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TH-3 Medium-Haul Application: System Considerations

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The medium-haul application of TH-3 was developed to provide an economically attractive system of moderate length and cross section without seriously compromising performance. To achieve high-quality transmission the radio transmitter-receiver bays and FM terminals common to the long-haul plant were used. Supporting equipment was both designed and adapted specifically for the medium-haul application in order to keep overall costs to a minimum.

I. INTRODUCTION

This paper discusses a radio system which has been made available to the Associated Bell System Companies to help meet their demands for high-performance transmission capability. It is made up of the TH-3 IF heterodyne radio bay and 4A FM terminals along with a number of supporting features. This system was formulated to be a flexible package that may be customized to specific transmission needs within the Bell System. Flexibility results from the optional use of a frequency-diplexed auxiliary channel, a one-by-one baseband protection switching system, a single transmitting/receiving antenna, and the use of shelters to house the equipment. These features collectively distinguish the medium-haul concept from that which is typically called long or short haul.

In spite of the difficulty establishing a model for the medium-haul system, since the anticipated applications are so varied, a 1000-mile, 1800-circuit system model (38 hops with 4 baseband switching sections) has been selected. This choice represents a reasonable compromise between the 4000-mile long-haul model and the 250-mile short-haul model and will be used to describe noise and reliability performance. This system will meet the two-way reliability objective of 0.02 percent and, depending on how the options are exercised, has a noise performance falling within the range from 35.5 to 36.0 dBrnc0. Extrapolation of performance data to other arrangements is relatively straightforward.

II. SYSTEM DESCRIPTION

The development of an overall radio system suitable for medium-length and medium-cross-section applications has resulted in the use of some existing subsystems, the adaptation of others, and some completely new designs. At the heart of the radio system are the TH-3 transmitter-receiver bays[1] and the 4A FM terminals.[2] These are used essentially as originally designed, while the power plant and the buildings are existing designs which require some adaptation for this application. Such items as the 300A protection switching system,[3] the E2 status reporting and alarm system for medium haul,[4] and the frequency-diplexed auxiliary channel[5] involved fundamental design work most of which was stimulated by the medium-haul application.

Figure 1 shows in a simplified manner the essentials of a medium-haul TH-3 system. Main stations, which are the switching section end links, are characterized by the presence of baseband signals. The 300A protection switching system shown in Fig. 1 may be at a main station or it may be physically isolated from the main station by as much as eight miles via wire line entrance links. If the system includes more than one tandem switching section, a back-to-back pair of main stations exists at the junction of the switching sections. Repeaters are characterized by the fact that the through signal does not go through an FM remodulation process; therefore, with the exception of the auxiliary channel signal, only RF and IF signals are present at repeaters.

The following paragraphs briefly cover some of the salient features of the blocks shown in Fig. 1.

2.1 *Basic Transmission Equipment*

This equipment includes the entrance links, FM terminals, and TH-3 transmitter-receiver bays. Standard 3A wire line entrance link gain and equalization equipment and 4A FM terminals are used with medium-haul systems. As with the entrance links and FM terminals, the TH-3 transmitter-receiver bay is identical for both long- and medium-haul applications.

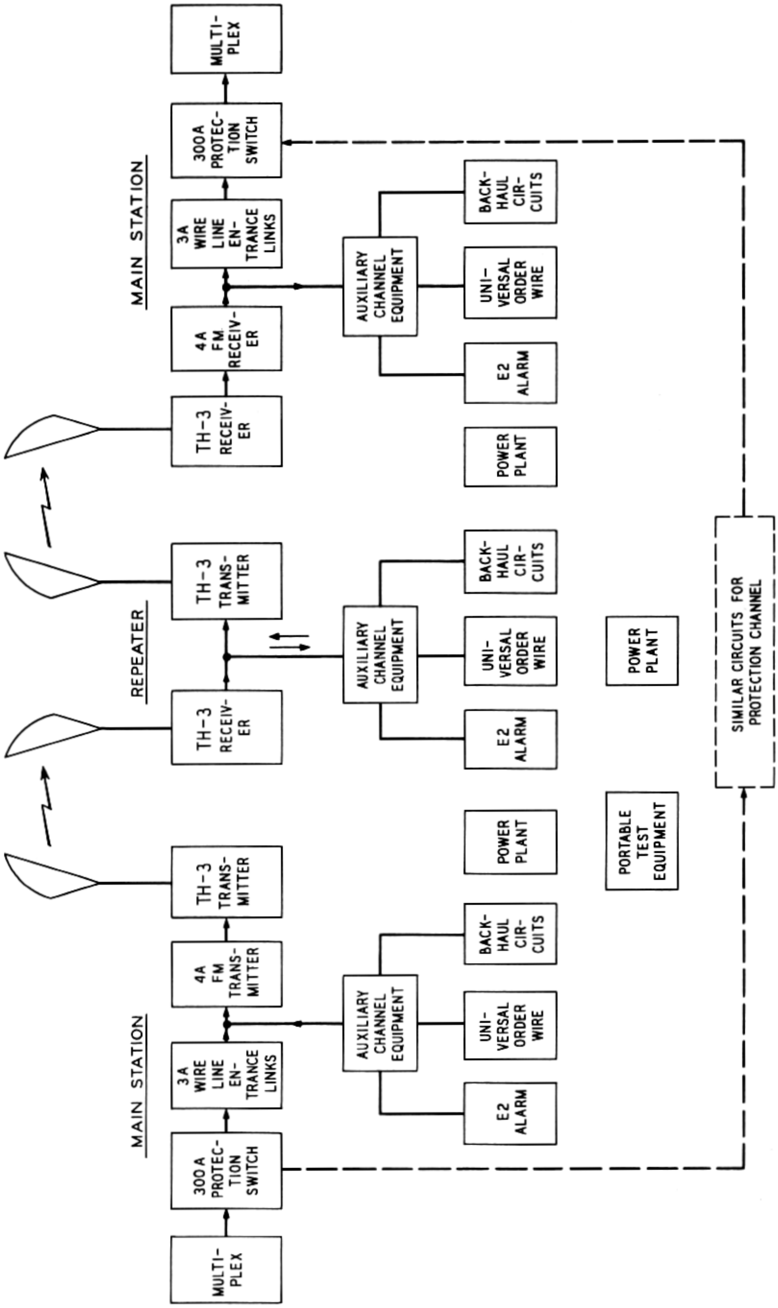

Fig. 1—Typical two-hop medium-haul system providing transmission in one direction. Similar equipment is required for transmission in the opposite direction.

2.2 *Baseband Protection Switch*

A new solid state protection switching system, designated 300A, has been developed to provide a one-for-one baseband switch for the protection of message service. Protection is provided by modulating simultaneously the two radio channels at the transmitting end of the switching section. All switching is done at the receiving end where the channel monitors, automatic logic, and controls are located. The comparatively high signal handling capacity of the switch and its low loss permit the entrance links and FM terminals to be included within the switching section.

2.3 *Auxiliary Circuit Facility*

The frequency-diplexed auxiliary channel is an inband (over the radio) transmission facility with access at each radio station. It operates above the normal 1800-circuit payload signal in a narrow band centered at 11.38 MHz. The basic auxiliary channel arrangement has available three voice-frequency circuits. Two of these would normally be used to carry order wire and alarm information, the third being available for other uses. With additional multiplex, up to 48 circuits for trunking may be provided. These "backhaul" circuits are intended to provide trunking facilities from a relatively remote location, near a repeater station, to a point where they would have access to the Bell System network. When 4A FM terminals are used, the auxiliary channel will have a noise performance roughly equal to that of short-haul radio (35 dBrnc0 for 10 hops).

Access to the auxiliary channel is straightforward at terminal stations since the baseband signal is present. At repeater stations a 4A FM receiver is bridged onto the IF signal path. The FM receiver output then provides a signal which may be utilized without any interference to the 1800 circuits in the through path. To modulate additional 11.38-MHz information onto the system a microwave FM modulator is placed in tandem with the microwave generator signal (local oscillator) driving the repeater transmitter modulator. By this means, access to the radio channel is available at each repeater station.

Since the auxiliary channel carries alarm information, it is important that transmission be highly reliable. For this reason, the auxiliary channel has its own protection switching system. The signal is fed over two RF channels; at each station along the route, the better performing RF channel is selected.

2.4 *E2 Status Reporting and Control System*

At the time the medium-haul concept was being established, an examination of existing alarm reporting systems showed them either to have capacity for too few alarms, indications, and orders, or to be physically too large and expensive for medium-haul purposes. In addition, the dc voltages associated with the power required for these systems was often not readily available at medium-haul installations.

One of the systems considered was the recently developed E1 status reporting and control system. This is a solid state digital system which includes data transmission facilities for use on a standard voice channel. Although in its existing embodiment it was large and costly for the medium-haul purpose, it had been designed using a modular approach. Stimulated by the medium-haul need, a modified version of the E1 system (called E2) was developed. This revised version eliminated the large cross-connect field that previously occupied one-third of the bay, and broke down the groups of alarms, indications, and orders into smaller packages.

The medium-haul needs involve approximately 12 orders and 90 combined alarms and indications at each station. The final remote E2 package handles this capacity with room for limited growth; i.e., a total of 32 orders and 128 combined alarms and indications. Capacity to grow to 256 alarms and indications exists by adding a small amount of hardware. A central E2 station for use with medium haul can control up to 64 remote stations. Each of these remote stations is "polled" by the central station for the status of its alarms.

The E2 package allows medium-haul systems to take advantage of the latest in designs and technology without incurring the large expense associated with status reporting and control systems tailored to larger needs.

2.5 *Portable Test Equipment*

Radio stations housing medium-haul TH-3 systems will frequently have as few as four transmitter-receiver bays along with a limited number of bays of supporting equipment. This is a small fraction of of the total amount of equipment located in a typical long-haul radio station. To minimize the cost of test equipment for medium-haul routes, use of portable test equipment is recommended. This test equipment is composed primarily of commercially available test gear housed in lightweight suitcases which can be easily transported. It may be stored at a central location, such as a maintenance station or alarm control center, from which it can be taken to any station that requires testing. Use of a limited number of sets of the equipment, depending on the length of the system, can drastically reduce the investment in test equipment compared to maintaining complete fixed test equipment at each radio station. Such a procedure is permissible because of the long test intervals that are expected to apply to both the TH-3 equipment and the supporting gear.

A feature of the TH-3 transmitter-receiver that helps make the portable concept attractive is the ability to replace any component in the bay without requiring immediate alignment with test equipment. This practice, when applied on a limited basis, will result in such slight impairment to system performance that precise alignment can be postponed until convenient.

The photograph in Fig. 2 shows a cart that permits stacking of the test equipment during maintenance. The test gear shown in the photograph is capable of maintaining the TH-3 radio bays with virtually the same accuracy attainable with test equipment dedicated to a station. Several additional commonly available test sets are used in conjunction with the maintenance of the auxiliary channel, order wire, alarm, and power equipment.

2.6 *Equipment Shelters*

An equipment shelter concept developed for short-haul radio may be used for medium-haul TH-3. This concept provides for factory installed and tested radio equipment with a minimum of field installation. Aluminum "truck body" type structures are available to house the radio equipment. Several different lengths are available depending on anticipated growth. For a radio system of this type where a limited amount of equipment is installed with a minimum of special modifications, this type of shelter provides a very economical building. A bay pivoting arrangement was developed to permit mounting the equipment against the shelter wall and still allow maintenance from both sides of the bay.

2.7 *Power*

The main source of power at medium-haul stations is a −24-volt battery reserve plant. Small amounts of power at +24 volts are indirectly supplied from the −24-volt plant by voltage converters. The current drain at a typical repeater station is 65 amperes, with a recommended battery reserve of about 33 hours. The 111A power plant specified for this system permits two alternatives: either a

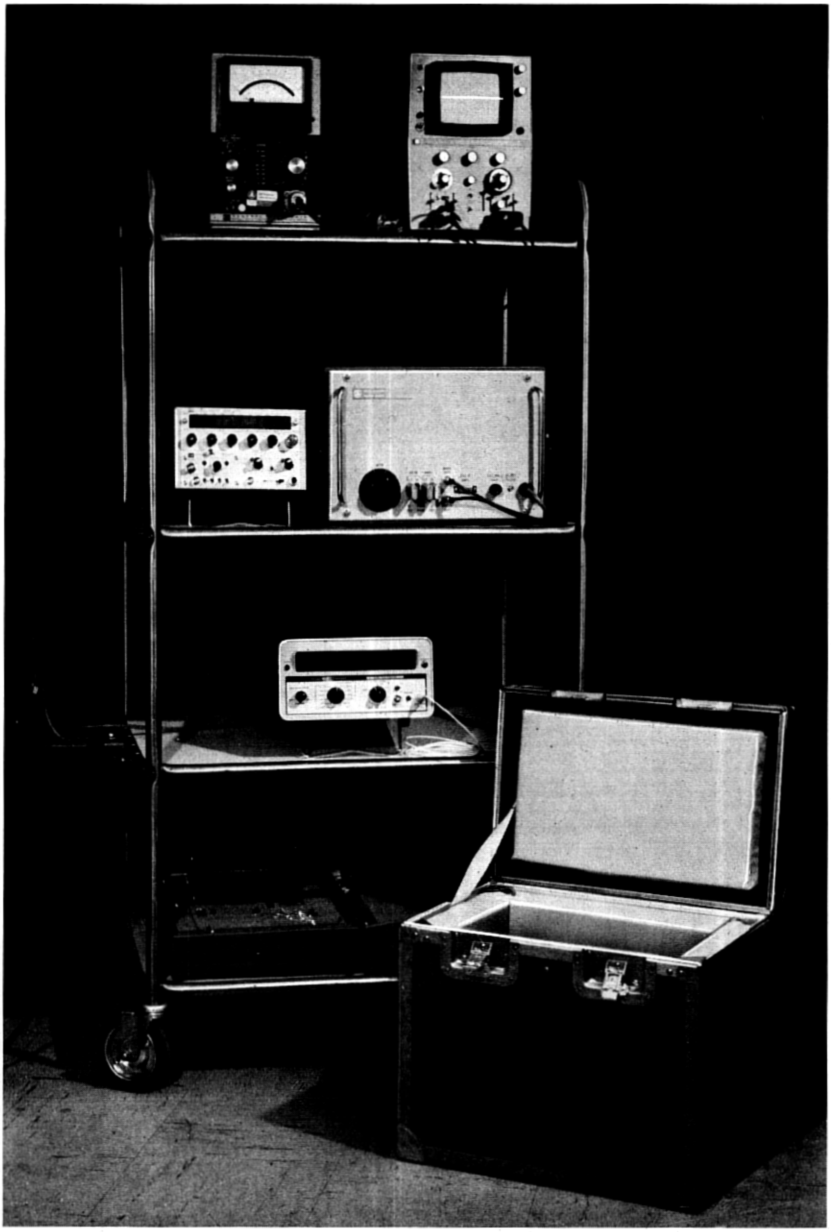

Fig. 2—Portable test equipment on cart.

rectifier which operates from three-phase primary power or a newly developed 100-ampere single-phase rectifier. The single-phase rectifier is necessary since some of the radio stations will be remotely located from three-phase lines.

2.8 *Environmental Limits*

To reduce building costs for medium-haul systems, the equipment shelters (or small buildings for that matter) may not be air conditioned, but fans and heaters might be required depending on local climatic conditions. An environmental temperature range of 40°F to 120°F was established for medium-haul systems, a range which can be maintained without air conditioning in most areas. This will reduce building costs. Performance of the equipment has been established to be satisfactory over this range.

III. BASEBAND MODULATING SPECTRUM

3.1 *General*

TH-3 medium-haul systems provide a usable baseband of up to 10 MHz capable of carrying 1800 message circuits or other broadband services. With the auxiliary channel and 300A protection switching system continuity pilot, the baseband spectrum of medium-haul systems contains signals having frequencies higher than the 1800-circuit message payload. The frequency deviation of medium-haul systems is therefore reduced compared to that of long-haul systems so that the necessary bandwidth* of the RF signal will not exceed the 30-MHz authorized bandwidth as specified by the FCC.

3.2 *Baseband Spectrum*

The composite broadband baseband signal that is applied to the FM transmitter is shown in Fig. 3. Power levels of the components are also shown. Part of the baseband spectrum is the 1800-message circuit load that is identical to that of the long-haul application except for its reduced total power. A continuity pilot which is used by the 300A protection switching system appears at 11.88 MHz. The auxiliary channel, consisting of a double sideband AM signal, occupies the frequency band from 11.09 MHz to 11.67 MHz with the auxiliary channel subcarrier at 11.38 MHz.

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* Necessary bandwidth (BW) as defined by FCC Rules: $BW = 2X$(highest baseband modulating frequency) + $2X$(peak frequency deviation).

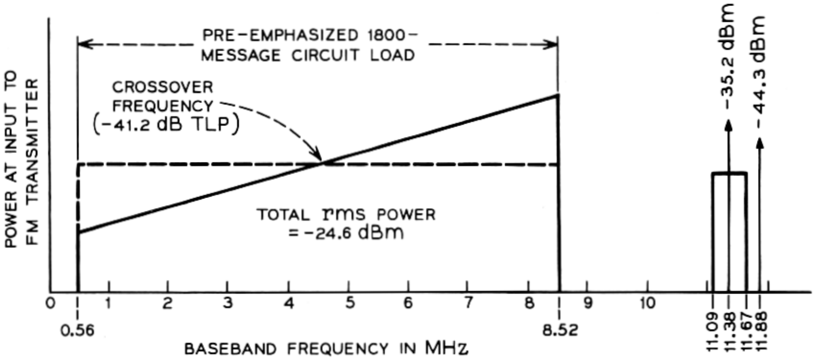

Fig. 3—Composite baseband spectrum at FM transmitter input.

3.3 *Frequency Deviation*

Immediately preceding the FM transmitter, the auxiliary channel signal is combined with the other baseband signals through a resistive combining network as shown in Fig. 4. Because the total power of the 1800-message circuit load is significantly greater than the power of the auxiliary channel signal or of the continuity pilot, the system's total frequency deviation is essentially controlled by the power in the 1800-circuit load. The −23.0 dBm power of the 1800-circuit load at the input side of the combining network is identical to the total baseband power delivered to the FM transmitter for long-haul applications.[6] The insertion loss of this network reduces the frequency deviation of the 1800-circuit load by 1.6 dB.

Based on the levels in Fig. 4 the rms frequency deviation of the

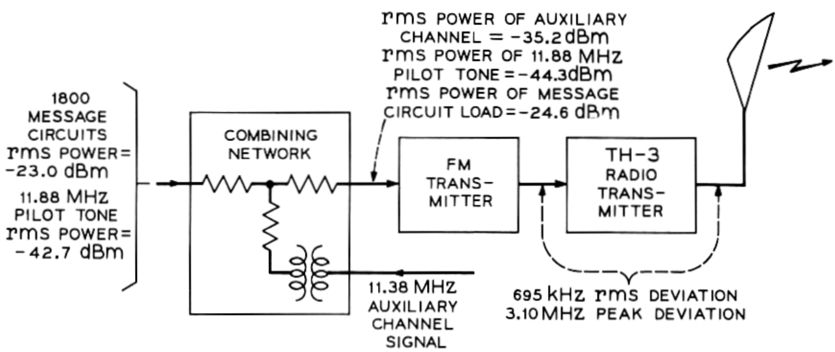

Fig. 4—Signal combining network and power levels.

various components of the baseband signal may be calculated. These are shown in Table I. The component deviations are then added on a root-mean-square basis resulting in a total rms frequency deviation of 695 kHz for the composite medium-haul signal.

Broadband message signals such as considered here have their peak frequency deviation related to the rms frequency deviation by a 13-dB peak-to-rms power factor.* This results in a 3.10-MHz peak frequency deviation for the composite medium-haul signal. Application of the definition for necessary bandwidth yields:

$$BW = 2(3.10 \text{ MHz}) + 2(11.88 \text{ MHz}) = 30 \text{ MHz}.$$

TABLE I—COMPONENT DEVIATIONS

1800-message circuit average busy hour rms deviation	663 kHz
11.88-MHz pilot tone rms deviation	69 kHz
11.38-MHz auxiliary channel rms deviation (carrier and sidebands)	196 kHz
TOTAL RMS DEVIATION	695 kHz

IV. ANTENNA AND FREQUENCY CONSIDERATIONS

Since route economy is a major consideration with the TH-3 medium-haul application, the use of a single antenna for transmitting to and receiving from a given direction is recommended. The horn reflector antenna is preferred because of its high gain and directivity but direct feed dual polarization parabolic radiators may also be used. New routes will generally use the single antenna approach since considerable cost savings result from simplified tower, waveguide, and building arrangements.

TH-3 medium-haul systems may also be added to established 4-GHz long-haul routes where existing buildings, towers, and antennas are available, in which case separate transmitting and receiving antennas would be used.

4.1 *Single-Antenna Frequency Plan*

The channel frequencies available for medium-haul systems are identical to those available for long-haul systems; that is, either a regular or staggered frequency plan may be used.[6] Having a choice

* A 13-dB peak factor is specified in the FCC Rules and Regulations for calculating necessary bandwidth.

of two frequency plans is important to medium-haul applications since, with only the regular plan available, interference might result between the TH-3 system and existing short-haul 6-GHz systems which use the staggered plan. The regular and staggered frequency plans allow a degree of flexibility when planning and designing new medium-haul routes.

Figure 5 shows channel assignments and antenna arrangements of a typical two-hop installation. The transmitters and receivers of a single radio bay are separated in frequency by the standard 252 MHz. This separation minimizes the possibility of the high-level transmitter signal interfering with the low-level receiver signal. Additional coupling loss between transmitters and receivers is achieved by transmitting and receiving on opposite polarities. In Fig. 5 only two frequencies are used for each two-way radio channel which will allow maximum utilization of the available 6-GHz spectrum.

4.2 *Interferences With Single Antennas*

With separate transmitting and receiving antennas, intrasystem interference that might be produced by the transmitted signal leaking into the receiving antenna facing the same direction is limited by the antenna's side-to-side coupling loss (typically 90 dB to 100 dB). Single antenna operation does not provide the high coupling loss of dual antennas; therefore, certain transmitter-receiver channel combinations may result in near-end intrasystem interference. For this reason, additional RF selectivity is available when single antenna operation is chosen.

4.2.1 *Tone Interferences*

The interferences that are attributed specifically to single antenna operation are related to the use of a 70-MHz IF. These are single-frequency (tone) interferences occurring at 4.13 MHz or 6.6 MHz in the baseband, depending on the channel combinations as discussed in Ref. 6.

4.2.2 *Additional Selectivity*

Additional selectivity, in the form of a nine-inch band-rejection filter located in the indoor waveguide runs (external to the bays), is specified to eliminate the interferences discussed above. The selectivity of these filters is such that system tone objectives will be satisfied.[6] Use of these filters will introduce a minimal amount of delay slope into some channels but the standard mopup equalization

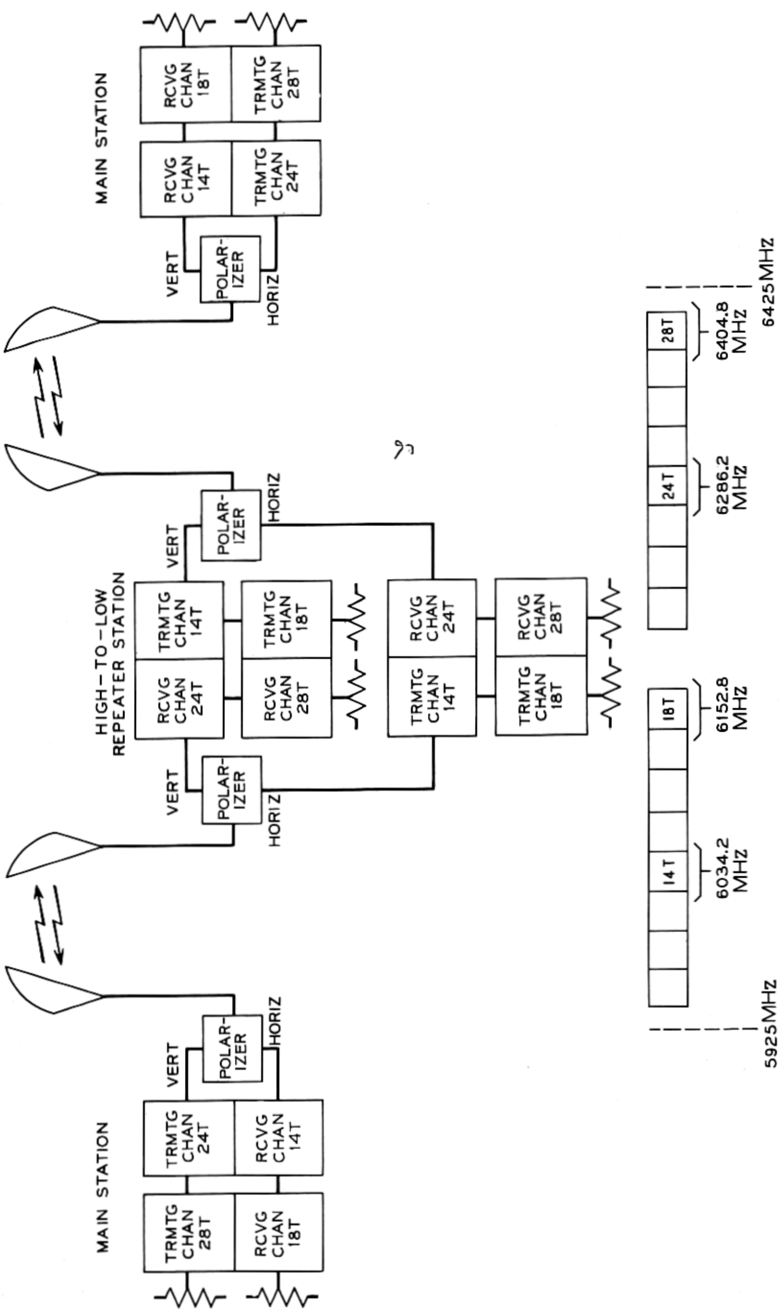

Fig. 5—RF channels and connections for a typical two-hop medium-haul system.

procedures remove this distortion. The reduction of interference level that is provided by the 4A FM transmitter's carrier-spreading circuit is not assumed in the selectivity requirements.[2] Routes using the 4A FMT will have additional margin from these interferences.

V. PERFORMANCE

The noise performance of a medium-haul TH-3 system is primarily determined by the noise performance of the FM terminals and the transmitter-receiver bays. Since these same items essentially determine the noise performance of long-haul radio routes, it is not surprising that the noise performance of medium-haul systems is approximately equal to long-haul systems scaled to the same length. Some of the features unique to medium haul, such as the auxiliary channel, reduced frequency deviation, and extended temperature limits, do have a small modifying effect on the overall system noise performance.

5.1 *Effect of Auxiliary Channel*

Since the auxiliary channel and broadband payload signals are jointly carried over these facilities, some intermodulation effects may occur. The message circuit showing the largest effect due to this noise is the top payload circuit. The noise in that circuit increases about 0.2 dB when the auxiliary channel signal is applied to a ten-hop system.

5.2 *Effect of Reduced Frequency Deviation*

The rms frequency deviation of the 1800-circuit load is reduced by 1.6 dB in order to satisfy FCC rules. To compensate for the lower signal level at the FM receiver output, the gain of the receiving wire line entrance link is increased by a corresponding amount. The reduced deviation results in a slight decrease in intermodulation noise and a small increase in idle noise. Field measurements indicate an increase in total noise of less than 1 dB with the reduced frequency deviation.

5.3 *Effect of Extended Temperatures*

The system noise performance is affected very little over the temperature range 40°F to 120°F. A small increase in system noise due to reduced transmitter power occurs at the high temperature extreme. At temperatures above 100°F, the reduced efficiency of the microwave circuits results in a small reduction of transmitter output power. The corresponding system noise is expected to degrade less than 1 dB, even when the overall route is exposed to these high temperatures. No significant changes in system performance occur at the low temperature extreme. Since the effects of these extended temperatures are slight, no special concern is required in engineering systems. The advantages of reduced building costs far outweigh the effects of the extended environmental range.

VI. APPLICATIONS OF MEDIUM-HAUL TH-3

6.1 *Morgan City-New Orleans System*

The first medium-haul application of TH-3 radio consisted of three hops installed by South Central Bell Telephone Company between Morgan City and New Orleans, Louisiana. The route layout and frequency plan are shown in Fig. 6. This system largely fulfills the description of the medium-haul application as covered in this article.

Existing VF landlines were readily available for carrying order wire and alarm signals. Therefore the frequency-diplexed auxiliary channel was not used. Single horn reflector antennas were installed at all stations.

At the Thibodaux repeater, potential interferences with other nearby routes did not allow a 252-MHz frequency shift for the through channels. Main station radio bays, each having independent transmit and receive frequencies, were installed to permit an appropriate shift of the RF frequencies.

Since the Morgan City-New Orleans route was the first medium-haul installation, particular attention was given to installation problems and overall system tests. No serious problems were encountered.

6.2 *Great Falls–Shelby System*

The second medium-haul TH-3 system was established by the Mountain Telephone Company on a route between Great Falls and

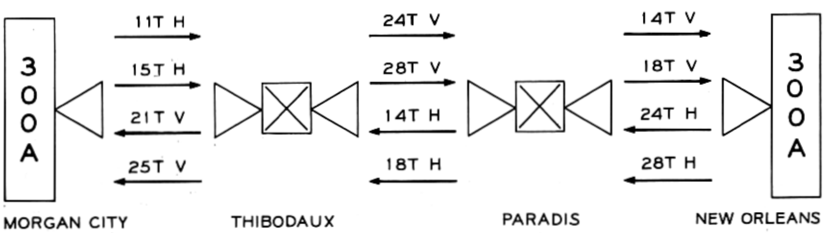

Fig. 6—Morgan City-New Orleans medium-haul installation.

Shelby, Montana. This system parallels an existing TJ microwave radio route, allowing the use of existing buildings, towers, and antennas. Figure 7 shows the variety of antenna systems employed. Careful choice of RF frequencies allowed the use of these existing facilities without creating any intrasystem interference problems.

This route also served as the first installation of the frequency-diplexed auxiliary channel. Details of the auxiliary channel performance are covered elsewhere in this issue.[5]

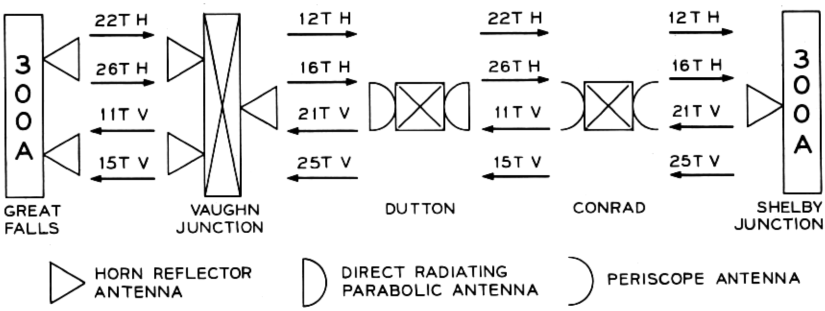

Fig. 7—Great Falls–Shelby Junction medium-haul installation.

VII. ACKNOWLEDGMENT

The medium-haul concept has been developed as the result of efforts by many people. The authors wish to acknowledge all those who contributed to the project. Cooperation from both Mountain Telephone Company and South Central Bell Telephone Company enabled us to measure the success of the medium-haul application.

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