Terminal Arrangements

By W. G. ALBERT, J. B. EVANS, Jr., T. J. HALEY,
T. B. MERRICK, and T. H. SIMMONDS, Jr.

(Manuscript received July 25, 1968)

New terminal equipment has been developed to provide the six-mastergroup signal that the L-4 repeatered line is capable of carrying. A major component of this equipment is the MMX-2 mastergroup multiplex, which translates six basic 600-channel mastergroups to their line frequency assignments in the range 0.564 to 17.548 MHz. Another component is the line connecting equipment, which contributes to shaping the line signal frequency characteristic and provides for blocking mastergroups. The purpose of this blocking is to provide dropping and branching with recovery of the spectrum for transmission of other mastergroups.

Mastergroup connectors are available for flexible interconnection of basic mastergroups without demodulation to supergroups. Finally, existing line protection switching equipment has been modified for use with the L-4 Coaxial System.

I. INTRODUCTION

The L-4 coaxial line is described in Ref. 1 as a transmission facility with a message capacity of six mastergroups. These six mastergroups are placed on the line in the frequency assignment shown in Fig. 1. Each mastergroup starts as a U600 basic mastergroup, formed by L-type multiplex (LMX) frequency-division multiplex equipment. An important function of the L-4 terminal equipment is the translation to line-frequency assignment of the six mastergroups. Earlier mastergroup multiplexing equipment, designed for the L-3 coaxial cable system and later used for TH microwave radio systems, has a capacity of three mastergroups.

The U600 basic mastergroup consists of 600 single-sideband channels stacked up in the frequency range 564-3084 kHz in 12-channel groups and 60-channel supergroups by frequency division multiplex techniques, using LMX equipment.[2] This frequency assignment is now

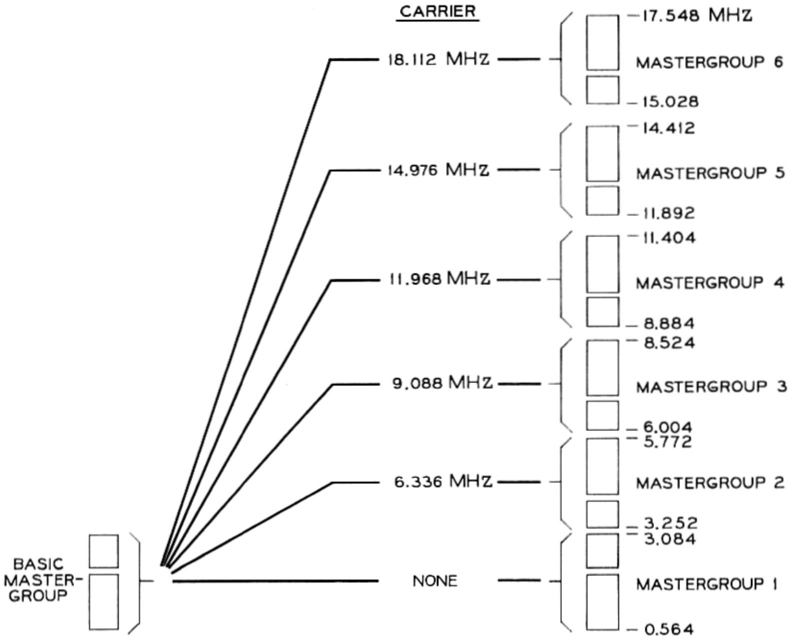


Fig. 1 — Six-mastergroup line frequency spectrum.

common to L-3 and L-4 coaxial systems, TH and TD-3 radio systems, and some TD-2 radio systems. This permits the greatest part of the terminal station equipment to be relatively high demand, common use equipment.

To provide the six-mastergroup multiplexing function, a transistor mastergroup frequency-division multiplex has been developed and manufactured. It is known as MMX-2 (mastergroup multiplex-2) and is distinguished from the earlier, electron tube equipment by naming the latter retroactively MMX-1.

MMX-2 differs from MMX-1 not only in number of mastergroups, but also in line frequency spectrum. Mastergroup 1 is common to all multimastergroup systems,* and is in fact identical in frequency spectrum with the basic mastergroup; that is, it is applied to the line without frequency translation. The frequency spacing between mastergroups, a constant 80 kHz in MMX-1-equipped systems, has been increased to a constant four percent (approximately) for L-4 coaxial

---

* This is not strictly true, since the earlier systems add a supergroup below 564 kHz, and define the resulting 660-channel signal as mastergroup 1.

and other MMX-2-equipped systems.* This was done to permit blocking and branching of mastergroups at line frequencies with practically realizable filters.

Thus two major functions of the L-4 terminal have been described or implied above:

(*i*) Multiplexing of up to six basic 600-channel mastergroups is provided by the MMX-2 equipment. The MMX-2 equipment also provides demultiplexing for the other direction of transmission.

(*ii*) To reduce costs, as well as to improve performance by virtue of reducing and simplifying the equipment in a built-up connection, line blocking and branching of mastergroups is provided by the L-4 line connecting equipment. Thus only dropped mastergroups need be demultiplexed; others go through completely passive filters to continue along a backbone route ("through mastergroups") or go through filters and amplifiers to side-legs or branch routes (branched mastergroups).

The line connecting equipment is physically separate from the mastergroup multiplex and is contained in the line transmitting, receiving, and common bays. In addition to mastergroup blocking and branching, as discussed above, line connecting equipment provides several additional functions:

(*i*) Two of the three full-time line pilots, 11.648 MHz and 20.448 MHz, are generated by precision, free-running crystal oscillators in the common bay and distributed to the transmitting bays.

(*ii*) A 512 kHz pilot, which is used to mutually synchronize MMX and LMX circuits in different offices, for actuating the L-4 terminal low band-edge regulators, and for actuating protection switches in the line connecting circuits, is stabilized in amplitude in the common bay and distributed to the transmitting bays. This pilot is generated by an office primary frequency supply not specifically a part of the L-4 equipment. The three pilots are either bypassed through the office or blocked and reinserted.

(*iii*) Signal shaping, consisting of 6.1 dB square-root-of-frequency pre-emphasis and de-emphasis, is included in line connecting component equipment called MMX-2 connecting circuits.†

---

* MMX-2 equipment for microwave radio, providing three-mastergroup capability and differing slightly from the L-4 version, has also been developed.

† Additional shaping in the transmitting main repeater brings the pre-emphasis to about 18 dB as it leaves the office.

(*iv*) Connection of the entire line signal to the receiving remote-control center is provided, as well as connection of the command channels to and from the remote-control system.[3]

(*v*) Test and patching access is provided.

(*vi*) Equalization for the slope in the transmission frequency characteristic of interbay office cabling is provided.

(*vii*) Access for emergency restoration of service of L-4 systems over other L-4 systems (baseband restoration, a term carried over from radio systems) is provided. Restoration of other systems, and of L-4 over other systems, is available also. This involves restacking of mastergroups, however, and is provided by MMX equipment.

Two additional important functions are provided by terminal equipment not specifically line connecting or multiplex:

(*i*) Interconnection with L-multiplex circuits has already been mentioned. Interconnection of basic mastergroups on the office side of the MMX circuits can be made via mastergroup connectors between L-4 coaxial systems and radio systems or other coaxial systems. This provides a means of routing mastergroups without using LMX equipment, which produces cost savings and performance improvements. It competes favorably with line branching because it is more flexible in administration (reassignments involve virtually only office cabling changes) and at present represents the only means of interconnecting intact mastergroups between L-4 coaxial and other systems.

(*ii*) Modified L-3 electron tube equipment, in conjunction with the line connecting circuits, provides automatic standby line protection of L-4 repeatered lines for up to nine working coaxial pairs (a fully equipped 20-coax cable).

Figures 2 and 3 show the L-4 terminal arrangements as described above, including MMX, line connecting, protection line switching, and mastergroup connector functions.

II. MMX-2 MASTERGROUP MULTIPLEX

The MMX-2 mastergroup multiplex provides the steps of modulation and demodulation between the basic mastergroup and the L-4 line signal. In addition to modulators and demodulators, it provides redundant, automatically switched carrier and pilot supplies and automatic transmission switching circuits.

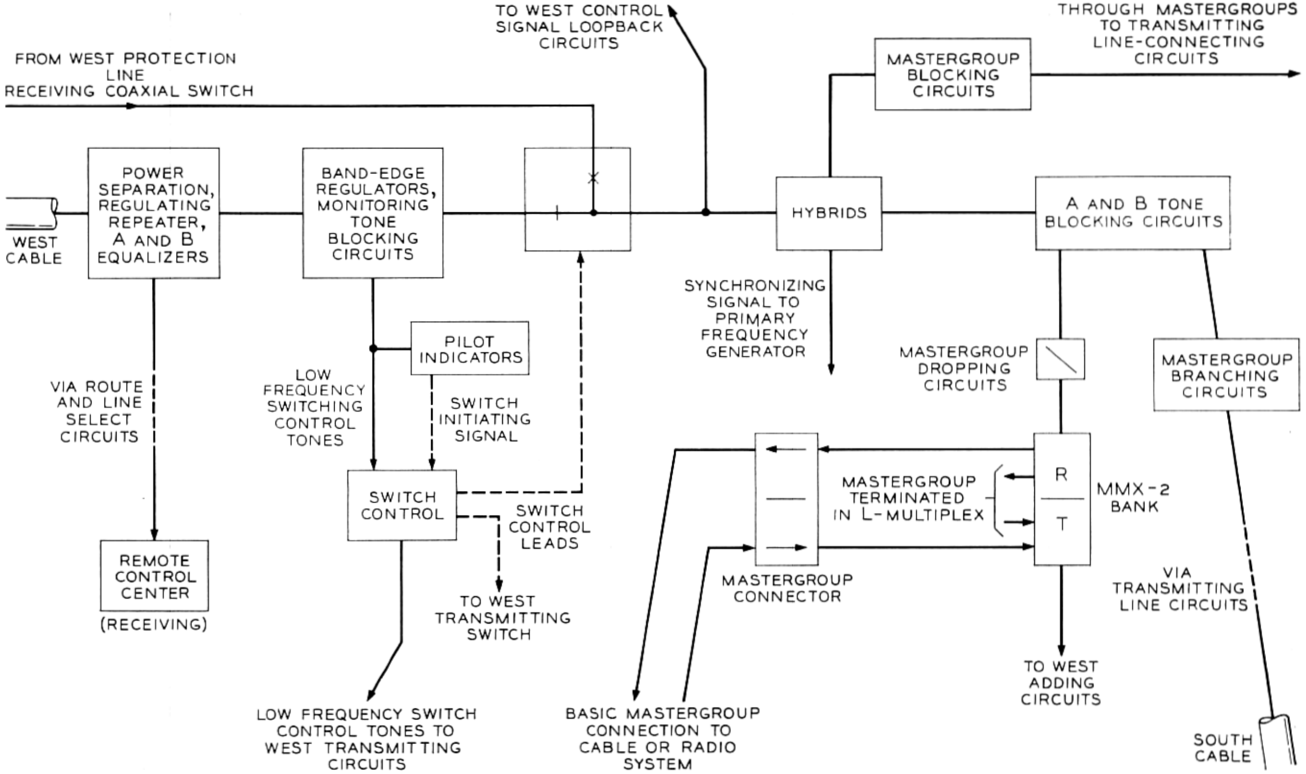


Fig. 2 — Receiving terminal.

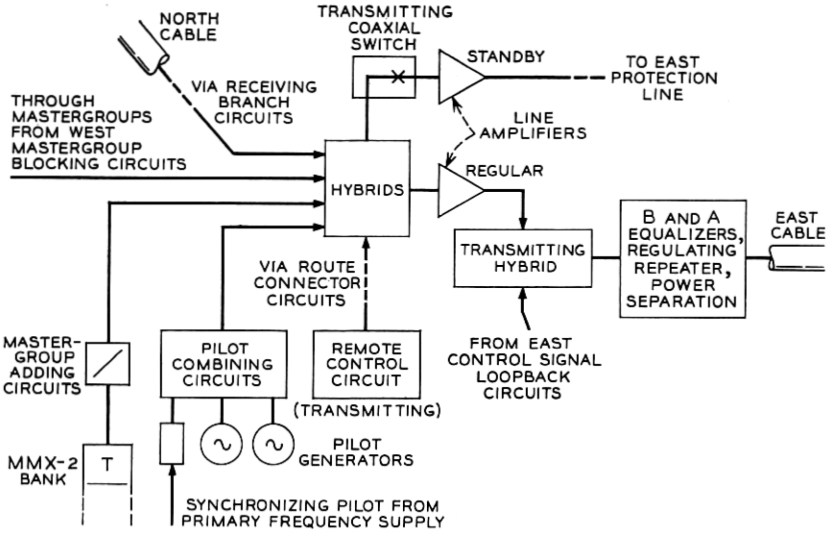


Fig. 3 — Transmitting terminal.

2.1 *Transmission Circuits*

2.1.1 *Transmitting Circuits*

The MMX-2 transmitting circuits are shown in the block diagram, Fig. 4. The output of the LMX equipment, a basic mastergroup, is connected into one input of a hybrid after having the mastergroup pilot (2.840 MHz) bridged on. The second input of this hybrid is available for emergency patching. The net side of the hybrid is connected to a test jack through a 10.8 dB pad providing a −35 dB transmission level test point for measuring the input signal. The primary output of the hybrid is fed into a second hybrid which provides two outputs. One output feeds into the regular modulator circuit, and the other feeds into the spare modulator circuit via the transmission switching circuit.

The modulator circuit consists of a low-pass filter, a diode modulator, a low level amplifier, a band-pass filter, and a high level amplifier, in that order, except for mastergroup 1. Mastergroup 1 uses only a low-pass filter and an amplifier.

The output of the modulator circuit is applied to the pilot hybrid. The hybrid provides two outputs. One output is connected to the transmission switching circuit and from there to the transmitting

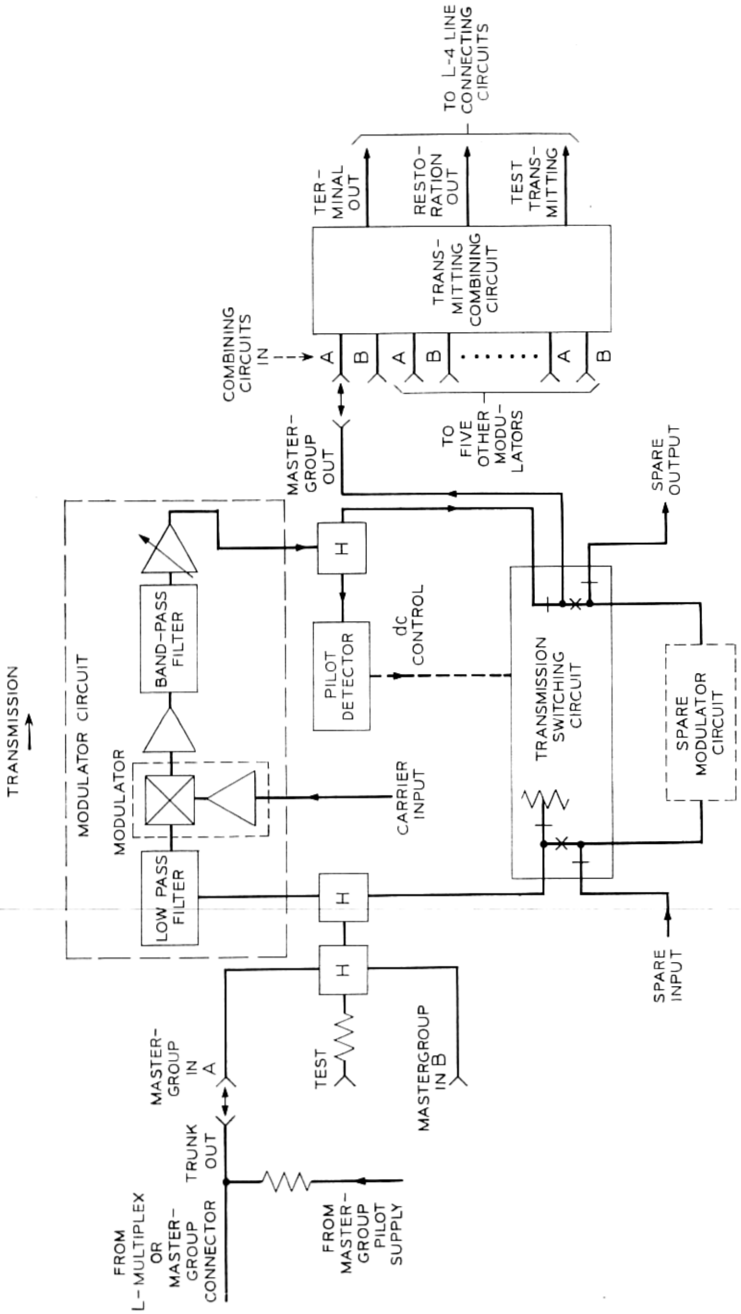


Fig. 4 — MMX-2 transmitting circuits.

combining circuit. The second output feeds the pilot detector which controls the operation of the transmission switching circuit.

The combining circuit provides twelve input ports and three output ports. Six of the input ports are normally connected to modulator circuits operating at the six different mastergroup frequencies. The remaining six input ports are normally terminated and are available for emergency patching. Since the frequency responses of the input ports vary slightly, they have been matched to the six mastergroup frequencies to optimize the overall circuit performance. The primary output port of the circuit is connected to the L-4 line via the line connecting equipment. A second port provides a test output point at −45 dB transmission level. The third output port provides for permanent connection to service restoration equipment.

2.1.2 *Receiving Circuits*

The broadband signal received from the L-4 line is connected to the receiving splitting circuit. This circuit provides 12 equal-level outputs for one input signal. Six of these outputs are connected to regular demodulator circuits, while the other six are connected to the spare demodulator circuits via the receiving transmission switching circuit.

The demodulator circuit consists of an input amplifier, a band-pass filter, a diode demodulator, a low-pass filter, a low level amplifier, and a regulating amplifier, except for mastergroup 1. For mastergroup 1, the circuit consists only of a band-pass filter, a low level amplifier, and a regulating amplifier, since no frequency translation is required. The output of the regulator is connected via the transmission switching circuit to an output hybrid which provides a normal output that connects to LMX equipment and a spare output which can be used for monitoring the demodulator output as well as for emergency patching.

2.1.3 *Modulator Circuit*

The low-pass filter is provided to suppress spurious signals above the basic mastergroup frequency band which may be generated in preceding transmission circuits. It is a constant resistance design and so maintains a good impedance, greater than 26 dB return loss, at frequencies up to 35 MHz with the exception of a band between approximately 4.2 and 4.8 MHz, where it falls to a minimum of 15 dB return loss. This provides a good resistive termination for the following modulator without necessitating the addition of large amounts of padding which would be required otherwise. By maintaining a good impedance up to and beyond 35 MHz, the filter properly terminates not only the wanted but the unwanted sidebands produced by the modulator.

The modulator is a double balanced ring modulator which uses a 460C multiple diode. The diode consists of four epitaxial silicon, planar wafers, connected in a ring and encapsulated in a TO-55 enclosure. The diode elements exhibit a reverse recovery time (t_{rr}) of less than 4 nanoseconds and capacitance at 0 volts of less than 4 picofarads. Broadband transformers are used at both the input and output of the modulator, which allows the use of identical modulators for all of the mastergroups. The modulator has a conversion loss of approximately 5.1 dB* at any of the mastergroup frequencies, with a variation of ± 0.05 dB maximum across the mastergroup frequency band. It maintains a carrier balance of greater than 38 dB at the highest carrier frequency (18.112 MHz), and greater than 45 dB at the lowest (6.336 MHz).

The modulator package also includes a carrier amplifier which provides approximately 17 dB of gain. This amplifier serves two purposes. First, it reduces the required level of carrier signal which must be cabled from the carrier supply to the modulator, with a consequent reduction in the amount of carrier signal coupled into low level transmission cables within the MMX-2. Second, it provides isolation in the carrier path between modulators fed from a common carrier distribution circuit. The amplifier consists of two common emitter stages with local feedback. It operates with a +3 dBm input signal to drive the modulator at +20 dBm. At this level, the modulator exhibits a stiffness of greater than 10:1 with changes in carrier level.

A set of useful modulation coefficients for the modulator can be defined as the ratio of unwanted to wanted sideband powers, with the wanted sideband power at 0 dBm at the output of the modulator. That is

$$M_{2(MOD)} = \frac{P_{(F-2A)}}{P_{(F-A)}}, \qquad M_{3(MOD)} = \frac{P_{(F-3A)}}{P_{(F-A)}}$$

where F is the carrier frequency and A is the input signal frequency. These coefficients were measured and found to follow the expected dB-per-dB change for $M_{2(MOD)}$ and 2 dB-per-dB change for $M_{3(MOD)}$ with changes in input signal level. In addition, close agreement was found between measured and calculated $M_{A-B(MOD)}$, $M_{2A-B(MOD)}$, and $M_{A+B-C(MOD)}$, where the calculation was based upon measured $M_{2(MOD)}$, $M_{3(MOD)}$, and a power series expansion. For a typical modulator, $M_{2(MOD)}$ was found to vary by approximately 5 dB with carrier frequency and $M_{3(MOD)}$ by approximately 8 dB. With the worst case

---

* Theoretical minimum conversion loss is 3.9 dB using resistive terminations.

carrier applied, $M_{2(MOD)}$ is typically -45 dB and $M_{3(MOD)}$ typically -42 dB. MMX-2 noise computed using these parameters agrees to within 3 dB of noise measured using noise loading. With noise loading, the back-to-back MMX-2 noise was found to be between 11 and 15 dBrnC0, depending on the mastergroup measured, which meets the terminal objective of 19 dBrnC0 with adequate margin.

In order to meet the MMX-2 noise requirement, it was necessary to operate the modulator at a relatively low signal level to limit its modulation noise contribution. To achieve this and yet avoid introducing excessive thermal noise, it was decided to follow the modulator with a low level amplifier before filtering. Two requirements are placed on the low level amplifier. It must have (*i*) a relatively low noise figure, and (*ii*) good modulation characteristics, since it must carry the full modulator output, including the carrier leak and the unwanted sidebands.

The 266 type amplifier was developed for this use, as well as for use in several other positions in the MMX-2 circuitry. The basic amplifier has a noise figure of 10 dB and modulation characteristics such that $M_{3(MOD)}$ is better than -93 dB at 17 MHz and $M_{2(MOD)}$ is better than -80 dB at 0.7 MHz. The amplifier was constructed such that padding could be added at either or both the input and output if required. For the low level amplifier, it was found that 5 dB of padding was required at the input to provide a proper termination of the higher order modulator sidebands. The amplifier, coded 266A, consequently has a noise figure of 15 dB and input return loss better than 35 dB across the L-4 frequency band. A second 266 amplifier, the 266C, is used as the high level output amplifier in the modulator circuit. This amplifier is adjustable over ±2 dB around a nominal 12dB gain.

The band-pass filters used in the modulator circuits are the only components which differ from mastergroup to mastergroup. They are, however, similar in their requirements stated in terms of the modulator output signals. These are:

Type of product	Minimum discrimination (dB)
Signal leak (S)	60
Carrier leak (C)	70
Unwanted sideband ($C + S$)	84
$2C$	70
$2C + S$	44
$3C + S$	74
$3C$	85
$4C$	65

In addition, a requirement is imposed by the use of the filters in the demodulators as well as the modulators; that is, that the band of signals in the adjacent mastergroup be suppressed by 84 dB minimum (see Section 2.5).

2.1.4 *Demodulator Circuit*

The demodulator circuit uses many of the component parts of the modulator circuit. The diode demodulator is identical to the modulator except for a slight mechanical rearrangement. The amplifiers are 266 types which differ from those used in the modulator circuit only by the amount of input and output padding required in their specific circuit application.

The unique feature of the demodulator is the transmission regulator. This is the first use of a transmission regulator for the mastergroup frequency band.

2.1.5 *Transmission Regulators*

The regulating circuitry serves two functions. It provides flat gain regulation and it develops the pilot out-of-range signal to activate the receiving transmission switches and alarms. Figure 5 is a diagram of the regulator.

The feedback regulator uses the demodulated mastergroup pilot at 2.840 MHz to control the output level of each mastergroup from the receiving side. The regulator circuit is conventional and uses a pilot pick-off-pad, pilot selection filter, pilot amplifier, detector, and comparison circuit. The comparison circuit controls a current to a thermistor in the feedback circuit of the transmission amplifier.

2.1.5.1 *Regulation Control Loop*. The pilot pick-off-pad provides a termination at the output of the high impedance transmission amplifier. The pad loss is 15 dB, which gives 30 dB return loss against impedance variations of the crystal pilot filter. The pilot amplifier has two sections separated by a series tuned circuit. Each section has negative feedback to stabilize the gain, which is approximately 50 dB for the two sections when measured with a 75-ohm termination. A rectifier connected to the high impedance output of the pilot amplifier converts the ac signal to dc in the adjustable load resistance.

The output impedance of the pilot amplifier is made high by series feedback; the detected direct current is practically independent of the load impedance and the temperature-sensitive rectifying diode drop. The dc voltage, however, is dependent on the load resistance, which is made variable to obtain the correct regulator output power. The detector and comparison circuit reference is the battery return. This

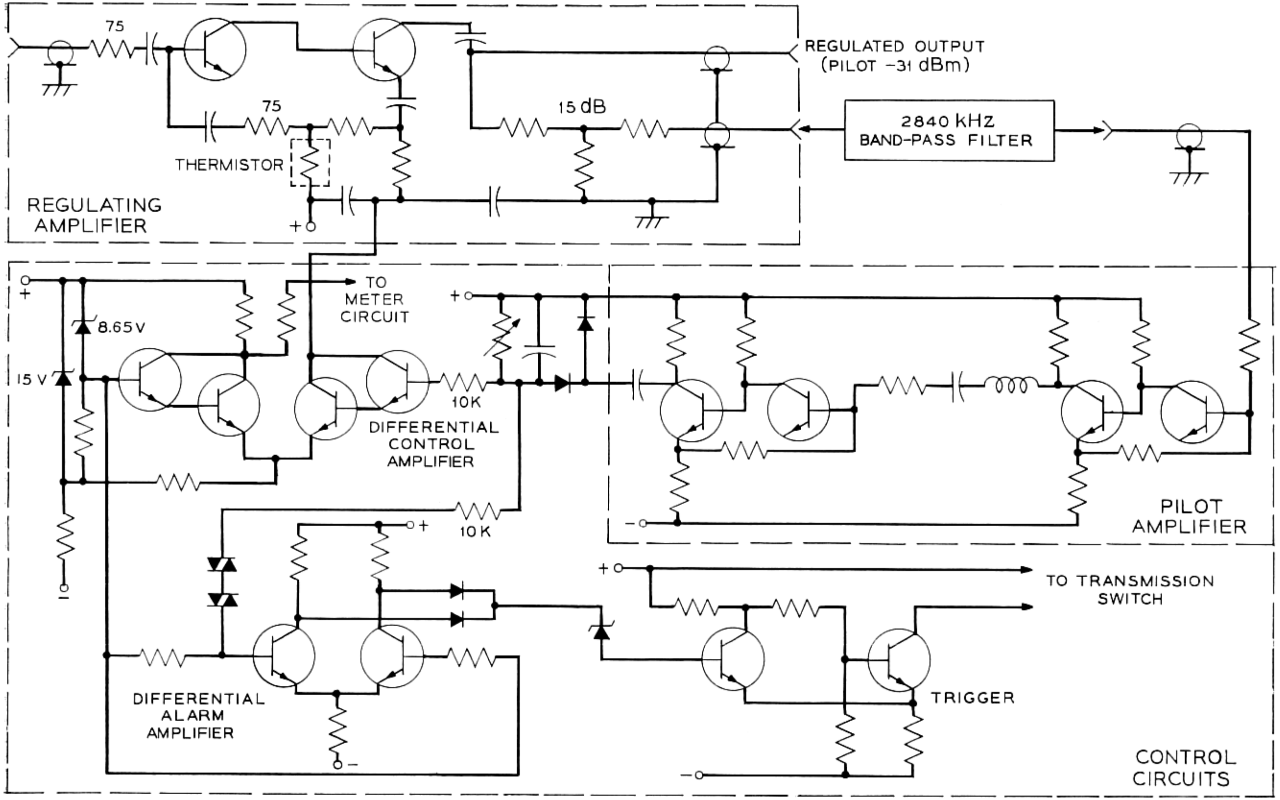


Fig. 5 — Mastergroup transmission regulator circuit.

is done to eliminate ground loop problems. The comparison circuit input is fed from the rectifier through a 10,000-ohm isolation resistor; the comparison circuit consists of a pair of Darlington connected transistors in a differential amplifier configuration. A stable reference voltage from a low temperature coefficient breakdown diode is fed to the second input of the differential amplifier.

The reference side of the differential amplifier provides a current to the meter in the pilot and carrier measuring circuit which gives an up-scale indication for a high pilot input voltage. The control current path is from the other side of the differential amplifier to the thermistor in the regulating amplifier.

2.1.5.2 *Regulating Amplifier.* The regulating amplifier uses series feedback on the second stage and shunt feedback on the first and is similar to the transmission (266 type) amplifiers used throughout the terminal equipment. The maximum output power required corresponds to a +15 dBm sine wave, while the average message output power is near 0 dBm.

This relatively high output power precluded placing the regulating thermistor element directly in the path of the output ac current at the second stage emitter. The sensitive thermistor element used would have heated and allowed the total mastergroup power to affect the regulator gain. Instead, the feedback network was changed from the basic L Form used in the 266 type amplifiers to the configuration shown in Fig. 5. This allows the control current to be fed in at a zero signal voltage point while the maximum thermistor signal voltage is no greater than the input voltage.

The regulator can pass a +20 dBm signal and has modulation coefficients of $M_{2E} = -75$ dB and $M_{3E} = -95$ dB. The stiffness is approximately 30 : 1 over a ±3 dB range of input, and the total gain variation is ±4 dB.

2.1.5.3 *Regulator Alarm Function.* The out-of-range alarm signal is derived by comparison of the detector output and reference voltage in another differential amplifier. The collectors of this differential amplifier are connected by a diode OR circuit. The higher of these two voltages is used to set a Schmitt trigger which opens an alarm relay. The alarm is designed to trigger at a pilot output error of ±3 dB.

2.1.6 *Transmission Switching Circuits*

The transmission switching circuits in the MMX-2 represent a departure in terminal design. While protection switching is not new to the Bell System, switching in multiplex transmission circuits is new. Prior to the MMX-2, automatic protection switching in terminal circuits was confined to carrier and pilot supplies.

The transmission switching has one spare for each three regular circuits. It operates in a modulator-by-modulator or demodulator-by-demodulator mode rather than sparing a full mastergroup bank. The main features and method of operation are basically the same for transmitting and receiving circuit switching.

2.1.6.1 *Transmission Switching Control.* The transmission switching circuits operate in both an automatic and a manual mode. In the automatic mode, the transmitting switching circuit is controlled by the pilot detector circuit, while the receiving switching circuit is controlled by the regulator, which is described in Section 2.1.5.

The pilot detector consists of a demodulator, a 2.840 MHz pilot pick-off filter, an amplifier, and a rectifier-Schmitt trigger circuit. A line frequency output from the pilot hybrid is fed into the demodulator, which translates the signal back into the basic mastergroup frequency band. The demodulator is the same type of circuit described in Section 2.1.4. The 2.840 MHz pilot is selected by the crystal pick-off filter and amplified. The amplifier feeds an 864 network, which consists of a rectifier, a Schmitt trigger, and a relay driver.

Under normal operating conditions, the input stage of the Schmitt trigger is held in conduction by the rectifier. A drop in input pilot level by more than 5.5 dB will cause the Schmitt trigger circuit to change state. With the trigger circuit in its normal state, the relay driver, which has the transmission switching control relay as its collector load, is biased on, operating the relay. When the trigger circuit reverses, the driver releases the control relay. When the input signal rises to within 0.5 dB of its normal level, the trigger circuit reverts to its normal state, reoperating the control relay.

The switching is controlled manually by operating a three-position switch physically associated with the regular modulator. The switch positions are designated LOCK, NORM, and MAN TR. In the LOCK position, the transmission switching is disabled. The NORM position is the regular mode of operation; automatic switching is enabled. The MAN TR position switches the service from the regular to the spare modulator. When the switch is thrown into the MAN TR position, it provides a closure which simulates a release of the control relay; the switching is then accomplished in the same manner as for an automatic switch.

2.1.6.2 *Switching Sequence.* when a transfer is made, the signal is connected through the spare modulator to the output via five relays. The final relay is controlled by a series connection of contacts from the first four. This insures that the signal is connected into the final relay before it is operated. The final relay carries transmission through early-make-break contacts and, consequently, the signals through the regular and spare modulators are double fed to the output and simultaneously double terminated. This condition is removed only when the break contacts have operated. By maintaining as nearly as possible identical amplitude and phase through the two transmission paths, transmission disturbance is minimized during operation of the switching. This type of operation is highly desirable in the manual switching mode used to free a regular modulator circuit for maintenance. Obviously, it is of no real value on operation in the automatic mode, since this implies that transmission has already been lost. Since the same sequence occurs when the switch is released either automatically or manually, it minimizes the hit in both modes upon return to normal.

2.1.6.3 *Switching Alarms and Indicators.* The alarms are arranged to give a minor alarm for any failure which does not cause a loss of service. For example, the failure of a regular modulator with a successful switch to the spare circuit would initiate a minor alarm. A failure which involves loss of service brings in a major alarm. That is, if a switch did not occur upon failure, or did occur but returned to normal because of subsequent failure of the spare, a major alarm would be initiated. Alarm lamps are associated with each modulator as an aid to trouble location; a common bay alarm lamp is also provided.

In addition to the alarm lamps, several other indications are provided. Indicator lamps associated with the manual switch control light when the switch is in other than the NORM position. A CLEAR lamp is included which lights when a failure has occurred and then has restored to normal. The lamp remains lighted until manually released. It is intended as an aid in locating circuits which develop intermittent troubles which clear before a maintenance man has the opportunity to observe alarm lamps. A TR lamp lights when the switching is operated.

2.2 *Carrier and Pilot Supply*

The MMX-2 carrier supply is composed of two major parts (see Fig. 6). The first is called the binary generator. Its function is to generate all the binary multiples (2^0, 2^1, 2^2, . . .) of its 64 kHz input

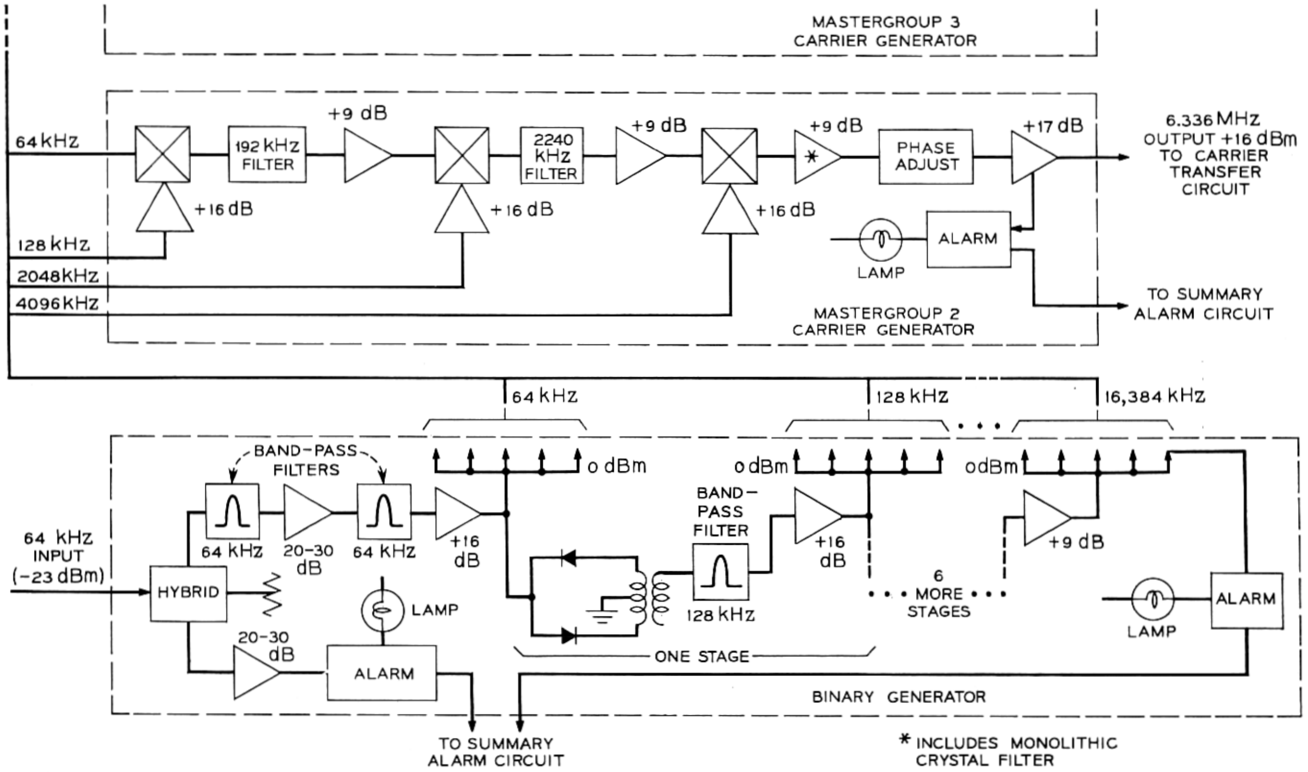


Fig. 6 — Carrier supply circuits.

through 16,384 kHz ($2^8 \times 64$ kHz) and distribute certain of them to the individual carrier generators. The second part consists of five carrier generators, one for each carrier frequency required. These combine three or four input frequencies in modulators to obtain the mastergroup carrier frequencies.

2.2.1 *Binary Generator*

The binary generator is made up of eight similar stages. Each stage filters, amplifies, distributes and rectifies the frequency from the previous stage. The second harmonic from the rectification process becomes the input frequency to the succeeding stage. The filters required are described in Section 2.5.3. The amplifiers are required to have about 16 dB of gain. Each has two stages, the first with local shunt and the second with adjustable local series negative feedback. The amplifiers are identical for all stages requiring rectification, except for transformers.

There are two outputs taken from each amplifier, one at +8 dBm at 15 ohms and the other at +15 dBm at 75 ohms. The first is fed to a series tuned distribution circuit with five outputs, one of which is used for a test jack. The other outputs are connected to the carrier generators. The other amplifier output is fed to the full wave rectifier.

The rectification and filtering provides the second harmonic at about 0 dBm for the succeeding stage. The signal level is such that the rectifying diodes actually overload slightly in that they are heavily saturated; one does not turn off before the other conducts on the opposite half cycle. Significant compression results with about 0.8 dB change in output for a 1.0 dB change in input. Thus input level variations are successively reduced in each stage. This is a desirable level of operation, since a somewhat lower level would have resulted in expansion of input variations.

The first stage of the binary generator actually requires more amplification and filtering than the others, since the input of 64 kHz from the primary frequency supply is at a relatively low level (−23 dBm at 135 ohms). This distribution level was chosen as an optimum compromise between a high level which could cause interference in other circuits and a low level which would be subject to noise pick-up. The preamplifier is adapted from previous designs in N carrier. It is a very useful design which uses two stages with hybrid feedback around both. Its gain is variable with a range of approximately 9 dB.

The extra input signal filtering is provided by two crystal filters to ensure that no spurious signals are accepted. In addition, the power leads to the preamplifier and first three multipliers are specially filtered, since the large multiplication ratio makes them especially susceptible to phase jitter pick-up. Measurements show that multiplication of input jitter is the dominant source of phase jitter in the MMX-2 carrier supply. The last stage, at 16,384 kHz, has no rectifier and only amplifies and distributes the filtered signal from the previous stage. This 9 dB amplifier is basically a utility design developed for use throughout the carrier supply. A single transistor with both series and adjustable shunt feedback is used. Computer calculations were used to find the optimum values of shunt and series feedback elements to be used to obtain the required gain range at maximum return loss.

2.2.2 *Carrier Generators*

The carrier generators for each mastergroup frequency are very similar. As an example, the mastergroup 6 carrier at 18,112 kHz (the 283rd harmonic of 64 kHz) is formed as follows, using double-balanced ring modulators. First, frequencies of 64 and 256 kHz from the binary generator are mixed, and the sum frequency at 320 kHz is selected by a band-pass filter. This 320 kHz is mixed with 2048 kHz from the binary generator to obtain 1728 kHz, which is mixed with 16,384 kHz from the binary generator to obtain the 18,112 kHz carrier frequency. The mastergroup 3 carrier generator requires only three input frequencies; all others require four. Each modulator unit contains a ring modulator with two transformers and a fixed gain (16 dB) carrier amplifier very similar to the one used in the binary generator. The input power levels are 0.0 dBm for both signal and carrier inputs. The modulator (8 dB) and filter losses (0.5 to 3 dB) are made up by adjustable (9 ± 3 dB) single stage amplifiers (262 type) similar in design to the 9 dB amplifier described in Section 2.2.1. The electrical filters used between modulators, as well as the monolithic crystal filter in the amplifier following the final modulator, are described in Section 2.5.3.

The final amplifier (261A) in the carrier generator provides the 13 to 18 dB gain required to drive the distribution circuits and the alarm circuits.

2.2.3 *Carrier Transfer and Alarm Circuits*

The MMX-2 carrier supply is composed of two complete binary generators, each serving one set of carrier generators. This is done to improve the reliability and to allow replacement of portions of one carrier supply while the other maintains service. A carrier transfer unit connects either the A or B carrier generator to the plug-in distribution circuit (see Fig. 7). This distribution circuit, contained in the carrier transfer unit, provides a total of 15 outputs from a three-way hybrid circuit. Test taps are provided on both the distribution circuit and idle carrier generator outputs.

Several alarm circuits are provided as part of the carrier supply. Each binary generator has an input and output alarm. Each carrier generator has an output alarm, and one tap of the distribution circuit is used to generate a major carrier alarm. Each alarm has an associated alarm lamp, which is connected to the alarm circuits so as to cause only the alarm lamp in the first affected unit to light, thereby providing a definite indication of the trouble location. The carrier generator alarms drive the carrier transfer circuit to select the working carrier generator if one fails. IDLE lamps indicate which units are not in service. Provision is included for manual transfer and for prevention of manual transfer to a failed carrier generator.

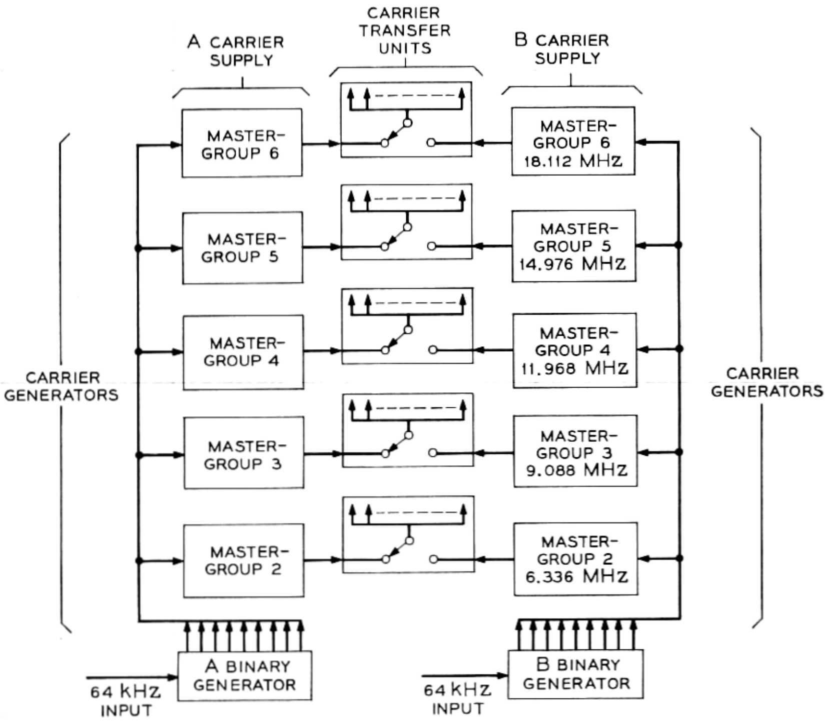


Fig. 7 — Carrier supply arrangement.

Before manual transfer can be made, the carriers must be brought into approximate (±20°) phase coincidence by manual adjustment of phase shifters in the carrier generators. This prevents maintenance transfers from seriously affecting service. A manual inhibit circuit in the carrier transfer unit prohibits transfer until the adjustment is made.

Emergency transfer switches are also provided for use in case transfer must be made and phase coincidence cannot be obtained. The manual inhibit circuit has a meter on the front of the bay to indicate when phase coincidence has been obtained. This meter is also sensitive to level differences between the two sides of the carrier supply. Thus, when a good phase null cannot be obtained because of a level difference, a check of the carrier amplitudes should be made.

In the MMX-2 carrier supply, there is no preferred side (except A when both are failed). Thus when a carrier generator is returned to operation, no automatic transfer is made. Each of the carrier generator alarm circuits is connected to the pilot monitoring panel and to the summary alarm circuit which is described in Section 2.3.

2.2.4 *Mastergroup Pilot Generator*

A mastergroup pilot (2840 kHz, −20 dBm at the 0 dB transmission level point) is used to indicate the level of the entire mastergroup. This pilot is added to the transmitted mastergroup at the input to the transmitting circuits before modulation. Thus it appears in the transmitted line spectrum shifted by the mastergroup carrier frequency. This pilot must have very accurate and stable magnitude (±0.02 dB) and frequency (±7 Hz) as well as high reliability. It is used to activate the mastergroup regulator at the receiving MMX-2 terminal.

Figure 8 shows the mastergroup pilot generator arrangement. The 2840 kHz signal is generated directly in unsynchronized crystal oscillators. The oscillator circuit uses a common emitter oscillator stage with output limiting, followed by a buffer amplifier driving a temperature compensated limiter. An output filter and level control follow the final limiter. The dc power for the oscillator circuit is regulated by a breakdown diode.

Each supply contains two oscillators and associated alarm circuits. These alarm circuits control a transfer circuit in a manner similar to the mastergroup carrier supply transfer control. The actual relay transfer switches required a very careful electrical and mechanical design in order to obtain the required 60 dB isolation. This high degree of isolation is required to prevent the idle oscillator output from

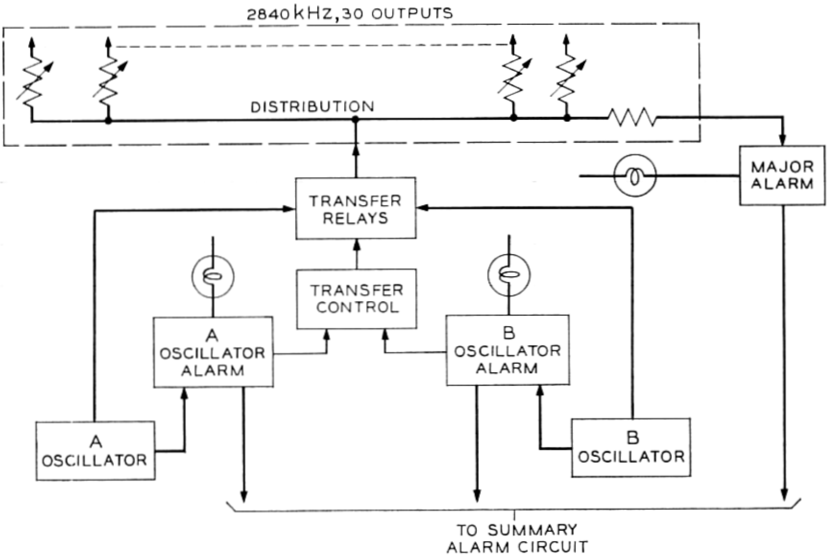


Fig. 8 — Mastergroup pilot generator.

beating with the working oscillator output. The idle oscillator output is fed through the transfer circuit and a pad to a front panel test jack.

The working output from the transfer switch connects to a distribution circuit that has 31 outputs. Twenty-four of these are connected to the transmitting mastergroup trunk inputs. Six others are connected through relays to spare mastergroup trunks. The relays are used to remove local pilot from these trunks if pilot is already present in the input. Each tap in the distribution circuit is individually adjustable. The final tap is used for a loss of pilot (major alarm) indication.

2.3 *Alarms and Maintenance*

The summary alarm circuit (SAC) performs the function of collecting all the electronic alarms in the MMX-2 bay and processing them for connection to external alarm circuits. The external alarm circuits are the office audible, visible, annunciator systems, and the remote alarm system. In addition, some remote status and command signals are connected through a portion of the SAC terminal strips. The only bay alarms which are separated from this unit are the fuse alarms, which are connected through their own relays at the top of the bay.

The electronic alarms in the bay are grouped according to function and classification. These are: transmitting major and minor, receiving major and minor, carrier major and minor, pilot major and minor, and dc to dc converter alarms which are treated as major alarms although no loss of service results with the loss of only one converter.* The status signals indicate the spare modulators or demodulators in use. The command inputs are used to reset the transmission switches and to reset the SAC major and minor alarm outputs. All electronic alarm leads are brought individually into the SAC terminal strips to allow more detailed grouping if it becomes desirable later.

An important feature of the SAC is that it is ready to process another alarm immediately after it is reset, even though the first alarm is still in existence. "Reset" in this case means that the external indication of the first alarm is interrupted.

To set the SAC, a pulse, connected only during the initiation of an alarm, is used to set a bistable flip-flop. When the flip-flop is reset, it is immediately ready to recognize the next pulse. The resetting of an alarm does not cause a new alarm. Refer to Fig. 9; the pulse is formed by connecting the relay drive voltage through bunching contacts on the relay. When the relay is energized, this connects a negative pulse to the summary alarm circuit. This pulse breaks down the avalanche diode and sets the flip-flop. When the relay drive voltage is removed, the coil voltage immediately reverses and is clamped to +0.7 volt by CR1. The bunching of the contacts then connects a short portion of this voltage to the SAC. This voltage polarity does not set the flip-flop to the alarm condition. Since the lead to the SAC is connected only when the contacts bunch, there is no loading effect on pulses which might originate in other alarm circuits connected to the same flip-flop.

The flip-flop outputs are used to drive relays connected to the external alarm circuits. The transmitting and receiving alarm pulses are positive, but the operation is identical except that an NPN flip-flop is used. The dc-dc converters provide a permanent closure to the SAC. This closure is differentiated to generate a pulse which is processed in the same way.

The individual alarm lamps on the alarmed unit remain lighted when the SAC is reset so that the alarm information is not lost.

---

* The loss of one converter is considered to be a major alarm situation because of the serious hazard to service which exists in the bay in this condition.

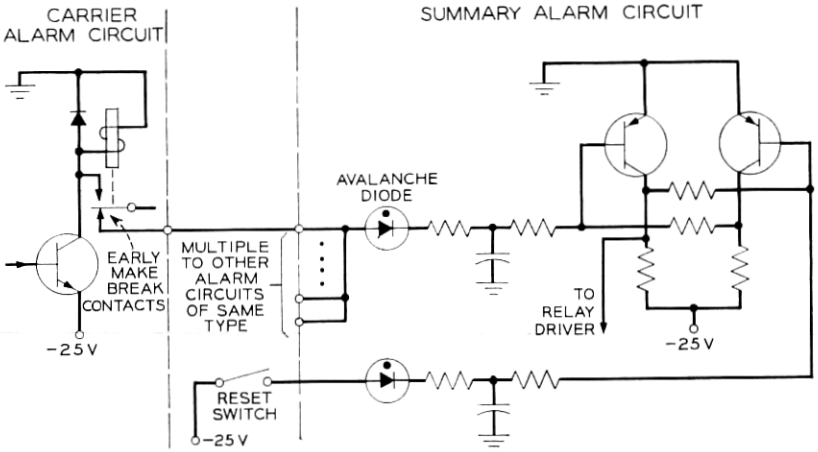


Fig. 9 — Typical alarm circuit.

The SAC is connected to two illuminated pushbuttons mounted in the front center of the bay. One is for major alarms, the other for minor alarms. The pushbuttons light when the SAC recognizes an alarm. When the button is pressed the SAC is reset.

2.4 *Physical Design*

The MMX-2 is a shop-assembled, -wired, and -tested unitized double bay which contains the transmission, carrier supply, switching, regulation, patching, and alarm equipment for a maximum of 18 mastergroups (10,800 channels). It also contains six spare mastergroup units that are automatically switched into service when needed. A maximum of three MMX-2 bays is required at an office terminating a 20-pipe (including standby) L-4 coaxial cable.

2.4.1 *General*

MMX-2 bays are generally located in a central office or a main station, in the maintenance aisle or test area where the aisle spacing is sufficient to permit the use of rolling test consoles without restricting the operating personnel. Because this area is the center of office activity, a good bay appearance, without significantly increasing the cost, was considered a design objective.

Seven-foot-high framework, which would be ideal for the long range trend to offices with lower ceilings, was considered. However, all projections indicate that, for the manufacturing life of the MMX-2, the

11 foot, 6 inch framework would make the most efficient use of space. Bays are available in 11 ft. 6 in., 10 ft. 6 in., and 9 ft. 0 in. arrangements.

To avoid excessive amounts of interbay cabling, the MMX-2 bay was designed as a complete mastergroup system incorporating the patching, test facilities, and equipment in a double unequal flange duct-type bay. By locating the transmitting and receiving equipment in the same bay assembly and by shop wiring, a consistent cabling and wiring plan was developed to avoid the interference and crosstalk paths often the result of a variety of field wiring and cabling techniques. In addition, the equipment has been compacted to the extent that it is no longer physically or economically practical to use field assembly and wiring methods.

The MMX-2 bay is shown in Fig. 10. A consistent modular design pattern for both shelves and modules has been developed throughout the bay. Meters indicating the phase of the carriers are mounted in the center, front uprights of the bay, adjacent to the carrier supplies being served. The space at the rear of the center duct contains the carrier transfer equipment. By using this space, which has not been used in the past, the carrier supply cable connections are very short.

All bays are completely shop-wired and assembled with shelves, even though the associated plug-in units may not be equipped. This does result in an initial higher cost; however, experience has shown that field additions would result in a much higher cost in the long run. It also minimizes the possibility of inadvertently interrupting working systems while the field additions are being made.

In addition to the front aisle, a wiring aisle is required at the rear of the bay. This provides two aisle surfaces for heat dissipation and better use of cabling space. The MMX-2 cannot be mounted in aisles back to back with other equipment; however, in view of some of the floor-loading restrictions, back-to-back equipment layouts in telephone offices have become less attractive as the equipment becomes more compact.

2.4.2 *Equipment Units*

The shelf assemblies were designed primarily as holders for the plug-in modules. Where practicable, the amount of equipment provided initially was restricted. Most modular units plug in but without fixed connectors on the shelves. In this way tolerance problems associated with mating connectors are avoided.

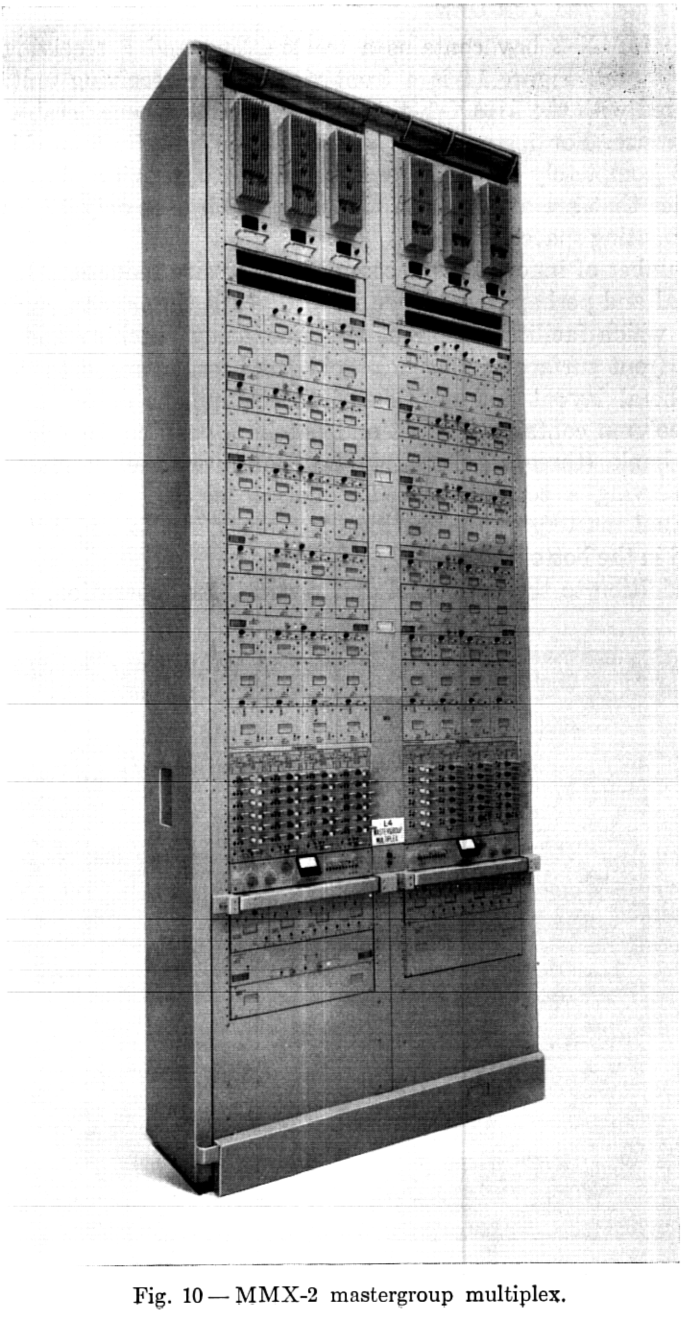


Fig. 10 — MMX-2 mastergroup multiplex.

2.4.3 *Patch and Test Unit*

Each MMX-2 bay contains a transmitting and a receiving patch and test unit. Figure 11 is a front view of the receiving unit. When compared with the MMX-1, this unit represents a considerable reduction in size. For instance, in MMX-1, a full 11 ft. 6 in. high bay almost completely equipped was required to provide the patching facilities that are available in this unit which uses only 12 inches of bay mounting space.

A number of innovations accomplished the size reduction. However, of equal and perhaps even more importance is the human engineering aspect which facilitates normal and emergency patching and testing.

The front surface of the jack field has been arranged to duplicate the general layout and position of the equipment units in the bay. Each column contains the test and patching position for one mastergroup bank (three regular and one spare), with each mastergroup bank serving a coaxial pipe. The horizontal lines separate the six individual mastergroups. The high frequency inputs and outputs are located in the bottom row.

In addition to the horizontal and vertical line separation, a general

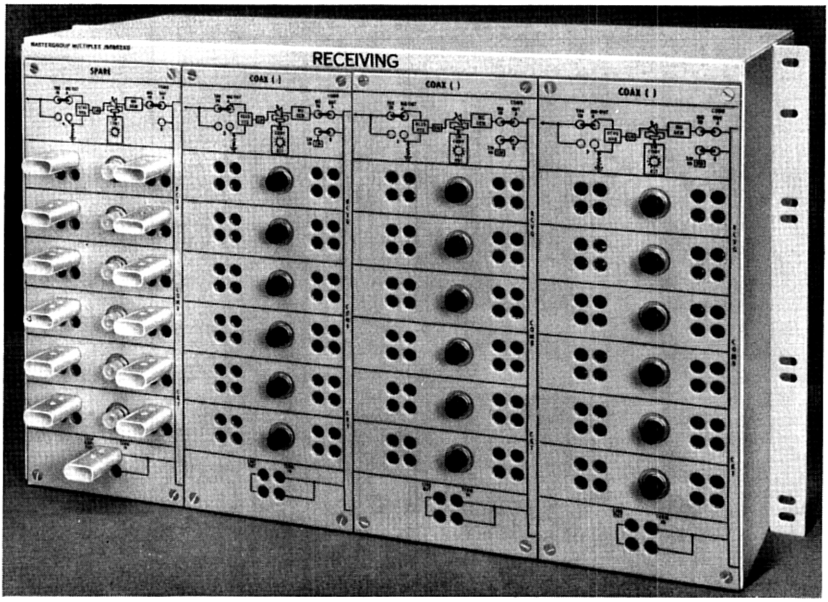


Fig. 11 — MMX-2 receiving patch and test unit.

block-type schematic is imprinted at the top of each column serving each mastergroup bank, giving the operating personnel a better understanding and means for associating the point in the system being patched.

The efficient use of the space available for the patching facilities was made possible by a complete new generation of Bell System coaxial jacks and plugs. They are scaled-down versions of the conventional reliable 477-type jacks and 356-type plugs. In addition to their use in the jack field, the new small coaxial jacks and plugs are used rather liberally for interconnecting apparatus within the bay.

Through the use of smaller transformers, it was possible to locate the input and protection hybrids and the combining and splitting networks to the rear of the jacks.

2.4.4 *Mastergroup Shelf Assembly*

Except for the mastergroup 1 shelf assembly, which does not have a carrier supply, the remaining shelf assemblies, for mastergroups 2 through 6, follow the same physical arrangement. Each MMX-2 bay contains six transmitting and six receiving shelf assemblies. Figure 12 shows a transmitting shelf assembly. A complete shelf assembly contains four (three regular and one spare) plug-in transmission modules and pilot detector modules.

The equipment for the carrier generator is located in the drawer which is hard-wired to the assembly. Apparatus can be replaced or maintained by extending the drawer on the built-in telescoping slides.

The front surface of the drawer is arranged to mount the lamps and switches required for transferring the carrier generator and also the lamps which indicate the status of the transmission modules. In order to accomplish the desired switch-lamp relationship in a reasonable space, new miniature lamps and switches were introduced. The new lamps, when illuminated, are sufficiently intense so that there is no difficulty locating them, even in a well-lighted environment.

The drawer is secured to the frame by a flush-mounted trigger-type latch which is used as a handle when released. This latch is rugged and provides a sure-lock that meets the MMX-2 shock and vibration requirements.

The framework for the shelf assembly is fabricated aluminum; the assembly is completely wired before being mounted in the bay. External connections are made, either at the terminal strips located on the sides of the shelf, or via coaxial cables spliced with 219-type connectors.

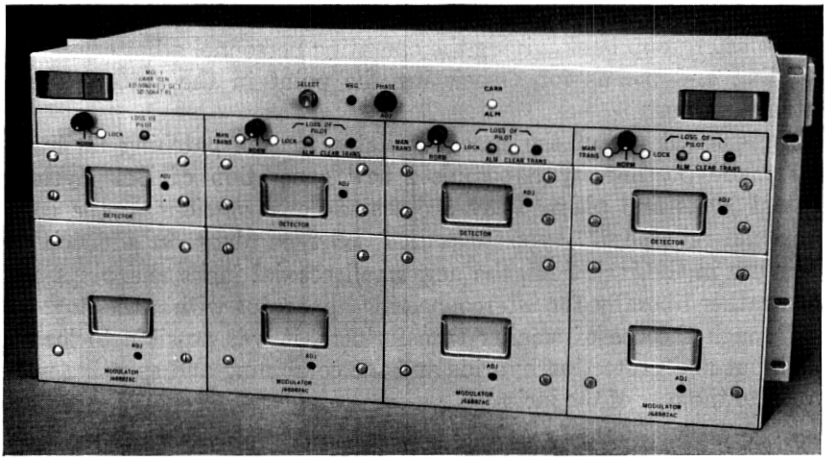


Fig. 12 — Mastergroup shelf assembly.

2.4.5 *Modulator Unit*

There are 24 modulator units in each fully equipped MMX-2 bay. Since mastergroup 1 does not require a step of modulation, the amplifier and detector apparatus are contained in a single plug-in type module. The modulator units for mastergroups 2 through 6 each contain two amplifiers, the modulator, a band-pass filter, and a low-pass filter. In order to achieve close-shielded connections, the above apparatus was connected by small coaxial plugs and jacks. Floating connections were avoided by sequential assembly and adequate clearance for the mounting holes to accommodate the normal tolerance variations.

For circuit reasons it was necessary that the input and output plugs of the band-pass filter be at opposite ends. In order to accommodate this requirement and still have a compact unit, the 266-type amplifiers that are connected to the band-pass filter are mounted in an upright position. This has the added benefit that the heat-producing amplifiers are on opposite surfaces of the MMX-2 bay.

The demodulator unit, which reverses the transmission process, uses essentially the same apparatus packaged in a similar type module.

2.4.6 *Carrier Supply Amplifier*

To avoid congestion or the possibility of a larger drawer, a monolithic crystal filter was developed and mounted as a part of the carrier amplifier shown in Fig. 13. The amplifier is secured to the base of the drawer with the input and output connections made through coaxial jacks and plugs. The amplifier components and the monolithic crystal filter are mounted on a printed wiring board. In order to maintain the high input-to-output loss, a special copper shield was required between the terminals of the filters.

The physical design advantages of MMX-2 over MMX-1 are:

(*i*) Floor space savings of better than 8:1 are realized.
(*ii*) Modules are equipped as required for service.
(*iii*) Service interruptions resulting from failure are significantly reduced by the automatic transmission and carrier switching.
(*iv*) Field testing and maintenance have been facilitated.
(*v*) Intraoffice cabling is reduced by intrabay shop cabling.
(*vi*) Complete flexibility for route assignment has been achieved.
(*vii*) The installation-to-service interval is reduced.

2.5 *Filters and Networks*

Frequency multiplexing, by its very nature, is a large user of filters and networks, such as band-pass filters, carrier and pilot selection filters, and band elimination filters. A variety of techniques and components are used.

Much of the L-4 networks' design and development challenge came because of three factors: the bandwidths are large, the transition bands narrow (4 percent) but adequate, and a large portion of the L-4 frequency spectrum falls in the awkward region for ferrite and air core inductors; that is, above 3 MHz and below 25 MHz. Ferrite

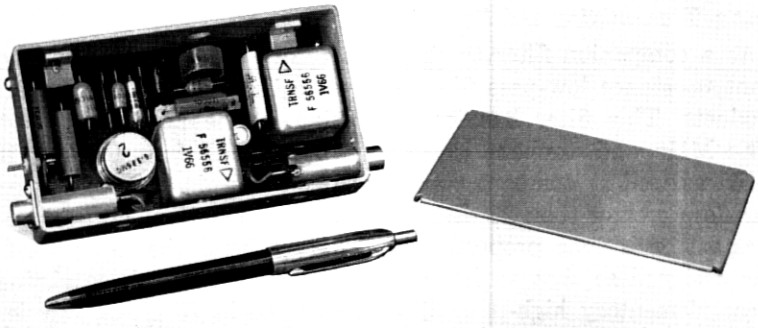


Fig. 13 — Carrier amplifier.

components are used wherever possible because of their generally superior Q, self shielding, and smaller size. Because of the extensive use of pilots and single-frequency tones in the L-4 system, about 50 percent of all of the filter designs required are crystal filters.

2.5.1 *Transmitting and Receiving Band-Pass Filters*

The L-4 mastergroup multiplex terminal requires a set of wide-band sharp cutoff band-pass filters: a transmitting (except for MG-1) and a receiving filter for each mastergroup. After analyzing the stop-band loss objectives for each mastergroup's transmitting and receiving filter (see Section 2.1.3), it was determined that the same design could be used for both. The mastergroup 1 receiving band-pass filter, with a bandwidth greater than 100 percent, is configured as a highpass-lowpass elliptic function filter of degree 9 and 12, respectively, with a 3 percent reflection coefficient for good inband impedance. High Q ferrite inductors are used in this band-pass filter. Mastergroup 2 through 6 band-pass filters use air core inductors, each mounted in a separate can with the rest of the filter section components. During the design and development stage, care was taken to correct for the large number of parasitics encountered. An insertion loss design of degree 22 proved satisfactory for mastergroup 2. Mastergroup band-pass filters 3 through 6 are image designs to facilitate development and tuning, with a newly developed terminating end section for parasitic correction, good image impedance and element values. Because of the effects of Q, each filter has an integral bridged-T amplitude equalizer. Figure 14 is a typical schematic diagram with the loss and return loss characteristics of a mastergroup band-pass filter.

2.5.2 *Transmitting and Receiving Low-Pass Filter*

As a companion filter to the mastergroup band-pass filter, a constant resistance low-pass filter is used to limit noise and modulation products. This filter has low distortion in the passband, 0.564 to 3.084 MHz, and stopband loss greater than 65 dB from 6.336 to 100.0 MHz, as well as constant resistance input impedance properties (return loss greater than 26 dB) from 0.564 to 35 MHz. To achieve the constant resistance properties in the stop band the low-pass filter was designed so that an impedance correcting network consisting of a complementary high-pass filter terminated in 75 ohms, the design impedance, could be used. The high-pass network contains fewer sections, 2 versus 4 for the low-pass network, because the system ob-

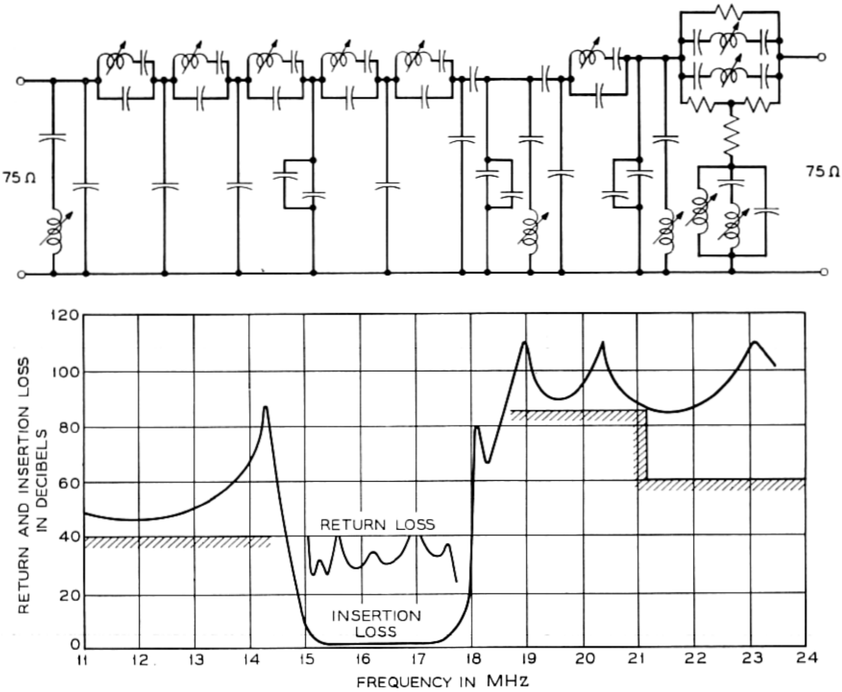


Fig. 14 — Schematic and loss versus frequency characteristic of typical MMX-2 transmitting and receiving band-pass filter.

jectives could be achieved by using an approximately complementary network, thus realizing some component economies. Small air core inductors with individual shields are used because of their stability and large useful frequency range. The disadvantage of low Q is not a great penalty; the small slope distortion across the band is corrected by a simple bridged-T equalizer.

2.5.3 *Carrier Supply Band-Pass Filters*

The L-4 carrier supply requires 21 narrow band-pass filter designs. Eight are used in the binary frequency supply. These are simple LC filters with midfrequencies (f_m) from 128 kHz to 16,384 kHz in binary multiples, 10 percent bandwidth, and more than 40 dB discrimination to $f_m/2$ frequencies. Another eight filter designs select the proper frequencies in the carrier generator. These are also LC filters, for the most part of greater complexity than the binary supply filters. All 16 filters are constructed with small shielded air core inductors mounted on printed wiring boards sealed in individual cans.

One of the more interesting and most unusual filter designs is the monolithic crystal filter (see Fig. 15) used in the carrier supply amplifier.[4, 5] An extremely narrow band with stopband losses in excess of 80 dB is achieved in a small volume, less than one-half cubic inch, crystal-only filter without the use of any additional elements.

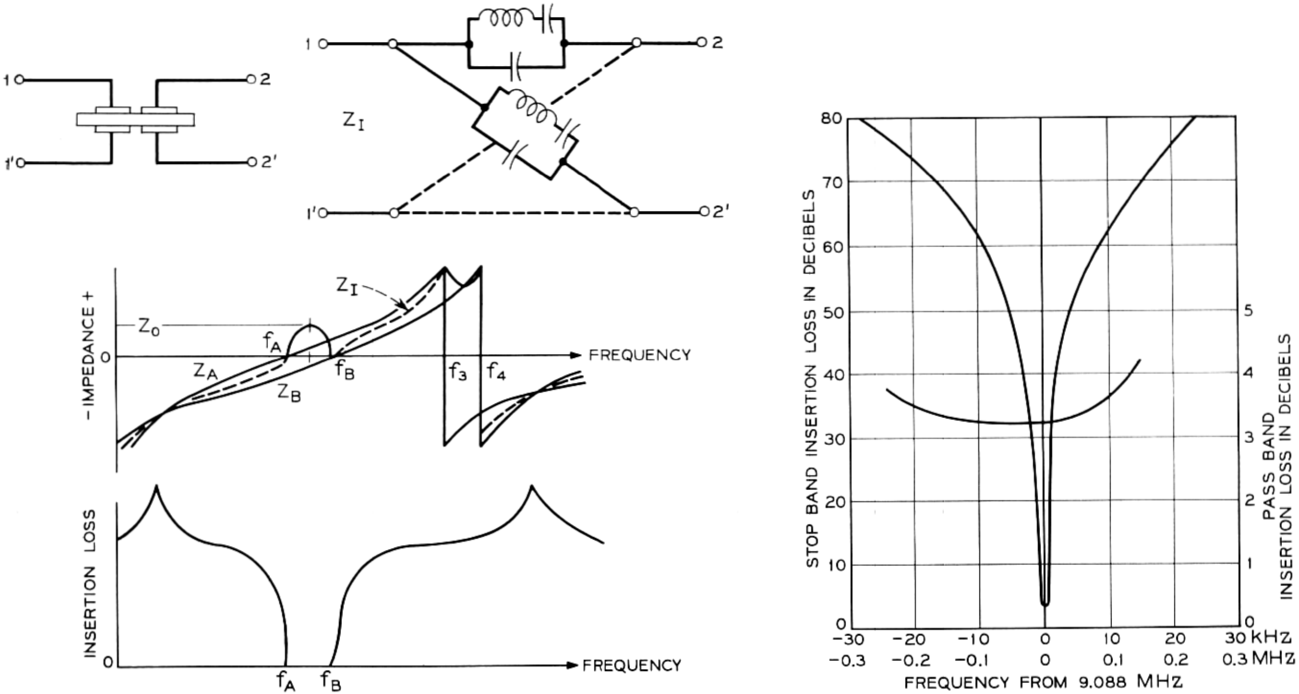
III. LINE CONNECTING CIRCUITS

As discussed in the introduction, the line connecting circuits are the means by which the L-4 line frequency signal is interconnected and controlled within a main station. Figure 16 shows the line connecting circuits in block diagram form. At a terminal point, these circuits interconnect the MMX-2 with the L-4 line. At through message stations, these circuits allow connection of all, or a selected part, of the received line signal to the transmitting line. In addition, the line connecting circuit provides line pilots, and controls the transmission or blocking of the various test and control tones required by the L-4 system through the main station.

One of the major influences in the design of the line connecting circuits was the initial decision that automatic protection would be provided for all active circuitry. While the transistor circuitry alone might have been considered sufficiently reliable not to require protection, the necessary power wiring, fusing, and power supplies, in addition to the basic circuitry with its susceptibility to operating error, constituted an unacceptable service hazard. As a consequence of this basic decision, it was determined that the major transmission path through the office should, if possible, be made completely passive. This requires a minimum of equipment in a through connection and results in better performance and higher reliability.

3.1 *Receiving and Transmitting Hybrid Networks*

The receiving and transmitting portions of the line connecting circuits contain hybrid networks which perform required signal splitting and combining functions. The receiving hybrid network splits the incoming line signal and provides five outputs at different levels. The lowest loss path through the network provides a connection to the blocking circuit, the major through connection in the office. The other outputs may be connected to: the receiving MMX-2 connecting circuit for dropping, the branching circuit, the sync receiving circuit, and a



CHARACTERISTICS OF SECOND-ORDER MONOLITHIC CRYSTAL FILTER

ATTENUATION CHARACTERISTICS OF 9.088 MHZ CARRIER SELECTION FILTER

Fig. 15 — Monolithic crystal filter.

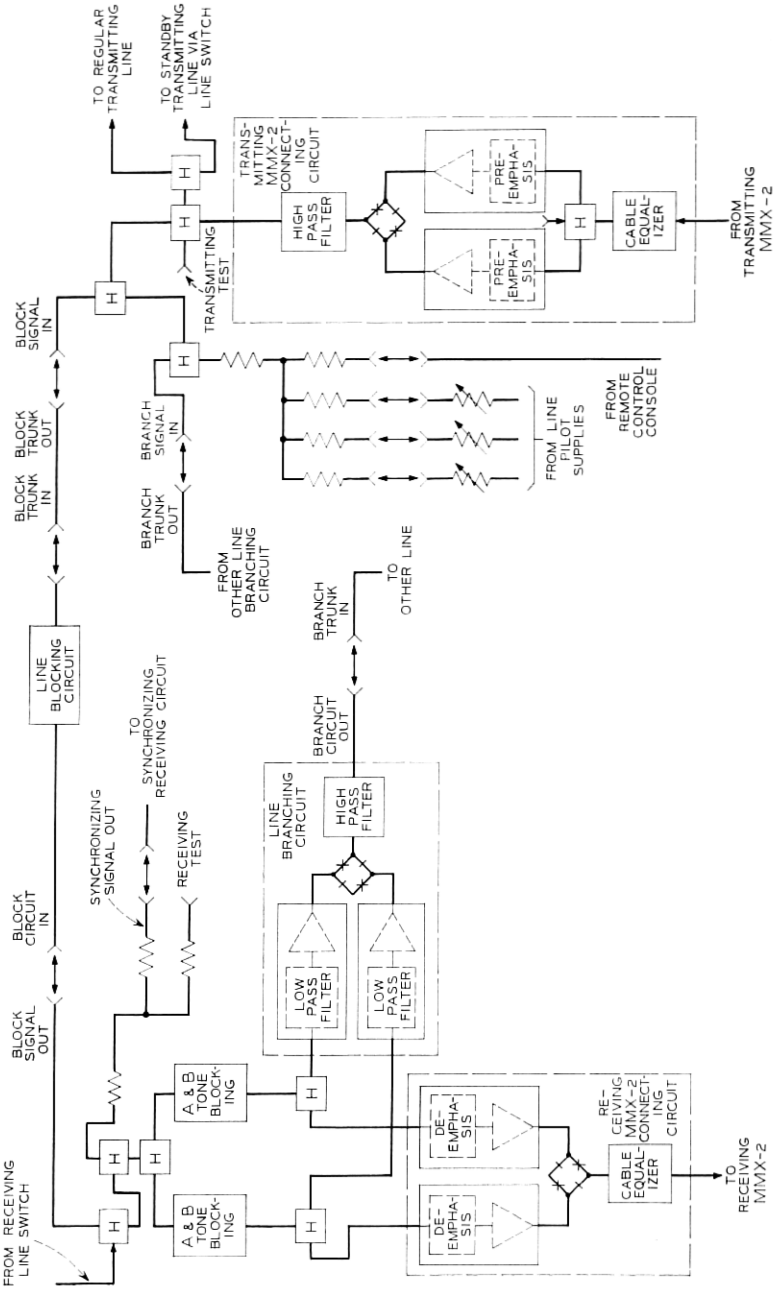


Fig. 16 — Line connecting circuits.

receiving test jack. The transmitting hybrid circuit accepts inputs from the blocking circuit, the branching circuit, the transmitting MMX-2 connecting circuit, the line pilot supplies, and the remote control center. Three outputs of the combined signal are derived. One output is connected to the transmitting line amplifier for the regular line. A second is connected into the transmitting line switching circuit where it can be connected into the protection line when required. The third output provides test access to the combined signal.

3.2 *Line Pilot Supplies*

There are three full-time pilots: 512 kHz for synchronization and low-edge regulation, 11.648 MHz for a line regulating pilot, and 20.448 MHz for the high-edge pilot. The two higher frequencies are generated in free-running crystal oscillators. The 512 kHz is obtained from the office primary frequency supply. Each office primary frequency supply can be synchronized by the incoming 512 kHz pilot.[6]

The two higher frequency supplies are almost identical, except for operating frequency, and are very similar to the 2.840 MHz mastergroup pilot supply in the MMX-2 bay. The major difference between the mastergroup and line pilot supplies is that each of the ten outputs from the distribution circuit for the line pilots can be connected through relays for local pilot insertion.

The 512 kHz supply's balanced input at −23 dBm and 135 ohms is processed by a clipping stabilizer, filtered and distributed. The clipping stabilizer has a 10 dB input dynamic range with only a 0.1 dB output change.

The clipper is a temperature-compensated diode circuit similar to the one used in the pilot oscillators. An input detector is used to change the bias in the clipper amplifier to cut it off if the input drops by more than 10 dB. This prevents placing a potentially noisy synchronizing pilot on the line.

The 512 kHz supply is redundant in the same way as all the other pilot supplies. The stabilizer alarm detectors, however, are "window" detectors which alarm when the output signals deviate in either direction by more than 0.5 dB from nominal. This is necessary since the stabilizers are very stiff, and only slight output errors must be detected in order to properly recognize an out-of-service condition.

3.3 *Synchronization Receive Circuit*

The synchronizing pilot at 512 kHz is obtained from the same splitting pad which provides the signal to the receive test jack. The power at this point is approximately −52 dBm, which must be amplified before the signal is distributed to the office primary frequency supplies. This function is accomplished in the 512 kHz synchronization receiving circuit. This panel provides three output taps at −23 dBm and 135 ohms balanced. The number of taps was intentionally limited to prevent connection of more than three primary frequency supplies.*

The input impedance of the synchronization receiving circuit must have a return loss in excess of 26 dB to prevent disturbing measurements made at the receive test jack. Also, it must accept the entire line spectrum. This necessitates a pad and amplifier at the input prior to the crystal 512 kHz pickoff filter. Thus the higher gain amplifier following the filter does not require a high level output capability, nor is the filter subjected to a high input level.

This panel is not redundant and has no alarm outputs. The line alarms adequately indicate the loss of the 512 kHz pilot and redundancy is not necessary since the primary frequency supplies can free run for a short time with little system impairment. Instead of redundancy, a mounting for a cold spare unit is provided in the panel. This prealigned cold spare can be manually placed in service in a short time.

3.4 *Line Blocking Circuit*

The blocking circuit's primary function is that of connecting only desired portions of the L-4 line signal from the receiving circuits to the transmitting circuits. The signal which is transmitted may consist of all or part of the message spectrum, line pilots and, under some circumstances, a part of the equalizer control signals.

In the early stages of developing the blocking circuits it was recognized that, although the ultimate in message signal blocking would be to have completely unrestricted blocking, there would be advantages if something less than this were acceptable. Consultation with the operating companies revealed that the more restricted plan of requiring only contiguous sets of mastergroups to be blocked was adequate.

By restricting the message blocking capability to only sets of contiguous mastergroups, a much more manageable system was made possible. Instead of using tandem connected band elimination filters, it is possible to use a parallel combination of a high-pass and a low-

---

* It is intended that there be one office master (and an alternate) primary frequency supply from which all other primary frequency supplies are synchronized.

pass filter which have overlapping stopbands to block the message signal. Consequently, the passed signal encounters the distortion and loss introduced by only one filter. Section 3.9.1 gives an example of blocking. The flat loss is 10 dB: 8 dB for the blocking filters, and 1 dB each for the splitting and combining filters. The total flat loss in the passband of the complete blocking circuit is 15.9 dB.

The L-4 system design allows the line pilots to be transmitted through as much as a complete frogging section, 800 miles maximum, without being blocked and reinserted. However, it is not a requirement that this be done. It is permissible to block and reinsert more often if necessary.

The 512 kHz line pilot is treated differently from the 11.648 and 20.448 MHz pilots because of its use as a synchronizing signal as well as a line pilot. In order to ensure good synchronizing, it was originally decided to transmit the 512 kHz pilot through the full system without blocking.* Each station bridges the synchronizing signal off the line in L-4. This is in contrast to earlier systems which blocked and reinserted frequently, sometimes at every main station, thus introducing onto the pilot the noise generated by the office synchronizing equipment.

In order to allow transmission of the 512 kHz signal over a full system, the line blocking circuit was designed to pass 512 kHz in all of its applications. For example, when mastergroup 1 is blocked, a 512 kHz band-pass filter is paralleled with the blocking filter. In addition, a blocking circuit which passes only 512 kHz was designed for use at points where the full message load is dropped.

The 11.648 MHz line pilot is blocked and reinserted whenever mastergroups 4 or 5 are blocked. When both are blocked, the message blocking filters remove the pilot as well. When one but not the other is blocked, some of the pilot signal will leak through, since the blocking filter is in its transition region at this frequency. In this case, a pilot blocking filter is added which suppresses the pilot by a minimum of 50 dB after which the pilot is reinserted. The 20.448 MHz pilot is blocked when mastergroup 6 is blocked. No additional pilot blocking filter is required since the message blocking will always suppress the pilot to the required extent.

Two other sets of signals are controlled by the line blocking circuit: the line switching tones and the equalizer control tones. The

---

* For reasons beyond the scope of this paper, the 512 kHz pilot is now blocked and reinserted at frogging points (approximately 800-mile intervals).

switching tones must be suppressed at every main station to avoid inter-section switching interactions. All of the equalizer control tones must be suppressed at main stations that have remote control centers. At stations without remote control centers, only the lower half must be blocked in one direction of transmission and only the upper half in the other direction.

Three filters have been designed to meet these requirements. At stations which require complete blocking, a 512 kHz highpass filter is used in the blocking circuit which suppresses the switching and control tones in the 280 to 500 kHz band but passes the 512 kHz pilot. When partial blocking is required, one direction of transmission uses a 400 kHz high-pass filter which blocks only the lower half of the control tones along with the switching tones. In the other direction, a complex filter is used which suppresses the switching tones and the upper half of the equalizer tones between 400 and 500 kHz.

Another version of the line blocking circuit is used with the protection line. This circuit is intended for use at main stations which do not have remote control centers and allows the equalizing test tones to pass through the office to the next main station, which must have a remote control center. Without this circuit, it would not be possible to equalize the far main section of the protection line when two-section equalizer control is required.[3] In addition, all line pilots, line switching tones, and equalizer control tones are blocked.

3.5 A *and* B *Equalizer Tone Blocking Circuit*

At the inception of the L-4 system design, it was planned to provide A and B equalizer test tone blocking in the main transmission path at every main station which was equipped with a remote-control center. This would isolate the equalizing sections from each other and obviate any need for coordination between remote-control consoles. As the design of the system and of the required blocking filters progressed, it became apparent that this was not practicable. The complexity of the filter design was such that ultimately eight filters were required, with a combined loss to the passed signal of approximately 59 dB exclusive of padding needed to avoid impedance interactions. Inclusion of this large number of networks with the necessary amplification in each main station with a remote control center would have seriously strained the L-4 system amplitude and phase distortion requirements. Therefore, it was decided to place the tone blocking circuit in the dropping and branching paths. Consequently, a through mastergroup encounters only one of these circuits in a frogging section, at the frogging point where it is dropped. In addition, it prevents interaction between systems by way of branching or interconnection through mastergroup connectors. Since the tones are passed through the blocking circuits within a frogging section, coordination between remote control centers is required in the frogging section.

Two complete tone blocking circuits are provided. Each consists of tandem connected tone blocking filters, amplifiers, and impedance isolating pads. The two circuits are fed from identical outputs from the receiving hybrid circuit. Each side has a hybrid circuit as its final component which provides an output to the receiving MMX-2 connecting circuit and another to the branching circuit. One side or the other is selected in the connecting and branching circuits.

3.6 *Receiving MMX-2 Connecting Circuit*

The receiving MMX-2 connecting circuit is composed of parallel transmission paths, each containing a de-emphasis network, an amplifier, and a hybrid. The hybrid on each side feeds an output to a coaxial switch and an output to a pilot detector circuit. The pilot detector circuit recognizes the presence or absence of the 512 kHz line pilot and operates the coaxial switch to select one of the transmission paths from the receiving hybrid circuit, through the A and B tone blocking circuits, and through the connecting circuit. The switching logic and power fusing have been arranged such that loss of a single main discharge fuse will not cause a loss of service.The logic is also arranged such that complete loss of the incoming pilot from the line will not cause a switch. The output of the coaxial switch is fed through a cable equalizer to the receiving MMX-2 terminal. The equalizer is capable of equalizing for up to 200 feet of cable between the receiving line bay and the MMX-2 bay.

3.7 *Line Branching Circuit*

The branching circuit is the complement of the blocking circuit. While the blocking circuit blocks sets of contiguous mastergroups, the branching circuit passes sets of contiguous mastergroups. The blocking circuit function is performed by parallel high-pass and low-pass filters with overlapping rejection bands. The branching function is performed by these same filters but having overlapping passbands and operated in tandem. While the blocking circuit often passes line pilots, the branching circuit never passes them.

The branching circuit requires the use of an amplifier because of the high loss introduced by the tandem connection of the message blocking high-pass and low-pass filters, 16 dB, as well as the pilot blocking filters and cable equalizer. Because of this, it contains a transmission switching circuit nearly identical to that used in the receiving MMX-2 connecting circuit.

3.8 *Transmitting MMX-2 Connecting Circuit*

The transmitting MMX-2 connecting circuit is a dual switched circuit which prepares the output signal of the MMX-2 bay for interconnection into the L-4 line by applying the required pre-emphasis and adjusting its level. The switching circuit is identical to that used in the receiving MMX-2 connecting circuit and the branching circuit. A 512 kHz signal is applied at the input of the circuit and used to operate the switching. A 544 kHz high-pass filter is used at the switch output to remove the 512 kHz signal as well as any undesirable low frequency noise originating in the MMX-2.

3.9 *Line Connecting Filters and Networks*

From a network point of view, the line connecting function is dominated by two very difficult filter designs: the mastergroup blocking and branching filters and the A and B tone blocking filters.

3.9.1 *Mastergroup Blocking and Branching Filters*

The blocking of contiguous mastergroups is achieved by a combination of one high-pass, one low-pass, and two split-apart filters. Five designs of each high-pass, low-pass, and split-apart filter are required to accomplish this versatility. For example, to block mastergroups 4 and 5, a low-pass filter that passes mastergroups 1, 2 and 3, a high-pass filter that passes mastergroup 6, and a pair of split-apart filters with transition regions in mastergroup 4 or 5 are required. The use of the more complex split-apart filters instead of a pair of hybrids gives two important advantages: the flat loss is reduced to 2 dB (1 dB per split-apart filter) versus 6 dB for a pair of hybrids, and more important, the inband return loss is good. The inband return loss would not be good in the case of hybrid use.

The low-pass and high-pass filters are insertion loss designs, each of degree 19. The split-apart filters are also insertion loss designs but of degree 6. A considerable amount of loss distortion, up to 6 dB, at the passband edge is a result of the steep transition band and the ferrite inductor Q of approximately 200. This distortion is equalized by bridged-T equalizers which are an integral part of each low-pass and high-pass filter. Figure 17 is a typical schematic diagram for a mastergroup blocking filter arrangement.

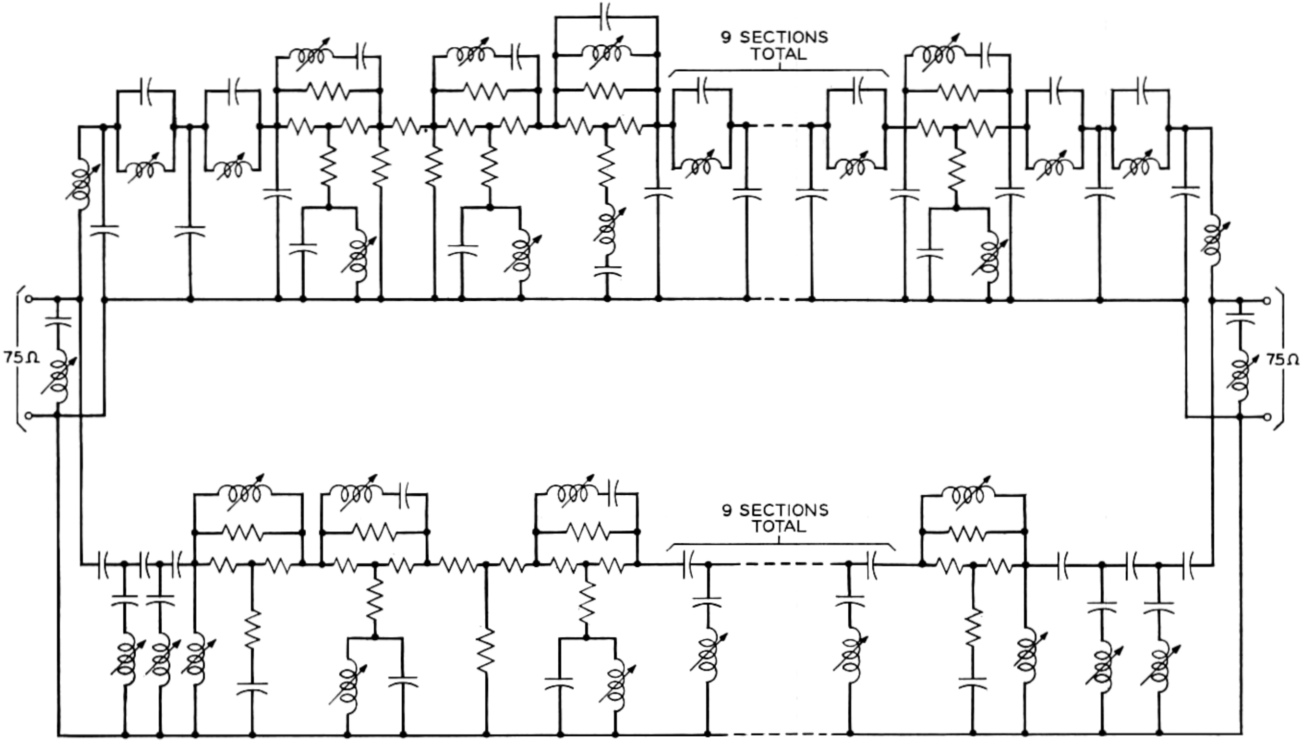


Fig. 17 — Schematic of typical mastergroup blocking filter arrangement.

Considerable care was taken during development of these filters to compensate for or reduce the parasitic capacitances, as well as to eliminate ground loops and other coupling paths. These filters must maintain discriminations in excess of 80 dB in the blocked mastergroups.

These same high-pass and low-pass filters (without the split-apart filters) are used in the mastergroup branching circuit. The appropriate high-pass and low-pass filters are chosen and put in tandem to form a band-pass filter to branch the mastergroups desired.

3.9.2 *512 kHz, 11.648 MHz, and 20.448 MHz Pilot Blocking Filters*

The blocking and branching circuits also contain the blocking filters for the three full-time line pilots, 512 kHz and 11.648 and 20.448 MHz. The 512 kHz pilot is blocked by a high-pass filter with a passband from 544 kHz to 21 MHz, suppressing 512 kHz by a minimum of 70 dB. The 544 kHz high-pass filter was designed with an equal ripple passband and arbitrary stopband with six finite-frequency poles and a pole at zero. Computer programs were used for the pole placement as well as for the synthesis. The severe objective of passband flatness, 0.1 dB up to 21 MHz, required extreme attention to detail during the physical realization of the filter.

The 11.648 and 20.448 MHz pilot blocking filters are conventional Dagnall crystal band-elimination filters. Both use the same electrical and mechanical structure; only the crystals are different. Since these band-elimination filters are always in the main transmission path, care was exercised to reduce all unwanted crystal responses. By using the trapped energy principle during crystal design, and AT cut crystals, the unwanted responses were reduced to an acceptably low level.

3.9.3 *Command, Line Switching, and Monitoring Tone Blocking Filters*

Command tones in the 300 to 500 kHz range, and monitoring tones in the 18.500 to 18.560 MHz range, must be blocked and passed in various combinations as outlined in Section 3.4. A scaled version of the 544 kHz high-pass filter reviewed in Section 3.9.2, designated the 512 kHz high-pass filter, passes from 512 kHz to 21 MHz and suppresses the command signals, 300 to 500 kHz, by a minimum of 40 dB. This filter is in turn combined within a complex network made up of input and output split-apart terminations with a band-pass filter, 316 kHz–396 kHz, an equalizer in the upper leg and the 512 kHz high-pass filter and equalizer in the lower leg (see Fig. 18). The overall characteristic of this command channel subgroup II filter passes the basic L-4 transmission spectrum with the 512 kHz synchronizing

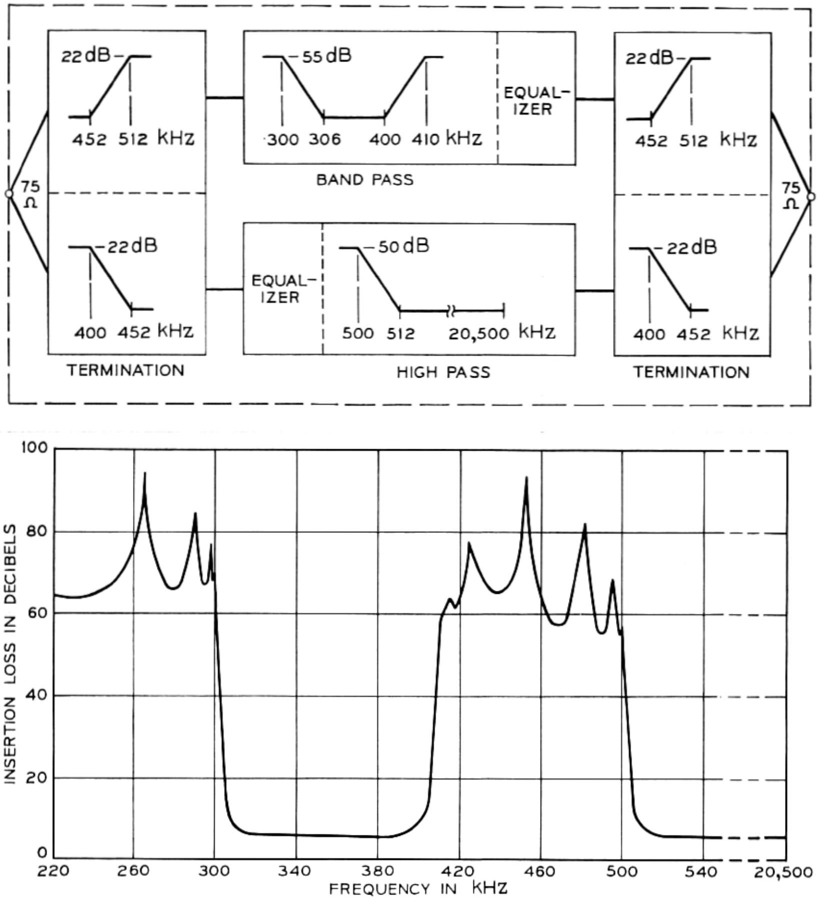


Fig. 18 — Command and line switching tone blocking filter.

pilot and passes subgroup II command channel tones while rejecting the line switching tones below 300 kHz and the rest of the command channel tones.

The sixteen monitoring oscillator tones, 18.500 to 18.560 MHz, are blocked by an LC band-elimination filter using a pair of special band-elimination sections and incorporating infinite-Q compensation.[7]

3.9.4 A *and* B *Equalizer Tone Blocking Filters*

The problem of suppressing a large number of single frequency tones, used for control of the A and B equalizers, by a minimum of 50 dB and passing all the L-4 message bands with less than 0.1 dB distortion had to be solved. Three design approaches were used. For frequencies 5.888 MHz to the highest B tone, 20.200 MHz (where the third overtone of a crystal resonating at the tone frequency falls above the passband of interest), a Dagnall type filter, combining a low-pass filter with shunting quartz crystals, is used. For frequencies 1.056 to 4.256 MHz (where the third overtone falls in the L-4 transmission band), the more complex band-pass-band-elimination filter principle is used. At the lowest tone frequency, 0.544 MHz, where the transition bandwidths are more generous, a conventional LC band-elimination filter using high Q ferrite inductors is used.

The Dagnall high frequency tone blocking filters consist of a number of low-pass filter sections, whose cutoffs are above the highest frequency in the L-4 band, with the shunt capacitance replaced by a crystal(s) and fixed capacitor. The crystals at series resonance shunt energy to ground, thus giving rise to the band-elimination effect.

At the low A and B tone frequencies, where the third overtones fall in the L-4 band and the unwanted responses were a problem, a considerably more complex design was used. Figure 19 outlines the complexity of a typical low frequency A or B tone band-elimination filter. The input and output band-pass and band-elimination split-apart filters were designed as complementary pairs with approximately 20 to 40 percent bandwidths; then a crystal band-elimination filter is inserted in the band-pass leg. The design of Fig. 19 consists of two

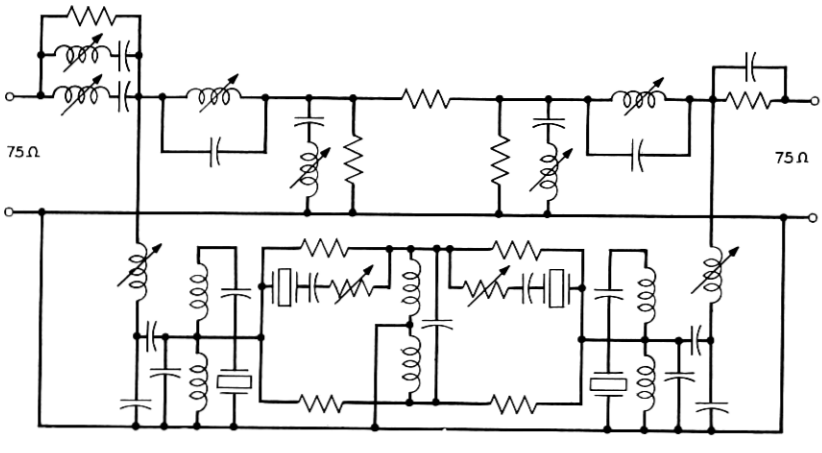


Fig. 19 — Schematic of typical low frequency A- or B-tone band-elimination filter.

crystals shunting the high impedance autotransformers and two special lattice bridge sections. These half-lattice bridge sections are low loss pads with a crystal shunting the large resistor. At crystal resonance, the effective resistance of the crystal shunts the high resistance leg, forming a bridge balance and a transmission null. This design is used to achieve sufficient suppression magnitude and bandwidth without the penalty of large insertion phase at passband frequencies. The network in the band-elimination leg compensates for the insertion loss and phase in the band-pass leg. The flat loss of one of these filters is nominally 8 to 9 dB.

IV. MASTERGROUP CONNECTORS

4.1 *Early Connectors*

Although in principle every message channel could be demultiplexed all the way to voice frequency level at a coaxial system main station, this is seldom done in practice. Many 12-channel groups and 60-channel supergroups are conveyed across the office without further demultiplexing, and fed to other coaxial or radio routes.

The filtering and transmission level adjusting circuits between systems are known as group or supergroup connectors. They provide economies and performance improvement by virtue of reducing the number of channel and group banks in a long distance telephone circuit. They also make possible the routing of group and supergroup bandwidth data circuits from system to system without spoiling the integrity of the wide frequency band.

In 1963 a mastergroup connector became available, capable of interconnecting basic mastergroups among L-3 coaxial and TH (and some TD-2) radio systems, specifically by interconnecting the MMX-1 terminals.

4.2 *Mastergroup Connectors for L-4*

New mastergroup connectors were designed for three reasons. New connectors were desirable to exploit the better band-pass filter in-band frequency characteristic made possible by the more generous spacing of MMX-2 derived mastergroups. New connectors were necessary to suppress the 2.840 MHz pilot in the MMX-2 derived mastergroup to prevent its interference with pilots on immediately connected or remote systems. Finally, field experience with the MMX-1 to MMX-1 connector indicated that a single equipment package containing the circuits for both directions of transmission would be desirable.

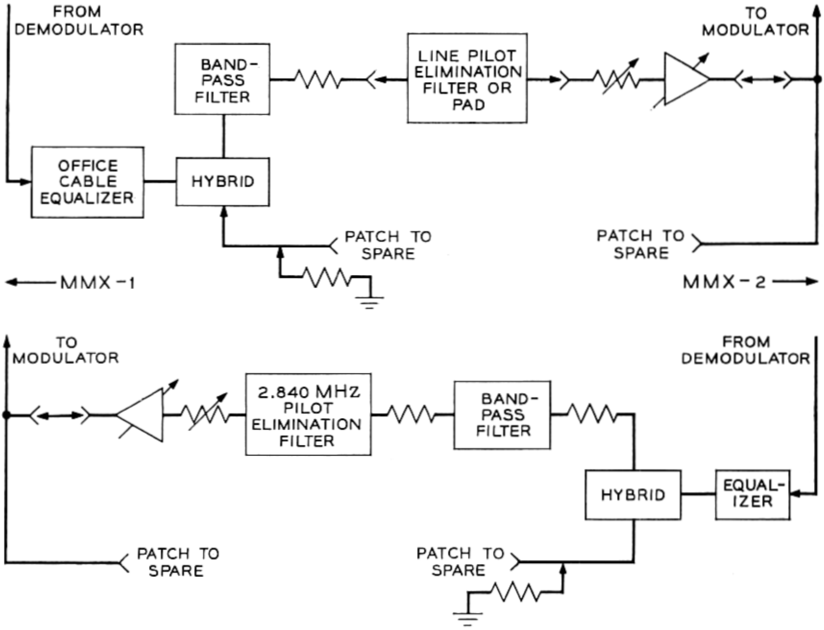


Fig. 20 — Mastergroup connector, MMX-1 to MMX-2 (two-way).

Consequently, two new two-way mastergroup connectors were developed. Figure 20 shows the MMX-1 to MMX-2 connector. The MMX-2 to MMX-2 connector is similar; both halves look like the bottom part of Fig. 20.

V. LINE PROTECTION SWITCHING

5.1 *L-4 Protection Switching*

One pair of coaxials on an L-4 route is assigned as a protection pair for the lines in service. The number of pairs in service is therefore nine for a fully equipped 20-coaxial cable route. To help meet early L-4 service schedules, the already available L-3 protection switching system was modified for use on L-4 routes.[8] The modification has two essential aspects:

(*i*) The L-4 pilots, used to signal the condition of the line to the switching control system, differ in number and frequency from those in L-3.

(*ii*) The modified system has been expanded to operate on a one-for-nine basis. Need for this modification is really a result of the use of the 20-coaxial cable instead of the older 12-coaxial or 8-coaxial cable. In principle, the expansion could also be used with L-3.

5.2 *Switching Control System*

The L-3/L-4 switching control system, developed in the early 1950's for L-3, depends on transmission of two types of signal. One consists of the line pilots (512 kHz and 11.648 MHz for L-4) which cause switch initiation if their power levels change substantially. The other is a revertive signal which goes back over opposite-direction lines to the transmitting office to control the transmitting switch. This signal consists of tones in the 280 to 290 kHz band. Finally, a 296 kHz forward-transmitted tone verifies operation of the transmitting switch and thus signals the receiving switch to operate.

The receiving control circuits are provided on each line and have access to the particular line via a hybrid in the receiving line connecting circuits, as suggested in Fig. 2. Each of the two line pilots is selected by a pick-off filter, amplified and rectified in a detector circuit. Each detector circuit drives a control microammeter. If any of the two control meters deviates more than 2 dB from zero, it activates office alarms, lights the alarm lamp associated with the meter, and initiates a "slow" switch, so called because the meter can take as much as a quarter of a second to swing past the 2 dB limit and initiate a switch.

The slow switch is intended for automatically switching out a badly misequalized line, or one for which a control pilot has drifted beyond 2 dB for any reason. In case of a catastrophic failure the 11.648 MHz detector provides, besides the meter drive signal, a dc signal which bypasses the meter and initiates switching action as soon as the pilot deviates plus 4 or minus 5 dB. The resulting "fast switch" is completed in about 15 milliseconds after the failure.

5.3 *Coaxial Switches*

Three types of coaxial switch are used in L-4: a 223B for the transmitting switch, 223C for the line terminating switch* and 223D for the receiving switch. To minimize the transient caused by a manual line switch, the 223D switch was designed as a make-before-break switch, using the 237 type sealed reed element for the contacts. On a manual switch there is no change in the regular line path until the receiving

---

* In case of total failure, the line terminating switch terminates the incoming line.

switch operates; the transmitting switch, which operates first, merely puts the message signal on the standby line as well as on the regular line. The "make" contacts are closed by an electronic timing circuit, which is an integral part of the 223D switch, before the "break" contacts are opened by the timing circuit. On switching back, the "break" contacts are closed first. In a multiline switching system, one to four regular lines are equipped (per direction). The switching control bays are connected so that these tones go back over two to five lines, including the standby line.

An "expanded multiline" system, good for up to eight lines (per direction), can be installed by connecting the four tones to the return lines in two groups; this adds space-diversity to the frequency diversity so that one out of eight lines can be identified by the tone frequency and the group it is found on at the transmitting station.

For 20-coaxial use, particularly for the early L-4 installations, further modifications provide "super-expanded multi-line" capability by extending the line grouping to three groups. This allows up to one-for-twelve switching, but one-for-nine switching is expected to be the maximum used in the immediate future.

Such expansions of multiline capacity by grouping return lines is simple in concept; the complications are in planning the grouping pattern changes with growth from, say, one-for-one to one-for-nine. These complications are beyond the scope of this paper.

REFERENCES

1. Blecher, F. H., Boyd, R. C., Hallenbeck, F. J., and Herr, F. J., "The L-4 Coaxial System," B.S.T.J., this issue, pp. 821–839.
2. Hallenbeck, F. J. and Mahoney, J. J., Jr., "The New L Multiplex—System Description and Design Objectives," B.S.T.J., *42,* No. 2 (March 1963), pp. 207–221.
3. Anderson, R. E. and Crue, C. R., "The Equalizer Remote Control System", B.S.T.J., this issue, pp. 953–981.
4. Beaver, W. D., "Theory and Design of the Monolithic Crystal Filter", Proc. 21st Annual Frequency Control Symp. Atlantic City, N. J., April 25, 1967.
5. Sykes, R. A., Smith, W. L., and Spencer, W. J., "Monolithic Crystal filters," IEEE, 1967 Int. Conv. Record, Part 11, pp. 78–93.
6. Kester, W. A., "A New Reference Frequency Standard for the L Multiplex System," B.S.T.J., *47,* No. 10 (December 1968), pp. 2183–2205.
7. Desdames, B., "Design of a Special Band-stop Filter by Means of Two-arm Structures with Three Cut-off Frequencies," Cables et Transmission, *19,* No. 1, (1965), pp. 27–29.
8. Elmendorf, C. H., Ehrbar, R. D., Klie, R. H., and Grossman, A. J., "The L-3 Coaxial System—System Design," B.S.T.J., *32,* No. 4 (July 1953), pp. 818–820.