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TECHNICAL REPORT

DATA NETWORK REFEREE (DNR)

CONCEPT REPORT

SWITCHING AND CONTROL SYSTEMS BRANCH
1842 ELECTRONICS ENGINEERING GROUP (AFCS)
SCOTT AFB, ILLINOIS 62225

26 MAY 1978

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A concept is presented for monitoring, detecting, and identifying faults and subsystem failures, on the functional level, in Data Communications Networks. A brief review is included of the operating conditions of some existing data comm systems.

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DIVISION CHIEF: Z. J. Bara

ZYGMUND J. BARA

BRANCH CHIEF: Harvey A. Bayless

HARVEY A. BAYLESS

PROJECT ENGINEER: John F. Hynes

JOHN F. HYNES

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JOHN F. HYNES
Project Engineer
Switching and Control
Systems Branch

SUMMARY

The purpose of this report is to discuss a concept, termed the Data Network Referee (DNR), which can provide direction for standardizing Fault Detection/Fault Isolation, and Diagnostic procedures in USAF Data Communication Networks. A basic premise of this concept is that any view of a clear distinction or well defined line of demarcation between ADP and Data Communication domains is an artificial one. It would appear that any sharp delineation faded some time ago when computer design passed from the second generation into the third generation architecture by introducing the concept of the channel controller. This statement is made to emphasize the thought that fault detection and diagnostic procedures must include all aspects of the system which has been designed to formulate and transmit data (no boundaries).

The DNR concept employs the tools of both hardware and software, with signals being monitored at each major node of a network by a Nodal Control Unit (NCU). These NCUs use a microprocessor to monitor either the data signals being transmitted over the network or a set of standard test signals which are generated by the Terminal Interface Units (TIU). The communication system operational data that is collected by the NCUs is analyzed and summarized by a Minicomputer System called Oracle.

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DATA NETWORK REFEREE (DNR)
CONCEPT REPORT

1. BACKGROUND.

1.1 INTRODUCTION. This technical report is concerned with the subject of management of data networks. More specifically, it is concerned with the mechanics of data network monitoring, fault isolation, and network diagnostics.

1.2 STATEMENT OF THE PROBLEM (GENERAL). Just as man himself has evolved to his present level of development, each of his concepts, his products, and his natural entrainment into integrated endeavors which have come to be known as "SYSTEMS", appear to undergo a similar evolutionary process. The history of communications systems and computer Automatic Data Processing (ADP) systems attest to the statement made above. Data processing and the requirement for data transmission lead to the communication-computer ADP complex. Data communication networks were created and began to grow in number at an exponential rate. The tools to manage these data networks were developed at a much slower rate and made their scarcity known to the System Engineer by widening the gap between that which is designed and desired, and that which is achieved. One of the primary reasons for this void has its origin, in a natural way, in the evolutionary flow of technology. The fact is that here began the intersection of many disciplines which up to this time had been separately developed each with its respective terminology, equipment, and standards. This scenario is not new; to the contrary, it is the familiar pattern of technological development.

As data networks are developed and expanded, the inverse relationship between network complexity and system reliability becomes much more evident. As the network grows in size, failures occur more frequently, and the period of time necessary for diagnosis and remedial action (time to repair) has a tendency to increase. Since one measure of system downtime is the percentage of productive time lost to failures, it becomes apparent that downtime increases as network size increases. Downtime is reduced through a concerted effort of increasing total system reliability and providing the means to achieve fast and accurate fault isolation and remedial action.

The computer ADP manager learned a long time ago that his operations required a set of systematic procedures and diagnostics. The communications engineer had established his working practices, tested by years of experience and guided by the demanding dictums of spectral purity and the limitations of bandwidth, with full knowledge of the fact that, "eternal vigilance is the price of good communications." What happens then during the synergistic mingling of these disciples? A rather superficial answer to this question is, of course, that a new entity, a new system emerges. This new system comes equipped with its own set of characteristics, its own personality, and the law of filial regression appears to make itself known in the inanimate world. Only when this new system behaves as a recalcitrant offspring do we begin to ask ourselves the proper questions.

1.3 DATA NETWORKS AND THE U.S. AIR FORCE (A Survey of some existing networks). With the aim of establishing some bounds on the data network fault isolation and diagnostic problem, as it exists in the USAF, a questionnaire was sent out to various commands. Weather nets, command and control networks, and various common-user systems were included in this survey. The object of this questionnaire was to identify the magnitude of the problem, and gather information on how existing network management tools and functions were performing their jobs of fault isolation and diagnostics. The questionnaire was organized to determine the procedures, equipments and capabilities possessed by a given network. (A copy of the questionnaire is included as Appendix A).

1.3.1 Data Network Questionnaire. Questionnaires were sent to the management of twenty-one data networks. Fifteen of these twenty-one questionnaires were returned. A list of the networks returning the questionnaire is given in Table I. One of the first requests made by the questionnaire had to do with the user's overall evaluation (in terms of satisfactory or unsatisfactory) of the data network performance. It is interesting to note that of the fifteen networks responding to the questionnaire, only two reported an overall performance evaluation of unsatisfactory.

The questionnaire reflects a wide variety of network configurations, equipments and operation procedures. These networks vary in size and have been engineered to use various combinations of bit rates, synchronization techniques, and multiplex schemes. Their topologies range from point-to-point to full fledged communication data networks. Data rates of these networks were classified as low speed (0-1200 bps), medium speed (1200-4800 bps), and high speed (4.8-19.2 Kbps). Of the fifteen responses, over 50% of the networks had multiplexed circuits. Four of these systems operate at data rates of 9600 bps or greater, with two systems going up to 19.2 Kbps. As a measure of the fault isolation and diagnostic capabilities, several questions were asked concerning fault detection, diagnostic equipment, data network performance history, and trouble-shooting procedures. Of those answering, only one had all the capabilities, and only one, again, had none of the capabilities. Diagnostic procedures appears to be the most lacking. Most of the responses indicated that the network troubleshooters worked on the basis of "experience", and they had no set course of arriving at the cause of the problems.

1.3.2 Domains and Parameters. In determining the equipments (test and measurement) to be used for fault isolation and diagnostics, it is convenient to think of the network as being divided into three domains: the data, time and frequency domains, See Fig 1.1. Each domain has a set of parameters which characterize it and which can be monitored.

TABLE I

DATA NETWORK SYSTEMS

Users Overall Evaluation of Data Network Performance

ADP-COMMUNICATION NETWORK DESIGNATOR	S	UnS	UnK*
1. AFLC Responsive Communications Network (ARC)	X		
2. Computer Resources For Engineering Simulation, Training, Education (CREATE) WPAFB, ACDSM, DPI 5802 (AFLC)	X		
3. Maintenance Analysis & Structural Integrity Information System (MASIIS) (AFLC)		X	
4. Numeric Control (NUMCON) (AFLC)	X		
5. Automatic Test Equipment (AFLC)	X		
6. Management Information & Text System (MITS) Hq. Air Force Audit Agency	X		
7. Major Command ADP Update System (ADCOM MAJCOM)	X		
8. Air Force Accounting & Finance Center Teleprocessing (AFAFC Teleprocessing)	X		
9. Military Airlift Command Integrated Management System (MACIMS) (MAC)		X	
10. Strategic Air Command Total Information Network (SATIN) (SAC)			X
11. Rome Air Development Center System (RADC)(AFSC)	X		
12. Information Central/Acquisition Management Information System (INFOCEN/AMIS)(AFSC)	X		
13. Air Force Systems Command Network (AFSC NET)	X		
14. Automated Weather Network (AWN) (CCPC)	X		
15. AFCS MAJCOM Update Computer Network	X		

* S=Satisfactory/UnS=Unsatisfactory/UnK=Unknown

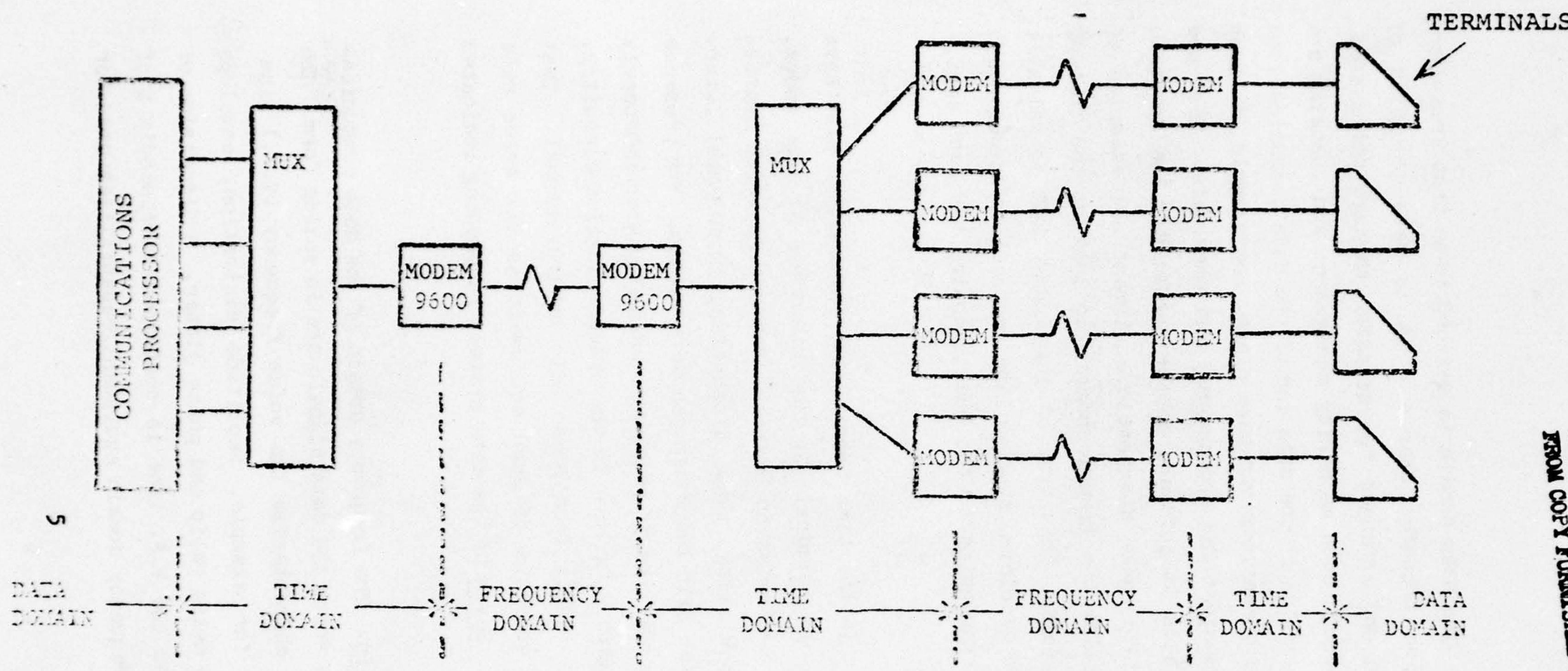


Figure 1.1 Domains of a Data Communications System

1.3.2.1 The Data Domain. The data domain is defined to be that area where the process of information transfer starts. It is here the bits of information are collected and arranged for transfer through the system. Protocol and control functions such as parity assignment and checking are performed. Software diagnostics of the data and of the data communications system are applied. These operations can take place, for example, in such devices as computers, communications processors, and terminals. Test and monitor procedures can reside in software and/or hardware. The Spectrum Datascope, Halcyon, and Intershake diagnostic equipment are examples of data domain tools which allow the troubleshooter to look at the control characters as well as the data. This type of diagnostic tool is valuable because it permits software problems, such as line protocol to be observed. Only five of the systems responding to the questionnaire had such equipment.

1.3.2.2 The Time Domain. In the time domain, the information bits have passed from the computer or terminal to the interface at the modem, multiplexer or other data transmission device. Parameters which characterize this domain are clock slips, skew, distortion, intersymbol interference and jitter associated with the modem recovery system. The presence of such phenomena indicates the kind of problems associated with improperly adjusted thresholds and possible failure in the synchronization circuitry. Of course, clock slips can result from phase bits on the channel. Test equipment for this domain consists of such equipment as bit error rate checkers and oscilloscopes. Seven of the data systems responding indicated the use of such equipment.

1.3.2.3 The Frequency Domain. The frequency domain of the data communications system is that area in which the data signals are in analog form. The parameters are those which characterize the voice frequency (V.F.) line. These parameters include, for example, amplitude distortion, envelope delay distortion, signal to noise ratio and phase jitter. A discussion of the parameters pertaining to the V.F. line is contained in Appendix B of this report. Much of the frequency domain equipment/capabilities used for testing has centered around signal comparison and loopback techniques. An excellent technique for this area is to monitor the eye-pattern of the V.F. circuit. Only four of the systems responding possessed capabilities in this area. This domain appeared to be the most lacking in capabilities.

1.4 SOME CONCLUDING REMARKS ON THE QUESTIONNAIRES. Table II summarizes network diagnostic capabilities of the data systems answering the questionnaire. To this information must be added that all of the systems reporting were dealing with at least two vendors, with some as many as six vendors. The orchestrations for "finger-pointing" are obvious. Such statements as "not knowing which vendor to call", and "vendors not assuming responsibility for an outage" were common. In addition, six of the systems had some form of encryption.

The requirement for an organized approach to the fault isolation and diagnostic problem is evident. Additional capability in the forms of hardware and software can be used by existing data systems, and a great deal of planning is needed for any future systems yet to be considered.

Although the questionnaires report trouble to some extent in every facet of the communication system, it appears that in general, networks that cover a large geographical area (CONUS wide) devote a preponderance of their trouble-shooting time to problems in the communication lines; whereas, networks that cover a relatively small area, such as a base, spend the major portion of their trouble-shooting time on communication equipment and terminals.

The dependence of data transmission error on transmission rate is again shown in the responses, with the reported error rates increasing as the transmission rate goes up. Also reported, as would be expected, was increased downtime for systems using older equipment (reliability factor), and protocol problems associated with new systems.

TABLE II

SOME NUMBERS FROM THE QUESTIONNAIRES

CAPABILITY	Number of Networks Reporting Capability
Systems with Fault Detection	9
Systems with Diagnostic Equipment/Capabilities	9
Systems with Diagnostic Equipment/Capabilities as Per Domain	
Data Domain	5
Time Domain	7
Frequency Domain	4
Systems with Performance History	6
Systems with Troubleshooting Procedures	3
Those Requesting Additional Fault Isolation and Diagnostic Capabilities	
In Terms of Hardware	11
In Terms of Software	7

Finally, lack of available equipment spares, vendor response time measured in terms of hours, little or no systematic procedures for attacking an existing problem (in some cases no detection of an existing problem), no capability for alternate routing, and a scarcity of record keeping on system outages and how they were corrected, all add to the general commentary on the status quo of many existing data communication systems.

2. DATA NETWORK REFEREE (DNR)

2.1 INTRODUCTION. This section will discuss a concept of network monitoring which has been given the name of Data Network Referee (DNR). The purpose of the DNR is to perform fault isolation and diagnostics of data communication networks. The objectives of the DNR are discussed in the following paragraphs.

2.2 OBJECTIVES OF DATA NETWORK REFEREE CONCEPT.

2.2.1 Assign Responsibility. The DNR subsystem must assign responsibility for data communication system failure. It must be able to rapidly detect a fault in any area of the data communication system and identify the failed function.

2.2.2 Enhance Availability. The DNR subsystem must enhance the data communication system availability by decreasing system down time (increase Reliability). This is done by:

a. Providing a set of systematic test and record keeping techniques.

b. Providing a means to identify potential trouble areas, and making available the control functions to introduce communication system operating options where they are available and applicable.

2.2.3 Feasibility. The DNR subsystem must be feasible both technically and economically. The system will utilize proven STATE-OF-THE-ART components and subsystems, and should be easy to use and not require an engineer to operate.

2.2.4 Compatibility. The DNR subsystem must be compatible with:

a. Common Carrier equipment and policy.

b. Established network practices and protocols.

3. THE APPROACH TO THE CONCEPT.

3.1 WHAT THE SYSTEM DOES. It was decided of necessity that a useful network monitoring system must accomplish a certain minimum number of functions. First, it must be able to monitor the performance of the network while data is being passed. Secondly, it must be able to initiate and perform tests on the network, not only when a circuit fails, but periodically as a preventative maintenance measure and as a means of determining system availability. It is a must that such a system be able to accurately and rapidly diagnose problems to an equipment level (modem, multiplexer, line, etc.) so as to permit diagnosis and eventual restoration. The system must have a means of reporting results to one or more operators via printed output and major/minor alarms. The system must also have a means of collecting and recording data in real time both as an aid for fault diagnosis and for keeping an account of system status over a period of time. Finally, a capability to analyze the recorded data over a period of time (non-real time) is required. Such a capability would be valuable for correcting persistent faults and predicting future system availability and performance requirements.

The concept was first formulated by analyzing the basic anatomy of a data communications network. Typically such a network consists of a data center, such as one or more CPUs, with many data links radiating outward, like the spokes of a wheel, to terminals or other computers at remote locations. At various places, each of these links (comprising many channels) may further branch out to form several individual links. These points of branching or concentration are called "nodes" and are usually characterized by the location of one or more multiplexers, modems, and other equipment at that point. Therefore, the basic data network anatomy can be represented by major links, nodes, and branches as shown in the generic example of Figure 3.1.

This fixed topological structure gives rise to the basic idea of monitoring the performance of the network at every node (with a "Nodal Control Unit" or "NCU") and at every entrance into the network communication system (through a "Terminal Interface Unit" or "TIU") which is located between every terminal (or computer) and the input to the communication line which is usually a modem or line driver. Thus we have the basic concept requirement that data from a terminal or computer must first pass through a TIU before entering the communications network and every node of the network must be monitored by an NCU. As required, NCUs within a data network will be able to communicate with each other.

The final aspect of the concept involves a third element called the ORACLE whose main function is to gather the recorded data from all NCUs in the system and analyze it over a period of time. Thus ORACLE from time to time is able to report on the overall condition (status) of the data communication networks it monitors. Types of analyses outputted would be statistical in nature and would include past performance, testing procedures used, areas of weakness, and predictions on future system performance and availability. If communication between the NCUs and ORACLE were lost, the NCUs and TIUs would be capable of performing the necessary fault isolation and diagnostics but with reduced long term effectiveness. Figure 3.2 illustrates the basic struture of the concept.

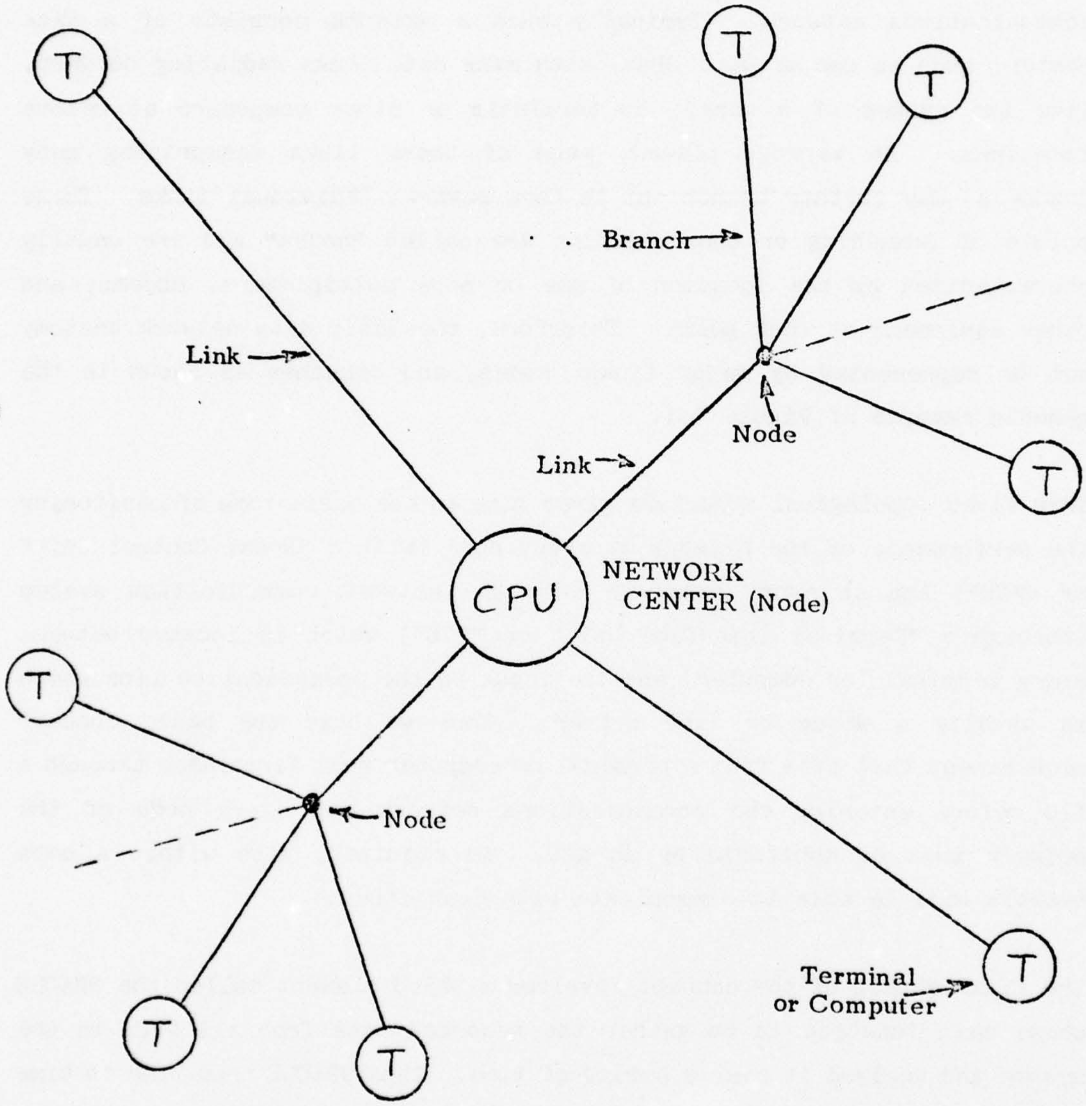


Figure 3.1 TOPOLOGY OF A TYPICAL DATA COMMUNICATIONS NETWORK

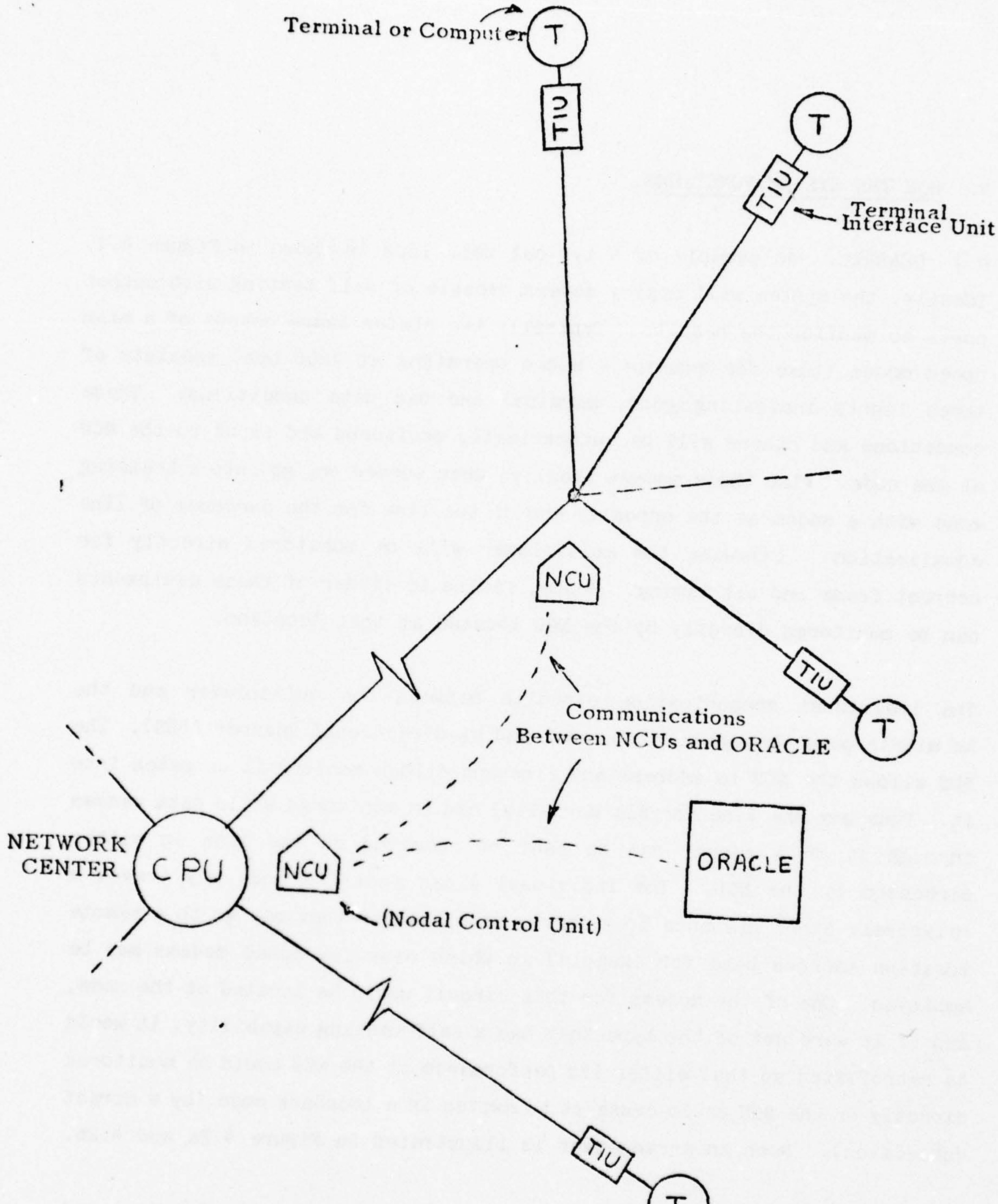


Figure 3.2 BASIC NETWORK MONITORING CONCEPT

4. HOW THE SYSTEM FUNCTIONS.

4.1 GENERAL. An example of a typical data link is shown in Figure 4.1. Ideally, the system will employ modems capable of self testing with output ports to monitor the results. Typically the status lamps output of a high speed modem (take for example a modem operating at 9600 bps) consists of three lights indicating good, marginal and bad data conditions. These conditions and others will be automatically monitored and input to the NCU at the node. Also these modems ideally, when turned on, go into a training mode with a modem at the opposite end of the line for the purposes of line equalization. Likewise the multiplexer will be monitored directly for correct frame and bit timing. Hence, faults in either of these equipments can be monitored directly by the NCU located at that location.

The individual communication circuits between the multiplexer and the terminals pass through a patch panel and bi-directional scanner (BDS). The BDS allows the NCU to address any line and either monitor it or patch into it. Thus any one line (or all serially) can be monitored while data passes through it or a signal can be sent or received on the line in either direction by the NCU. The individual lines from the node may travel a relatively short distance to a nearby terminal, or they may go to a remote location (across base for example) in which case low speed modems may be employed. One of the modems for this circuit would be located at the node, and if it were not of the type that had a self testing capability, it would be retrofitted so that either its performance at the NCU could be monitored directly or the NCU could cause it to switch in a loopback mode (by a direct connection). Such an arrangement is illustrated in Figure 4.2a and 4.2b.

Again referring to Figure 4.1, a TIU is located between the terminal and its entrance to the communications line (which may be a modem or a line driver as the case may be). The TIU will, in addition to sending and

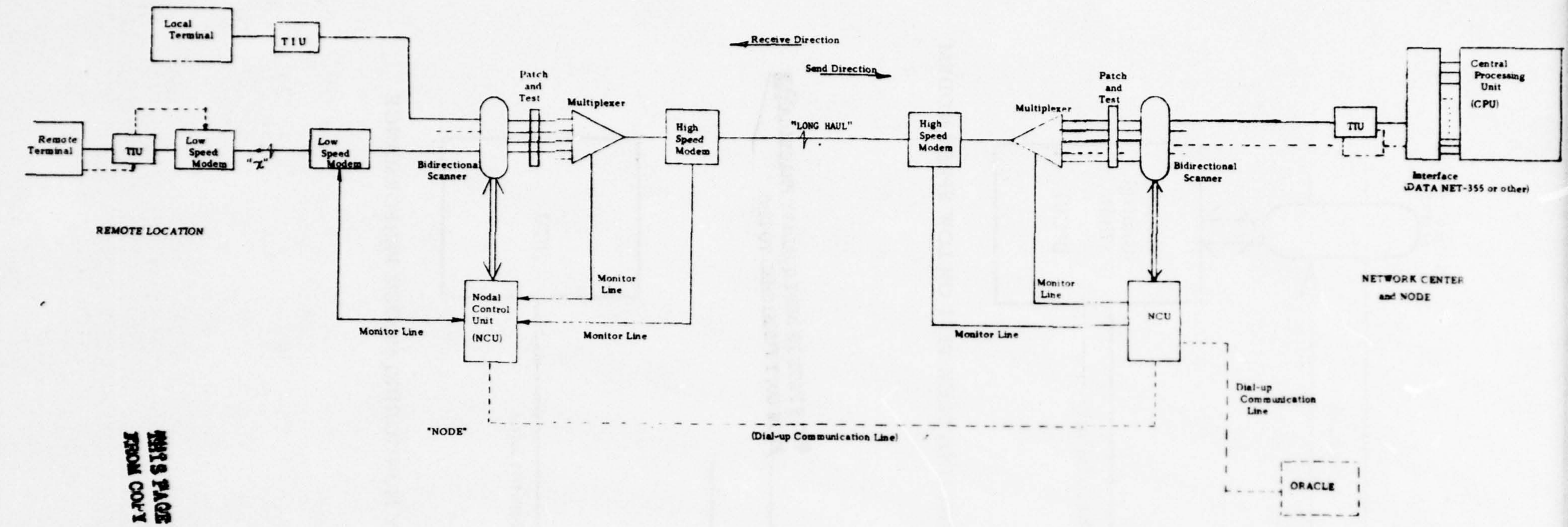


Figure 4.1 TYPICAL DATA LINK ILLUSTRATING NETWORK MONITORING CONCEPT

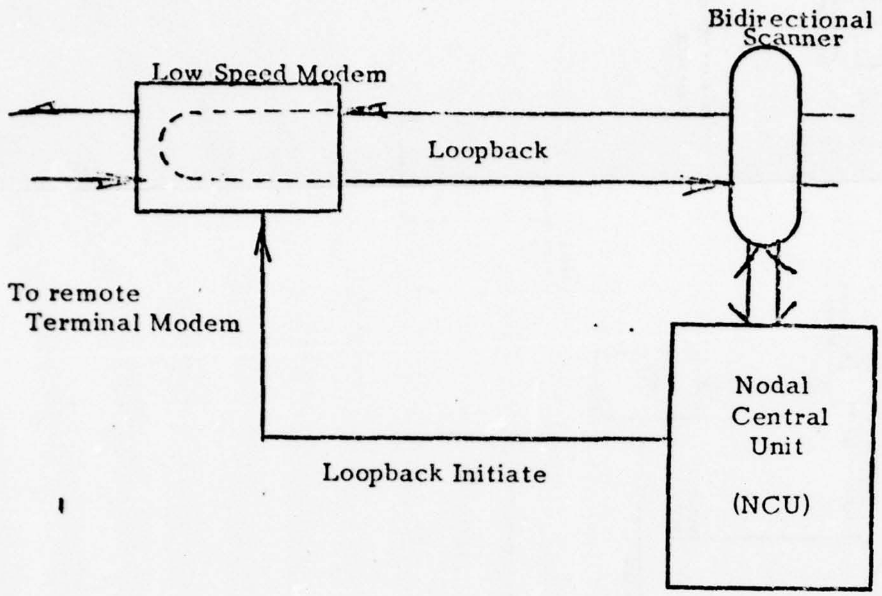


Figure 4.2a NCU INITIATING LOOPBACK TEST ON LOW SPEED MODEM

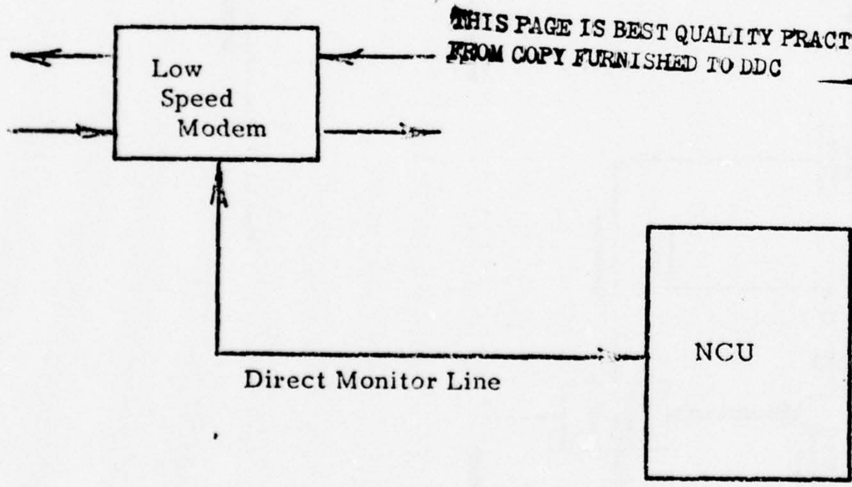


Figure 4.2b NCU DIRECTLY MONITORING MODEM PERFORMANCE

receiving test signals, be able to initially switch the modem or line driver at the terminal into a loopback mode by sending a test signal to it and evaluating its return. This simple test, illustrated in Figure 4.3, can be performed when the terminal is initially switched on and off.

One of the fundamental requirements of this concept is that the terminal's on/standby switch control the operational mode (data/test) of the TIU. When the terminal is on and sending or receiving, the data passes through the TIU unhindered. When the terminal is switched to standby mode, the TIU is automatically activated (by relay or other means) to its test mode and a fixed test pattern sent out on the line. Thus the network is constantly being exercised either in the data or the test mode. Lack of any signal is an indication of a circuit fault.

4.2 CIRCUIT MONITORING AND TESTING. Looking at the data circuit in Figure 4.1, during the data mode, the NCUs are systematically scanning each line and monitoring various aspects of the data (timing, etc.) and constantly comparing it with stored preset standards. Irregularities are alarmed and recorded and, if necessary a test is initiated on the particular line. In addition, the NCUs are directly monitoring the modems and multiplexers at the nodes. The following parameters are analyzed by the NCU while data is being passed:

Synchronization

Receive clock
Send Clock
Frame synch (Multiplexer)
Delay time
Spectrum Ratio
Continuity of data signal
Carrier loss (modem)

On-Line Indication of Line Quality (Eye-Pattern)
Quality of data (modem)

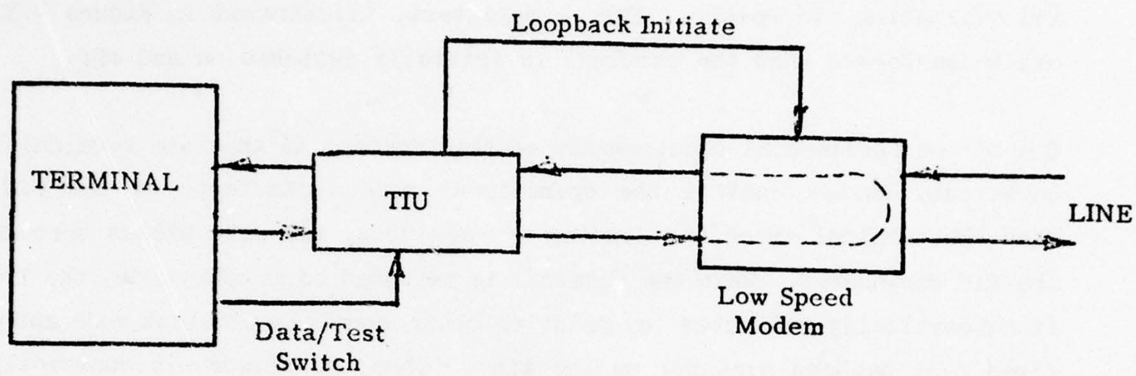


Figure 4.3. TIU INITIATING LOOPBACK TEST ON LOW SPEED MODEM

Let us assume, at this time, a 4-wire (full duplex) circuit. When the terminal is placed on standby, the TIU immediately checks out "its modem" (or line driver) by performing a loopback test. A faulty modem triggers an alarm (which may be a light) at the TIU where the terminal operator can recognize that the modem is faulty. The operator may then report this condition to an operator at one of the NCUs by a phone call. If all is well, the TIU puts out a fixed test pattern (call it "A") on the line. If the system is operating properly, the "A" reaches the first NCU (NCU-1) which recognizes it and immediately goes from the monitor mode to the patch mode and resends the test signal "A" down the line to the next NCU (NCU-2) which recognizes it as the valid test pattern. NCU-2 also goes into the patch mode and sends "A" down the line to TIU-2 at the network center. (There could be other NCUs along the way depending on the number of modems along the line.)

TIU-2 recognizes the "A" signal and goes into the test mode, isolating the CPU from the line and sending a "B" test pattern back to NCU-2 which in turn recognizes the "B" and resends it to NCU-1. NCU-1, recognizing B, resends it to TIU-1. When TIU-1 sees the "B" pattern, it will continue sending the "A" to NCU-1. Failure to receive the proper test pattern at the NCUs and TIUs causes an alarm and printout to occur. By knowing at what points the signal was good and bad, coupled with direct performance of the modems and multiplexers, allows the faulty portion of the circuit to be isolated.

If TIU-2 at the network center (CPU) fails to receive the correct "A" pattern, it will continue to operate in the data mode not being aware that the remainder of the network is in the test mode. Failure of NCU-2 (which is in the test mode) to receive a "B" from TIU-2 causes an error to be flagged for that portion of the circuit. In any case, NCU-2 will send the correct "B" pattern to NCU-1 to check that portion of the circuit. NCU-1 will resend the "B" to TIU-1 which, upon recognizing it, will continue sending "A" to NCU-1. If TIU-1 does not receive a "B", it will send a fault pattern (F_A) to NCU-1. It should be noted that in the event that the circuit between TIU-1 and NCU-1 is faulty (for example a break in the line at point "X" in Figure 4.1), the "A" test pattern will never reach NCU-1, and the rest of the system will never know TIU-1 is in the test mode. This problem is overcome since these "unrecognizable" signals will eventually reach the CPU causing "NACKS" to be constantly returned. These can be recognized by NCU-2 which would then place the system in a test mode to isolate the problem. In addition, the operator at the terminal can call an operator at one of the NCUs (or vice-versa) and report erroneous data. The terminal and NCU operators can then place the circuit in the test mode from both ends and quickly isolate the problem.

When the system is in the test mode the NCUs check the fixed test patterns for the following by comparing them with stored replicas:

Bit Error Rate (BER)
Phase error
Phase jitter
Phase hits and dropouts
Impulse noise (Gain hits)
Pulse level
Clock Slip Rate

One of the characteristic features of this concept is that all monitoring and testing of the lines is done on the digital portion only. This minimizes the necessity of expensive analog measuring equipment. Furthermore, the above digital test should prove sufficient for isolating and diagnosing most of the common faults in a system. A more detailed analysis of the circuits can be made with more sophisticated portable equipment at the patch panels that would exist along the line. Such would probably be the case for quality of service acceptance tests.

It is the intention of this concept that the network monitoring system be as flexible as possible and take advantage of existing facilities. For example, if a spare channel exists between two nodes (one leg of a multiplexer), it may be used by the NCUs to pass a test code pattern (pseudorandom or fixed) so as to monitor that portion of the network continually. In the case of two-wire (half duplex) lines, the test pattern sequence would have to be modified; however, the basic idea would remain the same.

4.3 NODAL CONTROL UNIT (NCU). The NCU is the most important element in the network monitoring system. It performs the following functions:

a. Monitors each circuit, modem, multiplexer, crypto unit or other such equipment at a node.

b. Initiates tests on each circuit.

c. Collects and records data on system performance in real time.

d. Prints out information.

e. Provides alarms.

f. Performs a self-test to insure accurate operation.

g. Communicates with other NCUs and ORACLE as required on a dial up basis.

Figure 4.4 shows the basic components required in the NCU. Except for the I/O devices such as the printer and keyboard, the power required would not be very great. The possibility then exists for use of a battery (emergency) supply which could be kept on float during operation from external power. Also, the keyboard and printer could be plug-in (optional) in the case of NCUs located at nodes distant from the network center.

A printout from the NCU would consist of the status of the system upon the conclusion of any test or upon detecting any deviation from normal operation. The printout would include a unit (modem, etc) or line identifier followed by the detected condition. It would be optional to print out if a unit or line were operating normally. Each system would have a plan showing each unit and line with its identification (alphanumeric or otherwise) clearly noted. This would keep the microprocessor language simple and save storage space. The date and time of each incident would be noted. An example of a printout <u>might</u> look like this:

```
01 June 77 1330
MOD1:CD, MUX2:05, L38:SL
L38:BER
01 Jun 77 1430
L38:OK
```

The above printout says that on 1 June 77 at 1330 hours, "Modem 1" had a carrier dropout, multiplexer 2 went out of synch, line 38 had a signal loss, and line 38 failed the BER criteria on the test pattern. At 1430 hours the same day, line 38 was restored to an acceptable condition. The operator at the NCU would refer to a manual of the system to find the location of a particular unit or line. The above merely indicates what might consist as a printout. Trial and error on a concept implemented system would resolve the best format for data printout.

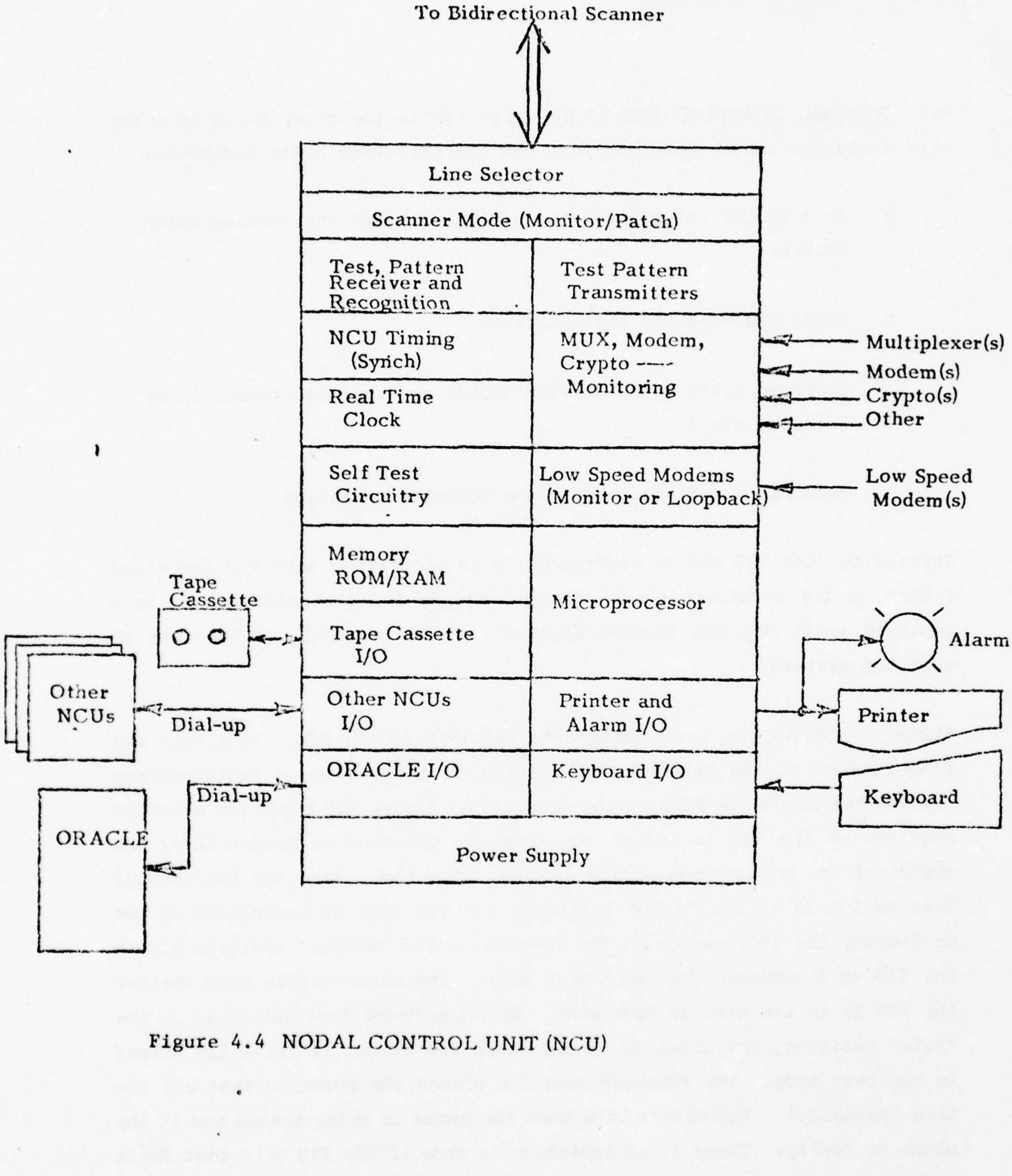


Figure 4.4 NODAL CONTROL UNIT (NCU)

4.4 TERMINAL INTERFACE UNIT (TIU). The TIU is the entry point into the data communication system. It performs the following basic functions:

a. Acts as the interface between terminals and the communication system.

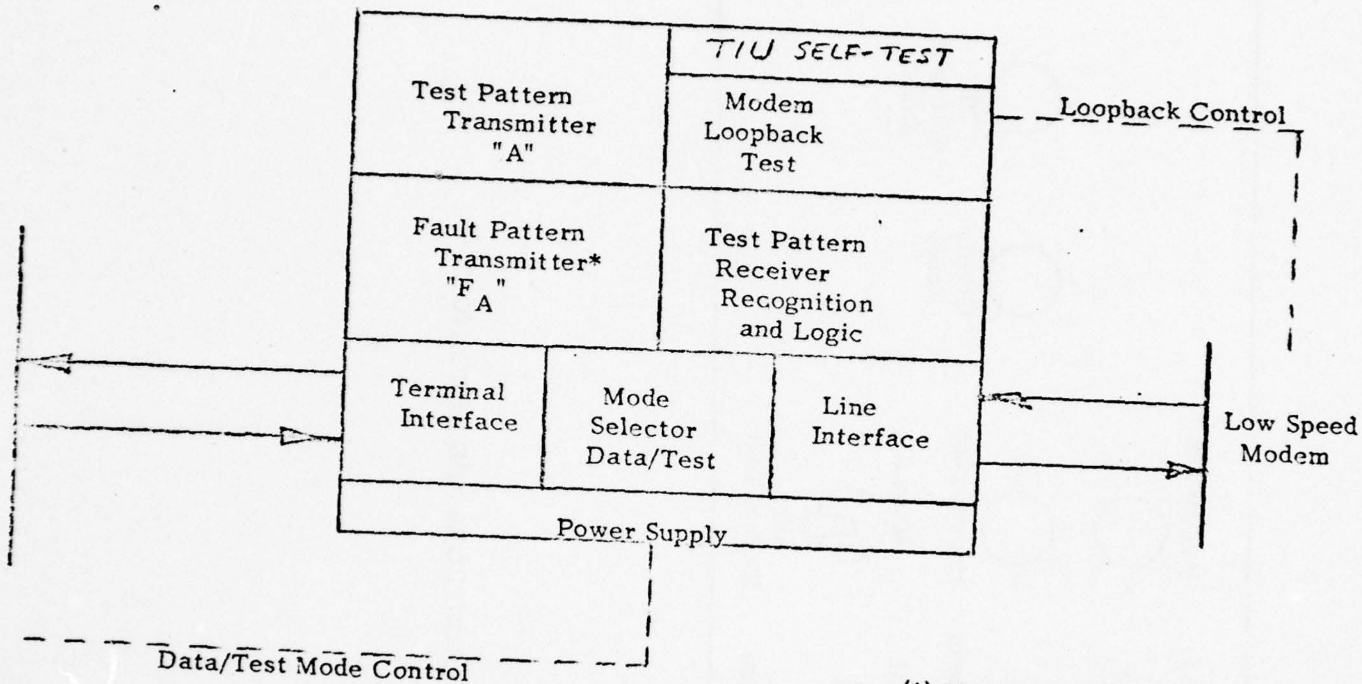
b. Sends and receives test patterns.

c. Performs tests on associated modems or other equipments (line drivers, etc.)

d. Performs a self-test to insure accurate operation.

Physically, the TIU can be configured on an electronic card and installed either in the terminal (where new systems are being considered) or in a separate small box and located adjacent to the terminal, in the case of existing systems.

Figure 4.5 shows the basic components required in the TIU. Note that the TIUs located at the network center (CPU) do not require a fault pattern transmitter as do the TIUs at the terminals. Figure 4.6 shows the controls required at the TIU to assist the terminal operator in ascertaining the status of the network monitoring system at his end. When the Auto/Manual Test switch is in the "Auto" position, the TIU mode is controlled by the On/Standby (or off) switch on the terminal. The "manual" position places the TIU in a constant (manual) test mode. Indicator lights show whether the TIU is in the test or data mode. When the Modem Test switch is in the "Auto" position, the modem is checked when the system is initially placed in the test mode. The "Manual" position places the modem in test all the time (manually). Indicators show when the modem is being tested and if the modem is faulty. There is an indicator to show if the TIU self-test fails (TIU is not functioning properly) and if a crypto unit associated with the terminal has reset. (See Section for the discussion of a crypto associated circuit.)



(*) Used with TIUs located at terminals only

Figure 4.5 TERMINAL INTERFACE UNIT (TIU)

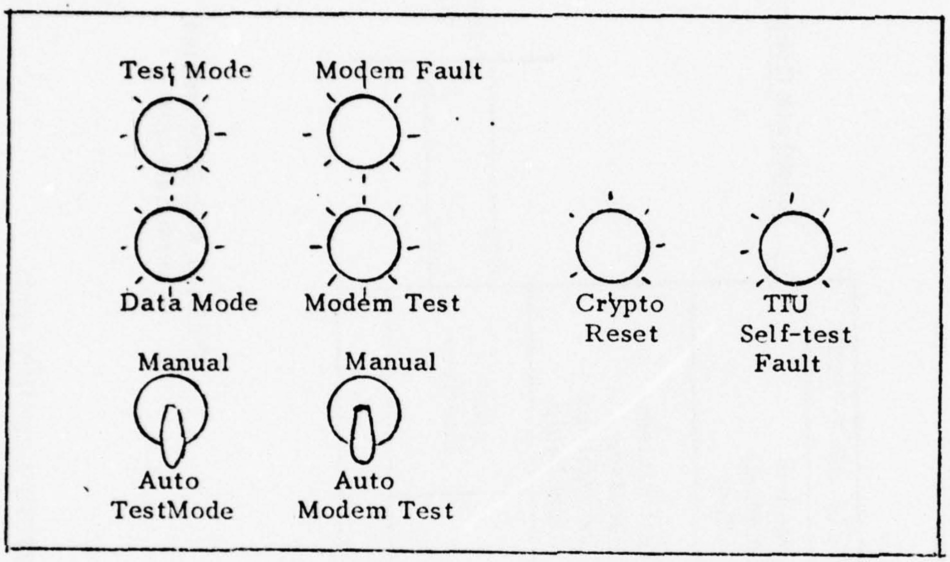


Figure 4.6 TIU CONTROLS AND INDICATORS

4.5 SYSTEM OPERATION WITH CRYPTO UNITS. If the communication network employs encryption devices (either single channel or bulk), the situation is a bit more complicated. In the case of single channel encryption, the solution is to place the TIUs after the crypto units as illustrated in Figure 4.7. If this were not so, the NCUs would not recognize the test pattern sent by the TIUs. Any monitoring lines from crypto units would have to be isolated before going to the TIU. If a terminal is located in a room separate from the crypto unit and modem, an isolated cable would be run to the terminal location to a remote unit having the TIU switch and indicator functions.

If bulk encryption is used, the situation is easier since the encryption device is located by the multiplexers as shown in Figure 4.8. In this case, the NCU will be evaluating "red" data and would be located in a secure area. The NCU would have to be properly isolated when communicating with another NCU in a "black" area or ORACLE which would definitely be in a "black" area. This situation is discussed in the section detailing the description and function of ORACLE.

4.6 ORACLE. One of the basics of the network monitoring concept is ORACLE which is envisioned as a central processing facility which receives inputs from the NCUs of the various subscribing data networks and performs the following functions:

a. Collects data from NCUs.

b. Checks and collates this data.

c. Performs analyses (statistical)
   Short/long term trends
   System error analyses

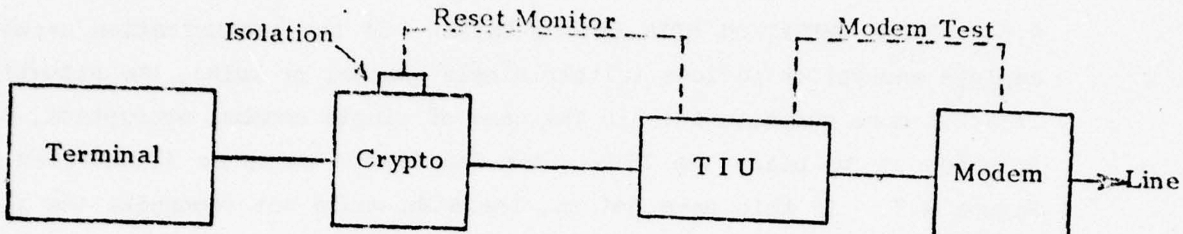


Figure 4.7 SINGLE CHANNEL ENCRYPTION CONFIGURATION

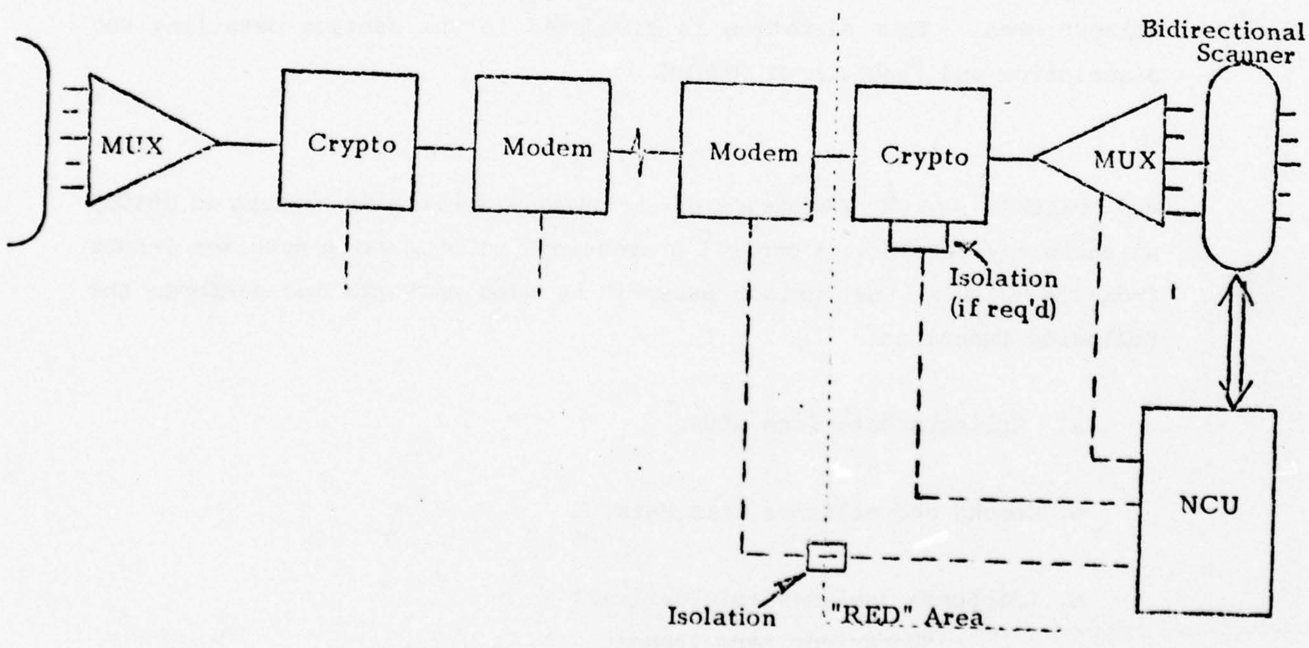


Figure 4.8 BULK ENCRYPTION CONFIGURATION

d. Initiates test procedures (on data system and NCUs) and records test-fault-remedial action sequences.

e. Updates system records and files.

f. Prints out periodic reports.

4.7 Oracle Configurations. ORACLE can assume a number of configurations, only two of which will be discussed here.

CONFIGURATION I: ORACLE assumes the form of an independent minicomputer Data Base System which operates on DNR data received from the NCUs of a data communication network. In this configuration, ORACLE is not necessarily dedicated to one data communication network. It can serve a number of data networks by allocating a fixed amount of its time and assets to handle preselected routines for each data communication network that joins the system, while keeping in reserve some of its capabilities for special functions and situations that will arise in a given member system.

Data comes to ORACLE over DIAL-UP lines. Four cases are considered:

a. ORACLE calls the NCU for Data Dump.

In this case, the data that is recorded in the tape cassette of the NCU of a DNR subsystem is sent to ORACLE. This data contains the results of the major activities and deviations from certain prescribed criteria at that node over some period of time. The duration of time covered by a given "Cassette Dump" could be a day or a week or whatever duration of time that proves satisfactory for successful operation of the system. ORACLE receives this data by calling the NCUs on the DIAL-UP line and requesting a dump. This is a routine operation and initiated under the routine Data Collection Mode of ORACLE.

b. NCU calls ORACLE for Assistance. This case will usually be initiated by the NCU while in an emergency situation. This can happen, for instance, when major performance criteria have been failed or exceeded certain acceptable margins at a particular NCU. The particular NCU at which this condition has occurred may be unattended, and the NCU calls ORACLE or the Master NCU of the system. This is a cry for "help" from the NCU to ORACLE. In this case, the NCU Dials-Up ORACLE and receives immediate attention. When action has been taken, the communication line is dropped by ORACLE.

c. An NCU calls another NCU through ORACLE. All NCUs have the capability of alarming and printing out failure conditions; however, not all the NCUs will require attendants or an operator. If an alarm condition exists at such an unsupervised NCU, the NCU is instructed by its internal program to initiate a call to a Master NCU whose outputs are supervised or monitored by operating personnel. This call could go through ORACLE or direct to the Master NCU. With this call, whatever alarm conditions exist at the troubled NCU will be alarmed and printed out at the Master NCU.

d. ORACLE calls one or more NCUs to instruct. This case can be thought of as a Command Call made by ORACLE to one or more NCUs in a data communication system. The purpose of this call is to place in the NCU some instruction or special test to be performed at that node. For instance, it could command the NCU located at point A to load and transmit a pseudo-random sequence or "Fox Message" to an NCU located at point B and have NCU-B make the applicable tests on these signals.

CONFIGURATION II: Another, more conservative, approach to ORACLE is to have its functions accomplished by the computer associated with the data communication network. This arrangement is feasible only when the ADP system has room to spare, a possibility that is usually rather remote. The main reason for its discussion here is that it represents one way of starting an ORACLE and testing its feasibility and potential.

4.8 Existing vs Future Data Networks. The discussion in this report concerned itself primarily with existing data communication networks (along with the myriads of different modems, multiplexers, line drivers, etc.) and a means to address most of the configurations possible with these equipments. Many of these equipments (for example low speed modems) do not incorporate self-test features. Equipments for future networks along with replacements in existing networks are envisioned as containing <u>self-testing</u> features. The functions of the TIU could be built into the terminal. Modems would perform various loopback operations, for example, with connections for <u>external control</u> and <u>monitoring</u>. This would simplify the circuitry of the NCUs and TIUs and provide for a more efficient fault isolation and diagnostic capability, especially in the analog portions of the system. The purchase of <u>such equipments</u> capable of self-testing (etc) should be incorporated into standards for communications systems. This is further discussed in the Recommendations portion of this report.

4.9 SYSTEM RESTORATION BY NCUs. The previous paragraphs have discussed the DNR concept for Fault Detection and the use of Diagnostics for identification of the system function that has failed. If the DNR is associated with a data communication network that employs any redundancy in its communication subsystems, such as Modems or Multiplexers, the NCUs can provide the automatic switch-over to restore a system that has failed. Also, the same capability exists for alternate routing of data traffic by the NCUs if the alternate circuits are available.

5. <u>IMPLEMENTATION OF THE DNR CONCEPT</u>

In order to implement the DNR concept and investigate its feasibility, it is necessary to fabricate the required hardware and software, or a reasonable representation of it, and try it out on several lines of a data communication link. As far as possible, this implementation should resemble the basic product in its function. Implementation will, of course, allow for experimentation, and modifications would be expected as various portions of the concept may not prove feasible in an operating environment.

On two or three links of an existing communications system, MACIMS for example, such a setup would require at most two NCUs and six TIUs. Instead of a bidirectional scanner (BDS), the NCU could be manually switched between the three or so lines it monitors and tests. The "NCU" itself need not be a single unit affair; indeed, it could be an array of modular units (separate printer, keyboard, microprocessor and memory, test signal transmitter and receiver, real time clock, etc). Such items as the line selector, scanner mode circuitry and self-test circuitry would not be mandatory during initial implementation tests. This "NCU" should, at this time, be supplemented with test equipment such as a data scope and BER tester. This will ensure that the NCUs properly react to inputs from the lines, modems, multiplexers and other communications equipment it monitors. The TIUs, which are relatively simple, can be easily fabricated, perhaps with some of the automatic functions handled manually. ORACLE, for this implementation, can be a portion of an existing Data Computer System and can be accessed by a local terminal. The overall implementation can be carried out in various stages (increasing in complexity) as the concept proves itself.

6. RECOMMENDATIONS.

Downtime of a data communication system can be reduced by a substantial amount when a first level (functional level) monitor and test subsystem such as the DNR is used to observe trends and identify potential problems. These trends should be identified early enough so that corrective action can be taken before they result in a fault of sufficient magnitude to bring the communication system down.

The following recommendations are made:

a. Comprehensive acceptance tests for compliance with specifications should be performed on all lines and equipment of any new data communication systems or any additional lines or equipment being added to existing operating systems. All lines or circuits should be fully characterized, through testing, before becoming part of the communication system. Admittedly, this exercise has always been considered one of the first things done (supposedly) in setting up or adding to a system. However, actual practice and experience indicate that this is not always the case. It is reiterated here to emphasize its importance.

b. All future exhibits, STATEMENT OF REQUIREMENTS (SOR), STATEMENT OF WORKS (SOW), etc., shall provide that all communication equipments (Modems, Muxs, Line Drivers, etc.) have built into them the capability for self-tests whose outputs appear at a set of connector pins.

c. Provisions should exist for physical access and electrical connection to all major subsystem equipment and circuits in the data communication system for monitoring and testing purposes.

d. Standards should be developed for both quality and availability of line and equipment used in data communication systems.

e. Installation and performance standards should be developed for network monitoring subsystems.

f. A set of procedures and reporting techniques should be investigated and defined for network monitoring.

g. Additional investigations should be made into the use of software techniques, such as COLTS, and the use of Hardware/Software trade-offs in the monitoring problem. In this connection, some of the existing techniques such as the eye-pattern can be integrated more into the monitoring system through the use of hardware and testing algorithms.

h. Consideration should be given to a plan for testing the concept presented in this report. This plan could follow the steps described in paragraph 5 above.

APPENDIX A

DATA NETWORK QUESTIONNAIRE

A copy of the questionnaire that was sent to the various ADP - Communication Networks.

Location ____

Data Network Identifier ______________________________

1. <u>Evaluation</u>. Users overall evaluation of data network performance.

Satisfactory	☐	
Unsatisfactory	☐	(Check one)

Optional remarks: (Please identify those features which are primarily responsible for the rating assigned above.) ____________________

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2. <u>Data Network Equipment Configuration Diagram</u>. Provide a diagram depicting interconnection of network equipment. Identify each equipment item shown by manufacturer and model. Identify each leased equipment item and/or transmission path. When multiple vendor's equipment are present, identify those items provided by each. A sample diagram is attached which amplifies and displays the desired level of detail.

3. <u>Operating Conditions</u>. Identify the conditions of data network operation, e.g., hours per day, and days per week. If all terminals do not operate during the same period of time, identify the operating conditions for each terminal. Identify each bit rates, traffic flow statistics, response times and communications protocol concept, etc.

4. Fault Detection. Does any of the data network equipment automatically indicate the presence of errors, equipment malfunction, or substandard performance?

Yes ☐

No ☐ (Check one)

If yes, please identify the type and location of indication, the equipment that provides the indication, and type of personnel most likely to receive the indication, i.e., operators, maintenance personnel, etc.

5. Data Network Performance History. Is performance data available (outage records or trouble tickets)?

Yes ☐ (Check one)

No ☐

If yes, provide a synposis of equipment and/or transmission path malfunctions for the past 365 days. ____________________

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6. Troubleshooting Procedures. Provide a copy of any instructions provided to assist operators or maintenance personnel in the identification of malfunctioning path(s).

7. Diagonostic Equipment. Are any diagnostic aids provided for fault isolation purposes (hardware or software)?

Yes ☐ (Check one)

No ☐

If yes, address the following:

a. Are the diagnostic aids included in the data processing equipment?

Yes ☐ (Check one)

No ☐

If yes, complete the following:

(1) Describe the features provided by each applicable piece

of equipment. ____

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(2) Briefly discuss the utility of each feature. ______________

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b. Are the diagnostic aids contained in equipment separate from the data processing equipment?

Yes ☐

No ☐ (Check one)

If yes, complete the following:

(1) Describe the features provided by ea~h applicable piece of equipment. ____

____

(2) Briefly discuss the utility of each feature.

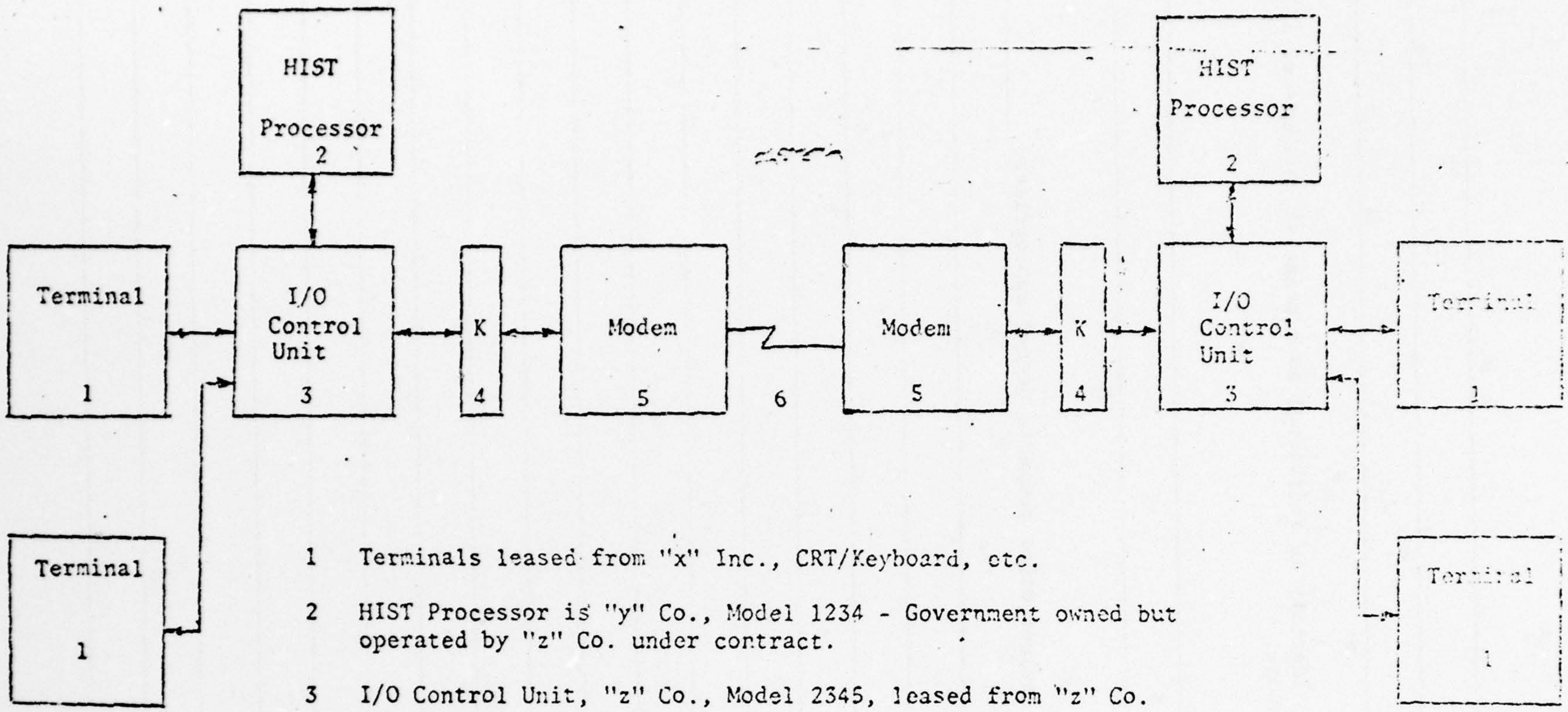
8. Diagnostic Capability. From an operator's point of view, identify the diagnostic capabilities required for satisfactory data network performance, e.g., additional hardware/software features (specify), fault isolation, procedures, etc. Also, include the desired method for implementation, i.e., as part of the data processing equipment or separate from the data processing equipment.

9. Point of Contact. Identify an individual as a point of contact for information regarding the data network.

NAME: ______________________________

AUTOVON NUMBER: ______________________________

10. Other Comments. Include other comments deemed appropriate. ______________



1 Terminals leased from "x" Inc., CRT/Keyboard, etc.

2 HIST Processor is "y" Co., Model 1234 - Government owned but operated by "z" Co. under contract.

3 I/O Control Unit, "z" Co., Model 2345, leased from "z" Co.

4 Crypto, KG-XX, O&M by AFCS.

5 Modems "x" Inc., Model Nr. 22, sync @2400 b/s; O&M by "z" Co., contract.

6 Part base cable, O&M AFCS; part leased 3002 from Bell.

APPENDIX B

DISCUSSION OF ANALOG CIRCUIT PARAMETERS AND DIGITAL DATA TRANSMISSION PERFORMANCE

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1. GENERAL

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   e. Impulse Noise

5. CONCLUSIONS

6. RECOMMENDATIONS

7. BIBLIOGRAPHY

APPENDIX B

DISCUSSION OF ANALOG CIRCUIT PARAMETERS AND DIGITAL DATA TRANSMISSION PERFORMANCE

1. GENERAL. In the past communication systems were used primarily for exchange of voice frequency information, and the characteristics of a 4 KHz voice channel were not critical. Imperfections in the communications system added distortion to the voice information, but usually the information could be understood. The human ear is a very forgiving receiver. Terminal equipment sophistication and changes in our defense posture have placed additional requirements on our communication systems. More and more the 4 KHz voice channel is used to pass digital data information, and digital data signals are more sensitive to perturbations of some analog parameters than are voice signals.

Every year the amount of digital data information passed on communication systems has steadily increased. This has been accomplished primarily through an increase in the speed at which the data information is passed. High data rates have been found to be extremely sensitive to perturbations of some analog parameters.

This Appendix will discuss the relationship between analog circuit parameters and digital data transmission performance.

As a start, the parameters in DCAC 310-70-1, Supplement 1, were studied for correlation to digital data transmission performance. Then the area of spectrum ratios was investigated.

2. PARAMETERS NOT NORMALLY CONSIDERED CRITICAL: Longitudinal balance, impedance, frequency translation, and single tone interference parameters are not considered critical because:

a. They are very seldom found out of tolerance or

b. Even when they are out of tolerance, they don't appear to significantly affect digital data transmission performance.

1) Longitudinal Balance.

Longitudinal balance is an indication of the difference in impedance between each conductor and ground of a balanced line. The greater the difference in impedance, the more susceptible the line is to feedover from other sources. This may show up as crosstalk, increased idle channel noise (ICN), or phase jitter.

No past studies have been found that show a direct correlation between longitudinal balance and digital data transmission performance. Also past Scope Creek evaluations show that rarely does longitudinal balance not meet the MIL Standard of 40 dB. For these reasons, longitudinal balance is not considered a critical test.

2) Impedance.

The impedance test measures the impedance of the VF channel input and output at the terminal. It looks at the frequency band 300—3400 Hz. Mismatches in channel impedance could result in poor frequency response, signal power loss, or inaccurate signal level measurements. This test by itself is not considered critical. It could best be used as a troubleshooting device. Past Scope Creek reports have indicated that this is normally not a problem.

3) Frequency Translation.

Frequency translation is a measure of the change in frequency of a signal as it travels over a communications channel. In general, modems can track frequency translation and few errors will occur until a certain threshold is reached. After this point, synchronism is lost and throughput is reduced to zero percent. Most modems have a threshold greater than 10 Hz and very rarely will the frequency translation be greater than this.

4) Single Tone Interference

This test is aimed at detecting low level single tones that impair the quality of voice transmission. Any single tone with a high enough level to significantly affect digital data transmission performance will be detected when making ICN measurements. This test can be used as a troubleshooting device but in itself is not considered a critical analog test.

3. PARAMETERS THAT MAY BE CRITICAL: The following parameters have demonstrated that they can significantly affect digital data transmission performance. Normally they are compensated for and thus are only a contributing factor. If allowed to degrade, these parameters will become critical and cause poor digital data transmission performance.

a. Envelope Delay Distortion.

Envelope delay distortion does not normally result in poor digital data transmission performance by itself. What it does is make the modem more susceptible to other degrading factors. In one study it was found that a circuit that met C2 specifications for delay distortion needed a signal to noise (S/N) of 21 dB to obtain a bit error rate (BER) of 10^{-5}.

C2 specifications are shown in Table 1. This was for one particular modem at 9600 bps. The same modem on a circuit that did not meet C2 specifications needed a S/N of 25 dB to obtain a BER of 10^{-5}. The same relationship is true for impulse noise and delay or phase jitter and delay.

TABLE 1

IC2 Envelope Delay Specifications

1000 - 2600 Hz:	less than 500 usec
600 - 2500 Hz:	less than 1500 usec
500 - 2800 Hz:	less than 3960 usec

Another reason that this test is not considered critical is that delay distortion is fairly easily compensated for. External delay equalizers can be installed on most circuits and most newer modems have internal equalizers that automatically compensate for delay distortion.

b. Frequency Response.

The comments made about envelope delay distortion are also applicable to frequency response. Frequency response in itself will not normally degrade digital data transmission performance significantly. It will make the circuit more or less susceptible to changes in other analog parameters such as phase jitter, S/N, or impulse noise. Also, external amplitude equalizers or automatic equalizers in the modems are often used to correct any frequency response problems.

c. Harmonic and Intermodulation Distortion.

Harmonic and intermodulation distortion are random error causing mechanisms. Studies show that these are not significant factors in data performance because in most cases, their measured value is at least 30 dB below the fundamental test tone.

d. Net Loss and Net Loss Variation.

Net loss is not normally a problem single pads or amplifiers can be used to compensate for it. Net loss variation may be a problem due to the dynamic range of the modem. If the data signal is near the edge of the dynamic range of the modem, the variations in the net loss could cause the data signal to be outside that dynamic range, resulting in errors. Installers or users tend to set their modems so that the data level is on the high end of the modem. This provides the user with the greatest fade margin but variations of the data level on the plus side will put the data signal outside the dynamic range of the modem and cause errors. Users or installers should check the incoming data signal level, its variations, and the dynamic range of the modem and make the necessary adjustments.

e. Composite Data Transmission Level.

Generally the composite data transmission level is set at -13 dBm0. This may be critical because this composite level is one of the factors that determines the signal to noise ratio (S/N) and S/N is critical to data performance. This test is normally used for level discipline.

4. PARAMETERS THAT ARE CRITICAL: The following parameters are considered critical because if degraded, they will adversely affect data transmission performance.

a. Idle Channel Noise.

Idle channel noise (ICN) is directly related to signal to noise ratio. Assuming the data signal remains at a fairly constant level, ICN can be used as a good indicator of data performance. S/N is a composite indicator; anything that affects the signal level or the noise will be measured. Problems with longitudinal balance, single tone interference, harmonic or intermodulation distortion will increase the ICN or decrease the S/N ratio. Impedance, net loss variation, and composite data level will affect the signal level and hence the S/N ratio. Specific requirements will depend on the data transmission rate and type of modem used but in general a S/N of 26 dB will provide a BER of 10^{-5} or better.

b. Phase Jitter.

Phase jitter's effect on digital data transmission performance depends largely on the type of modulation used in the modem. A modem that uses phase modulation will be affected more by phase jitter than a modem that uses amplitude modulation. One study by RADC, published in March 1971, looked at 13 different modems using different modulation schemes and came to the conclusion that if the peak-to-peak phase deviation is greater than 5 degrees, a BER exceeding 10^{-5} must be tolerated. A study of data transmission on Autovon circuits came to the same conclusion but indicated that newer modems may very well make a BER of 10^{-5} feasible. A more recent study on an ICC modem 96 Multi Mode indicated that this modem would operate with a BER of 10^{-5} with peak-to-peak phase jitter (60 Hz) not greater than 30 degrees. As the frequency of the phase jitter decreases from 60 Hz, BER increases significantly. Less than 18 degrees peak-to-peak phase jitter at 30 Hz is needed in order to obtain a BER of 10^{-5}.

c. Spectrum Ratio.

A spectrum ratio test is very similar to a S/N test. A 4 KHz VF channel is divided into an arbitrary number of equal slots and sampled individually. Forty slots of 100 Hz each is a convenient method. The spectrum ratio is obtained by taking the composite amplitude of certain slots and dividing this by the composite amplitude of certain other slots. Electronic Systems Division (ESD) evaluated some spectrum ratios in an operational environment. They used the 10th, 15th, and 20th slot for the numerator slots and the 33rd, 34th, and 35th slots for the denominator slots. The numerator slots were in the middle of the channel where the data signal should be and the denominator slots were near the edge of the channel where there should only be noise. The spectrum ratio was obtained by dividing the composite amplitude of the numerator slots by the composite amplitude of the denominator slots. The slots for this spectrum ratio were chosen with the idea of testing fully loaded VFCTs. Different types of data signals would require using different slots. The ESD evaluation concluded that the spectrum ratio did measure a relative S/N ratio and we have already concluded that S/N ratio is a good indicator of data transmission performance. More study is needed to determine the optimum selection of slots for different types of data signals and the threshold settings. The major advantage of this test is that it can be performed in service; there is no interruption of service to the customer.

d. Phase Hits.

Phase hits are a burst error mechanism which can substantially affect the BER, especially if the modem uses phase modulation. A threshold of 15 degrees for a hit and 100 hits in 15 minutes are usually used as standards. Studies indicate that phase hits are a frequent problem on data circuits. One study correlating phase hits and BER had means of 1.2 to 300 hits resulting in 10^{-6} to 10^{-2} BER respectively for a data rate of 9600 bps. The modem used in this study used a multi-level vestigial sideband type of modulation. This means that phase hits can be used as an indicator of data performance but it is not a composite parameter. Phase hits may not always be a problem, since other parameters could be degrading data performance.

e. Impulse Noise.

Impulse noise is definitely a cause of errors in digital data transmission. The number of errors caused depends basically on the amplitude, rate, and duration of the noise pulse. Impulse noise is a predominant factor on low speed data circuits, e.g., 2400 bps or less. At higher bit rates, other analog parameters become significant also.

Another factor to consider is that impulse hits appear to occur in bursts or clusters. This means that even though the BER may be greater than 10^{-5}, the throughput may still be acceptable. Thus, impulse noise can be considered a good indicator of data performance.

5. CONCLUSION: Longitudinal balance, impedance, frequency translation, and single tone interference are parameters that are not critical to digital data transmission performance. Past experience has shown that these parameters are rarely out of tolerance or that digital data performance is relatively insensitive to them. Only if they are extremely bad will they affect digital data performance.

Envelope delay distortion, frequency response, harmonic distortion, intermodulation distortion, net loss, net loss variation, and composite data transmission level may be critical parameters depending on their value and the value of other parameters. Envelope delay and frequency response can be compensated for by the use of equalizers. Harmonic and intermodulation distortion can be a problem if there is too much nonlinearity in the circuit. This can be detected when determining the S/N ratio or spectrum ratio. Net loss is not normally a problem after installation but net loss variation can be. This will also show up in the composite data transmission level test. The variation of level can be a problem if it falls outside the dynamic range of the modem.

There are five parameters or tests that are critical to digital data transmission performance.

Impulse noise is basically a burst error mechanism so that while the BER may be degraded significantly, the throughput may not be as bad as one would expect. Impulse noise is a dominate factor at lower data rates ($\leq$ 2400 bps). At higher data rates ($\geq$ 9600 bps) it becomes an equal factor along with S/N ratio. Between 2400 bps and 9600 bps it gradually becomes less significant, depending on other parameter values.

Phase hits are also a burst error mechanism. This parameter is more dominate on systems that use phase modulation. But phase hits, like impulse hits, are usually random in nature. This would be useful as a troubleshooting device but not very useful as a detection or monitoring device.

Phase jitter is a critical factor, again, more so for phase modulated systems. Not only is the peak-to-peak phase deviation important, so is the frequency of the phase jitter. Studies indicate that the lower the frequency of the phase jitter, the more disruptive to data transmission performance. Newer modems, such as the ICC 96 Multi Mode, are less sensitive to phase jitter than the older modems. They can operate at 9600 bps when it experiences less than 30 degrees phase jitter (60 Hz).

At higher data rates, idle channel noise (ICN) plays an increasing important role. ICN is an important component of the S/N ratio, and the S/N ratio is a good indicator of data transmission performance. ICN is a composite parameter; anything that affects the idle noise of a system such as phase jitter or crosstalk will show up here. Present modems require approximately a 26 dB S/N ratio for operation.

With the exception of the composite data transmission level test, the spectrum ratio test is the only one that can be performed in service. Indications are that the spectrum ratio is correlatable to S/N ratio which is correlatable to BER or data performance. More study is needed on spectrum ratios, but it appears to have excellent possibilities as a detection and monitoring device.

After spectrum ratio limits have been determined for different data signals, it can be monitored on a periodic basis. This would help identify data problems before an actual outage occurs.

In conclusion, the analog parameters that affect digital data transmission the most are spectrum ratio, idle channel noise (S/N ratio), phase hits, phase jitter, and impulse noise. Important analog parameter tests are: spectrum ratio, idle channel noise, phase jitter, phase hits, impulse noise, envelope delay distortion, composite data level, and frequency response. These should be used in conjunction with some digital parameter tests such as BER or parity error checking. The spectrum ratio can be used in service on the analog signal to give an indication of the quality of the digital data transmission performance. The other analog parameters can be used for troubleshooting or analysis.

6. RECOMMENDATIONS: Studies done so far indicate that spectrum ratios may be useful for monitoring and evaluating digital data transmission performance. Recommend that further testing be done in this area to conclusively define the correlation between spectrum ratios and different types of digital data traffic.

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