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The AR6A Single-Sideband Microwave Radio System:

Terminal Multiplex Equipment

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A combination of new multiplex facilities provides the 6000-message-circuit loading for AR6A radio. It includes a Mastergroup Translator Type-B (MGTB) arrangement that accepts five U600 mastergroups to translate and combine them into a Multimastergroup (MMG) spectrum. A new multimastergroup translator for radio accepts two such MMG spectra from MGTB to produce the intermediate frequency signal and pilots for the AR6A line. A pair of pilots from the Bell System reference frequency transmission unit may be added to the MMG spectrum to be recovered at the receiving end for office synchronization. An office master frequency supply sends synchronization frequencies accurate to within one part in 10^9 for the MGTB and Multimastergroup Translator-Radio translating equipment. Description, design features, and performance characteristics are described in detail below.

I. INTRODUCTION

This section describes the frequency-division multiplex facilities that form and recover the 6000-message-circuit load for the AR6A† Radio System. Starting with the U600 mastergroup (MG)‡ spectrum formed by existing multiplex facilities, terminal equipment recently

* Bell Laboratories.
† Amplitude Modulation Radio at 6 GHz for the initial (A) version of the system.
‡ Acronyms and abbreviations used in the text and figures of this paper are defined at the back of this *Journal.*

developed to form the multimastergroup (MMG) spectrum for the L5E Coaxial Cable System is also used to form the MMG spectrum for AR6A. This equipment is the Mastergroup Translator Type B (MGTB).

An assembly of five MGTB mastergroup translators translates for five U600 input signals (0.564 to 3.084 MHz), each having a 2.840-MHz mastergroup pilot. The combined outputs of the five translators form an MMG spectrum to which a 13.920-MHz continuity pilot is added. This MMG spectrum occupies the frequency band of 8.628 to 21.900 MHz.

Two such MMG spectra are used as inputs to the Multimastergroup Translator for Radio (MMGT-R). The transmitting MMGT-R terminal combines each MMG with specific recovery and radio-line pilots and modulates each MMG separately to form the IF spectrum of 59.844 to 88.460 MHz. Figure 1 shows the basic mastergroup, MMG, and IF spectra.

Figure 2 shows the process used in MGTB and MMGT-R terminals to translate and recover the ten U600 basic mastergroups.

An accuracy of one part in 10^9 is required for some carrier and pilot frequencies to generate, administer, and recover the mastergroup, MMG, and IF spectra. This accuracy is achieved by synchronizing the carrier and pilot generators to the 2.048-MHz Bell System frequency standard. For locations where this signal is not available, two reference pilots generated by the Bell System Reference Transmitting Unit (BSRTU) are added to the first MMG of an AR6A channel. The precise 64-kHz frequency difference between these pilot tones of 11.200 and 11.264 MHz is derived from the nationwide Bell System Reference Frequency Distribution System. The Bell System Reference Tone (BSRT) receiver unit retrieves the 64 kHz from these pilots for synchronization of the Office Master Frequency Supply (OMFS), which serves the MMGT-R and MGTB facilities.

II. MGTB TRANSLATOR

2.1 Introduction

The block diagram of the mastergroup translator is shown in Fig. 3. Each translator provides modulation and demodulation, serving both directions of transmission. The same basic design is used for all five translators for AR6A. Only the carrier generator frequency and the bandpass filters in the modulator and demodulator are changed to achieve the desired translated spectrum.

2.2 Improved spectrum utilization

Earlier designs of mastergroup multiplex equipment translate and combine up to six mastergroups to form an MMG spectrum with

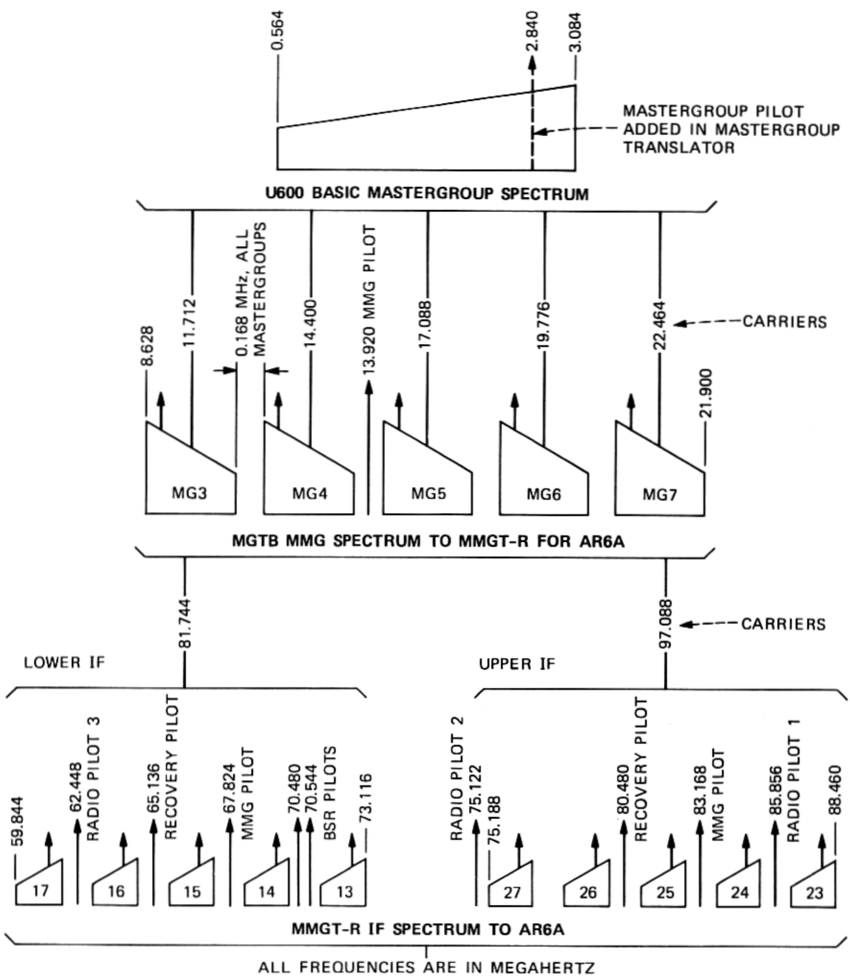

Fig. 1—AR6A terminal equipment spectra.

unequal spacing between the mastergroups. Use of that equipment permitted transmission of 18 mastergroups (10,800 voice circuits) per single coaxial cable or four mastergroups (2400 voice circuits) per FM radio channel.

For the L5E System[1] MGTB equipment translates and combines up to eight mastergroups with a fixed spacing of 168 kHz between mastergroups in the MMG spectrum. By applying three of the MGTB MMG spectra to associated equipment, a total of 22 mastergroups (13,200 voice circuits) are transmitted over a single coaxial cable.

This concept of improved spectrum utilization was carried over into the AR6A development by using five MGTB mastergroups (3 through

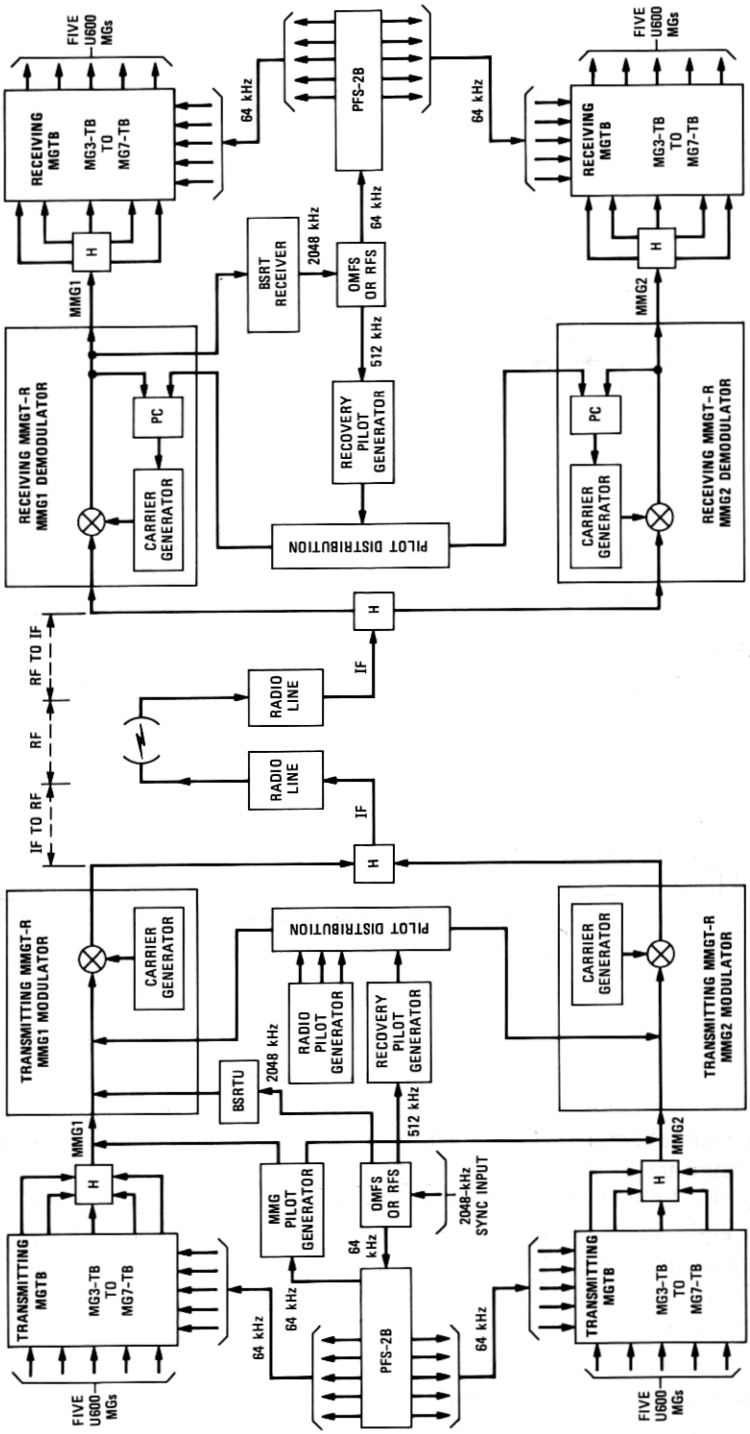

Fig. 2—Block diagram of AR6A terminal equipment.

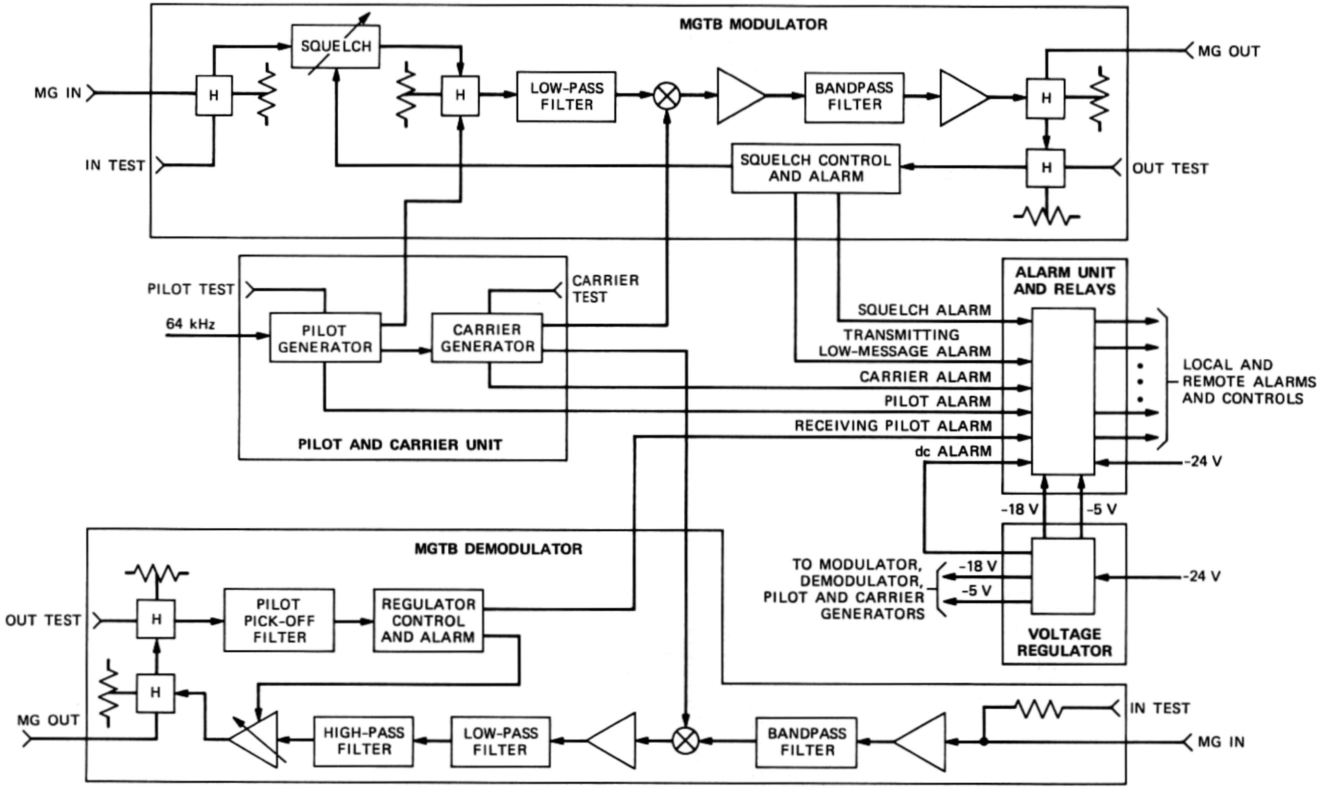

Fig. 3—Block diagram of mastergroup translator shelf.

7) to form the MMG spectrum for input to the MMGT-R. These particular mastergroups were selected to facilitate the realization of filters within the MMGT-R equipment.

2.3 Small size and low initial cost

With MGT designs, the only common equipment in a bay is its battery, fuse, and synchronization distribution panel. Cost of this common equipment is a small portion of the cost of a fully equipped bay. Hence, the incremental growth cost per mastergroup is essentially the cost of the MGT shelf itself. An MGTB bay occupies only half the space needed for earlier equipment designs providing equivalent capability. All circuits for an MGT mastergroup are contained in five small plug-in units per shelf, permitting simplified maintenance or replacement.

2.4 Overall design features

The five plug-in units of an MGTB mastergroup translator are a voltage regulator, alarm unit, pilot and carrier generator, and modulator and demodulator units. These five units contain the circuitry required to translate the U600 mastergroup signal to and from its line spectrum. Test jacks on the plug-in units permit signal monitoring at the inputs and outputs of the modulator and demodulator and at the outputs of the mastergroup pilot and carrier generators.

Transmission and circuit function alarms are displayed locally by indicators on the alarm plug-in and atop the bay. They are also made available to remote surveillance systems. These alarms may be operated in a latched mode, which causes retention of alarm indications until a memory release function is performed.

During a persisting alarm state, the audible alarms are silenced by depressing an Alarm Cutoff (ACO) switch on the alarm unit.

2.5 Circuit design features

2.5.1 Voltage regulator circuit

A −24 volt office battery input drives two series voltage regulators to provide −18 and −5 volt outputs to power the mastergroup translator shelf circuits. The dc drain on the office battery is 1.3 amperes per MGTB shelf.

2.5.2 Pilot and carrier generator circuit

A −20 dBm0, 2.840-MHz mastergroup pilot is used to indicate the relative signal level of the mastergroup. This pilot is added in between supergroups of the mastergroup signal in the transmitting circuit before modulation. Thus, it appears in the line spectrum translated by the carrier frequency. This pilot is used for automatic regulation and alarming. The pilot generator oscillator is phase locked to a stable Primary Frequency Supply (PFS) synchronization source which is locked to an OMFS. Hence, the stability and frequency accuracy of the mastergroup pilot are essentially the same as those of the OMFS supply.

The 64-kHz synchronization signal from the primary frequency supply is divided down to 32 kHz. This 32 kHz is used as a reference signal at one input of a phase comparator. The output of a voltage-controlled crystal oscillator, also divided down to 32 kHz, is fed to the second input of the phase comparator. Phase comparison of these two signals results in a dc control voltage to the oscillator to alter its frequency until the phases of both 32-kHz signals at the comparator inputs are identical. This constitutes the phase-locked loop concept of signal generation wherein the generated signal is stated as being phase locked to a reference signal. A filter at the generator output suppresses harmonics of the pilot frequency.

The MGTB carrier generation is similar to that of the mastergroup pilot generation previously described. The same 64-kHz synchronization signal used for pilot generation is used directly to phase lock the carrier generator to the Bell System reference signal. Two outputs at +10 dBm serve the modulator and demodulator in each MGT shelf. (See Table I for characteristics and performance of MGTB.)

Table I—Characteristics and performance of MGTB

Characteristic	Performance
Type of modulation	SSB-SC-AM
Number of VF channels	600
Basic MG spectrum (U600)	0.564 to 3.084 MHz
MG3B spectrum	8.628 to 11.148 MHz
MG4B spectrum	11.316 to 13.836 MHz
MG5B spectrum	14.004 to 16.524 MHz
MG6B spectrum	16.692 to 19.212 MHz
MG7B spectrum	19.380 to 21.900 MHz
Return loss, all ports across their spectrum	>20 dB
Back-to-back frequency response	flat within ±0.4 dB
Receive pilot regulation range	±5 dB
Loss of pilot regulation	Receiver reverts to normal manual gain setting when input pilot level deviates >−10 dB from nominal.
Noise performance (fully loaded and back to back)	<10 dBrnc0
Phase-jitter performance (back to back) with two independent carrier supplies	<1° peak to peak, Bell weighted
MG carrier phase jitter	<0.7° peak to peak, Bell weighted
MG carrier supply frequency stability	1×10^{-9} with PFS-2B supply and OMFS
dc current drain per MGT shelf	1.3 ampere, maximum at −24 volts dc
dc supply voltage	−20 to −28 volts dc

III. MMGT-R TRANSLATOR

3.1 Introduction

The MMGT-R provides frequency translation between MMG spectra at the MGTB translators and the IF spectrum for AR6A radio. Two MMG signals (MMG1 and MMG2) are individually translated and combined to form the lower and upper portions of the AR6A IF spectrum centered at 74.1 MHz. Three radio-line pilots, required for regulation in the AR6A System, are generated in the MMGT-R transmitter.

Because the signal output of the MMGT-R transmitter is single sideband, suppressed carrier, and amplitude modulated (SSB-SC-AM), minimal carrier energy is transmitted with the sideband information. To enable the receiving translator to track and reconstruct the transmitted message accurately, a substitute form of carrier is added to the message in the transmitting translator. This is a highly stable, 16.608-MHz recovery pilot that serves as an input to a phase-locked loop in the receiving translator to control its demodulator carrier frequency. This corrects frequency offset on message due to repeatered transmission.

MMGT-R terminals are protected on a basis of one protection T and R translator pair for up to 14 regular T and R translator pairs.

3.2 Overall description

3.2.1 Regular terminal

The block diagrams for the regular transmitting and receiving translator portions of the MMGT-R terminal are shown in Figs. 4 and 5, respectively.

In the transmitting direction, MMG1 and MMG2 with 13.920-MHz continuity pilots from MGTB are each translated independently up to adjacent frequency bands of the radio IF spectrum. Their combining produces a composite IF signal of two uncorrelated spectra of 3000 circuits each in the band from 59.8 to 88.5 MHz, centered at 74.1 MHz.

A number of pilots for functions required by MMGT-R and AR6A are generated within the MMGT-R transmitter and are added to the MMG signal at a −10 dBm0 level prior to translation. These include three radio-line pilots at 11.232 and 21.966 MHz in MMG2, and 19.296 MHz in MMG1. Their translated positions in the IF spectrum are shown in Fig. 1. They control automatic gain and dynamic amplitude equalizers in the radio receivers. They also serve as continuity pilots for the 500A Protection Switching System.

A 16.608-MHz recovery pilot is added to both MMG1 and MMG2 spectra prior to translation in the MMGT-R transmitters. This pilot is used in place of the suppressed carrier for demodulator carrier

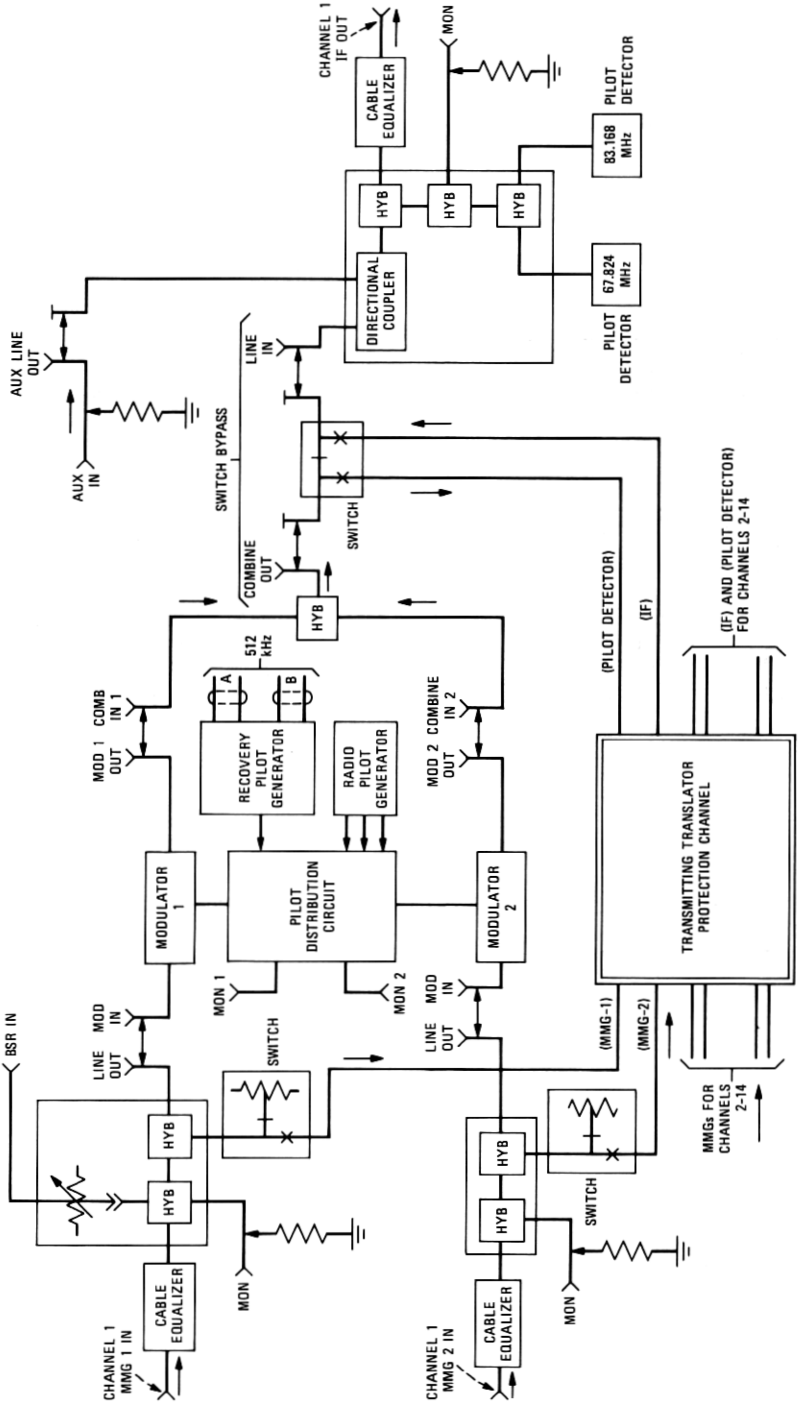

Fig. 4—Simplified block diagram of transmitting MMGT-R translator.

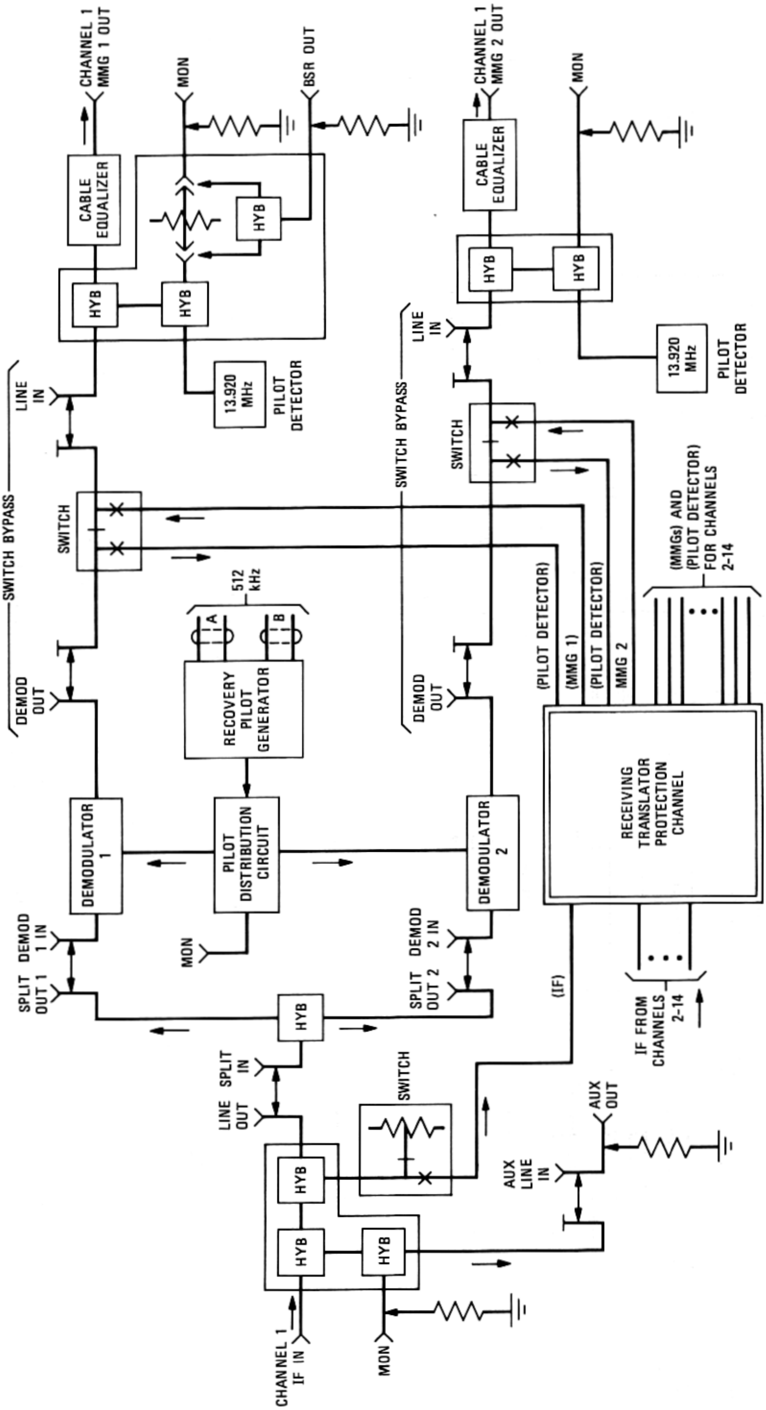

Fig. 5—Simplified block diagram of receiving MMGT-R translator.

frequency control at the receiving station. This function is discussed in greater detail later.

On occasion, it is necessary to use AR6A to transmit the Bell System reference frequency generated at Hillsboro, Missouri, to points not served by other carrier facilities. A BSRTU generator converts a 2.048-MHz reference frequency to two pilot tones separated by 64 kHz. These 11.200- and 11.264-MHz tones are added to MMG1 prior to translation in the MMGT-R transmitter. They are recovered at the receiving MMGT-R where a BSRT receiver converts their difference frequency to the original 2.048-MHz reference frequency. Although the absolute frequencies of the two tones may have shifted because of frequency error attributed to radio repeaters, their precise 64-kHz difference is preserved. Thus, the Bell System reference frequency integrity is preserved.

In the receiving direction, the IF signal from AR6A radio is passed through a splitting hybrid. A pair of upper and lower IF sideband filters separates the signal into its two original sideband components. Each sideband is then translated downward to the multimastergroup spectrum for further demodulation to the basic mastergroup spectrum in MGTB equipment.

3.2.2 Protection terminals

As shown in Figs. 4 and 5, protection transmitting and receiving translators are provided for equipment protection, maintenance, and restoration. The equipment required for this includes switches, pilot detectors, pilot oscillators, and a microprocessor control circuit. The switches, pilot detectors, and oscillators are located in the MMGT-R shelves. The 500B protection switch microprocessor control unit is located in an adjacent bay. Thus, only dc control leads are required between the 500B and MMGT-R bays, and transmission cable lengths are minimized.

Service is routed through the protection translator when a fault is detected in a regular translator or when a manual switch is requested. One protection translator provides protection for up to 14 regular translators. Receiving and transmitting translators are protected independently of each other. This results in two separate 1×14 switching arrangements under the common control of a single 500B controller at each MMGT-R location.

Loss of the 13.920-MHz continuity pilot in an MMG is detected by the MMGT-R equipment. When a failure occurs, the 500B controller transfers both MMG1 and MMG2 to protection even though a failure may have been associated with only one MMG. Local and remote alarms and indications are provided by the 500B.

3.3 Detailed description

3.3.1 Transmitting translator

Each transmitting translator includes all of the networks and circuits required to translate a pair of MMG signals to the lower and upper IF frequencies (see Fig. 1). The protection transmitting translator differs from the regular one only in the peripheral circuits associated with the input and output functions. Plug-ins MODULATOR 1 and MODULATOR 2 (see Fig. 6) each contain a balanced diode ring modulator, amplifiers, and a free-running, crystal-controlled carrier oscillator. IF bandpass filters select the lower sideband of each modulator.

A 16.608-MHz recovery pilot generator (RCVRY PLT GEN) is phase locked to a local 512-kHz signal derived from the OMFS which is locked to the Bell System reference. A hybrid transformer network distributes the recovery pilots to the MMGT-R modulators.

The radio-line pilots are generated by three free-running crystal oscillators at frequencies of 11.232, 19.296, and 21.966 MHz and are added to the MMG signals by the hybrid transformer network above.

The distribution network maintains at least 85 dB of isolation between the two MMG signal paths of an MMGT-R.

MMG1 and MMG2 input networks provide terminated monitoring access and split the signal to provide inputs to the protection translator. The Bell System Reference (BSR) input option is required only for MMG1.

An output port is available to make terminated measurements of the IF output signal. An auxiliary input port may be used for restoration. Pilot detectors monitor the translated 13.920-MHz continuity pilots to initiate a switch of both MMGs to protection when the level of either or both drops 6 dB or more.

3.3.2 Receiving translator

The receiving translator accepts an IF signal from AR6A via the 500A protection switch. This IF signal is split into two paths by a hybrid, following which the upper and lower IF bands are selected with IF bandpass filters. Each is then demodulated to the MMG

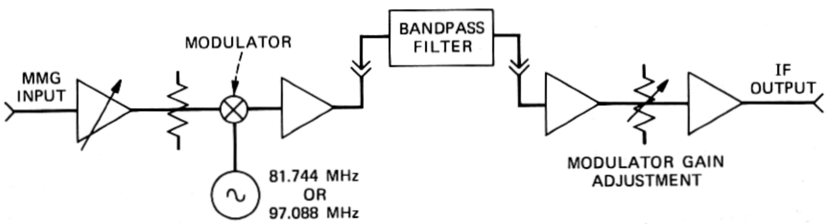

Fig. 6—MMG1 or MMG2 modulator.

spectrum for connection to receiving MGTB equipment. Plug-ins DEMODULATOR 1 and DEMODULATOR 2 (see Fig. 7) use ring-type modulators as in the transmitting direction. The demodulator carriers are generated by voltage-controlled crystal oscillators. Their frequency is controlled by a phase-locked technique to correct the frequency error that accumulates along the radio line. This technique is described below.

A 16.608-MHz recovery pilot is generated in the receiving office translator in a manner identical to that used in the transmitting office translator. It is phase locked to the Bell System reference via the local 512-kHz reference frequency at the receiving site. This 16.608-MHz signal serves as the reference input to the phase-locked loop of each demodulator carrier generator.

From each demodulated MMG in the receiving MMGT-R, the recovered 16.608-MHz pilot, with any frequency offset acquired over the radio line, is selected by a narrowband crystal filter. The phase of this received pilot is compared to that of the locally generated 16.608-MHz signal. Any phase difference between them is converted to a dc control voltage change. This voltage change alters the frequency of the carrier oscillator in a direction to correct frequency offsets of at least ±2500 Hz in the received signal. This technique ensures that the recovered MMG signal is a faithful reproduction of the original transmitted signal.

To enhance the pull-in range of the phase-locked loop, a low-frequency (≈2 Hz) oscillator has been added to the loop filter feedback circuit. This oscillator is activated upon interruption of one or both phase comparator input signals, and when activated, it modulates the

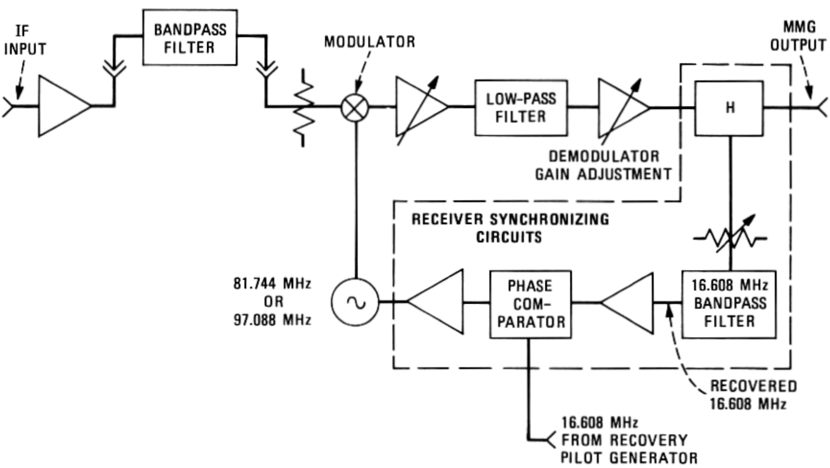

Fig. 7—MMG1 or MMG2 demodulator.

oscillator dc control voltage with sufficient amplitude to sweep the carrier frequency over a range of ±2500 Hz from nominal. This facilitates recapture of a restored signal. In addition, the low-frequency signal is peak detected to generate an out-of-lock alarm and a protection-switch request. Once the loop reacquires lock, the low-frequency oscillator is immediately disabled and has no effect on normal operation.

To accommodate space-diversity applications, the receiver phase-locked loop has been designed such that large phase hits coupled with sudden signal up fades will result in less than 2 ms of loop-phase instability.

The receiving IF network provides terminated monitoring access and splits the signal for protection switching. It also provides an auxiliary output for restoration. Signal monitoring access is provided at both translated MMG outputs. Pilot detectors monitor the recovered 13.290-MHz continuity pilots to initiate protection switching. On a 6 dB or more drop in level of either or both MMG pilots, both MMGT-R translators will switch to protection.

3.3.3 Recovery pilot generator

The 16.608-MHz recovery pilot generator is shown functionally in Fig. 8. Reproducing the transmitted signal accurately is highly dependent upon synchronizing the pilot generator to accurate 512-kHz reference frequency signals. These are derived from the OMFS, which, in turn, is locked to the Bell System frequency source at Hillsboro, Missouri.

To enhance overall reliability, redundant 512-kHz inputs, designated A and B, are supplied to each recovery pilot generator. This is done over separate 135-ohm balanced cable buses and, where possible, via different cable ducts.

The recovery pilot generator accepts two 512-kHz signals, filters them in narrowband crystal filters, amplifies them, and via a divider, converts each to a 32-kHz square wave. A logic switch, preferential to the A signal, provides the selected 32-kHz square wave to one input of a digital phase comparator. The second input to the phase comparator is derived from a portion of the 16.608-MHz crystal oscillator output, which is converted to a 32-kHz square wave. Phase comparison of these two signals results in a dc control voltage that locks the oscillator precisely at 16,608,000 Hz.

Manual test operation of the 32-kHz logic switch is provided. However, phase hits could occur due to reference frequency signal switching. To prevent this, manual switching in the regular channel recovery pilot generator is inhibited unless service is being carried on the protection channel. Conversely, a manual switch in the protection

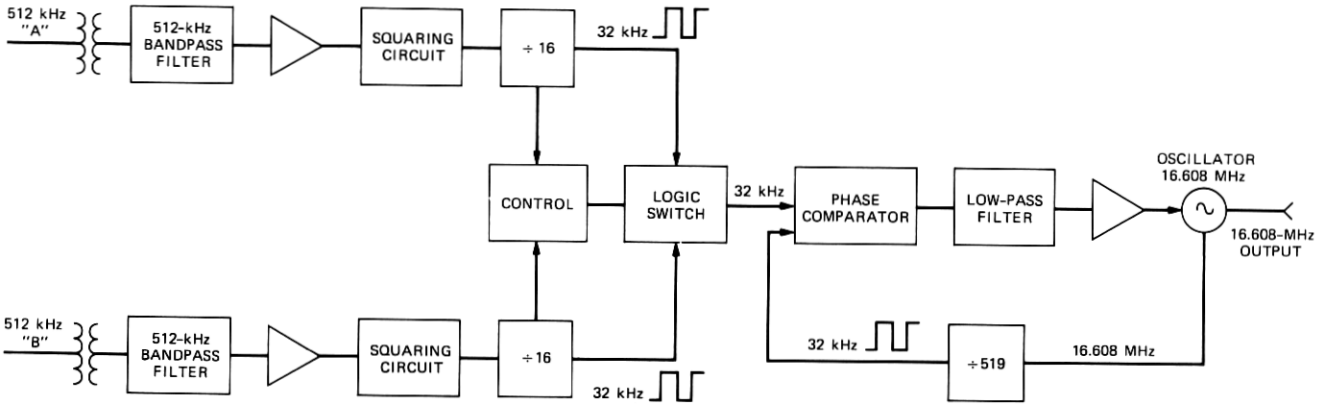

Fig. 8—Functional diagram of a recovery pilot generator.

channel recovery pilot generator can only be made when the protection channel is idle. (See Tables II and III for characteristics and performance of MMGT-R.)

3.4 Realization of objectives

The performance objectives listed represent acceptable levels of performance. Measured data reflect a level of performance better than the values shown. Examples may be seen in Figs. 9 and 10. Figure 9 shows a plot of amplitude versus frequency for a production transmitting and receiving translator pair connected back to back. Figure 10 shows representative noise load data for the same equipment in the same configuration. As the figure indicates, noise performance is thermally limited.

The overall amplitude versus frequency curve in Fig. 9 is a nonadjustable parameter. It is influenced by the response of the individual components (amplifiers, filters, etc.). The only equalization used with

Table II—Characteristics and performance of MMGT-R

Characteristics	Performance
Type of modulation	SSB-SC-AM
Number of MMGs	2 per AR6A channel
Number of MGs	5 per MMG (10 total)
MMG spectrum (MG 3-7)	8.628 through 21.900 MHz
IF output spectrum	59.844 through 88.460 MHz
MMG transmit input level	−41.6 dBTL
IF transmit output level	−23.9 dBTL
IF receive input level	−32.1 dBTL
MMG receive output level	−22.4 dBTL
Return loss (all ports)	>25 dB
dc power—input voltage	−20 to −28 volts dc
dc current drain (per shelf)	2.8 amperes maximum at −24 volts dc
Normal power dissipation per 7-foot bay (3T/R pairs)	400 watts
Protection	500 B − 1 × 14 maximum

Table III—Performance of MMGT-R

Performance Objectives	Worst-Case Deviation
Gain frequency response (1 − TR pair)	<±0.3 dB peak to peak across any MG
Noise performance (equivalent 6000-circuit load, 1 − TR pair)	<15 dBrnc0
Crosstalk	<−100 dB
Carrier leak	≤−70 dBm0
Spurious tones	≤−70 dBm0
Phase-jitter performance for ten terminal pairs in tandem	≤1° peak to peak, Bell weighted
Frequency stabilities (over 80° ±20°F temperature range and permissible power supply variation)	
Transmitter carrier oscillator frequency	±200 Hz
Radio-line pilot oscillator frequency	±4 parts per million

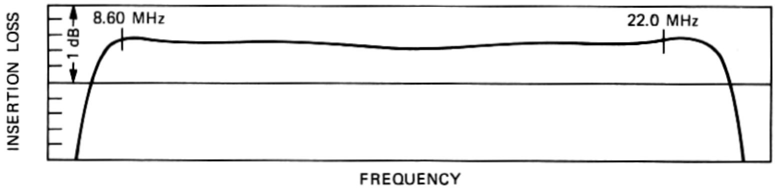

Fig. 9—Typical amplitude vs. frequency response of transmitting/receiving translator.

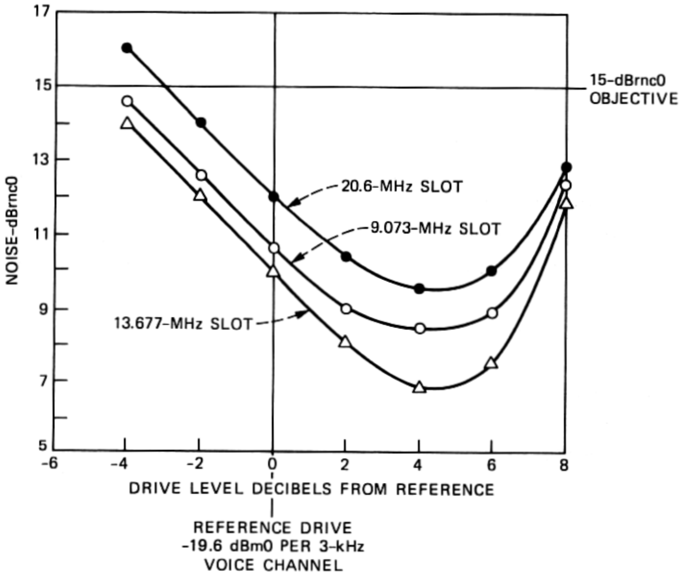

Fig. 10—Typical noise load performance of transmitting/receiving translator.

MMGT-R compensates for amplitude slope due to cable lengths in trunks between the MMGT-R, the MGTB, and the 500A equipment.

Mastergroups assigned to AR6A contain a mixture of analog-voice and voiceband data circuits subject to impairment due to excessive phase jitter. Strict phase-jitter requirements are placed on the transmit and receive carrier generators and on the recovery pilot generator to minimize phase-jitter transfer to data signals.

3.5 Physical design considerations

3.5.1 Goals

The physical arrangement of the MMGT-R equipment is oriented to achieve three major goals: (1) high reliability; (2) ease of installation, maintenance, and growth; and (3) cost-effectiveness. The first two items influence the third.

3.5.2 *Reliability*

When considering that an MMGT-R shelf carries up to 6000 two-way voice circuits and that a 7-foot bay carries up to 18,000 such circuits, reliability is of utmost concern. With this in mind, an early decision was made to minimize the amount of common equipment and to have each transmitting and receiving translator function independently.

This simplified the protection aspects of the system and minimized the risks to remaining operational parts of the system when equipment failures require repair or maintenance.

Carriers and recovery and radio-line pilots are all generated on a per-shelf basis with plug-in modules that may be replaced easily.

Converters of the dc-to-dc type are provided on a per-shelf basis with separate power for switching and transmission functions. A switching power failure does not impair transmission, and active transmission circuits are fully protected.

By locating switches and detectors in the same shelf as the equipment they protect, transmission cable lengths and interbay wiring and cabling are minimized.

The shelf and plug-in layouts promote rapid and natural heat dissipation. A combination of baffles and perforated cover assemblies permit the free flow of air vertically and from front to rear of each shelf. Each shelf has its own airflow pattern, avoiding high concentration of heat in the upper region of the bay.

3.5.3 *Ease of installation, maintenance, and growth*

The combination of the factors described previously led to a completely self-contained, totally connectorized shelf design. Thus, it requires no installer wiring for initial or subsequent growth installation. An alarm and fuse panel at the top of each bay constitutes the only MMGT-R common equipment. The protection MMGT-R and switch controller are naturally required with the initial installation to permit subsequent growth.

Redundant diode-firmed −24 volt power leads and 512-kHz reference frequency leads are connectorized and provided from the fuse panel to each shelf position in the bay. All active circuitry is of the plug-in type and all passive circuitry uses connectors for ease of removal or replacement. Access ports are provided for components outside protection switching boundaries to readily permit their bypassing for removal or replacement without delaying service restoration. These design concepts achieve a highly reliable and easily maintained circuit and equipment arrangement capable of "graceful growth."

3.5.4 *Cost-effectiveness*

As we stated earlier, achievement of the first two goals contributes significantly to providing a cost-effective system. By minimizing the amount of common equipment, the costs for new installations or for low cross-section systems with limited growth potential are reduced. Thus, the costs per circuit mile tend to be distributed more evenly. The reduced time required for installation and maintenance also contributes to lower overall operating expenses as well.

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AUTHORS

Antoine Dubois, E.E. Assoc., 1968, Merrimack College; Western Electric 1960–1967; Bell Laboratories, 1967—. Mr. Dubois began working at Western Electric Quality Assurance in 1960, and in 1967 joined Bell Laboratories, where he participated in the lineup of line-connecting and mastergroup-multiplexing circuits along the initial L-4 route. Since then, his responsibilities expanded to mastergroup administration. This includes mastergroup-multiplexing and associated circuitry used for multimastergroup transmission in cable and radio systems.

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Frederick M. Smith, A.E.E., 1960, Wentworth Institute; Bell Laboratories, 1960—. Since starting with Bell Laboratories Mr. Smith has been involved with such projects as short-haul microwave radio and terminal facilities. He is presently responsible for the MMGT-R multiplex terminal used with AR6A single-sideband radio systems.