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Digital Data System:

Testing and Maintenance

By S. M. FITCH and D. L. RECHTENBAUGH

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Reliability and maintainability are important aspects of the service objectives for the Digital Data System. Consequently, maintenance planning was an essential element in the DDS development. Maintenance features provided by the system include in-service performance monitoring, protection switching, comprehensive alarms, and the means for rapid fault isolation and repair.

I. INTRODUCTION

The service objectives for the Digital Data System described in the preceding article[1] represent substantial improvements over the performance and availability of existing data services. Since the DDS exists in the present telephone plant environment, it is subjected to the same kinds of random interruptions and failures that occur in that environment. Hence, special arrangements and procedures are provided to meet the more stringent service requirements.

To meet the desired service objectives, DDS equipment at the DS-1 (1.544 Mb/s) and higher levels monitors system performance full-time, with manual or automatic switching to standby equipment in the event of a failure.* Alarms on DDS equipment alert craft personnel to system failures. Many new features in the system permit rapid sectionalization of troubles on a one-man basis and rapid identification and replacement of defective units.

Since the DDS utilizes existing carrier systems for both exchange-area and long-haul transmission, maintenance planning is compatible with present and planned carrier maintenance and restoration procedures. The reliability estimates cited in the preceding paper have, therefore, included allowances for carrier system failures and restoration.

* The subrate data multiplexer (SRDM), which operates at the DS-0 (64-kb/s) level, also provides performance monitoring and protection switching (Ref. 2).

This paper describes the overall maintenance philosophy incorporated into the design of the DDS and the administrative organizations that implement this philosophy. The trouble detection and sectionalization capability designed into the system as well as restoration and repair procedures are also described.

II. OVERALL MAINTENANCE PHILOSOPHY

The maintenance philosophy for the DDS can be divided into two distinct approaches based upon the level of the digital signal, viz., DS-1 and above and DS-0 and below.[3]

2.1 DS-1 (1.544-Mb/s signal) and above

The 1.544-Mb/s signal utilizes existing (and planned) transmission facilities for both exchange area and long-haul transmission. Maintenance and administration of these facilities for the DDS, therefore, cover existing procedures for maintaining the exchange and long-haul transmission networks. Restoration techniques normally employed to protect voice services minimize outage durations. This includes automatic protection switching of long-haul radio channels or coaxial tubes on cable systems.

Since offices in the exchange area are often unmanned and because of the large number of customers affected by a DS-1 channel failure, performance monitoring and automatic protection switching of DDS T1 carrier lines minimize the number of outages and annual outage duration. Terminal equipment carrying DS-1 level signals on both exchange and long-haul facilities provides performance monitoring and either manual or automatic protection switching. In addition to the protection switching feature, the terminal equipment generates office alarms and indications that are useful in the sectionalization and repair of equipment failures.

Briefly, then, the DS-1-level maintenance philosophy is characterized by performance monitoring and protection switching features, use of alarms for trouble sectionalization, and reliance upon existing facility maintenance arrangements.

2.2 DS-0 (64-kb/s signal) and below

At the DS-0 and lower data rates, equipment is modularized on a customer-circuit basis so that a failure usually affects only one customer. Therefore, redundancy and/or protection switching are not provided except in the SRDM, common power supplies, and some common timing distribution circuits where a failure affects many customers. Instead, the ability to alert the customer to service outages and the means for rapid one-man sectionalization of failures are provided.

Testing a customer channel can be accomplished on both an in-service or out-of-service basis, depending upon the type of trouble.

In summary, the maintenance philosophy for DS-0 and lower-level signals is characterized by a high degree of test access and sectionalization capability.

III. ADMINISTRATIVE RESPONSIBILITIES

Since DDS service uses some of the same transmission systems used for voice service and encompasses customer stations in widely separated locations, a number of different organizations have administrative responsibilities for service maintenance. Figure 1 depicts typical equipment configurations* for several offices providing DDS service in a metropolitan area. The figure also indicates the areas of responsibility exercised by the following three administrative organizations charged with maintenance of DDS service:

(*i*) Serving test center (STC)—Responsible for all customer trouble reports and sectionalization of troubles at DS-0 and lower data rates.

(*ii*) T-carrier restoration control center (TRCC)—Responsible for restoration activities on DS-1 level channels in the metropolitan area.

(*iii*) Regional operations control center (ROCC)—Responsible for restoration activities on long-haul facilities.

The responsibilities of each of these organizations as they relate to DDS maintenance are covered in more detail in the following sections.

3.1 Serving test center

The STC is responsible for customer service on an end-to-end, individual-circuit basis. Every DDS circuit appears in at least one STC located at a hub office. From the STC, DS-0 level signals may be transmitted, received, or monitored on any customer circuit in either direction of transmission. The primary maintenance activities of an STC are receipt of customer trouble reports, circuit testing, restoral of service outages, and various administrative functions.

The STC performs three types of circuit tests: performance evaluation, in-service monitoring, and fault localization. Performance evaluation involves measuring the error performance of a circuit and is

* Most equipment shown in Fig. 1 has been described in detail in other papers in this issue (Refs. 2, 4, and 5). Brief descriptions of those units not described elsewhere appear in Appendix A of the paper entitled "System Overview."

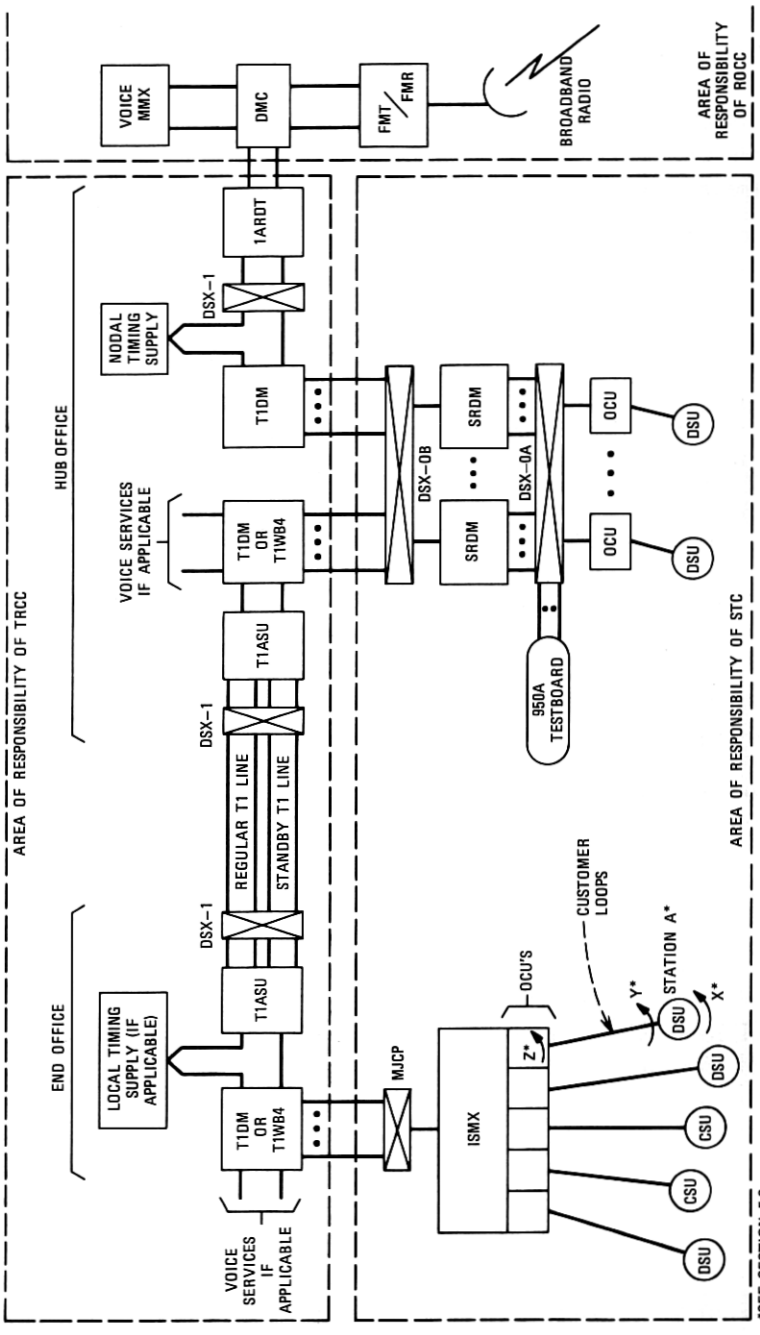

Fig. 1—Administrative responsibilities.

normally done before a circuit is turned over to a customer initially, after a service rearrangement, or after a service outage has been restored. In-service monitoring of an individual circuit is done on a byte-by-byte basis. The existence of certain repeated control bytes indicates specific circuit failures, thus aiding in the recognition and localization of failures. Fault localization permits one man to isolate faults to the network or to the station apparatus or loop facilities in either his local metropolitan area or a distant metropolitan area. These tests can be made on either two-point or multipoint circuits. Fault location within the network usually requires the cooperative effort of other STC or central office craft forces.

Customer service is restored after a fault has been isolated. Restoration activities include referral of trouble indications to other organizations such as the TRCC or ROCC, requests for dispatch of central office or station craft forces, and patching at the DS-0 level. Other functions include the responsibility for coordinating these activities and verifying that a circuit is again operational.

The administrative functions of an STC include administration of the DS-0 cross-connect, maintenance of individual customer records, and summary and reporting of DDS service results.

3.2 T-carrier restoration control center

The growth of T-carrier systems in many metropolitan areas has resulted in the implementation of administrative centers known as TRCCs. These centers have overall responsibility for administering the restoration of T-carrier facilities within a metropolitan area. Where possible, the restoration is on a terminal-to-terminal basis using "backbone" lines (maintenance spare lines) to minimize outage time. Sectionalization and fault-locating activities are the responsibility of the central office craft forces.

Since the T1 lines carrying DDS service are protected from most service interruptions by the T1ASU, the main function of the TRCC with respect to DDS service is to restore the failed line so as to minimize the interval during which the channel is being operated in an unprotected mode.

In the event of a service interruption, the TRCC advises the STC of the status of T1 systems carrying DDS service so that customers may be properly appraised of the situation. The TRCC also ensures that non-service-affecting DDS equipment failures are repaired promptly to minimize the duration of the unprotected mode of operation. This latter function will become increasingly important with the implementation of centralized alarm reporting arrangements and the resultant uncovering of many offices.

Alarms generated by the 1A radio digital terminal[6] can be used by the TRCC in analysis of terminal failure indications. In addition to alerting the central office craft personnel of 1ARDT equipment failures and the need for initiation of a switch to the spare terminal, these alarms can alert the TRCC of long-haul failures, thereby aiding in the interpretation of sympathetic alarms* generated within the metropolitan area. In the absence of a TRCC, these functions are performed by a terminal office.

3.3 Regional operations control center

Present long-haul broadband transmission facilities are administered by regional operations control centers. The primary function of these centers is to select and control the execution of plans to restore broadband facility failures. These centers are well established and interact with the STC and TRCC to provide information on the status of broadband channels carrying DDS service.

IV. CUSTOMER SERVICE

Customer service in the DDS is characterized by the service objectives described in Ref. 1. These service objectives are:

(*i*) Quality—Average of at least 99.5-percent error-free seconds.
(*ii*) Availability—Long-term average of at least 99.96-percent channel availability.

To achieve these objectives, the DDS provides in-service monitoring and either automatic or manual protection switching, equipment alarms, and rapid isolation and restoral of customer-reported troubles.

4.1 Service protection

As mentioned in Sections 2.1 and 2.2, the ability to protect DDS channels from incurring appreciable outage time is provided for all signals at the DS-1 level and above and usually for those DS-0 level signals that affect many customers.

4.1.1 Equipment

The three DDS equipments that provide in-service monitoring and automatic protection switching are the T1 data multiplexer (T1DM), the T1 data-voice multiplexer (T1WB4), and the SRDM. In each case, a performance monitor continuously verifies the operation of the equipment.[2] In the event of a detected fault, a protection spare is

* Sympathetic alarms are simultaneous alarms generated when a failure is detected in other equipment on the same circuit as the failed equipment.

automatically switched in place of the faulty unit and an office alarm is generated. The level of performance that results from fault detection and automatic protection switching is expected to satisfy the overall performance objectives cited above.

The 1ARDT provides a DS-1 data channel on existing radio systems for DDS as well as other services. It uses signal level and format monitoring to detect terminal failures and provides a manually initiated protection switching arrangement for service protection. If the 1ARDT location is not manned, the alarms and protection switching controls can be transmitted to a remote manned location.

4.1.2 Facility protection

Long-haul facilities carrying DDS service utilize the same protection-switching arrangements as are provided for voice services. Specifically, broadband radio systems provide the capability of automatically switching to a protection channel in the event of valid signal loss or fading. At the ends of each message unit radio link, automatic switching arrangements are provided to protect against failure of the wire line entrance link or FM transmitter or receiver. Digital Data System channels utilize these same protection switching arrangements. Similar arrangements are inherent in the design of all higher-level transmission systems.

In the exchange area, automatic protection switching arrangements are not normally provided for voice services. Therefore, a protected T1 line arrangement has been developed for the DDS. This arrangement provides a dedicated T1 line as a standby for each DDS line on a terminal-to-terminal basis. The lines are double-fed at the transmit terminal and switched at the receive terminal. Bipolar violations and pulse absences are the criteria for determining whether the regular and standby lines are working satisfactorily. Office alarms are generated in a failure of either or both T1 lines.

4.2 Trouble detection

Digital Data System central office equipment provides alarm information for detecting and sectionalizing failures. This information is presented locally within the office in the form of major and minor audible alarms as well as visual aisle pilots and status indications on the failed equipment. The major audible alarm is used only for a service outage and indicates to the craft forces that prompt corrective action is required. The minor audible alarm indicates that a failure has occurred that places the service in jeopardy of an outage. The visual aisle pilots locate the equipment generating the alarm, while the status indications denote the nature of the failure.

DS-1 level equipment (and the SRDM at the DS-0 level) also provides a set of status indications for transmission to a central location such as the TRCC. These indications can be used to rapidly sectionalize troubles from the central location, especially when failures occur in unattended offices.

Because of the large number of customer circuits affected by a DS-1 channel failure, extensive trouble detection capabilities are provided in DS-1 level equipment. Central office craft forces are alerted via office alarms to such failures as loss of input signal, clock or power failure, or high error rate. As a result, those troubles reported by the customer to the STC that have not already been brought to the attention of the central office craft forces normally relate to faults of individual DS-0 channels, loop facilities, or station apparatus.

V. TROUBLE ISOLATION

5.1 Alarm analysis

As described above, DS-1-level signal failures are detected and sectionalized by analysis of the office alarms. In nonservice-affecting failures, the alarms are confined to the failed equipment or that unit which detected the failure condition. These alarms are readily identified and do not require extensive analysis. However, in a service-affecting failure, sympathetic alarms may be generated. These alarms must be analyzed to determine the nature and location of the failure. As an example, Fig. 2 depicts a typical exchange area DS-1 channel between two offices. As shown, the channel consists of DDS equipment (T1DMs and T1ASUs) located in the terminal offices (A and Z) and interconnected by T1 lines. The regular and standby T1 lines are part of the protection switching arrangement provided by the T1ASU and usually employ diverse routing to ensure service protection. The restoration backbone line is a manually patched T1 line which appears at the DS-1 cross-connect (DSX-1) in each terminal office. It is administered by the TRCC and is used to temporarily replace a failed T1 line. The backbone line normally restores T-carrier voice services and is not dedicated to the DDS. The T1 lines pass through a number of intermediate offices (B through J) and are available at office repeater bays for testing during trouble sectionalization. However, signal failure alarms are only generated at the terminal offices. Figure 3 is an example of the alarm analysis procedures used by craft forces in a terminal office to localize troubles and restore service on a DS-1 channel such as that shown in Fig. 2. As shown in the figure, certain failures, such as a DS-1 signal failure, result in alarms from both the T1DM and the T1ASU, while other types of failures cause alarms in only one of the

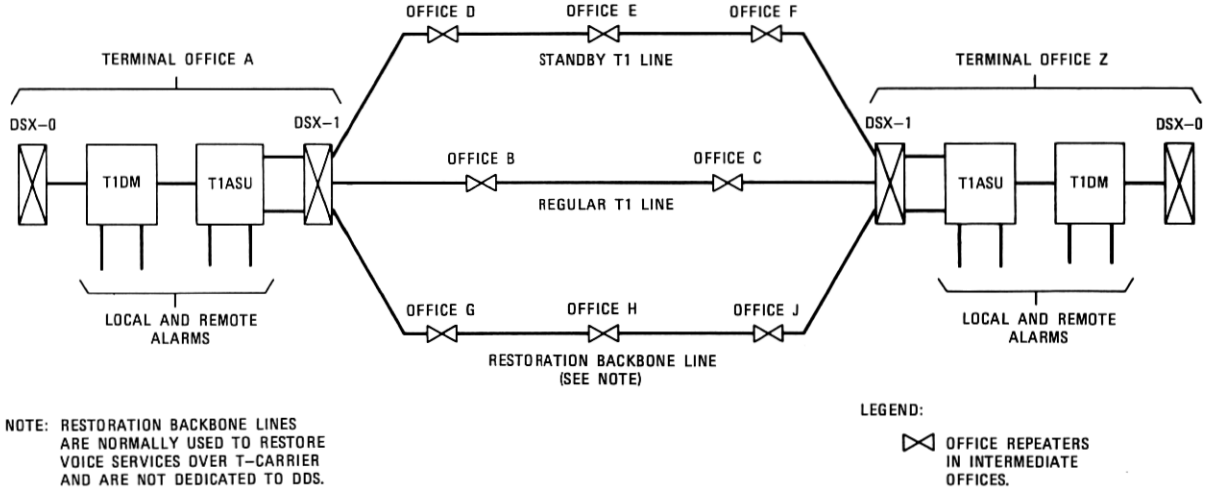

Fig. 2—A typical exchange area DS-1 channel.

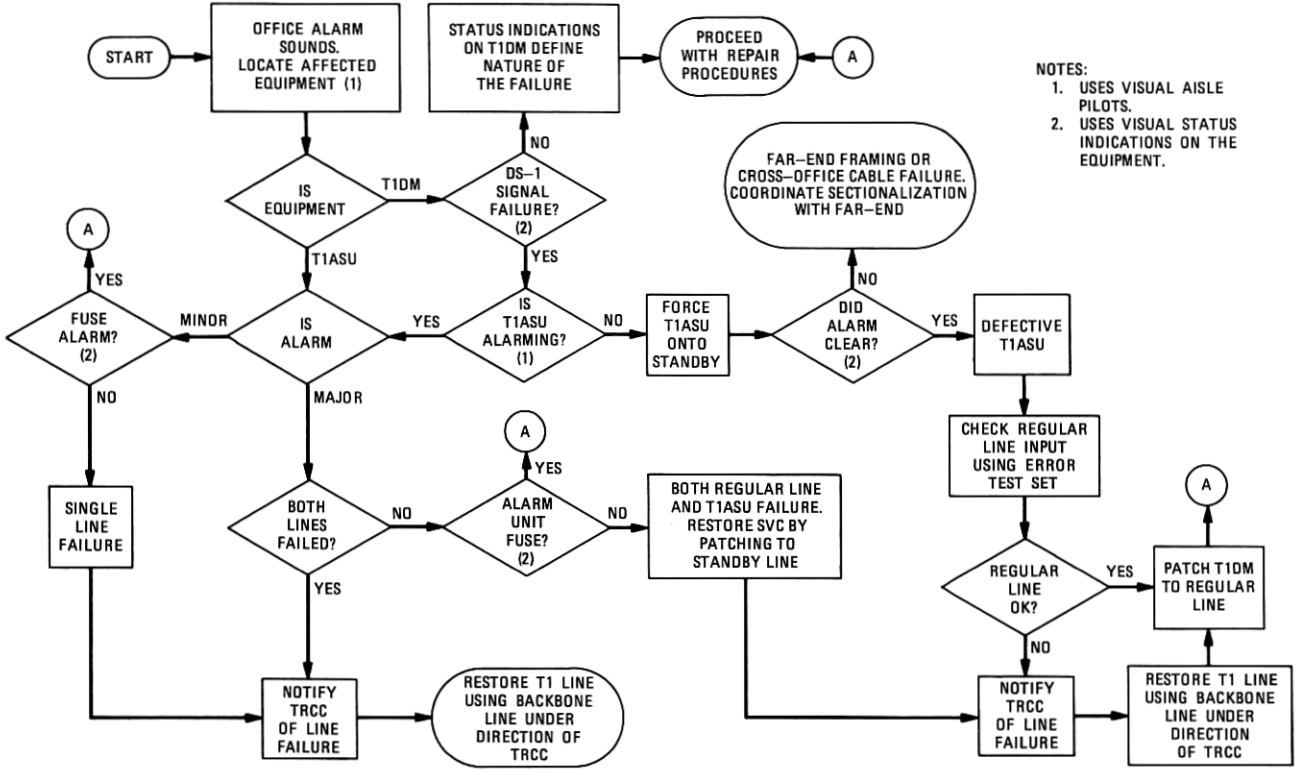

Fig. 3—DDS alarm analysis procedures.

units. In addition, some types of failures require coordination with the distant terminal office or the TRCC. It should be noted that the sectionalization procedures require minimal circuit testing to sectionalize failures to the defective unit and effect restoration. The alarm analysis described above can be conducted either by the local office craft forces using the office alarms or by a central location, such as the TRCC, using status indications at a remote manned location. Similar procedures are required to sectionalize other possible alarm conditions generated by DS-1-level equipment.

5.2 Customer-reported troubles

As noted earlier, all customer trouble reports are received by an STC. An STC is equipped with 950A testboards, supplemental jack bays, and a DS-0 cross-connect (DSX-0), each of which is specifically designed for use in the DDS. The 950A testboard and supplemental jack bays provide test access to individual customer circuits, while the DSX-0 permits interconnection of DDS equipment at the 64-kb/s level. Each testboard contains two newly designed data test sets, the digital transmitter and the digital receiver. The transmitter operates at the DS-0 single channel level and the receiver operates at both the DS-0 single and multiplexed channel level. In addition to their application in the STC, these test sets are used as portable units in DDS equipment areas.

When a customer trouble report is received at an STC, the customer circuit is monitored in both directions of transmission on an in-service basis for specific repeated control bytes. The existence of these control bytes indicates that certain fault conditions are present within the network. An example is the absence of a DS-1 signal on the long-haul portion of the circuit. This fault results in the repeated generation of a fixed control byte by the receiving T1DM. Whenever repeated control bytes suggest a network fault, further testing is required to isolate the fault. Between STCs, testing of DS-0 signals requires the cooperative efforts of craft forces from each STC. Within the metropolitan area, DS-0 level testing usually involves signal tracing and the cooperative efforts of STC and central office craft forces. The digital transmitter and receiver are used as portable units at the DDS equipment frames for this purpose. In local offices, jack and connector panels provide jack access in testing (as well as the interconnection of DDS equipment).[7] In addition, all input-output signals at the 64-kb/s level on all DDS equipment are available on individual circuit-pack face plates.

If no indication of a network failure is provided by monitoring, then loopback tests are made of the data service unit (DSU) or channel service unit (CSU) and the office channel unit (OCU).[4] The STC can remotely test these units by transmitting alternate loopback control

bytes and pseudo-random data. During loopback, data received from the STC are retransmitted back to the STC and error performance measurements are made. The tests can be made for every station on a customer circuit, whether located in a local or distant city or on a two-point or multipoint circuit. On a multipoint circuit, a station is selected for testing by means of the multipoint signaling unit (MSU) described later.

As an example of loopback testing and its use in fault isolation, consider station A in Fig. 1. Three loopbacks are associated with this station, one at the DSU-customer interface, one at the loop-DSU interface, and one at the OCU-loop interface. These are labeled X, Y, and Z, respectively, on Fig. 1 and are called DSU loopback, channel loopback, and OCU loopback. First, DSU loopback is attempted, followed by error performance measurements. If these tests are successful, then the customer circuit between the customer interface and the STC is satisfactory. If these tests are unsuccessful, then channel loopback is attempted. If these tests are successful and a preceding DSU loopback is unsuccessful, then a fault exists in the DSU. If channel loopback is unsuccessful, then OCU loopback is attempted next. If these tests are successful and a preceding channel loopback is unsuccessful, then a fault exists on the loop. If these tests are unsuccessful, then a fault exists between the OCU-loop interface and the STC. By using these techniques, STC personnel can rapidly isolate a circuit trouble to the DSU (either local or distant), to the loop (either local or distant), or to the network. Similar procedures are used for CSUs.

Loopback testing for multipoint circuits[1] requires special procedures at the STC. Consider the typical multipoint circuit in Fig. 4. This circuit consists of seven stations and three multipoint junction units (MJUs). The MJUs are located only in hub offices where all input/output ports of the MJU appear at a 950A testboard. It is apparent that, if a loopback command were transmitted downstream from the St. Louis STC on the main channel (the unnumbered input/output port of the MJU), all stations B through G would loop back simultaneously. The result would be garbled data at the digital receiver of the St. Louis STC. Consequently, before loopback testing on a multipoint circuit can begin, a specific station must be selected for testing. Using the multipoint signaling unit, an STC selects one branch (a numbered input/output port) of each downstream MJU for data transmission and blocks all other branches. The selection process involves a prescribed control dialogue in the DS-0 channel between the MSU and the MJUs. For example, an MSU in St. Louis can select branches one, four, and two in St. Louis, Chicago, and Boston, respectively, to set up an equivalent two-point circuit from the MSU to station G. Stations B through F

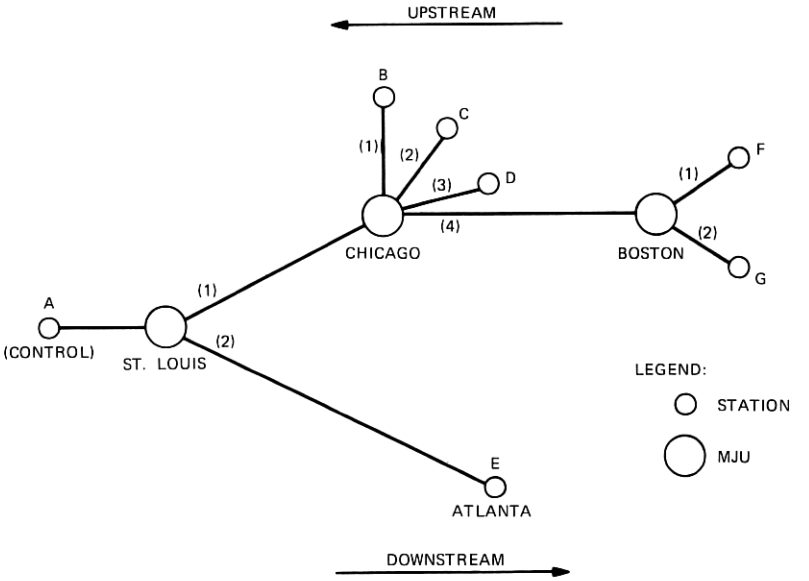

Fig. 4—A typical multipoint circuit.

are blocked and cannot transmit data to or receive data from the MSU. Now loopback tests for station G can be made as described above. Each station in turn can be tested in a similar manner.

If the control dialogue between an MSU and any MJU of a multipoint circuit fails, the affected STCs must determine whether the DS-0 channel between STCs or the MJU itself has failed.

VI. SERVICE RESTORATION

A service outage in DDS is restored by either of two techniques, depending upon the type of fault. The first is to manually patch around the fault and the second is to replace defective units.

6.1 Below DS-0

Station apparatus (DSUs or CSUs), loop facilities, and OCUs all operate below the DS-0 level. As described above, a fault can be isolated to each of these units from the STC. Once isolated, the method of restoration is different for each.

Station apparatus is restored by dispatching craft forces to the customer's premises. Service is usually restored by replacing the DSU or the CSU.

A loop facility is usually restored by isolating the fault to a cable segment with convenient access at each end. Restoration is then

accomplished by changing to a spare cable pair if available. If a spare is not available, the fault must be repaired. Since the DDS uses the standard loop plant, existing fault location and repair procedures are normally followed.

An OCU is restored by replacing defective circuit packs, power supplies, or fuses. The defective unit is isolated through analysis of bay alarms and use of portable test sets.

6.2 DS-0

Integral subrate data multiplexers (ISMXs),[4] SRDMs and associated performance monitors, and MJUs all operate at the DS-0 level. Restoration of this equipment again involves replacement of circuit packs, power supplies, or fuses. Defective units are isolated by the craft forces through the analysis of bay alarms, the use of the portable test sets, and, in the case of the SRDM, status indications. The status indications are a combination of indicator light-emitting diodes (LEDs) and LED digit readouts that specifically pinpoint defective units.[2]

6.3 DS-1 and above

As indicated in Section 2.1, service outages on DS-1 and higher level channels are normally encompassed by the procedures used to restore existing carrier systems. In the exchange area, the TRCC is notified of any T1 line outages by the terminal office and coordinates the facility restoration activities. Restoration of broadband facilities is coordinated by the ROCC.

As high-capacity routes between offices and cities in the DDS network are established, they will utilize higher-level transmission systems and will make restoration of individual DS-1 channels feasible by alternate routing by patching at the DSX-1. This alternative will, however, only be used when restoration cannot be effected using the normal transmission facility restoration plan.

DS-1 level terminal equipment (T1DM, T1WB4, T1ASU, 1ARDT, local timing supply, and nodal timing supply) is equipped with alarms, status indications, and local test features that enable craft personnel to isolate failures to a particular unit. Restoration is effected by replacing the defective circuit pack, power supply, or fuse. Occasionally, a defective T1ASU must be bypassed by manual patching to restore service while the unit is repaired.

VII. REPAIR

The repair philosophy for all DDS equipment in the central office is replacement of defective units such as circuit packs, power supplies,

or fuses. The defective units themselves are usually repaired at a Western Electric Company service center. Other failures such as faults in intraoffice cabling or connectors must, of course, be repaired on site. Station apparatus (DSUs and CSUs) are normally returned to a service center for repair.

Equipment and facilities not designed specifically for the DDS and shared with other services are repaired using existing repair procedures. Examples of these are customer loops, T1 lines, and radio systems. Spare station apparatus, circuit packs, and power supplies are required in sufficient quantities to satisfy DDS service objectives. In the case of unprotected units, service restoration depends upon rapid repair so that spare units are normally available at all central office locations. In the case of protected equipment, spare units are available in quantities sufficient to minimize the unprotected mode of operation and may be kept at a centralized location.

VIII. SUMMARY

Service objectives for the DDS place special emphasis upon the means for adequately maintaining the system. Throughout the development of the DDS, special consideration was given to the incorporation of maintenance features that aid in achieving the overall service goals.

To reduce the probability of a service outage, full-time performance monitoring and either manual or automatic protection switching arrangements are provided on the SRDM and on all equipment operating at the DS-1 level and above. Alarms are provided to alert central office craft personnel so that repair can be rapidly effected. In a service outage, these alarms, together with appropriate sectionalization procedures, permit rapid restoration of the service. The restoration procedures for facility failures are normally those used for voiceband services.

Below the DS-1 level, service outages are usually detected and reported by the affected customer. Provisions have been made in the DDS equipment design to enable the serving test center to rapidly sectionalize equipment and loop failures on a one-man basis. Restoration of service is then effected by isolation and replacement of the defective units.

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