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WT4 Millimeter Waveguide System:

Protection Switching, Auxiliary Communication, and Maintenance

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A statistical analysis shows two-way reliability of 99.98 percent or better for the WT4/WT4A system with two automatic protection channels and one manual patch channel for every 59 working channels and 20-year life expectancy for the repeaters. The feature of adding and dropping fully protected channels at intermediate repeater stations in a protection span is included. The equipment is divided into three bay arrangements: (i) span-terminating transmission bays which contain protection switches, performance monitors, and all interfaces with the high-speed communication signals as well as the auxiliary signals, (ii) the logic and control bays for the protection switching, and (iii) the order wire, telemetry, and fault locate bays. All auxiliary signals ride piggyback on special housekeeping bits in the broadband channels; double-ended access is therefore provided for the telemetry to ensure reliability. Fault locating is fully remoted and intended to operate with automated SCOTS systems. Typical, but partially equipped, bay arrangements were tested in the field evaluation test and were found completely satisfactory.

I. INTRODUCTION

The WT4/WT4A system[1] is intended to interconnect major traffic nodes in the toll transmission network. Figure 1 is a layout of such a span. Main repeater stations are located at the ends of the span and a number of important functions must be provided by span terminating bays at these locations. An obvious one is the interface with the rest of the Bell System. This function is performed by the cross-connect bays and the

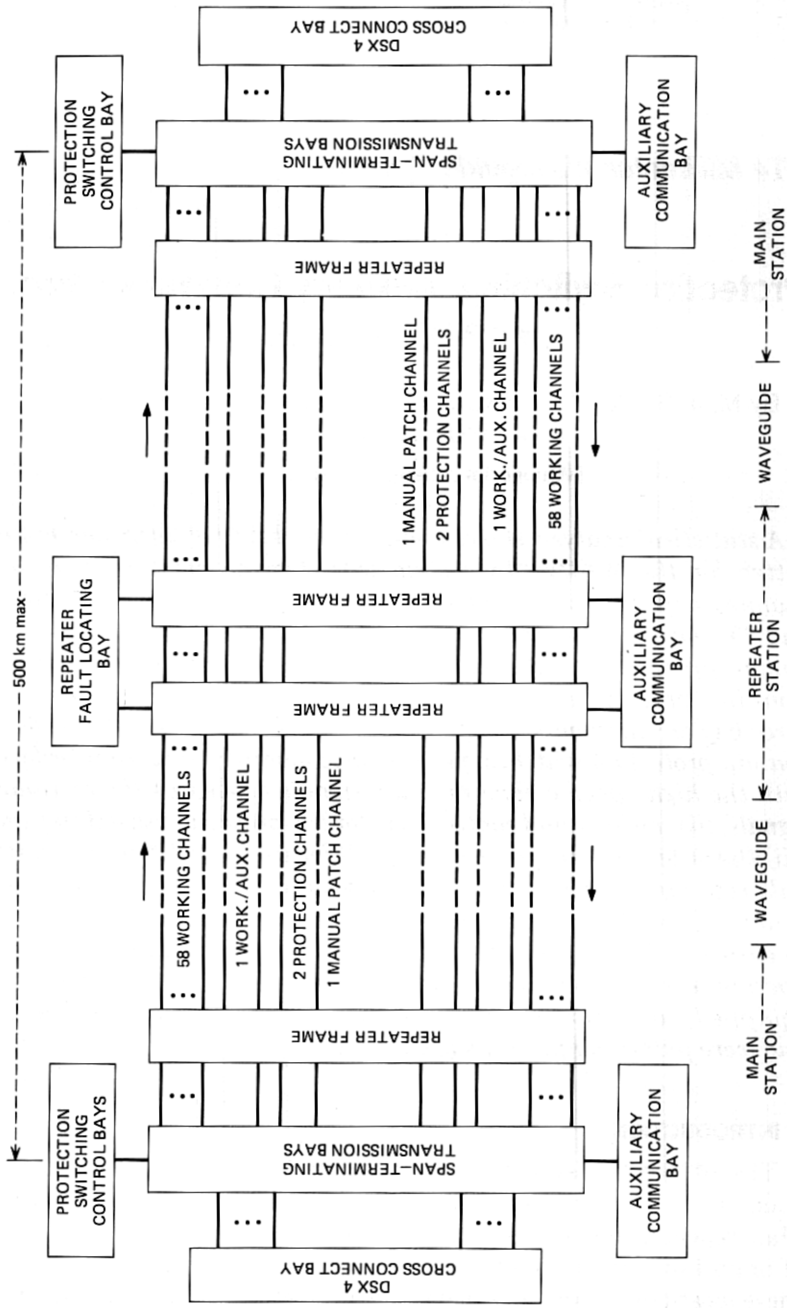

Fig. 1—Layout of protection span.

span-terminating transmission bays. The DSX-4 cross-connect bays are bays where all channels have baseband jack appearances; they serve to interconnect channels and route traffic in and out of the system.

Another function is protection switching. Protection switching must be provided at the ends of the span in order to keep the probability of service interruptions, or outages, on these important routes to a very small number. This is done by automatically transferring the traffic from any failed working channel to hot stand-by channels very rapidly ($\leq$100 ms).

In most other systems, all repeaters are identical and a reasonable number of spares can be strategically located to allow fast replacement of failed units and, thus, fast release of the protection channels. The WT4 system,[2] on the other hand, has 124 different repeater codes according to channel frequency; this calls for an impractically large number of local spares. Instead, WT4 is unique in using a manual patch channel. Unlike a protection channel which can be accessed only at the ends of the whole span and protect only one failure at a time, the patch channel is a hot stand-by channel which can be manually accessed at any intermediate repeater station within a span. It can be used to bridge any failed repeater in a hop by patching at the two ends of the hop at baseband where the signal format is the same in all repeaters. This temporary patch frees the protection channel, allows removal of the failed transmitter-receiver pair, and provides adequate time for a replacement pair to be sent from a large central spare depot. The power of a manual patch channel lies in the fact that pieces of it can be used to temporarily bridge many failed repeater hops as long as there is only one failure per hop. The statistics are such that two automatic protection channels and one manual patch channel in protection spans of 500 km will satisfy the Bell System objective of 99.98 percent availability per 6000 km of a fully loaded system. This assumes that the repeater has 20-year life, that it takes maintenance personnel 10 hours to establish a manual patch, and that it may take 300 hours before a permanent replacement repeater arrives and frees the patch channel. These numbers are operationally and economically reasonable.

There are also cases where it would be desirable to add and drop some of the traffic at points within a span. To meet this demand, the protection switching system allows for full protection switching of such add/drop channels at up to six add/drop stations within a span. Through-channels are completely unaffected; in fact, the entire topology is totally flexible.

Protection switching signaling, maintenance telemetry and commands, and operating personnel order-wire communication create a sizable need for auxiliary communications within a span. All these communications ride piggyback on some of the broadband channels by using special

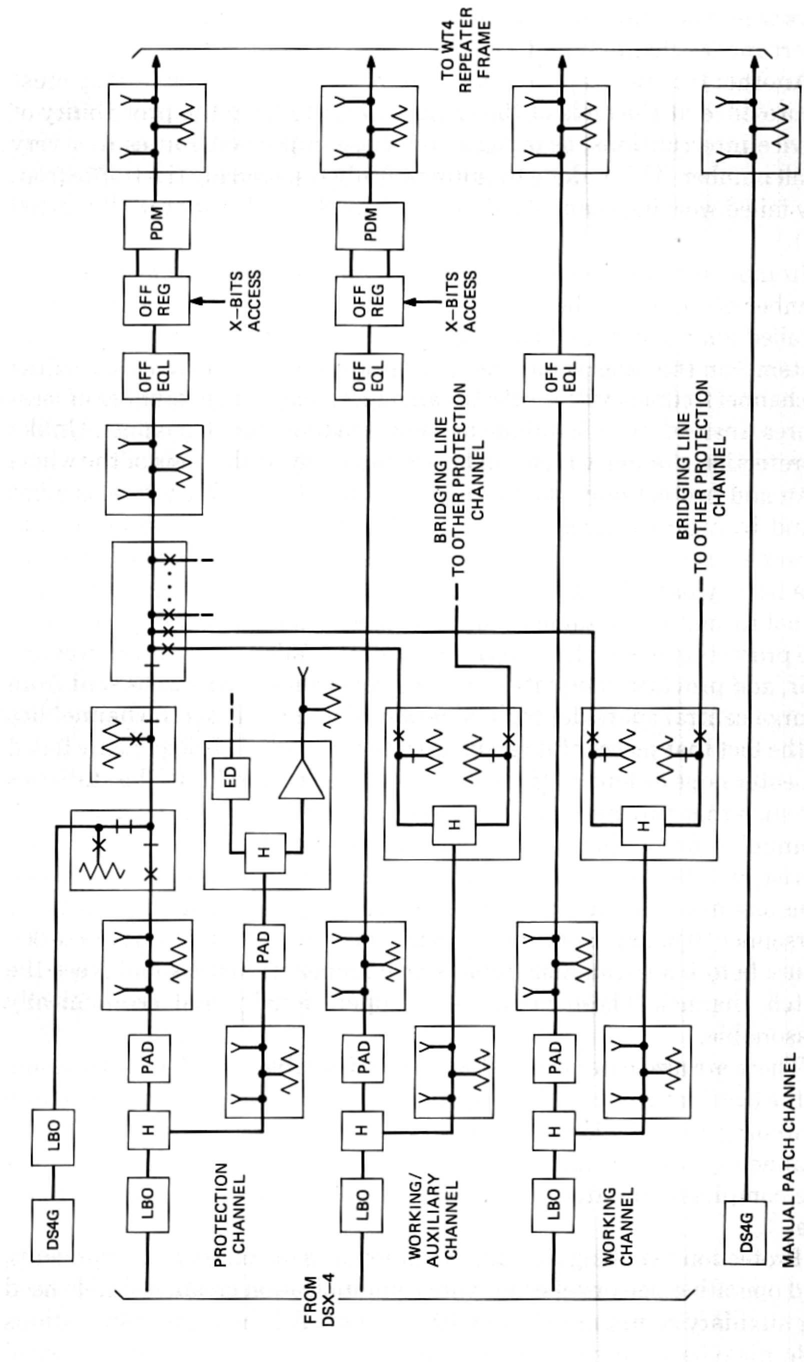

Fig. 2—Transmit section.

housekeeping bits supplied in the 274 Mb/s DS4 baseband format for just these kinds of purposes. This is an arrangement modeled after the T4M system.[3] For the WT4 system it provides inexpensive, fast, and highly reliable auxiliary communication because the signals travel inside the sheathed waveguide as opposed to a separate, repeatered multipair cable on the outside. The bits are referred to as X bits. They are used in triplets with majority decision and provide an extremely rugged bit stream with a total capacity of 58.3 kb/s per DS4 signal. The T4M system has developed a Protection Data Multiplex (PDM) unit which provides for insertion of the X bits and a Violation Monitor and Remover (VMR) which monitors the parity checks in the DS4 signal, removes any violations of the parity checks (but not the errors, themselves) and, as a by-product, extracts the X bits for reception. By inserting these units in the baseband portion of any WT4 channel, such as a channel can be used as a carrier of X bit auxiliary communication.

The protection switching system uses X bits on the protection channels in the opposite direction to carry the required signaling from the tail end of a span to the head end of the span and to any add/drop stations in between. The maintenance telemetry/command system and the order wire share the X bits on one of the broadband working channels, the working/auxiliary channel.

II. THE SPAN TERMINATING TRANSMISSION BAYS

The two-phase version of the WT4 system has 59 working channels. The two automatic protection channels serve most of the time as hot standby channels but on command may be accessed as additional working channels. When not carrying traffic, the protection channels (and the manual patch channel) are driven by a line drive signal consisting of a pseudorandom signal imbedded in a DS4 format.

Figure 2 shows the high-speed signal path through the transmit section for each type of channel. The DS4 signal first passes through a line build-out network (LBO) followed by a 3-dB splitting hybrid. The LBO is selected so that the total length from DSX-4 to LBO output is electrically equivalent to 50 m of 728A cable. The hybrid splits the signal into a through path and a bridging path that carries the signal through switches to the two protection channels. The signal in the through path is next passed through an equalizing network (OFF EQL) designed to restore the pulse shape in preparation for regeneration. For the working channel, the regeneration occurs in the transmitter located in the repeater frame, but for the protection and working/auxiliary channels the signal must pass through a regenerator-protection data multiplex (PDM) pair for X-bit access. The regenerator provides the data and clock levels required to drive the PDM. Jacks are provided to manually jump the bridging circuits in the event of a switch failure.

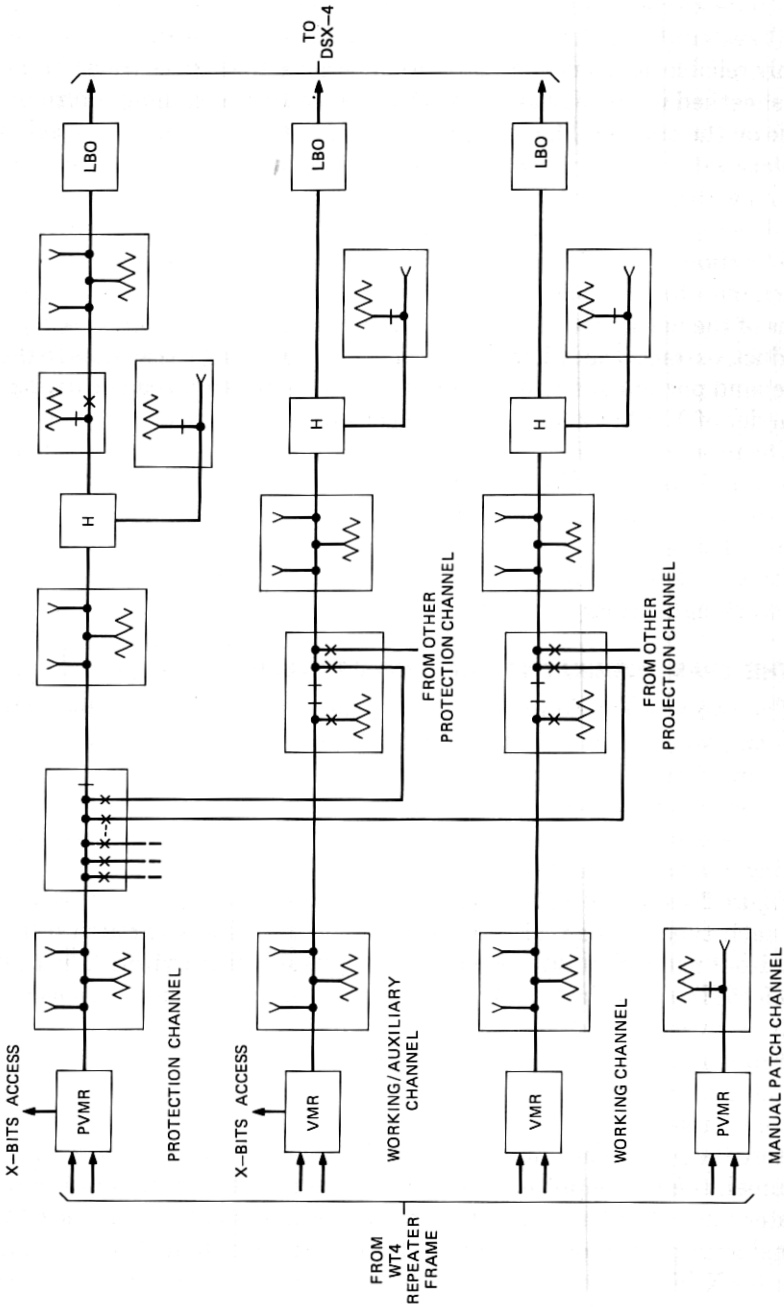

Fig. 3—Receive section.

In the receive section, Fig. 3, each channel passes through the violation monitor and remover (VMR) circuit for performance monitoring and X-bit access. The (P) signifies that the VMR also can detect the differences between a DS4 and a line drive signal. After monitoring, the DS4 signal passes through an LBO circuit similar to that in the transmit circuit. A hybrid and jack are provided at each output for maintenance purposes.

Four types of span-terminating transmission bays were designed: a 2 × 3 and a 0 × 10 bay for the protection switching station, and a 2 × 3 and a 0 × 10 bay for the add/drop station. The 2 × 3 bay contains the equipment associated with both the transmit and receive section for the two protection channels, the one working/auxiliary channel, two working channels, and the manual patch channel. The 0 × 10 bay contains ten working channels (transmit and receive section). Interbay cabling is necessary between these bays to complete the protection switching paths.

III. THE PROTECTION SWITCHING CONTROL BAYS

3.1 Overall system operation

A simplified block diagram of a typical one-way switching section using a typical protection switching arrangement is shown in Fig. 4. Transmission is from main station A to main station B over the 59 regular channels and protection channels X and Y. All of the switching in the section is done at baseband (DS4) by means of the reed switches located in the span terminating transmission bays. The head-end and receive-end switch networks are shown symbolically as single-pole, double-throw switches. The operations are similar to other 400-type protection switching systems.[4]

If the bit error rate of the incoming signal exceeds 10^{-6}, a switch request is generated for a working channel or a switch inhibit order for a protection channel. When a working channel VMR requests a switch, the receiving end logic determines whether a protection channel is available. If it is, a switch order is sent to the transmitting end, decoded, and the failed working channel bridged to the selected protection channel.

The transmitting end bridge provides transmission on the working as well as the protection channel simultaneously and also removes the DS4 line drive signal from the protection channel. The absence of this uniquely identifiable signal is a notification to the receiving end logic that the bridge at the transmitting end has been made. A receive end transfer is then made from the regular to the protection channel.

When the working channel again becomes good, the receiving end switch is restored to its normal state and a bridge release order is sent to the transmitting end. This reinserts the line drive signal on the pro-

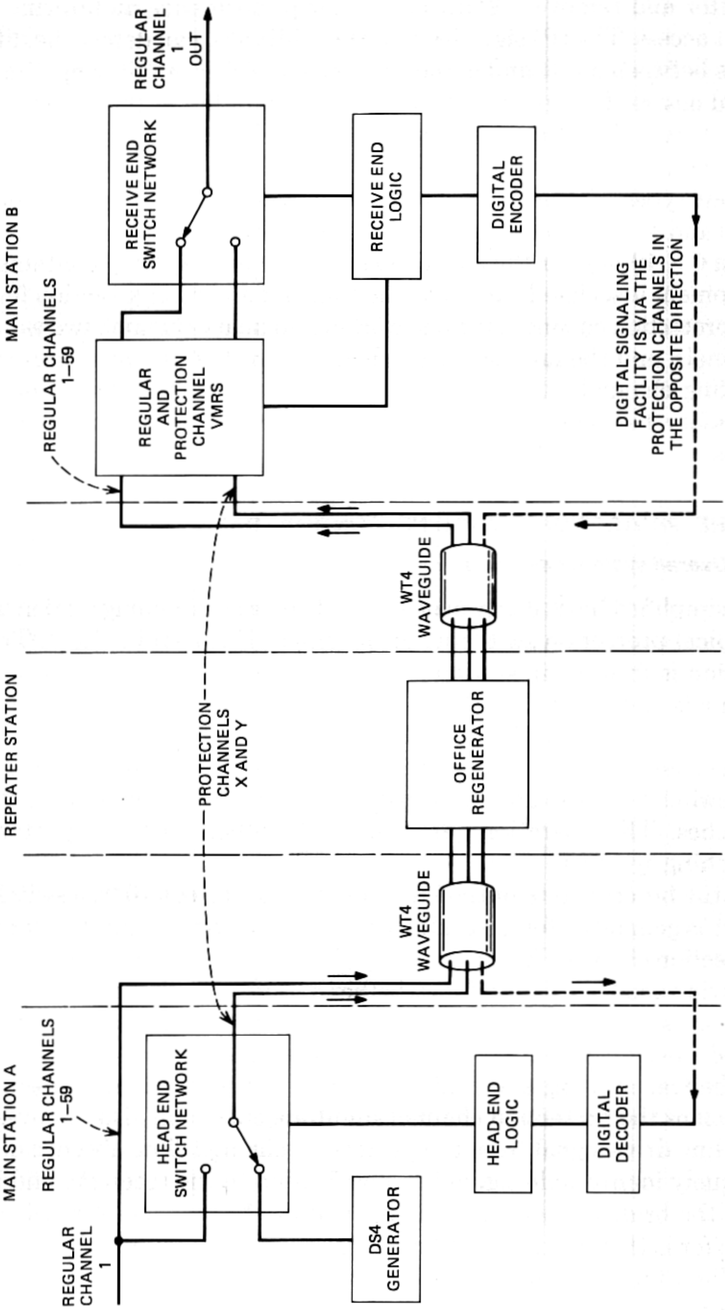

Fig. 4—Switching section—simplified block diagram.

tection channel and returns the system to its quiescent state. If the protection channels are accessed for use as additional service-carrying channels and such access service on protection channel X fails, an access switch request to protection channel Y is generated.

An actual operating test is the only effective way of checking for "quiet" failures. Once every 30 minutes, or on request, the 400A exerciser automatically tests all of the switching logic at both ends of the system and the signaling channel by a test sequence which includes head-end bridges from every channel to both protection channels. Operation of the receiving end switch is inhibited to prevent unnecessary transmission hits.

3.2 Signaling

The 400D signaling equipment is highly reliable since each switch order consists of a two-out-of-six codeword as well as three station address bits and a parity bit. Each station along the route is assigned a station address and within a station each channel is assigned a slot position in the bay. This switching topology is used with or without the add/drop feature. If the receiving end logic does not obtain verification that a switch operation is completed within a certain time interval, a switch order is originated to the second protection channel. If the second protection channel is not available, a service fail alarm is generated. Similarly, if an order to take down a switch is not carried out in the required time interval, the receiving end switch is held-operated and maintenance personnel are alerted. Any abnormal sequence of events, regardless of its origin, is processed, identified and translated to a warning to the maintenance personnel.

3.3 Manual control and alarms

Transmission through the WT4 system may be controlled by the operating personnel directly by operating the manual switch controls which are located at the receive end only. Manual control is used to set up access to the protection lines and to induce or lock-out switching as part of normal maintenance. An additional form of manual control independent of the logic operations is also used. It is called forced switching and places the transmit and receive switches under direct control of the operator. This is useful if the system malfunctions.

Since the major portion of the system control and logic is located at the receiving end of the system, most alarms are also initiated there. Forced switching is the only manual function performed at the transmitting end and there are only two alarms.

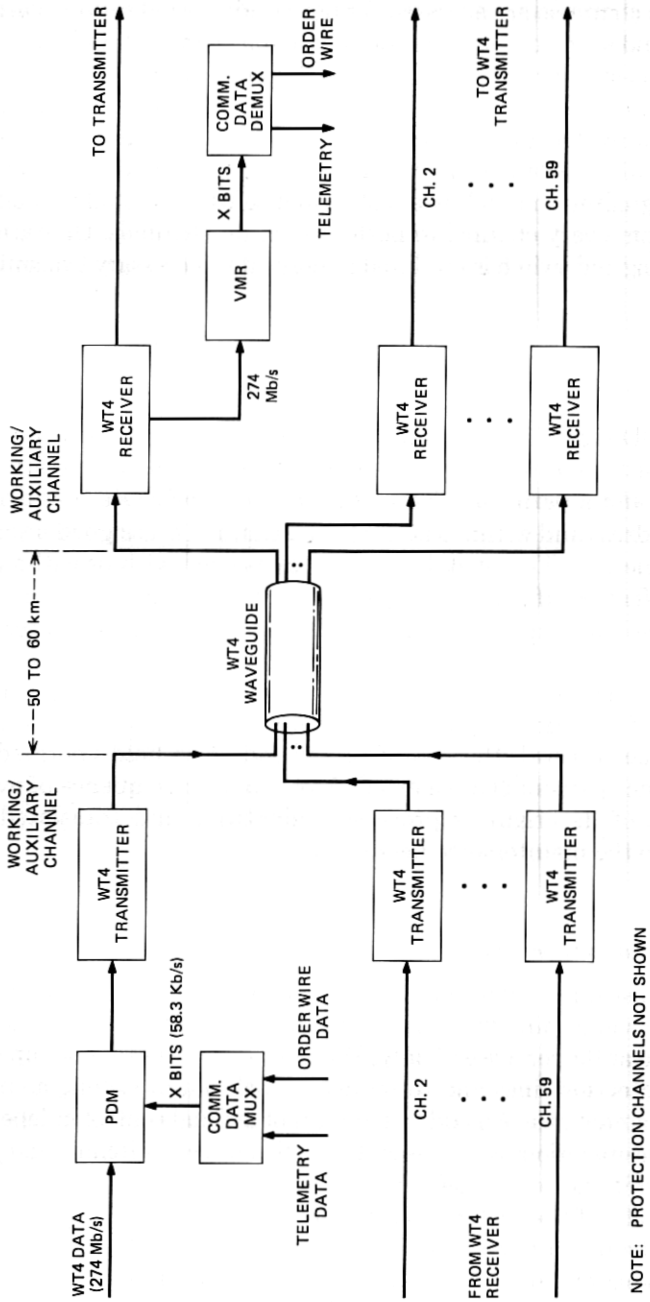

Fig. 5—Auxiliary communication via waveguide.

IV. THE AUXILIARY COMMUNICATION AND FAULT LOCATING BAYS

4.1 Telemetry and order-wire needs

WT4 electronics, waveguide pressurization equipment, power plant and converters, span terminating and protection equipments, building air conditioning and security must all be monitored and controlled by telemetry. Definite sequences of status polling and switch actions for fault locating and alternate telemetry access present further demands. All these functions can best be handled by a computerized control system such as SCOTS[5] (Surveillance and Control of Transmission Systems). The order-wire system interconnects all the WT4 stations in one maintenance area as well as the SCOTS central. Figure 5 illustrates the transmission of telemetry and order-wire data through one hop of WT4 waveguide. Every hop of the working/auxiliary channel is equipped this way. The two data signals are first time-division multiplexed in the CDM (Communication Data Multiplexer) to form the 58.3 kb/s X-bit data stream. At the receiving end of the hop, the high-speed data is amplified and detected by the WT4 receiver and sent to the VMR circuit, which extracts the X bits. Finally, the CDD (Communication Data Demultiplexer) separates the telemetry and the order wire circuits.

4.2 Telemetry network configuration

A typical WT4 telemetry network using E2A[6] remotes and a SCOTS central is shown in Fig. 6. The computerized SCOTS central interfaces with point-to-point private data lines to two WT4 protection switching stations via data sets. At the protection switching station, the received E2A format is converted to bits suitable for transmission via the X-bit format. The bits are received at all succeeding stations, converted back to the original E2A format, and sent to the local remote. The response data back to the central from the remotes go through the reverse process.

The central has the ability to poll the remotes cyclically for status or alarm indications and, when necessary, remotely operate switch relays.

4.3 Double access capability

The two data networks shown in Fig. 6 report to the same central computer, but are otherwise independent. The isolation switch at protection switching station B isolates one network from the other. Two remotes, however, are located at protection switching station B, and each is able to operate the isolation switch.

In the event of a transmission problem in either of the two networks, the computer reassigns the remotes beyond the trouble spot to the other

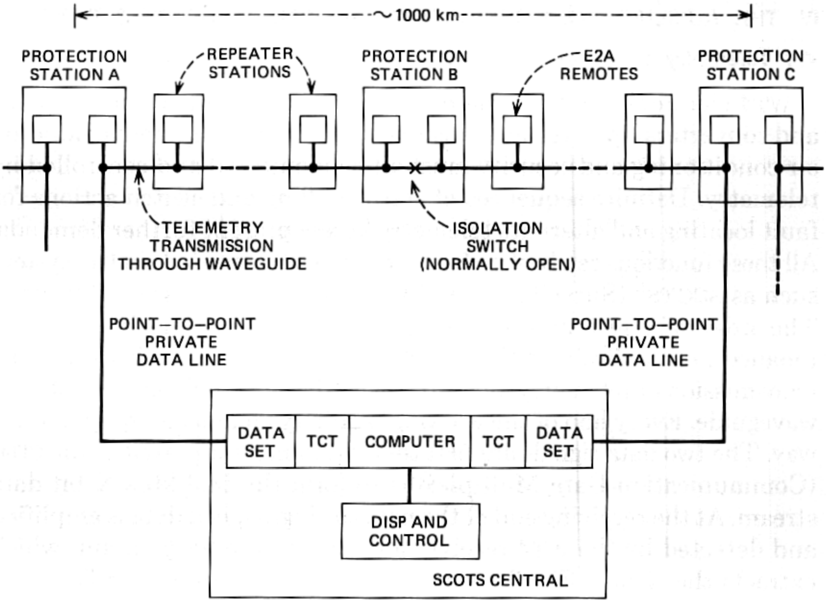

Fig. 6—Double access configuration.

network and sends a command through the trouble-free network to close the isolation switch. The closure of the isolation switch reestablishes communication between the central and the cut-off remotes.

4.4 Encoding of E2A signal

E2A uses 202T data sets which transmit asynchronous 1.2 kb/s, binary FSK (Frequency Shift Keying) signals with one tone for binary ones, another tone for binary zero, and no tone for idle.

The X bits have a transmission rate of 58.3 kb/s, but at least half of this capacity has to be allocated to order wire transmission. A maximum of 29.15 kb/s can be used for data bits. To provide the three types of data set line signals, and to avoid having to synchronize to a 1200 Hz clock, the following encoding rules were generated:

E2A data (1.2 kb/s)	WT4 data bits (≈ 29 kb/s)
1	1111 . . .
0	0101 . . .
Idle	0000 . . .

The data-bits are, therefore, a pseudo FSK signal with bit frequencies at approximately 29 KHz and 14.5 KHz.

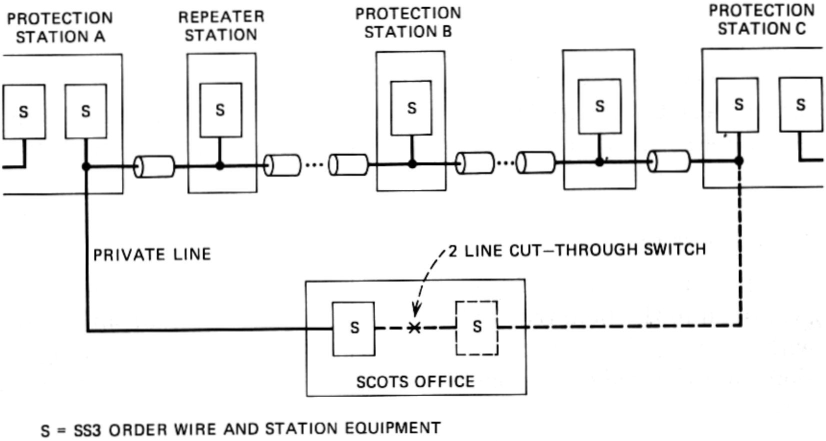

Fig. 7—Order-wire network with double access.

4.5 WT4 order-wire circuit

The WT4 order-wire network is configured in a manner similar to the telemetry network, see Fig. 7. Four-wire private lines connect the SCOTS office and the protection switching stations. Recently developed SS3 order-wire equipment with *TOUCH-TONE®* dialing is located in each station for signaling purposes. The dotted line in Fig. 7 is optional; it provides the ability to access all stations from the SCOTS office in the event of a single auxiliary network transmission failure. The two-line cut-through switch at the SCOTS office also enables stations to talk to each other despite a network cut. The cut-through switch is a special feature of the SS3 system and can be operated by dialing a special number.

Adaptive delta modulation is used to encode the voice signal into 29.15 kb/s digits. The quality of the voice signal is degraded each time it undergoes coding, and to avoid this the signal is sent through the delta modulator only when the local telephone handset is off-hook.

4.6 Repeater fault-locating bays

An important function of the telemetry in regular repeater stations is the locating of a faulty repeater.

From protection switching status information, the SCOTS central knows when a channel has failed; however, it does not know which repeater in the span has failed. It therefore issues an order to all repeater fault-locating bays to connect their Violation Monitor (VM) to the affected channel through a remotely controlled 124:1 switch array. The error rate of each repeater is reported. From this error rate profile, the central can deduce that the fault must have occurred either in the first receiver showing poor performance or, possibly, in the preceding transmitter. Maintenance personnel is sent to perform the manual patch which frees these two failure candidates for repair. The fault locating bay can also be operated locally by the maintenance personnel to check the performance of the patch units and, later, the replacement units prior to restoring of the protection switch.

V. CONCLUSION

Representative assemblies of all the span-terminating bays were evaluated in the field trial[7] which was arranged as a "hairpin" system with Netcong "East" and Netcong "West" as protection switching stations and the trailer in Long Valley as an intermediate repeater station.

Two 2×3 span-terminating transmission bays were assembled and partially equipped. The PDM and VMR were identical to those used in the T4M system, but preceded by cards to align the data and clock inputs.

The protection switching control bays included primarily existing 400-type (400A and 400D) protection switching equipment and some newly designed interface circuitry. However, operationally, the system was typical of the expected final design. The system was equipped as a two-for-three system (two protection channels for three regular working channels) and although only sufficient transmission equipment for four one-way channels was available, the four channels were arranged in several different combinations in order to prove in all system criteria. The add/drop feature was not equipped on this field trial.

Four bays of auxiliary communication equipment were constructed. Two of the auxiliary communication bays were installed in the span terminating frames in the Netcong station, and one in the repeater station at Long Valley along with the fault locating bay. Implemented with double access feature for the telemetry network, the circuits in the bays were arranged according to the description given above.

The field trial results showed that all features of the span-terminating bays worked exactly as planned and the designs would be adequate to survey and maintain the WT4 system in good working order.

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