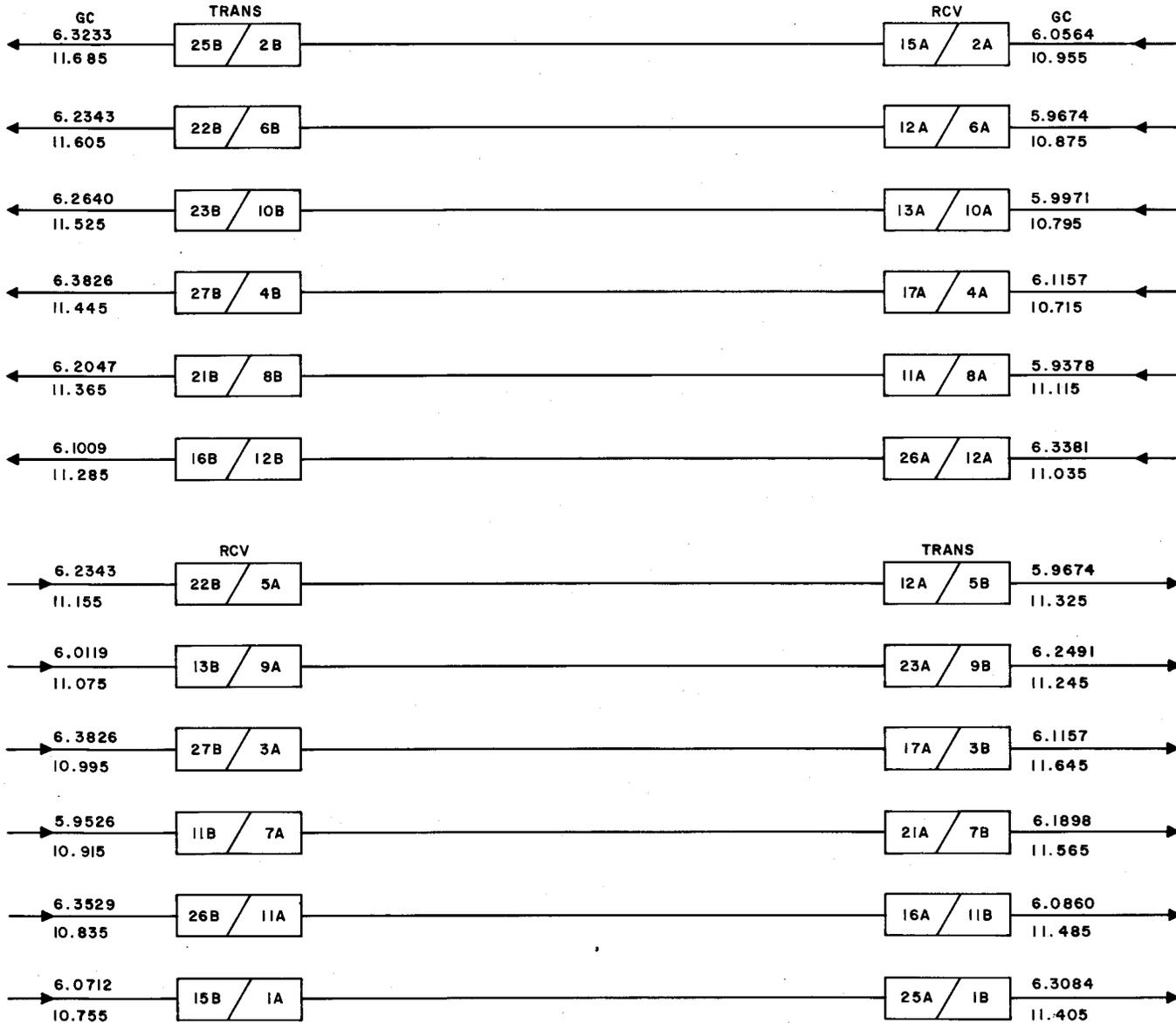
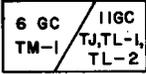


Fig. 12—TM-1/TL-1 Crossband Diversity Frequency Plan

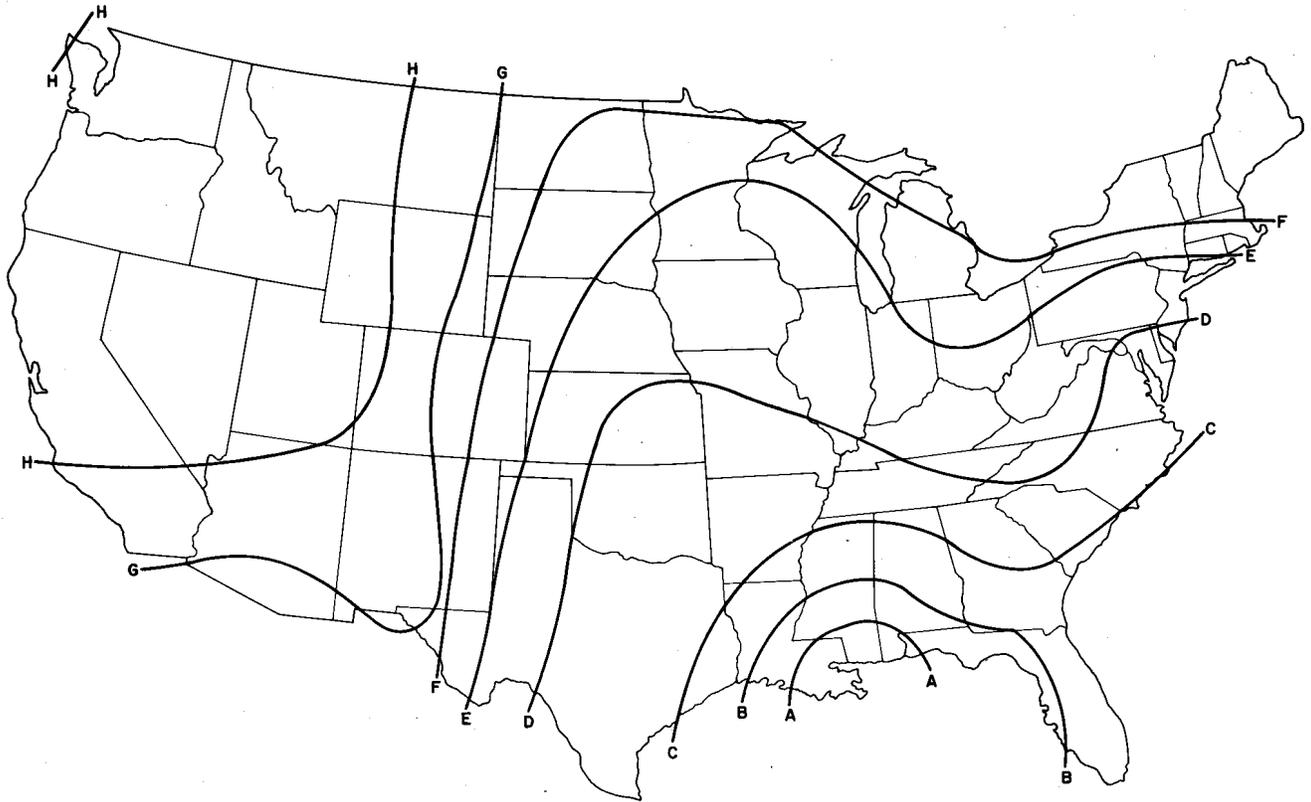


Fig. 13—Contours of Constant Path Lengths for Fixed Outage Time

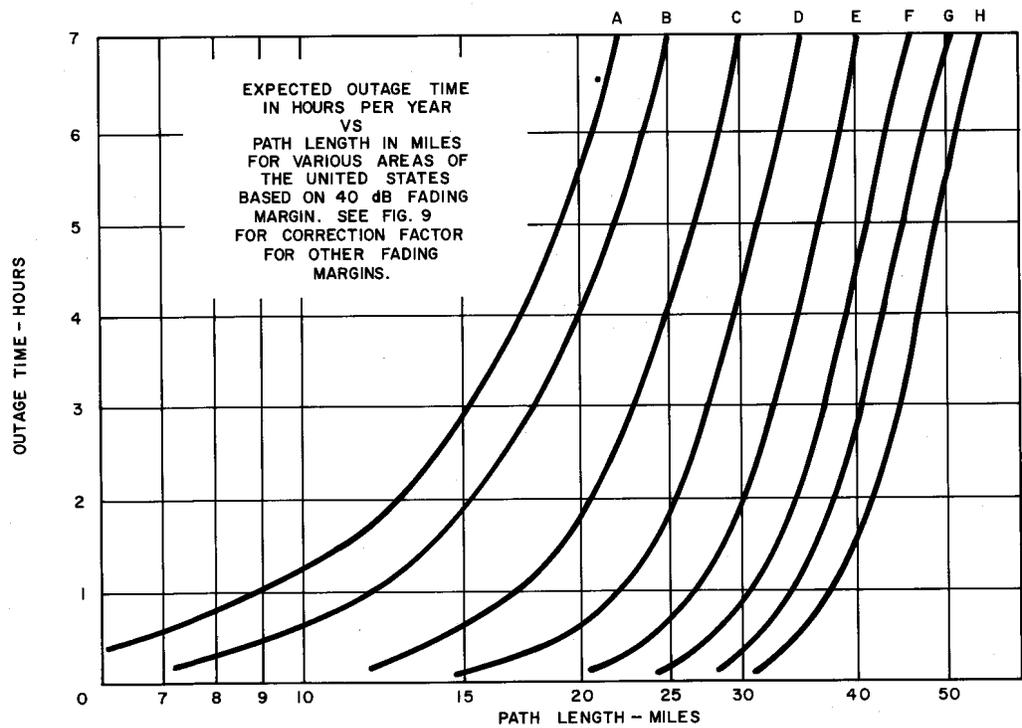


Fig. 14—Outage Line Curves Based on a 40-dB Fade Margin—Graph

SECTION 409-300-101

the overall system. Intermodulation noise is generated in the system through nonlinearities that cause sum and difference products of the baseband signals.

Fluctuation Noise

4.04 The magnitude of this noise in the baseband at a given level point depends on the following:

- (a) Radio frequency power output of each transmitter
- (b) Net path loss between the transmitter output tube and receiver converter
- (c) Noise figure of the receiver
- (d) Baseband amplifier and klystron idle circuit noise.

4.05 The noise power per cycle of bandwidth in the receiver input is substantially flat over the useful band. In a frequency modulation system, however, the resulting baseband noise per cycle normally increases 6 dB as the baseband frequency is doubled, resulting in what is called a triangular noise spectrum. This means that the noise at 1 MHz will be 6 dB less than the noise per cycle at 2 MHz. Of the various factors affecting fluctuation noise, the net path loss is the only one which is subject to large changes with time. Most of the time, path loss will differ only slightly from its free space value, but during fading conditions, the loss in a repeater section may increase by 30 to 40 dB or more. Frequency diversity on long paths will, in nearly all instances, prevent the fluctuation noise from increasing to a point where service is degraded beyond where it cannot be used. (Short paths will be less affected by multipath fading.) However, frequency diversity is of no help in the case of attenuation due to rain, and the baseband noise contribution from the affected section will increase as the received carrier decreases and may reach the point where the ratio of carrier to noise at the limiter becomes less than 10 dB. Beyond this point, the baseband noise increases rapidly in amplitude and the system is seriously degraded. In a TL-1 system, attenuation due to rainfall in excess of the fading margin is expected to occur only rarely, the percentage of time being a function of the system design. When the TL-1 system is used for telephony, the average noise power during

normal signal conditions should be substantially equal to the average noise on a high-grade toll circuit of the same length.

Intermodulation Noise

4.06 Nonlinearities in the frequency modulation and demodulation processes, transmission deviations at RF and IF, and nonlinearity in the baseband amplifiers can produce this type of noise. The TL-1 system is a straight FM system in that the frequency deviation is directly proportional to the amplitude of the modulating voltage and independent of its frequency. Modulation of the microwave carrier is produced by applying an amplified baseband signal to the repeller of the transmitting klystron. For distortion-free frequency modulation, the instantaneous frequency deviation must precisely follow the instantaneous modulating voltage at all times. Any departure from this ideal relationship causes intermodulation distortion which manifests itself in the baseband as crosstalk between circuits. To effectively minimize nonlinearities in the klystron modulation characteristic, the load impedance into which it works must be kept constant over the radio channel bandwidth. In TL-1 radio, this is done by installing an isolator in the output waveguide of each transmitter which absorbs reflections caused by slight mismatches which may exist in waveguide components or the antenna. These reflections would otherwise have the effect of "pulling" the klystron frequency by the changing load impedance. Nonlinearities within the klystron itself are kept sufficiently small by suitable design and optimized electrode voltages so that their contribution to distortion is at a minimum.

4.07 In the demodulation process, an FM IF signal is translated to a baseband signal. Here low distortion is achieved by utilizing a linear discriminator characteristic.

4.08 Frequency modulation is sensitive to amplitude and delay transmission deviations in the RF and IF passbands. The effect of these deviations is to produce cross modulation between message channels when TL-1 radio is used to transmit multichannel telephony. Delay distortion occurs in this system, as in all others, principally because of the cutoff characteristics of the IF passband.

D. Interference

4.09 Interference between channels of a microwave system can result from unwanted coupling between antennas. Overreach interference involves like-frequency transmission between repeaters which are three, five, etc., sections apart. A typical case would be a repeater No. 1 antenna crosstalking into a repeater No. 4 antenna, three hops down the line. A 3-section interference of this type is minimized in the TL-1 system since the interfering carrier arriving at repeater No. 4, although of the same frequency, is cross-polarized with respect to the desired carrier. Another typical possibility, involving 5-section overreach, is repeater No. 1 crosstalking into repeater No. 6. In this case, the interfering and desired carrier are of the same polarization, but conditions are improved somewhat because the interfering carrier must traverse five sections.

4.10 The magnitude of overreach interference depends on the directional pattern of the antenna system and, in general, is reduced to a small value by staggering the repeater paths so that they are not in line geographically. The effect of these interferences on the recovered baseband signal depends on the ratio of the magnitude of the interfering carrier to that of the desired carrier in each case. Both of these signals are subject to independent fading. The baseband interference, therefore, may reach a higher value momentarily during a deep fade. This will happen, however, only very rarely.

E. Frequency Diversity

4.11 The TL-1 radio system can be used to provide 1×1 frequency diversity operation. A frequency diversity channel utilizes two radio channels. This combination is called a diversity pair. A 240-MHz frequency difference exists between the channels of a pair which is adequate to reduce outage time due to multipath fading to a very small value. That is, during periods of multipath fading, a 240-MHz frequency difference assures that correlated fading will rarely take place on two channels of a diversity pair simultaneously.

4.12 Diversity switching is performed at baseband frequencies on a hop-by-hop basis. The received carriers of the two channels of a pair are continually monitored at each repeater in a comparator circuit, and the channel having the stronger carrier

is selected to supply the baseband output signal. Protection from equipment failure is also obtained from the diversity pair since one channel is always acting as a spare. Pilot tones of 2600 Hz are applied to each radio channel and monitored at each repeater to check through transmission. Failure of pilot tone in a working channel causes the protection channel to be switched in automatically. Pilot-tone failure also initiates an alarm system through contacts provided in the pilot monitor relays.

5. MULTIPLEX LOADING OF RADIO CIRCUIT

5.01 It is necessary to set the level of multiplex signals entering the radio so that the nominal peak-to-peak frequency deviation of a TL-1 radio channel is exceeded only a small percentage of the time. With larger swings, nonlinearities are encountered that cause excessive intermodulation distortion. If the multiplex level is set too low, however, receiver IF or fluctuation noise predominates and becomes excessive. There is no optimum value of system loading which will cause a small permissible amount of intermodulation distortion to be generated along with an acceptable value of fluctuation noise. In general, the deviation produced by a single message channel is determined by the total number of message channels applied to the radio, the type of multiplex, and the radio system load capacity. Therefore, on a heavily loaded TL-1 radio system, an individual message channel will produce a smaller deviation than on a lightly loaded system. In either case, the deviation caused by the total load remains essentially the same.

5.02 Multiplex signal levels at the radio input and output are adjusted within the multiplex or entrance links to achieve correct radio system loading. Span pads or step attenuators are provided to set these levels to accommodate various message loads, as illustrated in Fig. 15. No adjustments are made within the radio in this respect. Table E gives the multiplex level point at the radio MX IN and MX OUT jacks for different message systems and loads.

5.03 The pad and attenuator values required to obtain these levels are contained in the carrier system section related to the multiplex type.

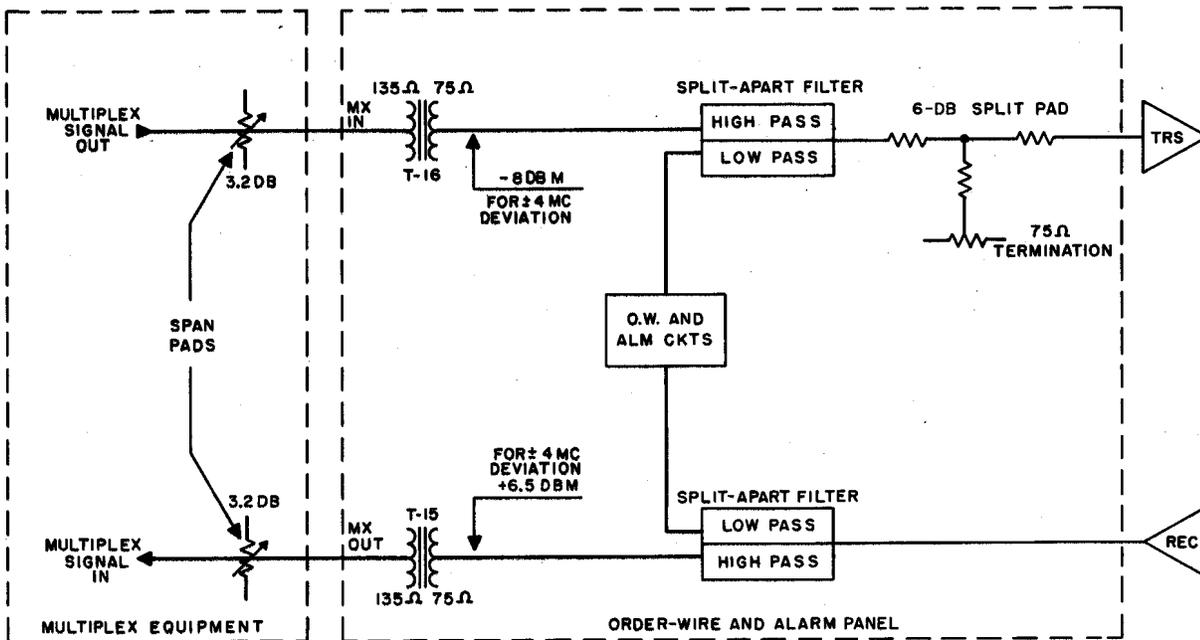


Fig. 15—Typical Radio Multiplex Baseband Interconnection—Block Diagram

TABLE E

TRANSMISSION LEVEL POINT OR SINGLE-CHANNEL POWER

MULTIPLEX	MX OUT	MX IN
L(240)	-22 dBm	-7.5 dBm
L(600)	-25.8 dBm	-7.5 dBm
ON	-34 dBm per carrier	-19.5 dBm per carrier
N	-28 dBm per carrier	-13.5 dBm per carrier

6. EQUIPMENT MAINTENANCE

6.01 A simplified maintenance scheme is used in the TL-1 radio system. The variety of initial and routine tests needed to ensure toll grade transmission, and the pieces of test equipment required, have been minimized. Defective units in a transmitter-receiver unit are readily removable and may be replaced directly with spare units. A number of built-in test features, including optimizing or transmitter linearity, and transmitter frequency and deviation adjustment, are performed with the aid of meters that are contained within the

transmitter-receiver unit on the meter and control panel. One meter on this panel permits monitoring of power-supply voltages, receiver crystal currents and automatic frequency control voltage, klystron currents, and transmitter RF power output. All initial and routine tests are performed with three pieces of test equipment: a KS-14510 volt-ohm-milliammeter, a J99262AA portable test set, and a Weston model 931 precision voltmeter.

6.02 The J99262AA test set is a fully transistorized ac operated instrument that is a combination voltmeter, signal generator, and attenuator. The

voltmeter provides ranges from -40 to $+13$ dBm and measurements may be made from audio frequencies to 6.0 MHz on a bridging or terminated basis. Measuring impedances are 75 and 600 ohms. The signal generator portion of the test set contains seven oscillators with frequencies of 2600 Hz, 100 KHz, 4.5 MHz, 66 MHz, 70 MHz, and 74 Hz. An electronic switch is included to give a 66- to 74-MHz switched output signal. The oscillator output is metered and can be varied by means of a 0- to 60-dB rotary attenuator and a 40-dB fixed pad. Output impedance is 75 ohms and frequencies

are selected by means of pushbuttons. This generator is used to make a variety of tests, such as IF and receiver automatic frequency control alignment, received signal strength measurements, receiver sensitivity adjustments, and baseband transmission tests.

- 6.03** The Weston model 931 voltmeter is a precision meter used to adjust power-supply voltages.
- 6.04** The KS-14510 volt-ohm-milliammeter is a standard general purpose test instrument.