The Automatic Protection Switching System of TH Radio

By A. J. GIGER and F. K. LOW

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It is the purpose of the automatic protection switching system to ensure continuity of service over the TH system. The protection system prevents any signal loss from occurring in case of fading, and it will restore service a short time after transmission equipment has failed. The over-all reliability of the TH system is thereby very substantially improved. Switching is done in switching sections. These usually contain a number of repeater stations, in which case the switching is normally done at IF. When a channel has to be switched, it is replaced over the full length of the switching section by a protection channel. Protection is also provided for FM terminal transmitters and receivers; in this case the switch is at IF on one side and at baseband on the other. In addition to the IF and baseband switches themselves, the system comprises monitors of various sorts, logic circuitry at each end of the switching section, communication facilities between ends over the auxiliary radio channel, and manual controls. In contrast to the rest of the TH system, which uses mostly electron tubes, the switching system employs solid-state devices entirely.

I. GENERAL CHARACTERISTICS

The protection switching system permits the replacement of a regular channel by an equivalent stand-by or protection channel. This is done automatically for fades exceeding 27 db in any repeater section and for equipment failures. It can be done manually to release the regular channel for maintenance.

The reliability objectives for the over-all telephone system are that the outage time of a channel should not exceed 0.01 per cent per year, or 0.05 per cent in the worst fading month in a 4000-mile circuit. Several factors like frequency spacing between microwave channels, the number of channels in TH, maintenance procedures, and the length of the switching sections make it necessary to provide two protection channels in TH to meet these objectives.

Protection against fading is possible because fading in microwave systems is generally frequency selective and tends to affect only one broadband channel at a time. A protection channel is normally available when a regular channel fades, and the protection switching system then acts as a switch-type frequency diversity system. However, with only 30-mc separation between radio channels, the probability of two adjacent channels fading simultaneously cannot be neglected

To perform maintenance on equipment, the channel involved is replaced by a protection channel, which makes the latter unavailable for other channels which might get into trouble. The need for two protection channels is again clearly indicated. Daytime maintenance of TH is recommended to avoid the period of heavy fading during the night and especially during the early morning hours. The longer the switching section, the higher is the probability of fading or equipment failure on a given channel, and the more difficult it becomes to meet the reliability objectives. Accordingly, switching sections contain at most ten repeater sections; the average is six.

Table I gives calculated channel outage times for a 4000-mile TH system, taking into account fading, equipment failures, daytime maintenance, and an average switching section length of six repeaters. The table shows that a single regular channel protected by only one protection channel does not meet the outage time objectives given above. The calculated outages, however, are not serious enough to warrant the

Table I — Calculated Outage Times for TH Automatic Protection Switching*

For 4000-mile route due to fading, daytime maintenance, and equipment failures. Average switching section length of six repeaters.

Channels Equipped		Worst Month %	Annual %
Regular	Protection		
1	1	0.111	0.038
2	1	0.167	0.057
3	1	0.222	0.076
2	2	0.0016	0.0005
3	2	0.0040	0.0011
4	2	0.0078	0.0019
5	2	0.0130	0.0033
6	2	0.0198	0.0049
Objectives		0.05	0.01

* Table by Mr. J. F. Laidig.

installation of two protection channels with the first regular channel. As soon as the second regular channel is installed, two protection channels are provided, and the outage time objectives are met even with the ultimate complement of six regular channels. It is of interest to note that in a system without protection switching, a broadband channel would be out of service several hundred hours per year due to fading and failures alone, not considering maintenance.

In addition to the outage time objectives, there are systems requirements imposed by the need to avoid transmission disturbances, called hits, produced by fading or maintenance switching. The requirements on hits vary with the type of service carried over the broadband channel — telephone circuits being more tolerant than telegraph or data. Switching hits can be caused by shorts, opens, misterminations or transient voltages produced by the switches themselves during the switching interval. The requirement on this is about 10 microseconds for the transient duration. Field tests show that the circuit design is such that these hits do not affect any services presently transmitted over TH.

A second type of hit is due to level or phase differences between the two channels involved in a switch. The objectives for this are that the instantaneous level change should not exceed 0.25 db at any frequency in baseband, and that the signal shift should not exceed 10 millimicroseconds. This latter requirement means that the absolute transmission time over a switching section (which could be over 300 miles) has to be the same for all eight channels within about six feet of IF cable. Meeting this objective turns out to be a rather involved feature of TH. Briefly, the differential delay of the channels is measured, and the shorter ones are built out to equal the longest with suitable lengths of IF cable. Every effort is being spent to hold the level and phase differences between channels within acceptable limits.

Another type of interference which is easily overlooked is produced by the removal of circuit units for maintenance. Special attention has been given to this problem, and as a result routine maintenance operations, especially on the switches, do not interfere with the signals carried over the broadband channels.

A transmission interruption cannot be avoided, however, when the signal in a channel suddenly disappears due to equipment failure. It takes the system a certain time to transfer service to a protection channel. The signal outage is from 5 to 40 milliseconds, depending on the length and the type of switching section. This figure is well below the 50-millisecond maximum set by seizure of the common equipment in a telephone dial office.

II. THE TH SWITCHING SECTION

As shown in Fig. 1, the switching sections on a TH route form an unbroken chain. Several types of switching sections are possible. The most common are IF-to-IF over several repeater stations and intra-office (local) baseband-to-IF (and IF-to-baseband) around FM terminals. Other types of switching sections are also possible, like the baseband-to-IF sections extending over radio repeaters shown in Fig. 1 and the very rare case of baseband-to-baseband switching.

Each switching section is completely self-contained and has no interconnection with other sections. A switching section protects both directions of transmission. The switching equipments for the two directions are essentially alike but independent of each other. Fig. 2 shows the block diagram of a generalized TH switching section for one direction of transmission. The different blocks of Fig. 2 are described in the following paragraphs.

2.1 *TH Broadband Transmission Facility*

This block represents different possible broadband transmission arrangements as, for instance, a microwave link with several repeater stations starting with radio transmitters at the input and ending with radio receivers at the output. In this case, ingoing and outcoming broadband signals are at IF (74 mc). For terminal switching only, the transmission facility represents transmitting or receiving FM terminals with inputs and outputs at either baseband or IF.

2.2 *Broadband Channel Monitors*

Associated with the transmission facility of Fig. 2 are monitors which check the broadband channels and produce an output if the channels they are associated with are in trouble. In TH, monitors are located at both ends of a switching section and at intermediate repeaters. In the TD-2 protection switching system[1] only one monitor, sensing the signal-to-noise ratio, is used per channel at the receiving end of a switching section. This method cannot be used in TH because a very noisy signal is replaced by an automatically inserted IF carrier.[2]

There are several different IF monitors, which sense the amplitude of the IF carrier. The monitor in the radio receivers operates from the automatic gain control (AGC) system of the main IF amplifier[2] and produces an output when the IF carrier drops approximately 27 db below normal, for instance, due to fading in the microwave path. For a sudden loss of carrier, this AGC monitor reacts relatively slowly (within about

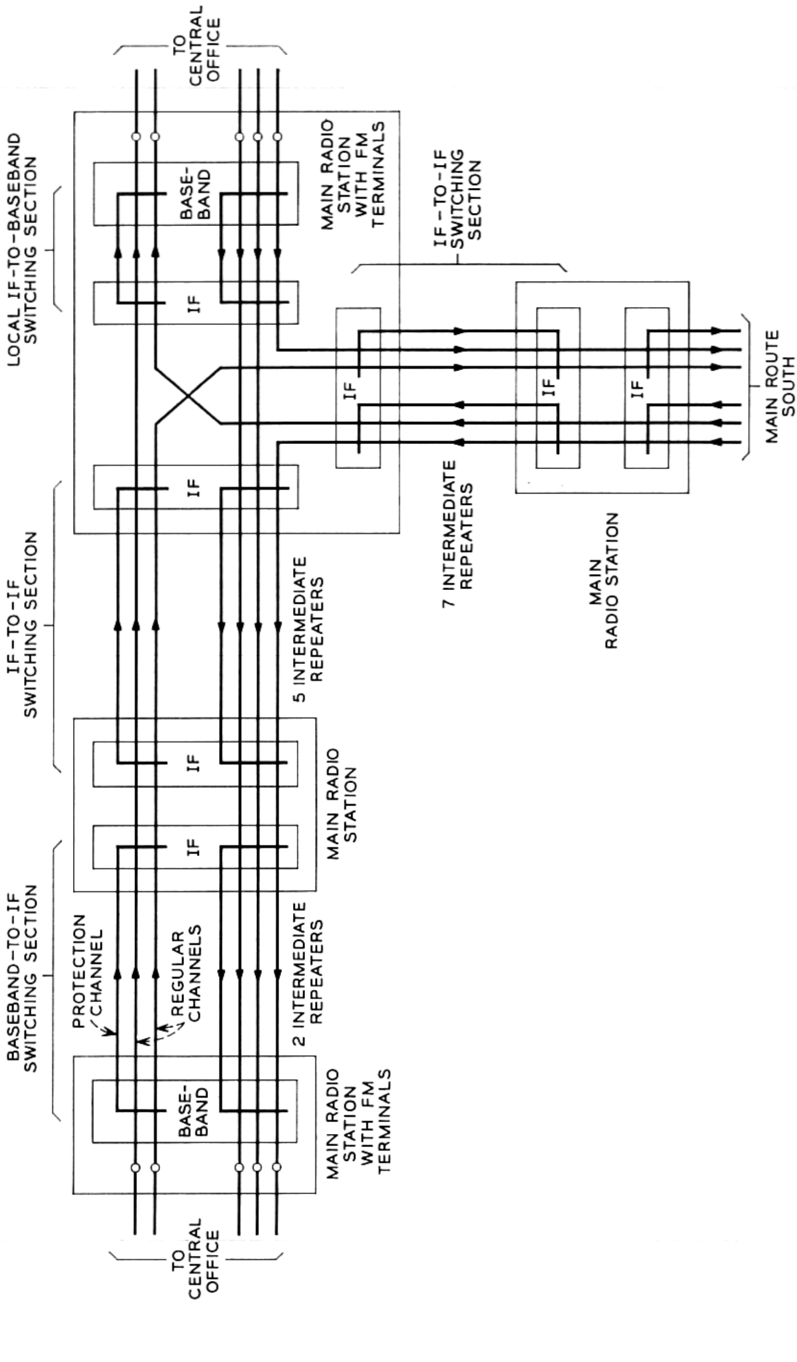

Fig. 1 — Types of TH switching sections.

7 milliseconds). A 2-millisecond response to equipment failure is obtained from the carrier resupply circuit of the radio transmitter.[2] Still another IF monitor is used at the very end of a switching section to indicate failure of the active equipment preceding the switches. In the FM receiver, a voltage proportional to the IF carrier is obtained from the frequency discriminator.[3]

Baseband equipment in the FM terminals is protected by monitors which operate when the dc operating points in the balanced baseband amplifiers have changed beyond a certain limit.[3] This monitoring scheme is considerably simpler than a pilot-tone method but only slightly inferior in its ability to detect trouble.

2.3 *Transmitting and Receiving Switches*

When a switch is requested, the regular channel is first bridged to a protection channel at the transmitting end and then switched to the protection channel at the receiving end. The transmitting switch is bridged across the incoming regular channels A to F as shown in Fig. 2. The signal on any of the six regular channels can be connected to either of the two protection channels, designated X and Y, without producing hits on the through-going channel. The transmitting switches at IF and at baseband are diode switches which operate within a few microseconds.

In the case of a fading or maintenance switch, the transfer at the receiving end occurs between two channels carrying essentially identical signals. A hitless transfer is ensured at IF by the use of diode switches which operate in 2 microseconds. The receiving baseband switches use relays. No transmission disturbances are caused, however, during the one-millisecond transfer interval due to the use of a hitless bridging method, as described in Section 4.3 below.

Not shown in Fig. 2 are minor subsidiary circuits. Associated with the transmitting IF switch are two oscillators which inject IF carriers into the protection channels when they are in the stand-by condition. Special access switches are provided in the protection channels at IF and baseband, to permit use of these channels as additional regular transmission channels under emergency conditions.

2.4 *Signaling Facility*

The special signaling facility (Fig. 2) is used to transmit the monitor indications to the transmitting end and the receiving switch orders from the transmitting to the receiving end of the switching section. The major portion of the logic for the switching system is located at the trans-

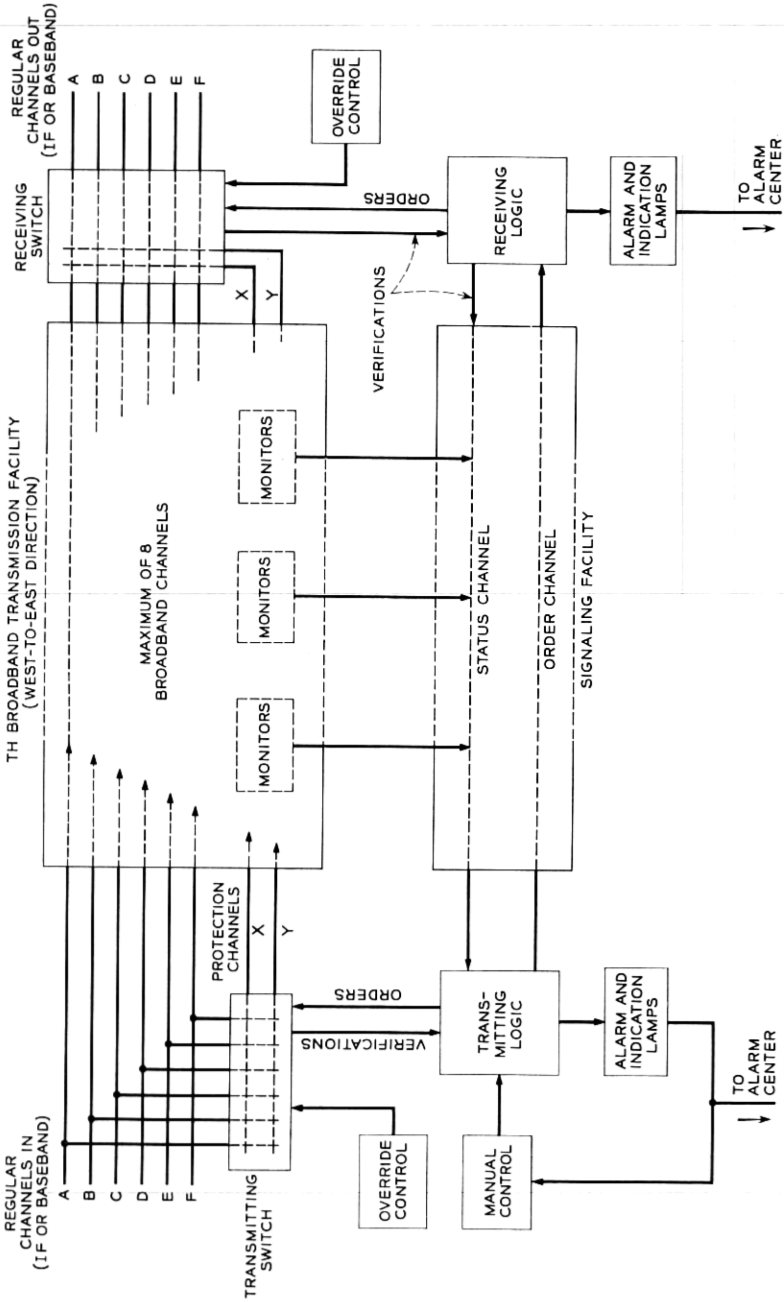

Fig. 2 — Block diagram of TH switching section.

mitting end. Whenever a switching section includes at least one microwave hop, the auxiliary radio channel[4] handles the signaling, which is then done by means of tones in the 20-kc to 36-kc frequency band.

Fig. 3(a) is a detailed block diagram of the signaling facility using tones as the information carriers. The monitors connect into the status channel, which has a maximum of eight tones, one per broadband channel, at 2-kc spacing from 21.5 kc to 35.5 kc. These status tones are produced at the receiving end of the switching section by the tone-transmitter circuit and are detected at the transmitting end by the tone-receiver circuit. Note that the direction of transmission of the status tones is opposite to that of the broadband channels which they are monitoring. Under normal conditions the tones are present, and the outputs of the tone receiver are positive voltages. If a monitor reports trouble in a broadband channel, the corresponding tone is suppressed as long as the trouble persists and the voltage in the output of the tone receiver drops to zero. Status tones can be suppressed by the tone-reporter circuits in the repeater stations or by operating a gate in the tone transmitter. Monitors at the transmitting end of a switching section do not suppress tones but instead operate directly on the output voltage of the tone receivers.

Two groups of four tones each are used for ordering the operation of receiving end switches. These order tones are spaced 2 kc apart, from 20.5 kc to 34.5 kc. The first four tones control the transfer of any of the six regular channels to protection channel X, and the second group of four tones is used for protection channel Y. The ordering code consists of interrupting two of the four tones, which gives six possible orders. The redundancy of the two-out-of-four code allows error checking to be employed on the receiving side with a considerable degree of immunity from noise.

In the signaling facility the West-East and East-West directions of the switching section are intermixed. A maximum of 16 interleaved status and order tones belonging to two different directions of broadband transmission travel together in the same direction over the auxiliary channel.

If the switching section includes only an FM terminal, the two ends of the switching section will not be separated by more than a few hundred feet and normally will be located in the same room. Now, the auxiliary channel is unnecessary and the protection switching signaling is done by on-off dc signals which are transmitted over separate wires (Fig. 3b). The dc reporter circuit accepts the monitor outputs and drops the normally positive output voltage to zero whenever a monitor indicates trouble. With wire interconnections, coding is not needed in the order channel.

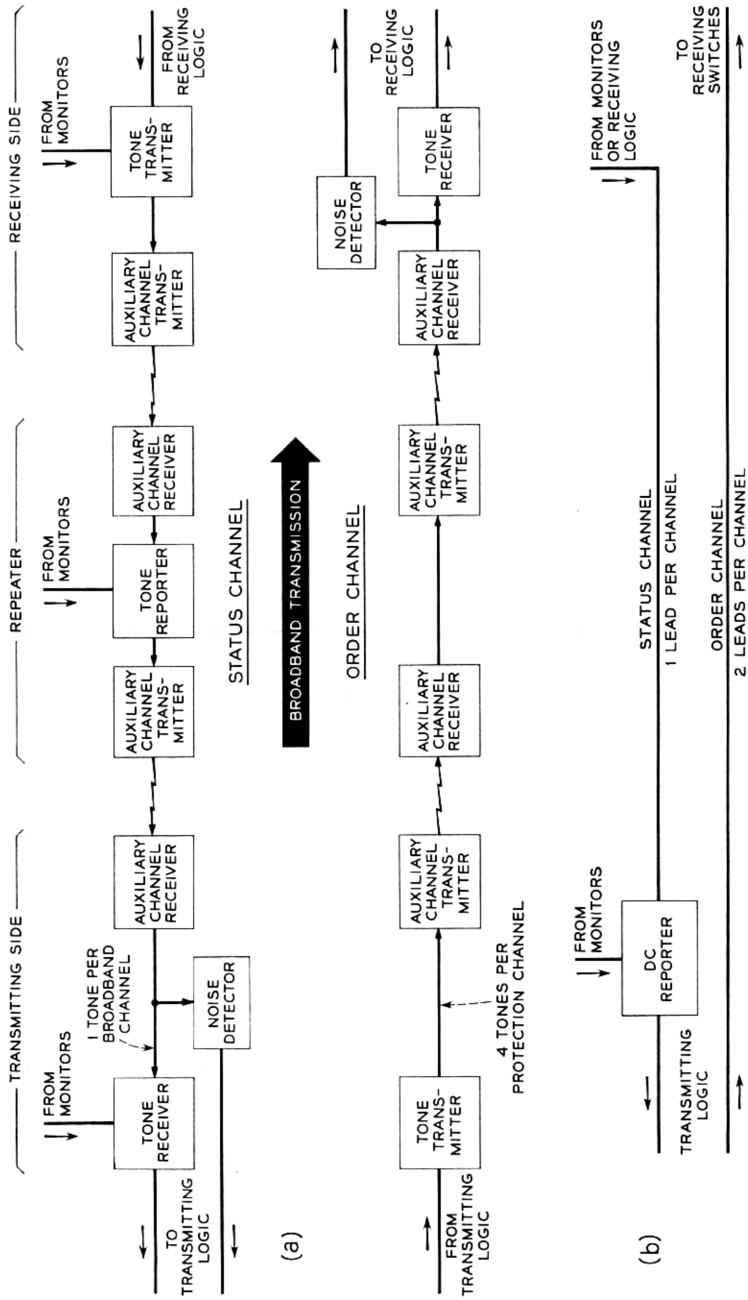

Fig. 3 — Block diagrams of (a) tone signaling and (b) dc signaling.

2.5 *Transmitting and Receiving Logic Circuits*

The main logic circuit is at the transmitting end of the switching section. With monitors in all repeater stations, on the average a switch request originates at the middle of the switching section. Because the transmitting switch always has to be operated first, the speed of operation is increased by sending the status information directly to the transmitting end of the switching section. The transmitting logic receives its orders from the monitors over the status channel or directly from a manual control circuit. The action of the logic circuit depends on the state of the switching section at the moment a switch request is received. If a protection channel is available, the logic orders the appropriate transmitting switch directly and the receiving switch over the order channel of the signaling facility. The transmitting logic also releases the switches after a channel has become good again. After ordering or releasing transmitting or receiving switches, the logic always waits for verification signals regarding the operation of the switches. The logic handles one request at a time. Due to the high speed of operation, such sequential operation is completely adequate.

If a broadband channel fades or fails and no protection channel is available, the logic issues an alarm indicating a loss of service. The transmitting logic also recognizes other trouble situations which may arise within the switching section. If a switch lasts longer than 45 seconds, it is most likely caused by an equipment failure and not fading, and an alarm is therefore produced. Failure to release a switch because of faulty switching equipment and the loss of all status tones due to an auxiliary channel failure also produce alarms. In case of status-channel failure, the logic maintains all previous assignments. If the carrier of a broadband channel disappears at the input of the switching section, switching is inhibited by the transmitting logic because the trouble condition exists ahead of the switching section.

The two-out-of-four code used for ordering the receiving switches in the case of tone signaling is generated in the transmitting logic and is decoded at the other end in the receiving logic. The receiving logic decodes and error-checks the incoming order and in turn sends out signals to operate the receiving switches. The receiving logic maintains the status quo of the receiving switches and issues an alarm if an ordering code containing a single error is received.

2.6 *Manual Control*

The manual control circuit works directly into the transmitting logic (Fig. 2). Two operations are possible. The first is a normal switch operation which transfers the signal from a regular channel to a protection channel. The manual switch control simulates a channel failure, and the logic processes this request as if it were a legitimate one. Such a manual switch makes a regular channel available for maintenance. The second manual operation is channel lock-out. The regular channels are locked out by making them appear good to the transmitting logic, regardless of the actual situation. Conversely, a protection channel is marked bad for lock-out. The locked-out regular or protection channels, therefore, are essentially removed from the switching system, and the regular channels in particular are unprotected. Lock-out is mainly used during maintenance operations. If a regular channel is temporarily carrying no signal, its lock-out results in better protection for the other channels. A protection channel is locked out if it is used as a regular channel for emergency make-good of a failed transmission facility not normally associated with the TH system. For this purpose, the protection channels are accessible through special access switches.

A set of lamps at the transmitting and receiving ends indicates the status of the switching system. Lamps indicating channel failure, switch assignments, manual switches and alarms are provided.

Manual control is also possible from a remote location. The C1 alarm system is used for the transmission of manual orders from the remote location to the switching station and of status information in the reverse direction for the operation of indicator lamps at the remote location.

2.7 *Override Control*

The override control circuits shown in Fig. 2 permit direct operation of the transmitting and receiving switches. The connection between the switches and the logic is thereby interrupted, and all automatic protection is lost. Previous assignments, however, are maintained by the override control. The override switches are used mainly when serious trouble in the logic circuits calls for taking them out of service for trouble-shooting and repair. This rather radical method is necessary because large parts of the logic are common to all channels and cannot be maintained on a per-channel basis.

No remote control is provided for the override switch control; thus service personnel must coordinate operations at both ends of the switching section. An override operation at one end of the switching section always maintains status quo at both ends. This is accomplished automatically in the case of tone signaling by interrupting all tones going to the other end. The loss of all tones makes the logic circuits inoperative, but previous assignments are maintained. For dc signaling only the transmitting override control circuit is needed, since this can operate transmitting and receiving switches simultaneously over wire connections.

III. THE AUTOMATIC SWITCHING OPERATION

The switching system, headed by the transmitting logic, can perform four main, different automatic switching operations. In the following sections the sequence of events is described, starting with the appearance of the initiating signal and ending with the completion of the automatic process.

3.1 *Signal Transfer from Failed or Faded Regular Channel to Protection Channel*

Trouble in a broadband channel is discovered by a monitor and reported over the signaling system to the transmitting logic. The transmitting logic selects a protection channel and orders the transmitting switch to be operated. If no protection channels are available, a service failure alarm occurs. A receiving switch order is sent out only after the logic has received a switch-verification signal and has checked that the trouble does not originate in the previous switching section. Depending on whether tone or dc signaling is used, the receiving switch is either operated through the decoding receiving logic or directly. The operation of the receiving switch concludes the important part of the switching cycle as far as transmission in the broadband channels is concerned. Depending on the kind of switching section, the time from the appearance of the trouble to the receiving switch transfer can vary from as little as 5 to as much as 40 milliseconds. This is the time the signal would be lost in case of a sudden equipment failure. The signal over a fading channel, however, is switched without interruption.

The operation of the receiving switch causes a steady verification signal to be fed to the receiving logic. This is translated by the logic into a short interruption of the status signal associated with the protection channel involved. This verification signal is then received in the transmitting logic, which recognizes successful completion of the switching operation.

If the verification signals from the transmitting and receiving switches are not received within 65 milliseconds, the transmitting logic tries to switch to the other protection channel. Where only one protection channel is available, the failed regular channel is locked out and a service failure alarm occurs. The lock-out forces transmission back onto the regular channel (see Section 2.6 above). Unlocking then requires a manual operation.

3.2 *Signal Restoral from Protection Channel to Operative Regular Channel*

When the failure or the fade in a channel is over, the monitors restore the status signal of the channel. The transmitting logic first releases the receiving switch over the order channel. After the receiving switch-release verification is received, the transmitting logic resets the transmitting switch, which completes the switch-release operation. The release verification is in the form of a short interruption of the status signal associated with the protection channel involved. If the receiving switch verification does not arrive within 55 milliseconds, the regular and the protection channels involved are locked out by the transmitting logic, and a release-failure alarm is issued. After clearing the trouble, the channels can be unlocked manually.

3.3 *Recognition of Failure in Previous Switching Section*

A loss of IF signal at the input of a switching section is immediately recognized by the first IF monitor in the regular channel involved, and a switch to a protection channel is made at the transmitting end. But the protection channel is also marked bad following the switch operation because there is no signal entering this channel either. The first and the second failure indication follow each other within a few milliseconds, which fact is recognized by the transmitting logic as a preceding section failure. The regular channel then is temporarily (110 milliseconds) locked out by the logic. During this time, other channels have a chance of getting served by the logic. The signal loss at the input of the switching section will in most cases not last longer than 40 milliseconds, namely the time it takes to make good a failure in the last part of the preceding switching section. (Only failures after the last carrier resupply circuit in a switching section cause loss of IF carrier.) After 110 milliseconds, the channel is unlocked. If the signal has not reappeared, the same inhibit check starts over again.

3.4 *Signal Transfer from Failed or Faded Protection Channel to Second Protection Channel*

If a protection channel carrying a switched signal fades or fails, a transfer to the second protection channel is made. This transfer always causes a short signal interruption (10 milliseconds) even in the case of fading, because transmitting-end bridging of two protection channels is not possible. The transmitting and receiving switches of the failed protection channel are immediately released by the logic, and the transmitting bridge to the second protection channel is established.

After waiting for the inhibit check, the receiving switch transfer to the second protection channel is ordered. If no second protection channel is available, no switches will be executed by the system.

The following sections give a more detailed description of some of the important circuits of the switching system.

IV. THE TRANSMITTING AND RECEIVING SWITCHES

The switches must meet the stringent transmission requirements of the broadband channels, provide switching operation which is fast and hitless, and be removable for maintenance without disturbing the signals on the channels.

4.1 *IF Switches and Associated Circuits*

A schematic of the transmitting IF switch is shown in Fig. 4. The switch is bridged across the regular channels by means of IF directional couplers. These couplers have negligible loss in the regular signal path but attenuate the signal to the switch by 20 db. The switches are, therefore, well isolated from the through line without the aid of bridging amplifiers. Directional couplers are needed, rather than resistive pads, to discriminate against the echo returned from the far end of the IF cable leading to the regular channel equipment. The 20-db bridging loss and additional losses through the switch are made up by two IF amplifiers in the switch outputs to the X or Y protection channels.

The gates are represented symbolically in Fig. 4 by boxes containing single-pole, single-throw switches. The signal going over channel A, after entering the switch, passes through the 3×1 interconnecting network and is usually terminated in a 75-ohm resistor through gate A/Z. To switch this signal to protection channel X, switch A/Z is opened simultaneously with switch A/X being closed. Through the 6×1 interconnecting network, the signal passes on to channel X.

The gate circuit, shown in Fig. 5(a), contains three diodes which can be forward or reverse biased by the application of the appropriate switching voltages. Simplified ac equivalent circuits for the ON and OFF conditions are shown in Figs. 5(b) and 5(c). The ON gate represents a matched resistive T pad with a 75-ohm characteristic impedance and 1.5 db of insertion loss. The gold-bonded germanium diodes used in this circuit have a 5-ohm resistance in the forward and a capacitance of 0.8 pf in the reverse biased condition. The loss through the OFF gate is about 90 db at 74 mc. A photo of the unit is shown in Fig. 6.

Since the ON gates have 1.5 db loss, the switch is arranged so that the

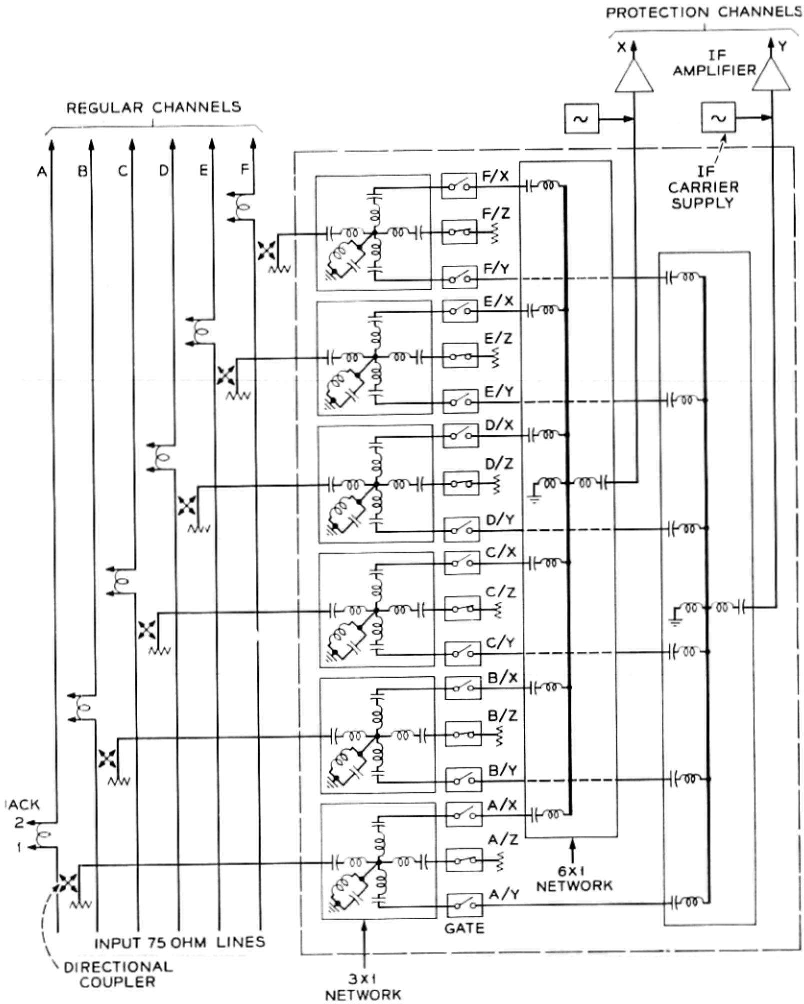

Fig. 4 — Schematic of IF transmitting switch and associated circuits.

IF signal passes through no more than one gate under any switching condition. It is seen from Fig. 4 that the incoming signal on channel A, for instance, after first going through the 3 × 1 interconnecting network, appears at the input terminals of three gates simultaneously. Only one of the gates is transmitting at a time and furnishing the 75-ohm network termination. The other two gates are OFF and load the network capacitively. The 3 × 1 network appears as a band-pass network to the

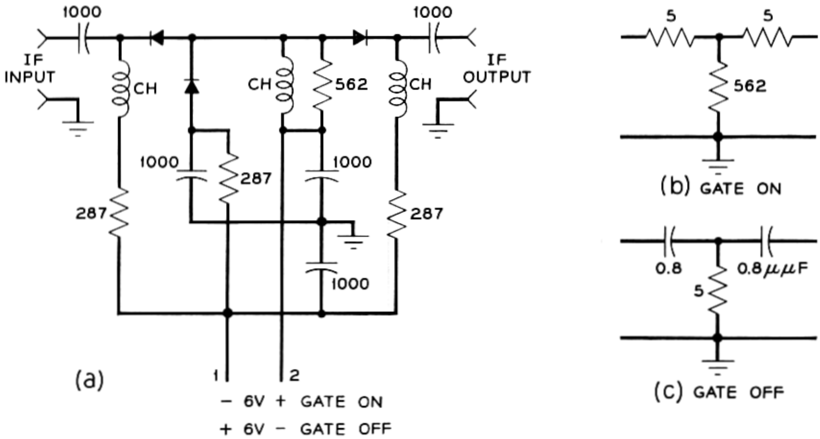

Fig. 5 — The IF gate: (a) circuit diagram, and ac equivalent circuits for the (b) gate ON and (c) gate OFF conditions.

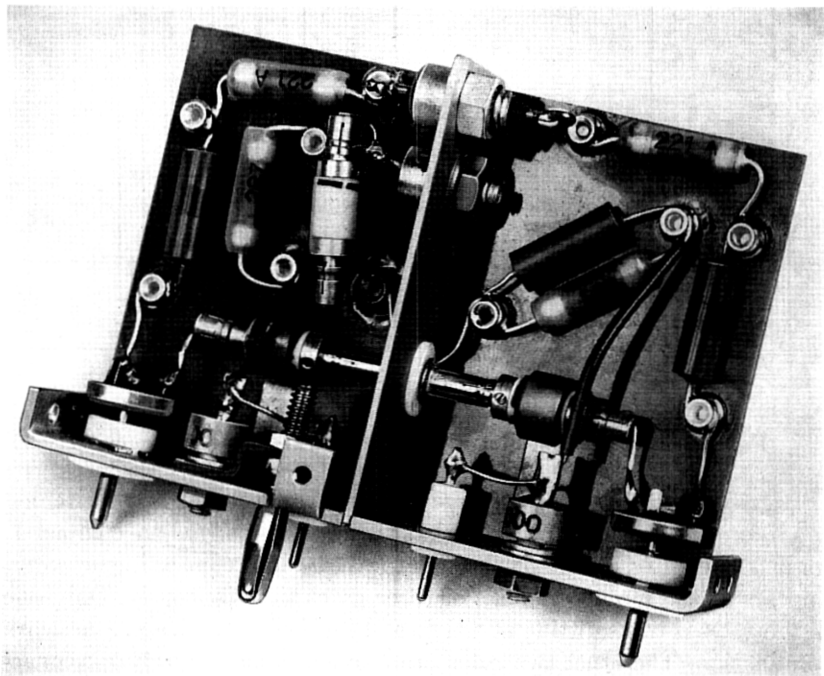

Fig. 6 — Photograph of the IF gate.

transmitted signal. The small capacitance of the OFF gates contributes to the total shunt capacitance of the filter. Over the 58-mc to 90-mc band, the gate capacitance is essentially unaltered by the series LC circuit which connects the gate to the shunt point of the filter. Due to symmetrical physical layout of the circuit, all three paths are electrically identical and have the same transmission characteristic.

Basically the same but somewhat more complicated situation exists at the output side of the gates where connection is made to a 6 × 1 network for either channel X or Y. There are six possible paths to each protection channel. If channel A, for instance, is switched to channel X, gate A/X is ON, and the other five gates, B/X to F/X, connecting to the 6 × 1 network for channel X, are all OFF. The same electrical and physical requirements as for the 3 × 1 network apply also for this 6 × 1 network. The equivalent circuit for the network and the throughpath is again a band-pass filter.

The IF gates and the 3 × 1 and 6 × 1 interconnecting networks are all built and tuned up separately. After they are assembled in an aluminum casting (Fig. 7) the following transmission requirements are met without further adjustments:

Insertion loss at 74 mc	1.9 db
Transmission flatness, 58 to 90 mc	±0.05 db
Return loss, 58 to 90 mc	≧28 db
Isolation between channels at 74 mc	≧86 db

The IF switch of Fig. 4 is equipped with only the minimum number of gates and networks needed for the number of channels installed. It is imperative, however, for a network to be electrically loaded with the full number of gates, or their equivalents, to maintain its transmission characteristic. Network connections to unequipped channels are terminated with the impedance of nontransmitting gates, simulated by passive dummy gates which have the same impedance but require no driving voltages. Fig. 7 shows a partially equipped switch.

An IF gate can be removed for maintenance without interruption or noticeable degradation of the broadband signal. Only a nontransmitting gate can be removed, and only one at a time. By suitable manual switching it is possible to bring any gate into the OFF position. To avoid serious transmission disturbances during removal of a gate, the switching voltage and ground are disconnected only after opening the IF connections to the gate. This is achieved by proper mechanical connector construction. On insertion, the IF connections are made last.

The gates are controlled by switch-control circuits. One control circuit serves the three gates associated with a regular channel, e.g. A/X, A/Y and A/Z. The circuit contains not only transistor amplifiers for the low-level logic signals but also an OR logic circuit for the operation

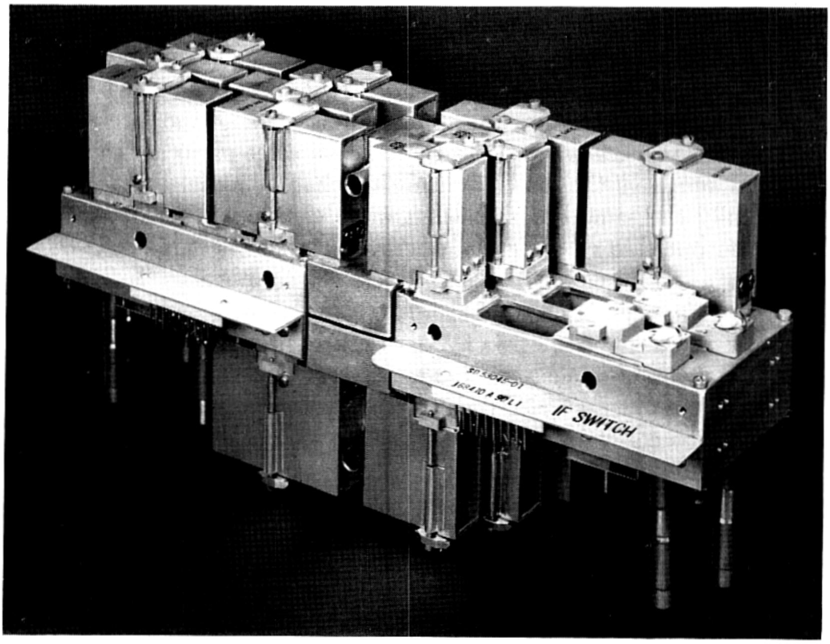

Fig. 7 — Partially equipped transmitting IF switch (4 regular and 2 protection channels).

of gate A/Z. The switching voltages change so fast that the transfer of the IF signal is completed within two microseconds. The presence of the correct operating voltage at the switches is taken as a confirmation that the switches have operated properly.

If no signals are switched over the protection channels, 74.13-mc carriers are injected to prevent the monitors from indicating the protection channels bad. The carriers are produced by the IF carrier supply circuits, which are bridged across the lines to the protection channels as shown in Fig. 4. The oscillators are started and stopped in synchronism with the switch operation through control signals from the transmitting logic. The IF carrier supply circuit is very similar to the IF carrier resupply circuit described in another article[2] of this issue. Its output power, however, is much lower because the carrier is injected at a low level point just ahead of the 22-db IF amplifier.

Specially developed jacks are inserted in the regular channel paths right after the 20-db directional couplers. These jacks give access to the regular channels for mainenance. A spring contact inside the jack provides a continuous path between the two sides of the jack under normal conditions. The conventional patch plug can therefore be dispensed with. A regular channel is made available for maintenance by first switching the signal over a protection channel and then plugging a 75–ohm termination into side 1 of the jack. The signal flow over the regular channel is now interrupted, and access to this channel is obtained through side 2 of the jack. The make-before-break insertion of the termination on side 1 produces a mistermination on the line during the very short insertion period, but this mistermination is isolated from the signal transmission path by the directional coupler.

The receiving IF switch is similar to the transmitting switch shown inside the dashed area of Fig. 4, except that the signals pass through the switch in the opposite direction. The Z gates, A/Z etc., are now connected to the outputs of the radio receivers instead of to terminations. The protection channels are not terminated by the switch under normal conditions, and the regular channels lose their termination when switched. This mismatch does not affect the transmission over the system, and the level-sensing monitors, which are located ahead of the receiving switch to supervise active equipment ahead of the switch, are isolated from the resultant reflected waves by directional couplers.

Like the transmitting switch, receiving switch transfers are completed within two microseconds. If the absolute delays of the regular and protection channels are equal, none of the transmitted services is affected by this two-microsecond transfer.

4.2 *Transmitting Baseband Switch and Associated Circuits*

The transmitting baseband switch with its associated circuits is shown in Fig. 8. The incoming baseband signals (e.g., from the multiplex telephone terminals) are normally connected through 0-db bridging amplifiers A to the FM transmitters. They can also be connected to the protection channels through the switch when necessary. The switch is composed of a number of diode gates and is quite similar to the IF switch with the exception that it is arranged in two stages. Any of the regular channels can be transferred to protection channel X through the first stage of the switch and to protection channel Y through the first and second stages in tandem. Baseband switches are generally used in the very short switching sections extending around a terminal, where one protection terminal is usually sufficient and only the first stage of the switch is needed. The two-stage switch therefore has the advantage of greater circuit economy over the single-stage switch used at IF.

The amplifiers A are bridged across the 124-ohm balanced line with a high impedance, and the termination for the line is provided through

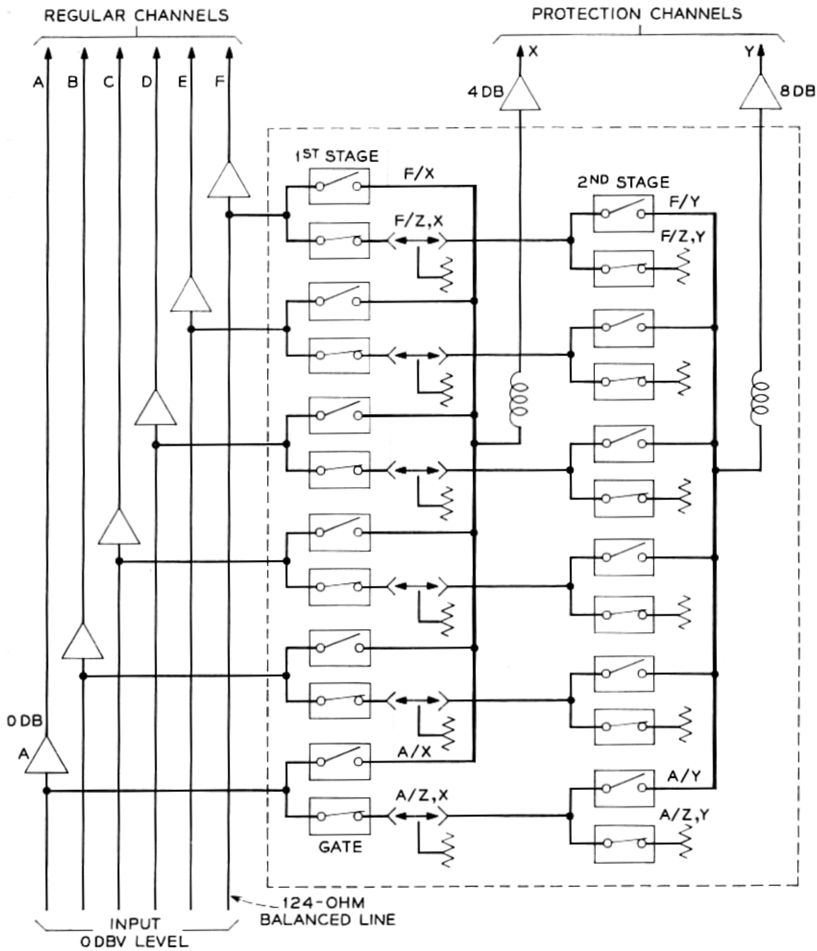

Fig. 8 — Schematic of transmitting baseband switch and associated circuits.

gates A/Z, X and A/Z, Y. If channel A is switched to channel X, for instance, the A/X gate is made transmitting simultaneously with the A/Z,X gate being made nontransmitting. The switching process requires 10 microseconds, and during this time the line is incompletely terminated. However, none of the services transmitted over TH is impaired by this effect. The networks used to couple the gates to the incoming line or the protection channels are low-pass filters, which are much simpler than the interconnecting networks in the IF switch.

The baseband gate must meet close transmission, return-loss, and isolation requirements, as well as very stringent requirements on the voltages which may appear on the line during and after the switching operation. The balanced 124-ohm baseband gate uses twelve diodes in a doubly symmetrical configuration as shown in Fig. 9(a). Figs. 9(b) and 9(c) show the dc equivalent circuits for the gate in the ON and the OFF state. If the driving voltages for the gate are exactly symmetrical to ground (±10 volts), less than 5 millivolts will appear at terminals 1, 2, 3 and 4 to ground. No adjustment of components is required to obtain this low pedestal voltage.

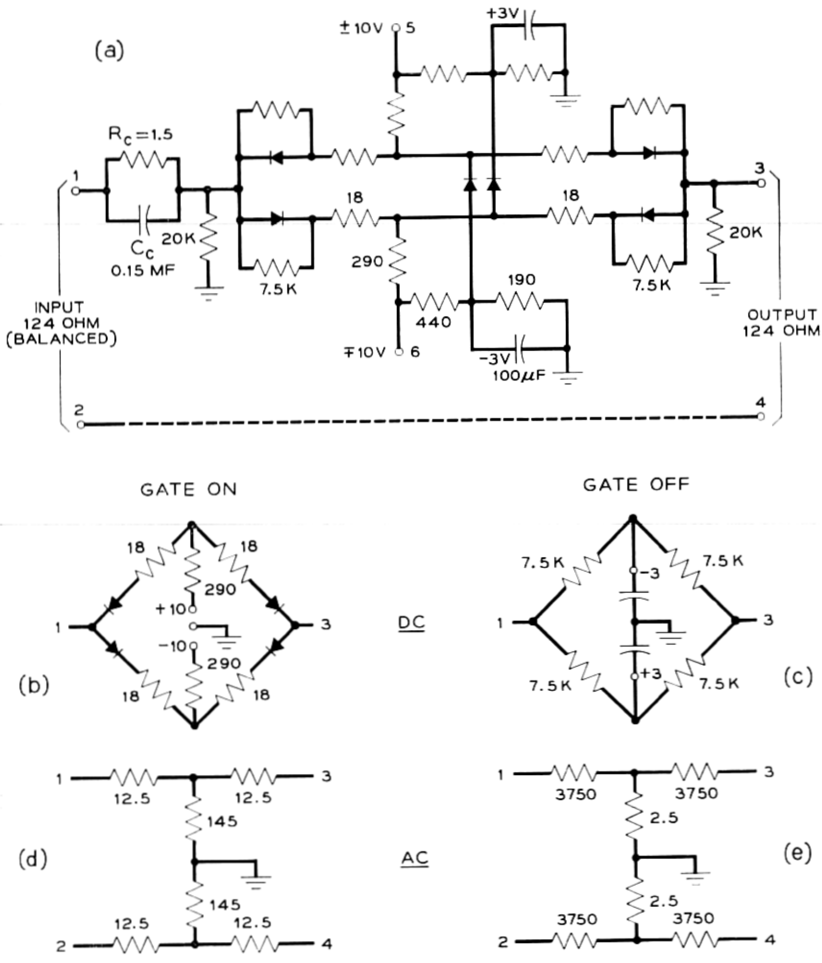

Fig. 9 — The baseband gate: (a) circuit diagram and equivalent dc and ac circuits (b through e).

The gate control voltage is produced in a special switch control circuit which receives its orders from the transmitting logic. One such circuit is needed to operate the pair of gates associated with a particular regular and protection channel, e.g., the pair A/X and A/Z,X. Special circuitry holds the unbalance of the ±10-volt gate control voltages within 0.2 volt, even during the 10-microsecond transition to ±10 volts.

Taking the slight assymmetry of the switching voltage into account, there never appears more than 25 millivolts from any gate terminal (1, 2, 3 or 4 of Fig. 9) to ground. A large part of this voltage appears as a longitudinal component on the 124-ohm balanced line and therefore does not interfere directly with the transmitted signal. Television, which passes through the switches at a −12-dbv level, is the service most susceptible to switching pedestals and transients. The TV interference becomes invisible if the symmetrical voltage is below 15 millivolts. Tests show that most gates in a baseband switch cause no disturbances at all to a TV picture, with some producing a barely visible streak across the screen.

The gates are designed to transmit frequencies from dc to 10 mc. The ac equivalent circuits are shown in Figs. 9(d) and 9(e). In the transmitting or ON state, the gate acts essentially as a matched resistive pad with approximately 4 db loss. This loss is compensated by a 4-db amplifier in channel X and by an 8-db amplifier in channel Y. Transmission flatness is improved by the addition of resistor R_c and capacitor C_c. These components equalize a 0.05-db transmission drop around 1 mc, which is due to the inductive character of the forward-biased diodes. The diodes are the same gold-bonded germanium diodes used in the IF switch. The transmission characteristics of the gates are as follows:

Insertion loss at 5 mc	4 db
Transmission flatness, dc to 10 mc	±0.02 db
Return loss, dc to 10 mc	≧38 db
Modulation products	−70 db
Isolation between input and output, dc to 10 mc in OFF state	≧86 db

As in the case of the IF switch, dummy OFF gates are used in the positions of the 6 × 1 interconnecting network which correspond to channels not installed. The general equipment arrangement is also similar to the IF switch.

The 0-db, 4-db and 8-db baseband amplifiers all use the same basic circuit (Fig. 10). They are balanced, transistorized amplifiers and differ only in the amount of feedback. Each side of the amplifier consists of three transistor stages using germanium diffused-base transistors with an alpha cutoff frequency of about 750 mc. Feedback is provided through resistor R_f which stabilizes the voltage gain of the amplifier to approxi-

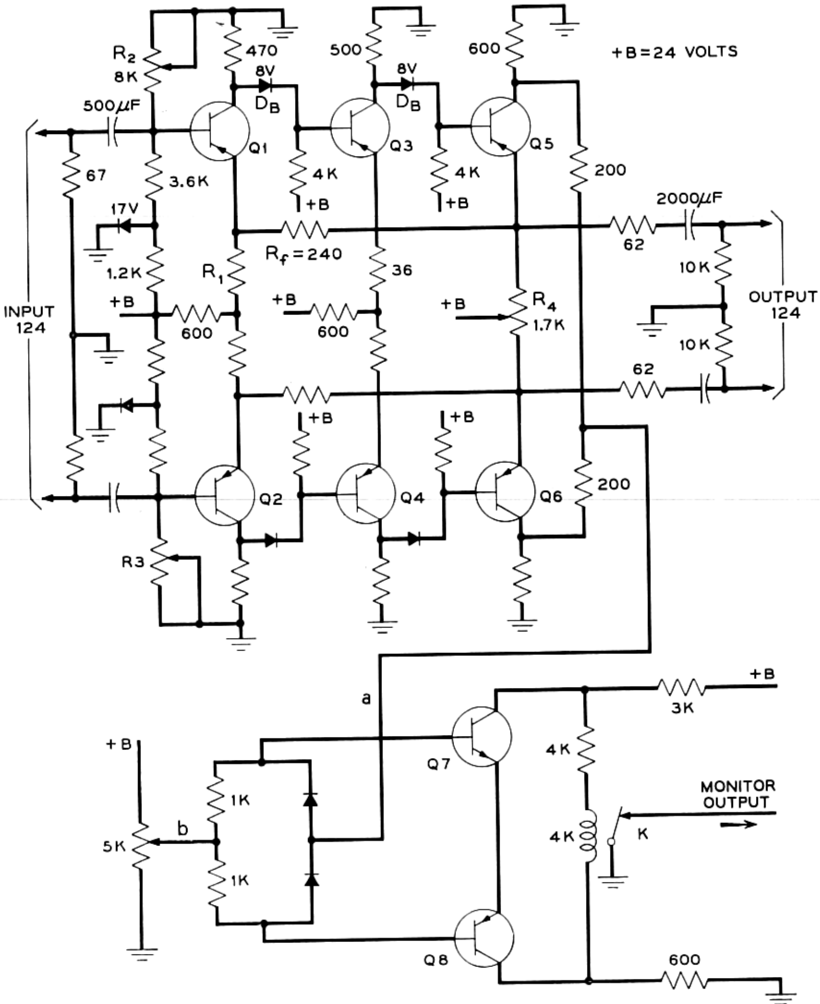

Fig. 10 — Simplified schematic of baseband amplifier.

mately $g = 0.5\ (1 + R_f/R_1)$. The different gains are obtained by proper selection of resistor R_1. The dc coupling of the amplifier by means of voltage breakdown diodes D_B avoids the use of large coupling capacitors and ensures stability of the feedback loop at low frequencies. The amplifier is coupled to the balanced 124-ohm lines on the input and output sides through large electrolytic capacitors which provide flat transmission down to a few cycles. Second-harmonic distortion in the amplifier is minimized by balancing voltages and currents in the amplifier through adjustment of potentiometers R_2, R_3 and R_4. The second and the third harmonics are at least 60 db and 80 db respectively below the fundamental for an output level of 0 dbv. Transmission through the amplifier is flat to ±0.03 db from 50 cps up to 10 mc. The input and output return losses against 124 ohms are better than 40 db. Longitudinal voltage components of the incoming signal encounter much higher feedback in the amplifier and are attenuated about 45 db.

Fig. 10 also shows the circuit used to monitor the amplifier. The voltage at point "a" is not affected by the signals going through the amplifier but is affected by almost any change in the dc operating points in the amplifier. The voltage "a" is compared with a reference voltage "b" in the bridge consisting of two diodes and two resistors. The bridge output voltage is applied to a differential amplifier using transistors Q7 and Q8. If the difference between voltages "a" and "b" exceeds about ½ volt, relay K, which normally is operated, changes state and marks the channel in which the amplifier is connected bad.

Special attention has again been given to the maintenance problem. Gates, baseband amplifiers and switch control circuits can be removed from and placed into the equipment bays without causing hits in the channels.

4.3 *Receiving Baseband Switch*

The receiving switch uses relays for the sake of low insertion loss, a choice which is feasible because of the possibility of a hitless signal transfer at the receiving end. A complete switch for six regular channels and two protection channels is shown in Fig. 11. It consists of 24 wire spring relays which can easily be cascaded because the loss through any of them is only a few hundredths of a decibel. To simplify Fig. 11 (and later Fig. 12), only one side of the balanced 124-ohm line is shown. A transfer from channel A to protection channel X, for instance, is made by first operating relay R1. The signal on channel X then appears at relay R2, which is operated next. In case of a maintenance or fading switch, the signals on X and A are identical and the transfer by relay R2 can be made hitless as follows. Phase 1 of Fig. 12 shows the relay R2 in its normal or de-energized position. The relay is then operated, and after approximately 10 milliseconds contacts 3 and 4 close (Phase 2). Under the assumption that the TH channels are equalized for absolute delay and equal level, the signals from X and A are identical, and the bridge provided by R2 will not change the output voltage. Note that as soon as either contact 3 or 4 is made, all four arms are connected; hence it is

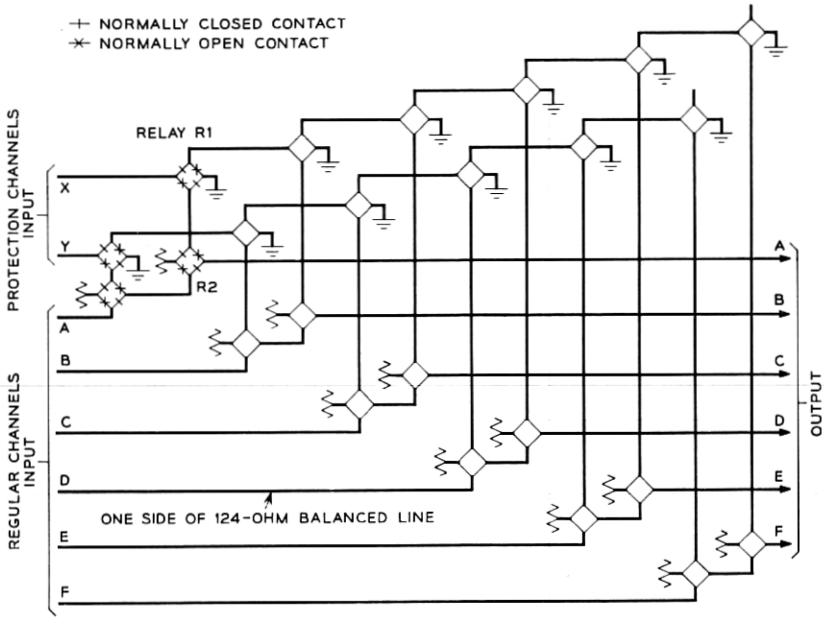

Fig. 11 — Receiving baseband switch for 6 regular and 2 protection channels.

immaterial which makes first or whether they both make contact simultaneously. After a period of approximately one millisecond, contacts 1 and 2 open and the hitless transfer from channel A to X is completed (Phase 3).

The two-step switching operation is necessary to provide enough isolation between regular and protection channels in the normal or un-

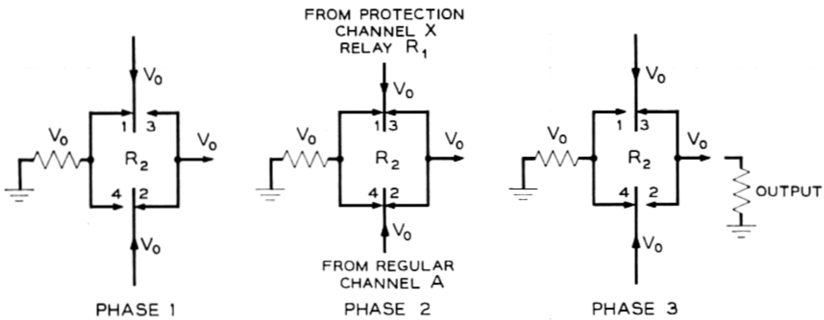

Fig. 12 — The three phases of a hitless signal transfer in the receiving baseband switch. Only one side of the balanced 124-ohm line is shown.

operated condition. The open relay contacts of R1 and R2 individually provide only 45 db of isolation. Cascading two open contacts in R1 and R2 with the connection between the contacts grounded provides more than 90 db of isolation at 10 mc, giving a comfortable margin over a requirement of 86 db. When channel A is switched to X, however, only the parallel capacitance of the single open contacts 1 and 2 (Fig. 12, Phase 3), and therefore only 45 db, separates the switched signal from the voltages appearing on channel A. The isolation is increased from 45 db to 60 db by the use of two pairs of neutralizing capacitors. These are connected from contacts 1 and 2 on each side of the 124-ohm balanced line to contacts 3 and 4 on the other side and thus introduce coupling of opposite phase. Isolation of 60 db is tolerable for this type of exposure because it is much less frequent than the one between protection and regular channel.

The two relays R1 and R2 are contained in a switching unit (Fig. 13) together with a transistorized control circuit. The transmission path in

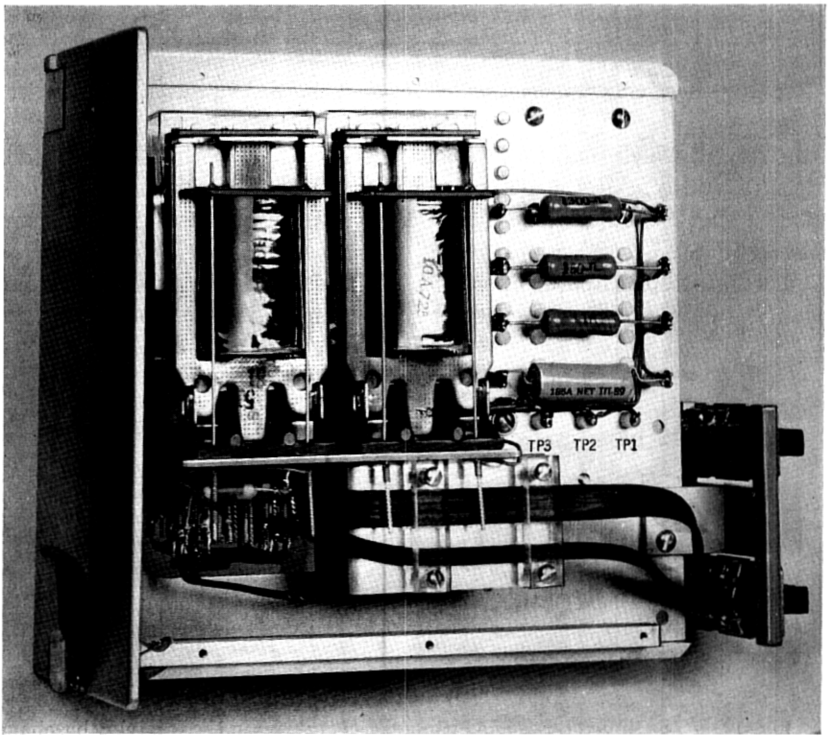

Fig. 13 — Photograph of receiving baseband switch.

the unit extends from a conventional multipin connector through the relays and back to the connector. The excess capacitance of the relays and connectors is compensated and the return-loss requirement of 40 db is met by making the connection with suitable lengths of 150- and 300-ohm "twin lead" cable, which acts as a small series inductance.

The receiving baseband switch, like the other two types, grows with the number of broadband channels installed. The addition of channels can be made without interference to the channels already installed. A switch unit can also be removed from the bay without disturbing service. After manual lock-out of the regular and protection channels involved, the initial small movement of withdrawal of the unit establishes a path in parallel with contacts 2 of relay R2.

V. THE SIGNALING FACILITY

The tones which carry status and order information over the auxiliary channel are produced in the tone transmitter circuit (see Fig. 3a) which consists of up to 16 separate oscillator circuits. At each end of a switching section, a maximum of eight oscillators is needed for the status channel of one direction of broadband transmission and a maximum of eight for the order channel of the other direction of broadband transmission. Due to the high output impedance of the tone oscillator circuits, they can be connected together in any number up to 16 across a 135-ohm unbalanced line leading to the auxiliary channel transmitter. The heart of the circuit is a Colpitts CW oscillator using one transistor. Each oscillator in the 20.5-kc to 35.5-kc range has a long-term frequency stability of ± 10 cycles over wide ranges in temperature and supply voltage. The tone is applied to the output through a gating circuit which, when operated, drops the normal tone level of -18.5 dbm on the 135-ohm line approximately 25 db. To avoid disturbing switching transients in the output, a balanced gate is used. This gate is operated by different input signals. The status-tone oscillators, for instance, can be keyed individually by the broadband monitors located in the receiving station or as a whole by operation of the receiving override switch. The status-tone oscillator associated with a protection channel can be interrupted for about 5 milliseconds by a receiving switch-verification signal coming from the receiving logic.

To reduce the interference into adjacent tone channels, which are only 1 kc away, the spectrum of the keyed tones is restricted by lengthening the rise and fall times to 1 millisecond. This is accomplished by circuitry in the balanced gate and the driver stage. The oscillator is supervised by a comparator circuit which checks whether the incoming voltage and the outgoing tone are compatible.

The tone-reporter circuits are used in the repeater stations to interrupt the status tones associated with channels faded or in trouble. The circuit consists of eight series resonant circuits tuned to the status-tone frequences. When an LC circuit is connected through a relay contact across the 135-ohm line in the auxiliary channel, the corresponding tone is suppressed 18 db; adjacent tones are only slightly affected.

The tone receiver circuit consists of a maximum of 16 detector circuits matching the tone oscillators at the other end of the switching section. Any number of tone detectors up to 16 can be connected across the 135-ohm line coming from the auxiliary channel receiver. The input circuit of each detector consists of a series resonant circuit which is connected to ground through the low emitter-base impedance of a buffer amplifier transistor. The filter represents a 135-ohm load for the tone it is tuned to and a very high impedance for all the other tones. The interaction between circuits therefore is very small. Additional filtering is provided in the collector circuit of the buffer amplifier transistor. The over-all 3-db bandwidth is about 400 cycles, which bandwidth leads to approximately two milliseconds delay of the keyed tone. After filtering, detection and amplification, a Schmitt trigger circuit provides positive indication that the tone has dropped below or risen above a specified level. The tone-detector output drops to zero when the tone level falls 12 db below normal. There is a 2-db protective hysteresis between the switch-off and the switch-on levels so that the tone has to rise to within 10db of normal to restore to a regular +8-volt output signal. These switching levels were chosen to take care of possible gain variations in the auxiliary channel under extreme conditions. In the tone-off state the low switching level makes the detector susceptible to accidental triggering by the fairly high auxiliary channel noise level. In the case of the status tones, such noise makes a failed channel look good temporarily. The protection switch is then dropped with the result that the channel is lost for at least the duration of the noise burst. To counteract this troublesome situation, an unsymmetrical delay circuit is built into the tone-detector circuit. Negligible delay is introduced when the tone disappears. The tone, however, has to be present at least 15 milliseconds before the tone-detector output rises to +8 volts. This delay is not detrimental to the normal operation of the system. Noise peaks lasting this long seldom occur. Measurements show that the number of accidental switches due to noise decreases about six orders of magnitude when the delay is increased from zero to 15 milliseconds.

If the noise from the auxiliary channel should become very high, false switches and service outages would happen quite frequently. It is then better to disconnect the switching system from the auxiliary channel. This is done by the noise-detector circuit, which connects directly into the transmitting or receiving logic where the status quo of the switching system is maintained. No further switch requests can be served in this case, however. Taking all the conflicting effects into account, use of the noise-detector leads to an over-all reduction of channel outages.

VI. THE LOGIC CIRCUITS

The purpose of the logic and the part it plays in controlling the various switching operations were given in general terms in Sections 2.5 and III. This section describes the constituent parts of the logic and their organization and also presents the major logic diagrams and basic circuits employed.

6.1 *Organization of Transmitting Logic*

A block diagram of the transmitting logic is shown in Fig. 14. The basic action circuits are represented by blocks in reverse type, while those performing control and checking functions are in regular type. The description specifically illustrates the use of the logic in an IF switching section in which tone signaling is employed between the transmitting and receiving ends. To facilitate the study of signal flow, the channel-status leads (Section 2.4) are shown coming into the transmitting logic on the left side, while all outgoing leads are shown on the right side. The status leads associated with regular broadband channels A through F are designated BS1 through BS6, while those associated with protection channels X and Y are designated BS7 and BS8.

The channel-status and memory circuits receive information not only from the status channel of the signaling facility but also from the manual switch control circuit and from points within the logic itself. The various situations encountered by the logic and, especially, the problem of keeping switching operations at both ends of the section properly synchronized make it necessary that the information outgoing from a status circuit, at times, be at variance with the true status of the radio channel it represents. In other words, it is sometimes necessary to make the status of the channel look "good" when it is, in fact, "bad" and vice-versa. The channel-status circuits, accordingly, include a flip-flop memory in addition to a system of gates in order to make possible the required controls.

When a regular transmission channel fades or goes "bad", the channel-status circuit presents a signal to the assignment circuit calling for the assignment of one of the protection channels as a substitute, provided,

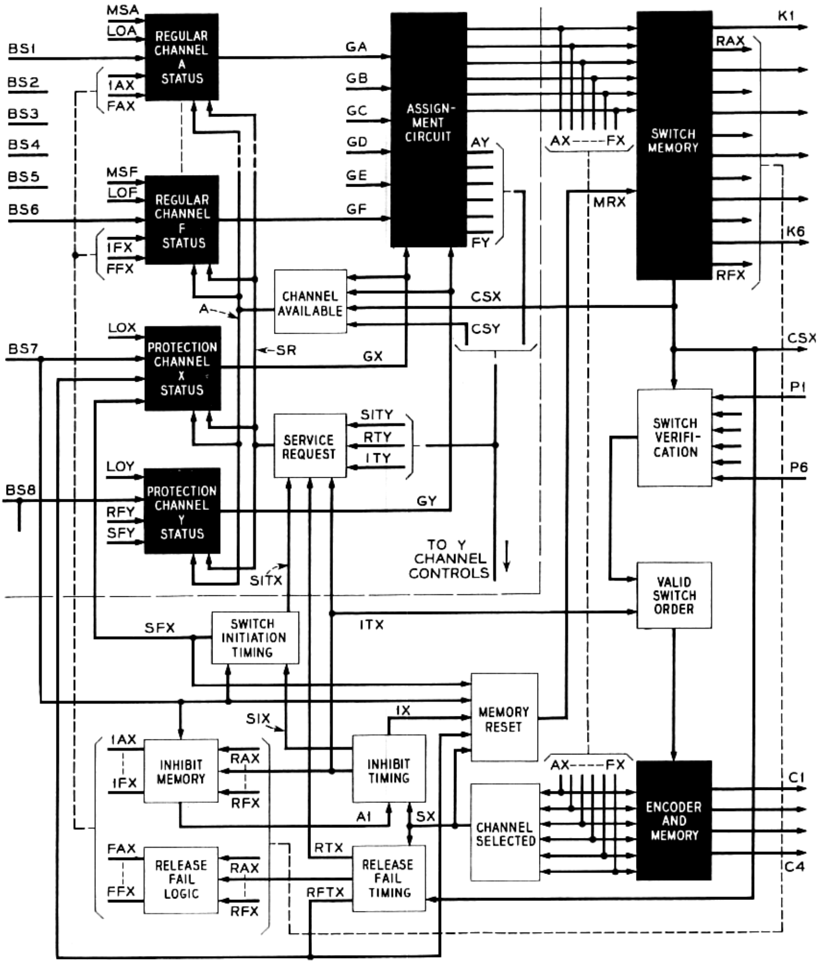

Fig. 14 — Block diagram of transmitting logic.

(a) there is at least one protection channel available for use and (b) the logic control and checking circuits are not busy serving some previous request for service. For a protection channel to be available, its transmission must be good, as indicated by the voltage level on the GX or GY lead, and it must not already be in use, as indicated by the voltage on the CSX or CSY lead. If at least one protection channel satisfies these conditions, the channel-available circuit makes this fact known to the channel-status circuit via the A lead. The service-request circuit, via the SR lead, can inhibit the generation of any new output signals in the channel circuits during the interval in which a previous request is being served. A request for service on the part of a channel, when permitted by A and SR lead indications, is made known to the assignment circuit by a change in voltage on one of the leads designated GA to GF. A signal on the GA lead, for example, if protection channel X is available, results in a signal outgoing from the assignment circuit on the AX lead. This leads into the next stage of the work cycle.

The circuits involved in the assignment function are common to both protection channels. The remainder of the circuits, however, are individual to a given protection channel. Thus, the six assignment leads designated AX to FX go to circuits associated with channel X, while the six leads designated AY to FY go to circuits associated with channel Y. In Fig. 14 the blocks below and to the right of the dashed line represent only channel X control circuits.

Immediately after the assignment signal is given on one of the AX to FX leads, a flip-flop in the switch memory is set which, in turn, puts out a signal on the corresponding K-lead. This calls for the operation of the transmitting switch that bridges together channel X and the regular channel requesting the switch. Simultaneously, a voltage change is made on the CSX lead, which causes the IF carrier supply for channel X to be turned off. The assignment signal also flows to the encoder and memory circuit, where it is translated into one of six possible two-out-of-four signal combinations for presentation to the tone transmitter of the order channel by way of output leads C1 through C4. The actual presentation is not made immediately, however. It is deferred for a short period of time pending (a) receipt of a signal from the transmitting switch verifying the fact that the switch ordered to operate has actually operated, and (b) the successful completion of a check, termed the "inhibit-timing check", which indicates that the transmission failure or degradation has actually occurred in the switching section under consideration rather than in the preceding switching section. Switch verification signals are received by the switch-verification circuit over leads P1 to P6 shortly after the orders are given over leads K1 to K6. The output of the verification circuit is a signal to the valid switch order circuit. This, if and when accompanied by an appropriate signal from the inhibit check circuit, allows the receiving switch order to proceed.

The third usage of the assignment signal is by the channel-selected circuit, which produces an output signal on the SX lead as soon as any of the six assignments possible with channel X have been made. The SX signal starts the operation of the inhibit-timing circuit, which immediately makes a voltage change on the ITX lead lasting for 8 milliseconds before reverting to its normal level. This ITX signal, in turn, (a) actuates the service-request circuit, (b) inhibits the action of the valid switch order circuit and (c) enables the inhibit-memory circuit. The service-request circuit, through the SR lead, gates the channel-status circuits so that no changes in their output signals can be made during the inhibit-timing interval even if changes actually take place on the status channels themselves.

If the transmission fade or failure that caused the channel-status indication to change from good to bad actually exists in the switching section under consideration, the inhibit-timing interval runs its course with no other event until the end of the interval. At this point, provided the verification signal from the transmitting switch has been received, the valid switch order circuit is permitted to gate the encoder and memory circuit so that flip-flops associated with the four outgoing order leads are set in accordance with the code already established. This action constitutes an order to the signaling equipment and thus to the distant receiving logic.

If the transmission failure is in the switching section preceding the one under consideration, the act of bridging a protection channel onto the regular channel does not restore transmission. On the contrary, the status of protection channel X changes from good to bad as soon as the X channel IF carrier supply stops and the monitor and status-detector circuits respond to the change. This occurrence, if it takes place, is during the inhibit-timing interval and causes a voltage change on the channel X status lead, designated BS7. Such change within this particular time zone is interpreted as a failure in the preceding switching section. The BS7 lead connects, in addition to other points, to the inhibit-memory circuit. An interruption in its normal potential during the ITX enabling period produces (a) a 110-millisecond pulse on the IAX to IFX output lead corresponding to the regular channel that reported the transmission failure and (b) a short pulse on the A1 lead going back to the inhibit timing circuit. This latter signal sets a flip-flop which prevents any further action towards carrying out the switch order. The pulse on the IAX to IFX lead serves to make the channel-status indication good again for a period of time ordinarily ample for the previous section to make good its own failure. The consequences of the channel being given a good indication are to release the assignment and to restore the SX lead to normal. This action, together with the presence of a signal on the IX lead, causes the memory reset circuit to restore the transmitting switch memory to normal and thus to release the previously operated transmitting switch. The inhibit-memory circuit was informed of the identity of the failed channel by a signal on one of the RAX to RFX leads which was produced by the transmitting switch memory when it first received the assignment information.

In the instance where the transmission failure is found to be in the switching section under consideration and the receiving switch order is allowed to proceed at the end of the inhibit-timing interval, the next work of the transmitting logic is to check that the receiving switch order is acted on. Arrangements are provided in the distant receiving switch logic and control circuits to interrupt, momentarily, the transmission of tone on the status channel corresponding to the protection channel being used, after the operation of the receiving switch has been completed. Such a momentary interruption received on the BS7 lead within what is termed the "switch-initiation interval" constitutes a signal that the receiving switch has been effected. This timing interval runs for about 65 milliseconds and is started by a signal on the SIX lead through the action of the inhibit-timing circuit at the end of its 8-millisecond interval and coincident with the transmission of the receiving switch order code. Throughout the switch-initiation timing interval, the SR lead, through the action of the service-request circuit, again prevents any change being made in the status indications of the channel circuits.

After the timer runs its course, a signal on the SITX lead causes the service-request circuit to revert to normal. This completes the normal switch operating cycle. The channel-status circuits are now free to respond to other changes that may take place.

In the event the switch-initiation check signal is not received, the switch-initiation timing circuit generates a short pulse on the SFX lead at the end of the 65-millisecond interval. This signifies that the initial attempt to switch failed and that another attempt should be made using the other protection channel, if available. The SFX lead pulse brings this about by causing the channel X status circuit to mark itself bad for a period of approximately 140 milliseconds. While this is not the true condition of the channel, such a signal has the effect of forcing a re-assignment to the other protection channel. At this point the transmitting switch memory is reset in preparation for the new assignment and the new switch attempt.

When a fade on a channel passes and the status indication on the BS1 lead, for example, turns "good", both receiving and transmitting switches are returned to normal as soon as possible to free the protection channel for other assignments. Assuming no other request is being served at the time, a good indication on BS1 will immediately set the memory flip-flop in the channel-status circuit so as to provide a good indication on the GA lead. This causes the assignment then in effect, AX for example, to be withdrawn. This does not cause any immediate change in the memory or controls associated with the transmitting switches, but it does cause immediate reversion to normal of the receiving switch order code. This constitutes a new order to the distant receiving logic signifying that the receiving switch in the X channel group, then operated, should now be released and a check signal sent back to the transmitting logic upon completion of the release. The withdrawal of the AX assignment also, at this time, causes the SX lead to revert to normal. This, together with the condition then existing on the CSX lead, causes a timer to start in the release fail timing circuit. The purpose of this is to check that the receiving switch release signal occurs within the time period allowed, nominally 55 milliseconds. The check signal, as during switch operation, is in the form of a momentary interruption of the voltage normally present on the BS7 lead. When this signal occurs, the SX lead being normal, the memory reset responds and restores to normal the transmitting switch memory circuit, which in turn releases the transmitting switch and restores the normal potential to the CSX lead. The latter, in addition to causing the IF carrier to be restored to the channel X transmission circuit, also signals the release fail timing circuit that the switch release operation has been completed. Both the timer and the service request circuit restore to normal.

In case trouble should develop and delay or prevent the transmission of the switch release signal, the 55-millisecond timer will run its course, set a flip-flop and produce a release fail signal on the RFTX lead. This results in an alarm, locked-in until released by maintenance personnel. During this period the transmitting switch is kept operated, the regular channel is marked good, and the protection channel marked bad. This is the best policy to follow according to the information available to the transmitting logic under these circumstances.

6.2 *Organization of Receiving Logic*

The receiving logic associated with one protection channel is shown in block diagram form in Fig. 15. The second protection channel requires a duplication of this circuitry.

When transmission is good on all regular channels, protection channels are not required, and a "no switch required" signaling code exists on the R1 to R4 switch-order leads incoming to the decoder circuit. An order for the protection channel to be switched in as a substitute for one of the six regular channels consists of the establishment of the two-out-of-four code combination corresponding to the channel affected. Any case of

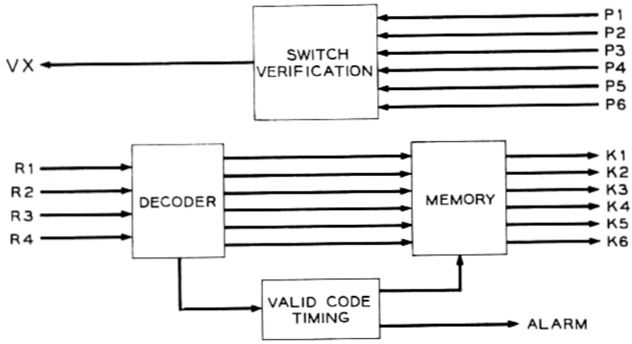

Fig. 15 — Block diagram of receiving logic.

one or three leads energized, or none at all, constitutes an invalid code which, if it persists for a sufficient period of time, will cause an invalid-code alarm to be given.

A two-out-of-four code is translated to a one-out-of-six code for presentation to the receiving switch memory circuit. The decoder acts instantly, but registration in the memory is deferred for about five milliseconds to make sure the switch request is valid and is not the result of impulse noise.

During the transition from the normal four-signal code to a two-signal code or vice versa, there will almost always be a momentary three-signal code indication as a result of differences between order tone signals in respect to transmission and detection times. This short, transient invalid-code indication normally serves to advise the valid-code timing circuit that a change in code has taken place and that a new timing cycle should be started. At the end of the timing period, an enabling signal is given to the switch memory circuit permitting the one-out-of-six input signal then present to operate its corresponding flip-flop memory and, through this, to cause the operation of the designated receiving switch. The enabling signal lasts just long enough to insure operation of the flip-flop. This strengthens the protection of the memory against unwanted interference.

Against the possibility that the change in code might be so perfect that no invalid-code transient would be available for triggering the timer, the latter is provided with a self-recycling circuit so that every six milliseconds an enabling pulse is generated, giving the memory an opportunity to readjust itself to any change in code, unaccompanied by an invalid-code transient that may have taken place in the preceding interval.

The operation of the receiving switch, or its restoral to normal, causes a voltage change on the appropriate lead in the P1 to P6 group, which causes the switch-verification circuit, to produce a four-millisecond pulse on the VX or VY lead, depending on the protection channel involved. This in turn causes a momentary interruption of tone on the corresponding status channel which, as previously explained, acts as a verification signal to the transmitting logic.

The preceding two sections describe the most general action of the switching logic. In some situations, elements can be omitted. As examples, with a transmitting baseband switch, the inhibit-timing check is omitted, and with dc reporting, the trnsmitting encoder and the receiving decoder are replaced by direct wire interconnections.

6.3 *Logic Circuit Elements*

The direct-coupled, transistor-resistor logic (TRL) gate is the basic building block used in the combinational and sequential operations of the control logic. This type of gate circuit, implemented by the silicon diffused-base NPN transistor (WE 16A), offers pronounced advantages in respect to over-all reliability, circuit simplicity and flexibility. Its speed of signal propagation, in the microsecond range, is ample for the needs of protection switching logic. The circuit and corresponding logic symbol are shown in Fig. 16.

If the potential at the input of any of the gating resistors, R_g, is raised to the prescribed level, the transistor conducts heavily (saturates), and the output signal voltage is nearly zero or ground potential. With all inputs at nearly ground potential, virtually no current flows in the collector electrode, and the output voltage then is relatively positive. The more positive level of input or output voltage is considered, for purposes of logical analysis, as state "1". The zero or less positive level of voltage is considered as state "0". Thus, with all inputs at state "0",

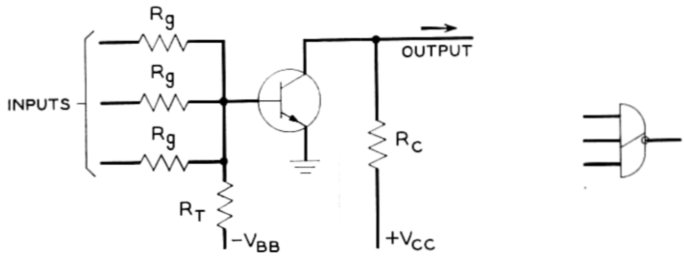

Fig. 16 — Basic TRL gate and symbol.

the output is at state "1" and, with one or more inputs at state "1," the output is at state "0". This is the action of an OR gate with the output signal inverted. The circuit is usually described as a NOR gate. In the symbol the slanting line signifies the OR function, while the small circle signifies inversion in the sense of the output signal. A gate of this type with only a single input is described simply as an inverter. In the symbol for this the slanting line is omitted.

The gate design adopted is conservative and allows for as much as 350 millivolts of noise at the base of the transistor. It will accommodate as many as four inputs and will drive, simultaneously, as many as four output stages of the same design or other circuits of equivalent loading effect. Interstage connections between the transistors of two gates are shown in Fig. 17. In some cases six- or seven-input gates are required, and two transistors are used with their collectors connected in parallel to a common resistor.

The limited amount of memory required in the logic dictates the use of a conventional, saturating type of bistable circuit, or flip-flop, for each bit of memory. The circuit and its representation are shown in Fig. 18. The control of certain memory functions is facilitated through the use of a special flip-flop design in which setting and re-setting are both effected over the same lead. This circuit is always used in conjunction with a two-transistor, bi-lateral switch that allows the flip-flop set-reset lead to be opened or closed as required. The combination of circuits and the symbols used to represent them are shown in Fig. 19.

The principal feature of the assignment circuit is another modified form of bi-stable circuit, similar to a flip-flop but differing in the manner of its control. This circuit element, together with two diode-type AND gates used to enable or inhibit its action, are shown in Fig. 20. The pur-

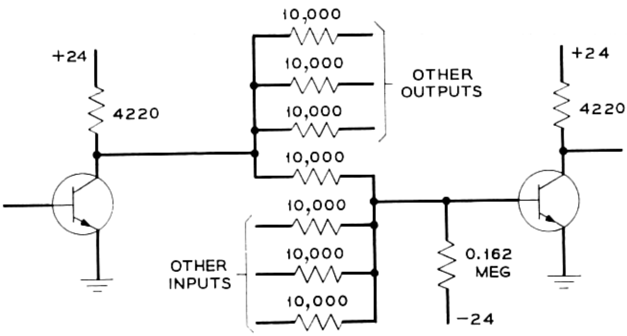

Fig. 17 — The TRL interstage connections.

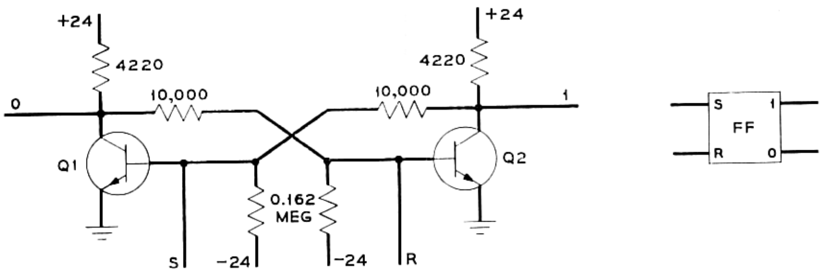

Fig. 18 — Standard flip-flop circuit and representation.

pose of this circuit is to assign one of the two protection channels to the regular channel corresponding to the bi-stable circuit in question and to insure that this protection channel cannot be assigned to a second regular channel at the same time. Preference as to which protection channel should be assigned to a given regular channel under normal conditions is determined by the position of the switch associated with the 0.1 mf capacitor.

If the normally preferred protection channel is not available for any reason, a small negative potential is present on one of the six AND gate leads associated with it. This allows forward current to flow through the diode and thus causes a slight negative bias on the base of the transistor, preventing the latter from operating. In this situation, the other "second-choice" transistor will operate provided, of course, its

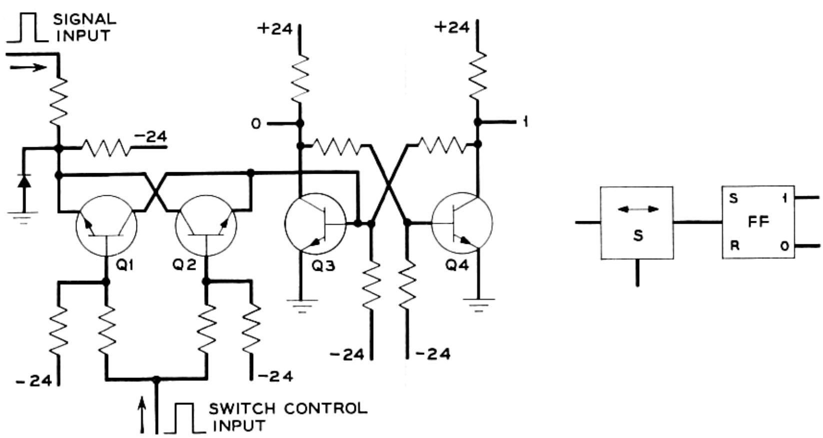

Fig. 19 — Bi-lateral switch and special flip-flop with symbols.

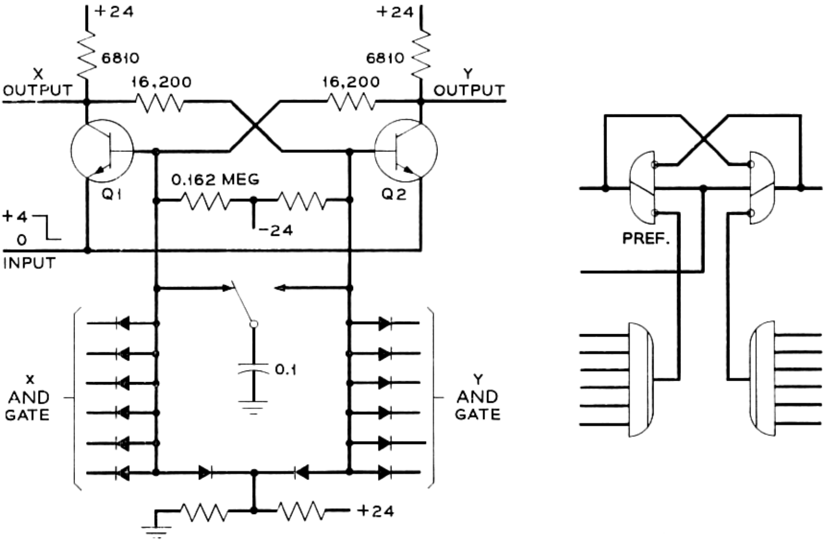

Fig. 20 — Assignment flip-flop with diode AND gates and symbols.

associated protection channel is available as signified by no current flow in any of the AND gate diodes.

In the symbolic representation of this circuit feature, the vertical line through each of the lower gates signifies the AND function. Each transistor of the bi-stable circuit, in terms of its logic function, may be represented as an OR gate (diagonal line) with respect to a "1" output in which two of the inputs are inverted as shown by the small circles.

Fig. 21 shows the circuit of a monopulser typifying several that are used in the logic for establishing time intervals for certain functions.

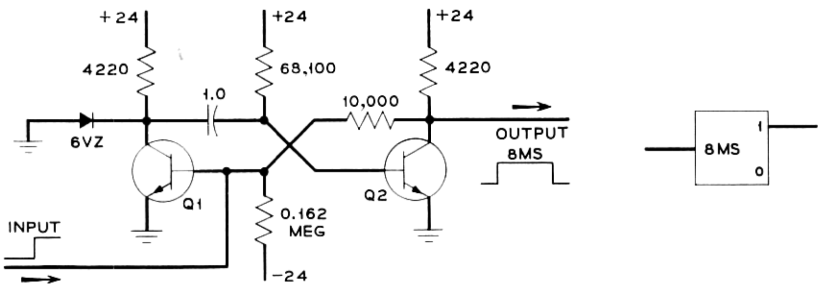

Fig. 21 — Typical monopulser and symbol.

Another important type of timing circuit employed is the delay timer shown in Fig. 22.

6.4 *Logic Diagrams*

Fig. 23 is a logic diagram of the regular and protection channel-status circuits and the channel-available and service-request circuits, indicated as blocks in Fig. 14. In addition to the TRL gates for handling the various input signals, this diagram shows the status-memory flip-flops, the bi-lateral switches and the timers employed. Most of the time the memory flip-flops and, consequently, the status indications on the GA and GX leads follow directly any changes in indications on the BS1 and BS7 leads. If the logic is busy making or releasing a channel switch, or if there is no protection channel available, signals generated in the service-request or channel-available circuits cause the bi-lateral switches to be opened and thus prevent any changes in the positions of the flip-flops until such periods have ended. The 50-microsecond delay timer in the control path of the regular channel switch serves to prevent unwanted operation of the switch during a small gap between the end of the inhibit-timing interval (signal on ITX lead) and the beginning of the switch-initiation timing interval (signal on SITX lead). The 5-millisecond delay circuit in the path of the protection channel status signal (BS7) lead prevents improper operation in the event of a general failure of the status-signaling transmission facility. The delay allows the logic of the alarm circuit (not shown) to determine that all channels have failed and to place switch-inhibiting signals on the SR and NSR leads.

A manual switch of a regular channel may be made by grounding the MSA lead. A positive voltage on the LOA lead (via a lockout control key) will prevent an automatic switch by the regular channel and, on the

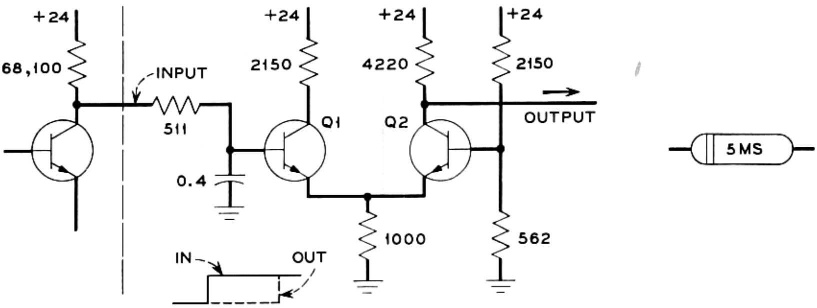

Fig. 22 — Delay timer and symbol with typical input circuit.

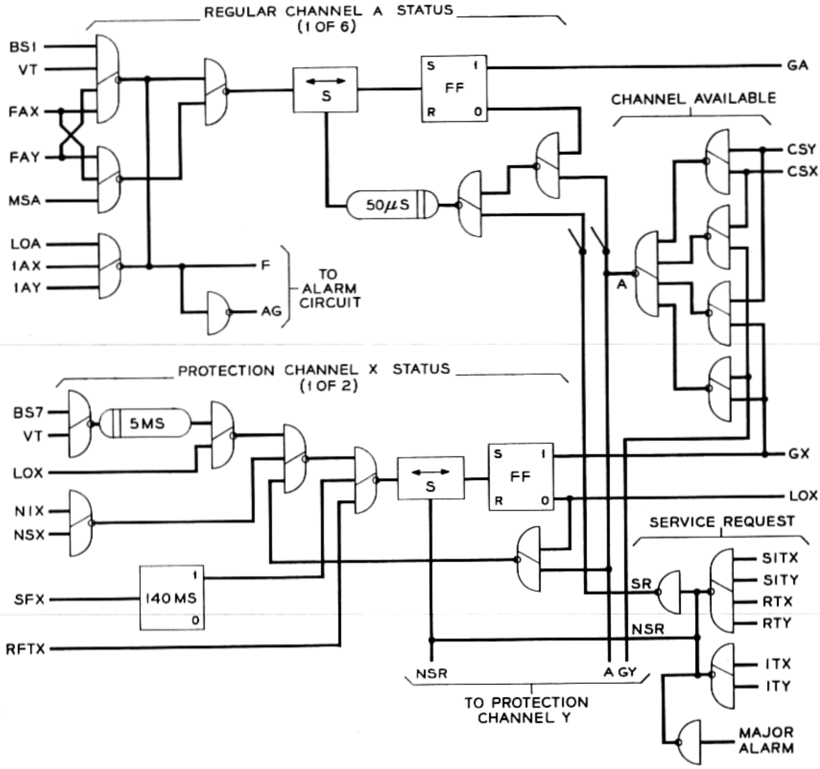

Fig. 23 — Logic diagram of regular and protection channel-status circuits, with associated channel-available and service-request circuits.

LOX lead, by the protection channel. The VT lead is used to inhibit any failed channel indications that may be received when it is desired to make out-of-service operational checks of the logic.

Fig. 24 is a logic diagram of the assignment circuit, shown in detail for three regular channels. Signal leads from the regular channel-status circuits enter from the left, those from the protection channels from below. The output leads, signifying by their designations the various possible assignments, are on the right. With the system normal, all input leads have a positive voltage and all output leads zero voltage.

The assignment flip-flops, discussed in connection with Fig. 20, are in the middle of the diagram. Each flip-flop output becomes one of two inputs to a TRL gate whose output, in turn, when it becomes positive, constitutes an assignment signal. In addition, these latter outputs, after

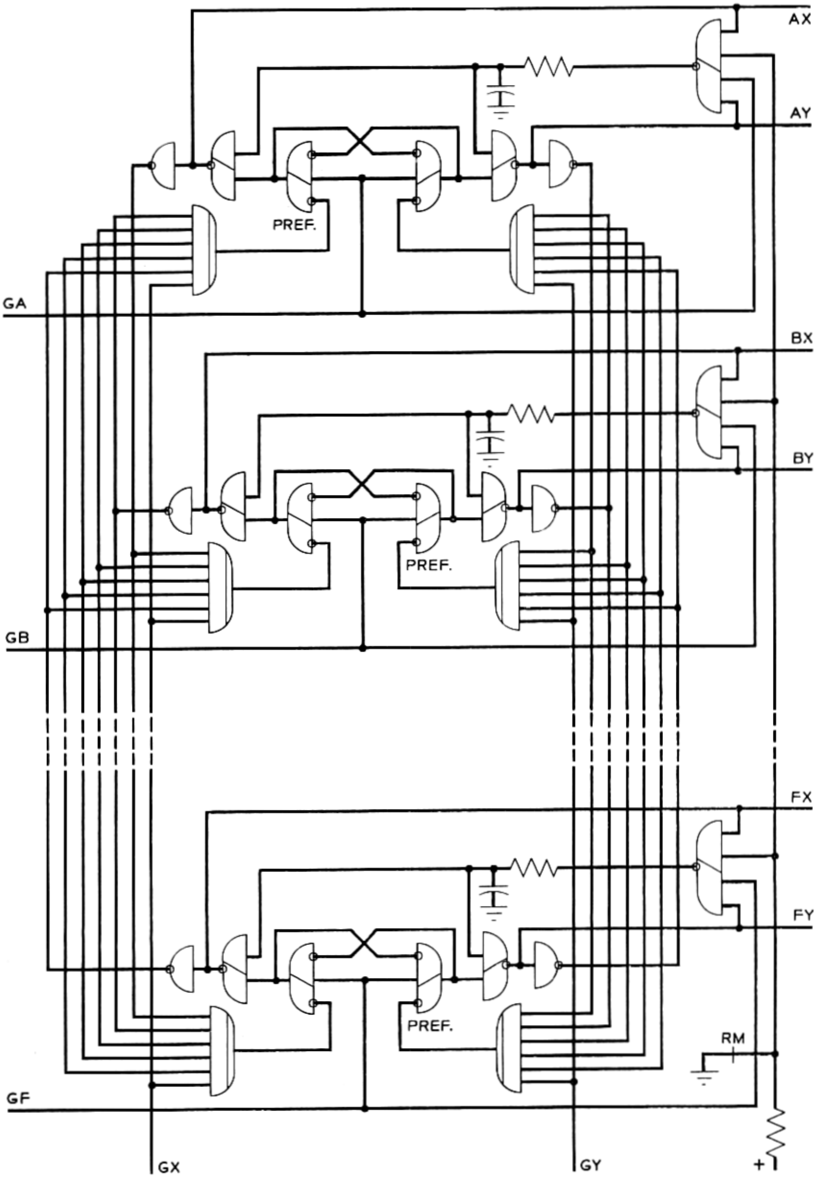

Fig. 24 — Logic diagram of the assignment circuit.

inversion, actuate all AND gates associated with the chosen protection channel, excepting that associated with the regular channel requesting the assignment. This prevents the chosen protection channel from being assigned to any other regular channel that may request a switch. Subsequent bids will result in the assignment of the second protection channel, regardless of the normal preference.

If an attempt to complete a switch is unsuccessful, and then the ensuing attempt on the other protection channel is also unsuccessful, it is essential that no repetition of this cycle be allowed until the difficulty is corrected. If this situation arises, both the GX and GY leads are at zero potential temporarily, along with a zero potential on the channel lead. Since no assignment signal (i.e., no positive voltge on output -X or -Y lead) exists under this condition, the gate at the right of the channel circuit is cut off and, as a consequence of its positive output signal, is locked in this position until either the regular channel withdraws its bid for a switch (GA lead again becomes positive), or until the RM key is manually operated by maintenance personnel. During such a lockout period the protection channels are available for assignments to the other regular channels. Although the lockout gate is momentarily cut off each time its channel input lead goes to zero, the effect of this is delayed by the RC circuit in its output until the assignment signal is established, whereupon the gate is restored to its normally operated condition.

The memory functions associated with the transmitting switch control and with the order-tone transmitter for protection channel X (as an example) are shown in Fig. 25. At the top of the figure are two of the six switch memory flip-flops. An assignment signal (positive voltage) appearing on one of the six leads, AX to FX, "sets" the corresponding flip-flop, and thus establishes a positive voltage on the K-lead, which in turn causes the operation of the proper transmitting switch. The same memory information in inverted form is also available on one of the RAX to RFX leads. This is utilized in certain circumstances by the timing and checking circuits. The K-lead voltage also operates one of the TRL gates connected to the CSX lead, reducing the latter's normally positive voltage to zero. This causes disconnection of the carrier supply and also notifies points within the logic of channel X's busy condition.

The switch-verification logic checks for agreement between the signals given a transmitting switch to operate or release and the signals received via the P-lead showing that the switch responded as directed. The output voltage of this circuit is normally zero, but becomes positive during the transient operating or releasing interval of the switch or in case of trouble when no verification signal is received.

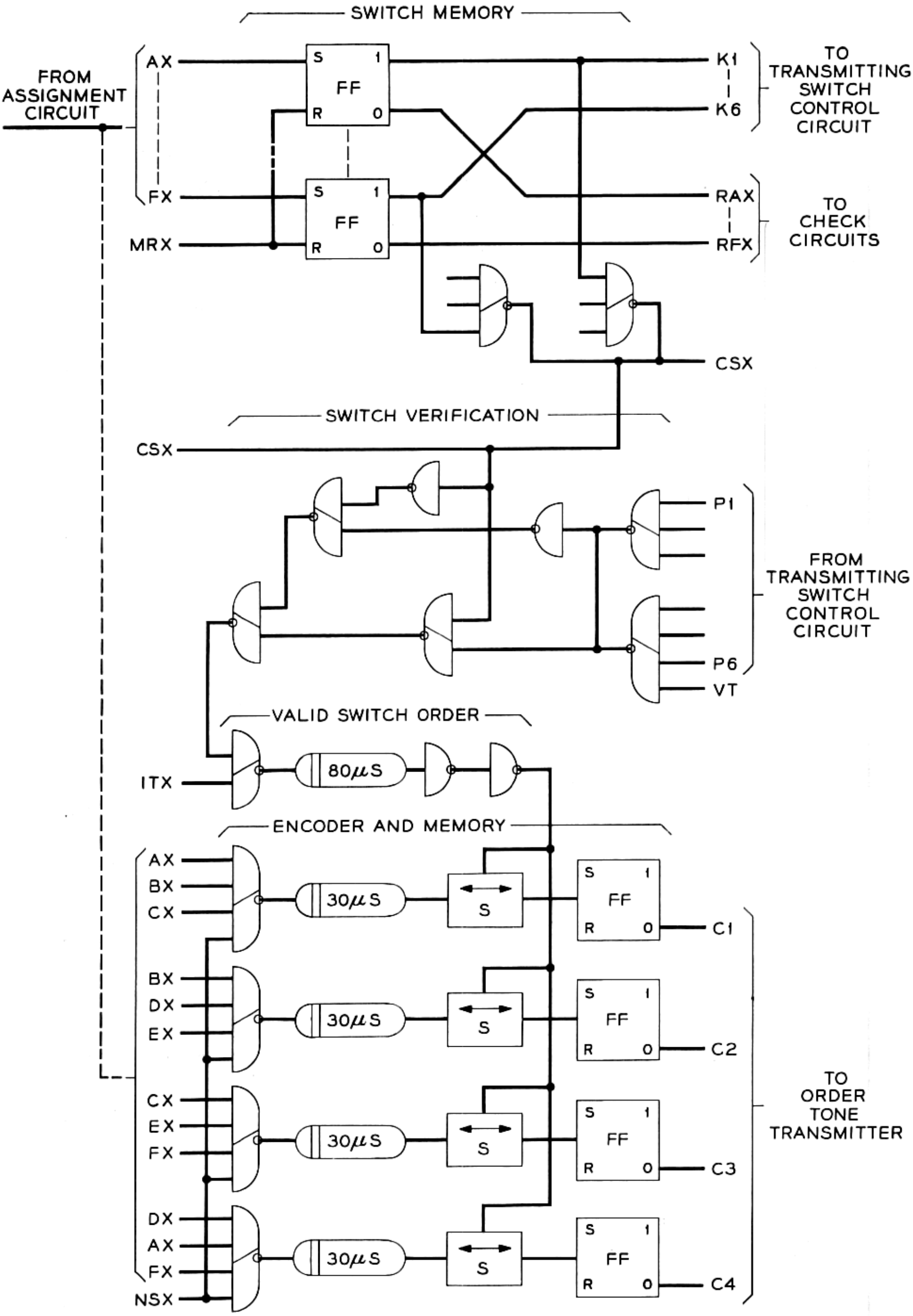

Fig. 25 — Logic diagram of switch memory, order encoder and related features.

The valid switch order circuit, under joint control of the transmitting switch-verification signal and the inhibit-timing signal, determines when it is time to permit a change in the setting of the memory flip-flops associated with the encoder and thus present the tone transmitter with a switch order. With the protection channel not in use, all four order-tone flip-flops are in the reset state with positive voltages on leads C1 through C4. The four TRL gates at the lower left comprise the encoder. Normally, the gate outputs are at zero voltage level owing to a positive voltage on the NSX lead. When a given assignment signal is established, the inputs of two of the encoder gates are made positive, and a microsecond later, due to action in the timing and checking circuit, the NSX lead voltage drops to zero. This combined action allows the outputs of two of the four TRL gate outputs to become positive, which constitutes basic encoding operation. The two positive outputs are delayed about 30 microseconds in transmission to allow time for the establishment of a positive voltage on the ITX lead, the release of the normally operated 80-microsecond timer, and the opening of the bilateral switches. At the end of the ITX signal, provided the switch-verification signal is present, and after the delay involved in operating the 80-microsecond timer, the bilateral switches close and thus permit the two flip-flops to be set in accordance with the encoder output signals. The 80-microsecond delay is required to allow adequate time for changing the assignment and its encoded equivalent in the event of failure to complete a switch on the first attempt and also to prevent premature setting of the order flip-flops in case the inhibit-timing interval check indicates the transmission failure to be in the previous switching section.

Fig. 26 shows the logic of the timing and checking circuits for channel X. The channel-selected circuit (lower right) receives the assignment signal simultaneously with the switch-memory and order-tone encoder. The output of the channel-selected gates is a positive voltage on the SX lead and a zero voltage on its inverted counterpart, the NSX. The change in SX lead voltage resets the inhibit flip-flop and triggers the inhibit-timing monopulser. The latter makes the ITX lead positive for a period of 8 milliseconds. The inhibit-memory circuit (left middle) contains the logic and temporary memories for producing a positive signal of 110-millisecond duration on the IAX to IFX lead corresponding to the channel assignment, in the event the voltage on the protection channel status lead, BS7, becomes zero during the ITX interval. This, if and when it occurs, indicates that the trouble is in the preceding switching section. The IAX to IFX lead signal forces the regular channel-status circuit to give a good indication long enough for the preceding section to complete a switch and restore transmission. The operation of one of the 110-milli-

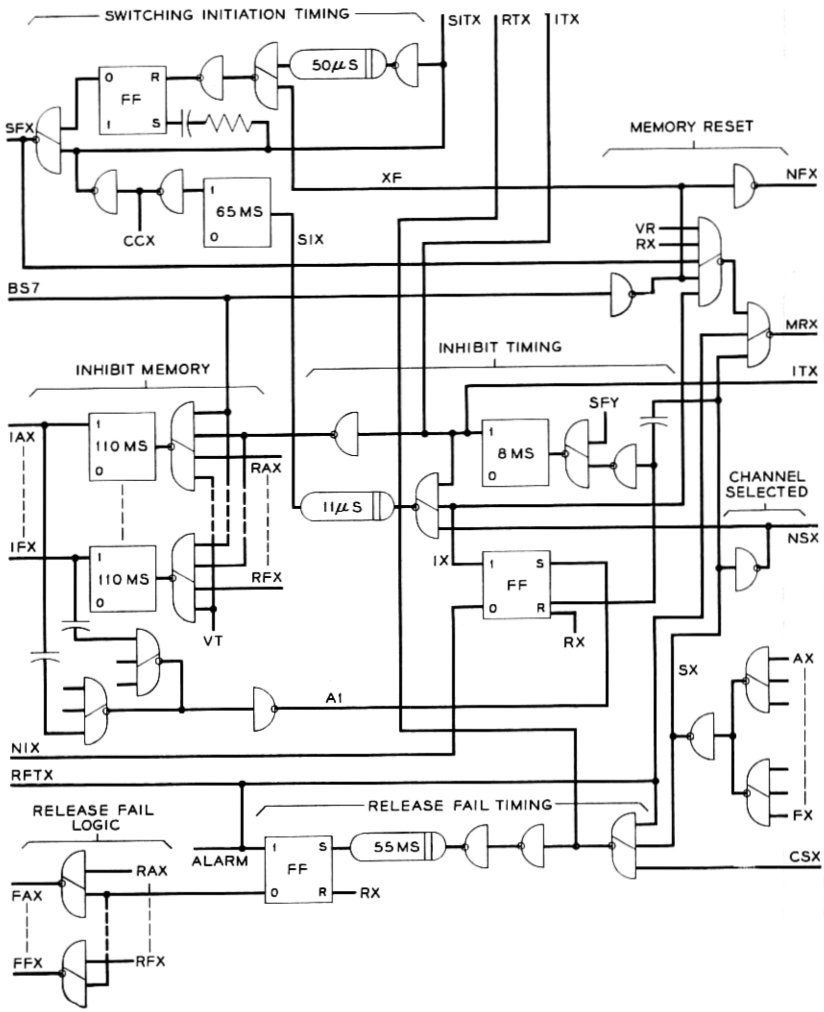

Fig. 26 — Logic diagram of timing and checking circuits.

second monopulsers also generates a transient impulse that sets the inhibit flip-flop which, in turn, drives the IX lead positive. This action prevents the operation of the inhibit-timing output gate and thus prevents the start of the switch-initiation timer, which otherwise would follow the end of the 8-millisecond ITX interval. At the end of this latter interval, the service-request circuit permits the channel-status circuit to respond to the 110-millisecond inhibit signal, the GA lead (Fig. 23) becomes positive, the assignment signal is withdrawn, and the SX lead potential reverts to zero. This, coupled with a positive IX lead, actuates the memory-reset circuit to make the MRX lead positive and thus resets the switch memory. The NSX lead, in reverting to its positive voltage state, normalizes the encoder without the order having been transmitted.

If no loss of positive voltage occurs on the BS7 lead during the 8-millisecond interval, the regular switching cycle is allowed to continue. The return of the ITX lead to zero potential, acting through the valid switch-order circuit, allows the encoded order to be transmitted and, coincidentally, causes the inhibit-timing gate output to become positive. This, after an 11-microsecond delay (to avoid response to short transient signals), produces a positive voltage on the SIX lead, which marks the beginning of the switch-initiation timing interval, during which the logic looks for an indication that the desired receiving end switch has been made. The SIX signal triggers the 65-millisecond monopulser, which drives and maintains the SITX lead positive for this period. The switch initiation flip-flop is set at this time for later use. The SFX lead potential, normally zero, is held at this level by the positive SITX lead input to the output gate. In the normal case, during this period, the BS7 lead will lose its positive potential for a few milliseconds as a signal from the receiving end logic that the receiving end switch has been completed. This occurrence will cause the XF lead to become positive and, by way of the gate leading to the switch-initiation flip-flop, cause the latter to reset and produce a positive voltage on its output lead. This will continue to hold the SFX lead potential at zero after the 65-millisecond period of positive potential on the SITX lead ends. In the absence of a signal on the SFX lead, no further action on the part of the X channel logic is required at this time.

In case a momentary interruption of the positive potential on the BS7 lead fails to occur before the 65-millisecond timing interval ends, the flip-flop will not have been reset before the SITX lead potential returns to zero. This permits the SFX lead potential to become positive. The same action, however, starts the delay timer which, after 50 microseconds, resets the flip-flop, and this in turn causes the SFX lead potential to revert to zero. The 50-microsecond pulse thus created on the SFX lead triggers the 140-millisecond monopulser in the channel X status circuit, which results in a second attempt to complete a switch, this time using channel Y, if available.

The circuit in the lower part of Fig. 26 checks that the release of a protection channel, when called for, takes place within the allotted interval of time. A regular channel becoming good causes the assignment signal to be withdrawn. This changes the voltage of the SX lead to zero and that of the NSX lead to positive. The latter causes the encoder and memory circuit to revert to normal, which constitutes a signal to the receiving logic that the receiving switch previously operated should now be released. When the SX and CSX leads are both at zero voltage, the lower NOR gate acts to produce a positive signal on the RTX lead, which starts the 55-millisecond delay timer. Normally, before this timer runs its course, there is a momentary interruption of the positive voltage on the BS7 lead, signifying that the receiving switch has released as ordered. This, in combination with zero voltage on the SX lead, actuates the memory-reset circuit to put positive voltage on the MRX lead, which resets the switch memory flip-flop. This, in turn, releases the transmitting switch. The CSX lead voltage becomes positive, which resets the 55-millisecond timer and thus forestalls the setting of the release-fail flip-flop. As soon as the release-verification signal ends (BS7 lead potential becoming positive), the entire protection channel becomes normal and available for a new assignment.

If the release-verification signal should not be received before the 55-millisecond timer runs out, the release-fail flip-flop will be set which, by making the RFTX lead positive, will hold the transmitting switch operated, mark the protection channel bad in its status circuit, and present a release-fail signal to the alarm circuit. In conjunction with the signal present on the affected lead in the RAX to RFX group, the flip-flop also causes a positive voltage on the FAX to FFX lead, which marks the regular channel bad in its status circuit. These actions prevent any further change in the regular or protection channel logic until maintenance personnel have determined that the circuits should be normalized and the alarm retired. This is done by a key operation which applies positive voltage to the RX lead for resetting the flip-flop.

The logic details of the receiving circuit for one protection channel are shown in Fig. 27. The decoder is on the left. With all order-tone channels normal, there is a positive voltage on all four input leads and zero potential on all six decoder output leads. The latter connect to the bilateral switches of the memory and also to a seven-input, two-section gate for indicating the presence of a valid code. The four-input gate in the lower part of the decoder has a positive output when all order-tone channels are normal. This represents the valid "no switch required" code. When a two-out-of-four code is established, the voltage of this gate returns to zero, while that of one of the six channel gates becomes positive. Except during transitions, there is a positive voltage on one of

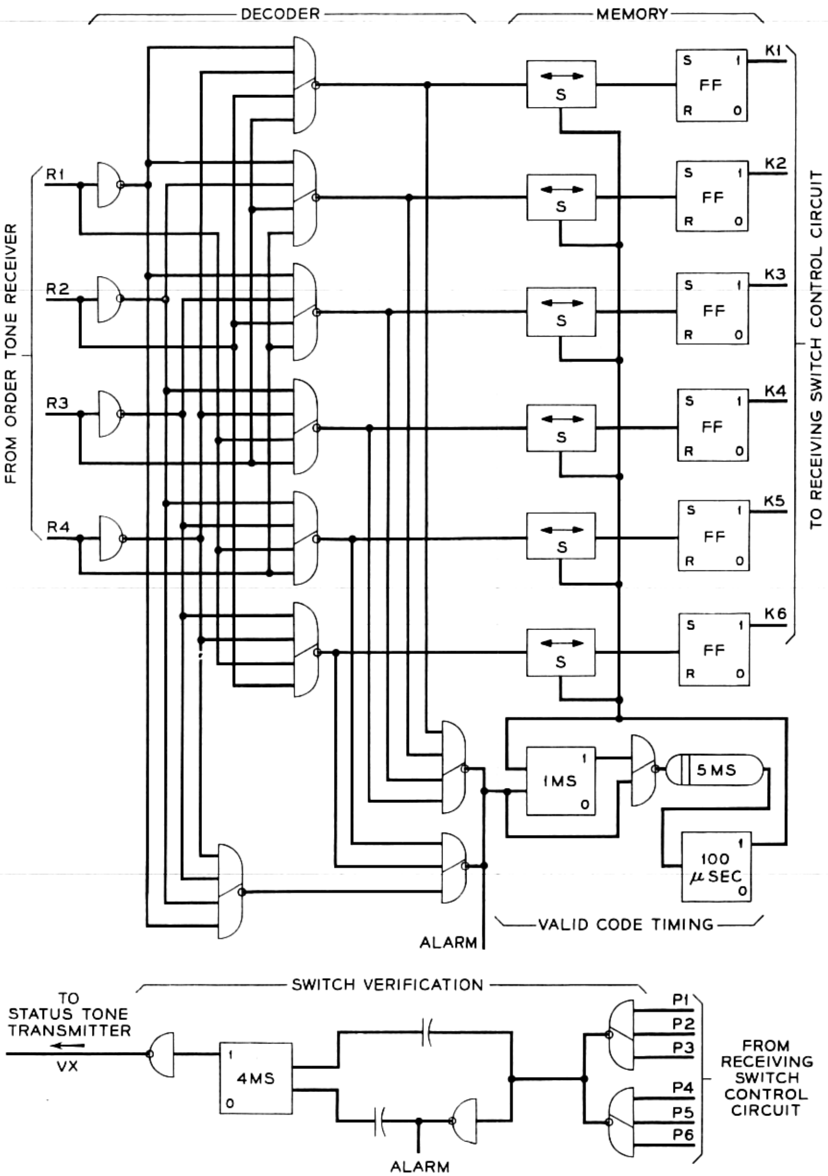

Fig. 27 — Logic diagram of receiving-circuit decoder, memory, checking and timing features.

the seven input leads and thus zero voltage on the output lead of the valid code gate at all times.

During a change in the incoming code, a transient one-out-of-four or three-out-of-four combination is a normal expectancy. Either will produce a momentary positive voltage on the output of the valid code check gate, which triggers the one-millisecond monopulser of the timing circuit. This resets the five-millisecond delay timer. At the end of the monopulser output or at the end of the transient invalid code indication, whichever occurs last, the five-millisecond delay timer starts to operate. On completion of its operation, it triggers the 100-microsecond monopulser, which operates the bilateral switches long enough to allow the operation of the channel memory flip-flop corresponding to the decoder output gate having positive voltage at this time. This arragement of delay and limited access to the flip-flops affords a high degree of protection against interference and simulated orders due to impulse noise.

In case the usual transient triggering impulse is not developed when a code change takes place, reliance is placed on the feedback circuit between the output of the 100-microsecond monopulser and the input of the one-millisecond monopulser. This keeps the three timing elements constantly recycling with a periodicity of about six milliseconds. While this does not guarantee the full five-millisecond time lag normally provided, it insures that a change in the status of the decoder does not go unrecognized for more than six milliseconds.

The setting of a memory flip-flop applies positive voltage to the associated K-lead which, through the receiving switch control circuit, causes the designated receiving switch to operate. Shortly after this, a verification signal in the form of a positive voltage on the corresponding P-lead is received which drives the output of the verification gate to zero. By the way of the inverter, this becomes a positive-going transient which triggers the four-millisecond monopulser. During the verification interval, the potential of the VX lead becomes zero and the status tone associated with the X protection channel ceases. This tone break constitutes the receiving switch-verification signal utilized by the transmitting logic. On the release of a receiving switch, the P-lead potential reverts to zero. This causes a positive-going transient via the upper capacitor, which again triggers the monopulser and creates an interrupted tone-verification signal as before.

VII. SYSTEM MAINTENANCE AND EQUIPMENT ARRANGEMENTS

Most active equipment will be tested periodically on a routine basis. The circuits to be maintained are easily removable for insertion in a special test set. Ref. 5 comprises a description of this set, together with the principal features of the testing procedure. Before a circuit is removed, the proper manual switching operation is made either to isolate the circuit from the system or to bring it into a passive state which allows its removal. The function of active circuits is replaced, either automatically or manually, before such circuits are completely removed. A large number of cards in the transmitting and receiving logic, however, cannot be removed for testing without first disabling the automatic portion of the switching system by an override status quo action. No preventive maintenance is anticipated on such cards.

If a trouble occurs somewhere in the switching system, alarms normally are issued. The type of alarm and the indication of lamps permit a fairly quick localization of the circuit area in trouble. Pin jacks located on the front plate of certain circuits are used to pinpoint the failed circuit. A failure in the transmitting logic is more difficult to localize. A special logic-tester is used in this case. Furthermore, a total of 12 message registers located in the transmitting logic count the number of completed switch operations. If an excessive number of switch operations are registered for a particular channel, trouble must be suspected, and the necessary actions can be taken to eliminate this condition.

Companion articles describe in some detail the equipment features[6] and the power supply[7] for the protection switching system. Most circuits for the switching system are built on cards which are easily inserted and removed from the equipment bays. Four types of 11-foot bays are used: the IF switching bay, the baseband switching bay, the control bay for tone reporting and the control bay for dc reporting.

The switching system is powered by a very reliable plant delivering +24 volts and −24 volts. A high degree of reliability and a stable voltage even under emergency conditions are achieved by the use of buffer batteries and the firm ac power equipment of TH as a source. The power plant is mounted in separate bays.

VIII. ACKNOWLEDGMENTS

Many members of the Laboratories have contributed to the development of the automatic protection switching system. Among them the authors wish to mention J. J. Degan, W. R. McClelland, R. K. Townley, H. I. Maunsell and R. H. Higgins.

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