GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 11/25/80

Project Title: HF/DF Remote Control Study

Project No: A-2785

Project Director: Dr. R.W. Rice

Sponsor: Federal Communications Commission

Agreement Period: From 9/30/80 Until 4/28/81

Type Agreement: Contract FCC-0357

Amount: $59,956 (fixed price)

Reports Required: Monthly Progress, Final

Sponsor Contact Person (s):

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Defense Priority Rating: None

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A-2785 #30

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 8/17/81

Project Title: HF/DF Remote Control Study

Project No: A-2785

Project Director: R. W. Rice

Sponsor: Federal Communications Commission

Effective Termination Date: 6/28/81

Clearance of Accounting Charges: 6/28/81

Grant/Contract Closeout Actions Remaining:

- x Final Invoice and Closing Documents
- _ Final Fiscal Report
- x Final Report of Inventions
- x Govt. Property Inventory & Related Certificate
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A-2785

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

October 29, 1980

Federal Communications Commission
1919 N. Street, N.W.
Room 744
Washington, D.C. 20554

ATTN: Mr. Ralph Haller
Chief, Monitoring Branch

SUBJECT: Progress Report Number 1 for the period 1 October 1980 to 31 October 1980 on Remote Control of HF Direction Finders (A-2785)

Dear Mr. Haller:

During this work period, we have been involved in the following major activities:

(1) We have met with monitoring and ECIB personnel at the Powder Springs site to collect information on current DF practices and activities and to familiarize ourselves with the development work being done on the type W system,

(2) We have begun collecting cost and technical data on modems that may be employed in the ultimate network configuration,

(3) We have begun to collect and tabulate technical and cost data on remotely controllable HF receivers which could be used at each DF site in the network, and

(4) We have identified and requested data pertaining to DF activity which will be necessary to properly design the DF network from a traffic flow standpoint.

Our visit to Powder Springs has given us a relatively clear picture of the DF activity at the monitoring station level. During the next work period, we plan on discussing our findings with you when you visit our facility in early November. In this meeting we will seek your comments on our current understanding of the local DF activity and also seek detailed inputs from you on DF related activity at the Washington control center.

In anticipation of the actual design and cost trade-off study to be performed later in this project, we have begun to collect a variety of technical and cost data. This information will be used to postulate several alternative configurations which will provide varying degrees of performance/flexibility at varying costs.

Actual network design will require a detailed knowledge of both the technical and administrative activities associated with the DF system. To that end, we have submitted a request to the FCC for DF activity data, and we anticipate that some additional requests will be made at a later time.

During the next work period, we will concentrate our efforts on establishing the requirements for the DF system. We will also continue to collect information on the various system components, and once have identified specific candidate equipment configurations, we will we obtain cost estimates from the various suppliers of communications channels for the required channels.

At present all work is proceeding on schedule and within budget.

Respectfully submitted.

Robert W. Rice, Ph.D.
Project Director

RWR/pf

APPROVED:

R. W. Moss, Chief
Communications Systems Division

A-2785

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

December 1, 1980

Federal Communications Commission
1919 N. Street, N.W.
Room 744
Washington, D.C. 20554

ATTN: Mr. Ralph Haller
Chief, Monitoring Branch

SUBJECT: Progress Report Number 2 for the period 1 November 1980 to 30 November 1980 on Remote Control of HF Direction Finders (A-2785)

Dear Mr. Haller:

During this work period, we have been involved in the following major activities:

(1) We have met with you, Mr. Don Taylor (EIC, Powder Springs), and Mr. Bill Kilpatrick (ECIB) on 7 November 1980 for an all day discussion of both current DF network operation and requirements of the new DF network. Our understanding of this discussion was documented in a letter sent to each of the FCC participants, and you have indicated basic agreement with the conclusions in that document. One exception to this was in the area of interfacing to the type W array. You suggested that we contact Mr. Kilpatrick for discussion of that item. This will be done during the next reporting period.

(2) We have continued to collect both technical and cost information on items such as receivers, spectrum analyzers, and computers to be used in the network.

(3) We have begun to interact with organizations such as American Satellite Corporation, RCAmericom, and Bell which may provide the required communications channels, and we are determining what channel types are available and what the associated cost is.

(4) We have begun to study possible network configurations for the various communications techniques.

Our original schedule had called for us to be involved in quantitative design of the DF network by this time and some of that quantitative design is being done; however, in the absence of the quantitative DF activity data requested in my letter of 20 October 1980, it is impossible to do parts of the required analysis accurately. It is urgent that the requested activity data be made available, preferably no later than 5 January 1981.

At present, all work is proceeding on schedule, with the exception noted above, and within budget.

Respectfully submitted,

Robert W. Rice, Ph.D.
Project Director

RWR/pf

APPROVED:

R. W. Moss, Chief
Communications Systems Division

A-2785

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 5, 1981

Federal Communications Commission
1919 N. Street, N.W.
Room 744
Washington, D.C. 20554

ATTN: Mr. Ralph Haller
Chief, Monitoring Branch

SUBJECT: Progress Report Number 3 for the period 1 December 1980 to 31 December 1980 on Remote Control of HF Direction Finders (A-2785)

Dear Mr. Haller:

During this work period, we have been involved in the following major activities:

(1) We have continued to collect cost and availability information on various communications channel options, telephone, satellite, HF radio, which will be used to perform the cost-effectiveness analysis for the entire network,

(2) We have begun implementation of the computer programs which will be used to determine suitable network configurations at the least cost, and

(3) We met with you and other FCC personnel on 15 and 16 December to discuss progress on this project and to observe a demonstration of the RCAmericom satellite system.

A result of the satellite demonstration was an expressed concern for the impact of the CVSD digitizing scheme on the recovered HF audio signals. It was agreed that this issue could best be settled by observing actual HF type audio after it had passed through the CVSD system. To that end, you offered to provide a tape recording of some typical HF signals, and I agreed to work with Scientific-Atlanta to record the results of CVSD processing on those signals. May I request that the test tape be provided no later than mid-January.

Our original schedule had called for us to be involved in quantitative design of the DF network by this time, and some of that quantitative design is being done; however, in the obsence of the quantitative data, the DF activity data request in my letter of 20 October 1980, it is impossible to do parts of the required analysis accurately. It is urgent that this data be made available, preferably no later than 5 January 1981.

At present, all work is proceeding on schedule, with the exception noted above.

Respectfully submitted.

Robert W. Rice, Ph.D.
Project Director

RWR/pf

APPROVED:

R. W. Moss, Chief
Communications Systems Division

A2785

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

January 30, 1981

Federal Communications Commission
1919 N. Street, N.W.
Room 744
Washington, D.C. 20554

ATTN: Mr. Ralph Haller
Chief, Monitoring Branch

SUBJECT: Progress Report No. 4 for the period 31 December 1980 to 30 January 1981 on Remote Control of HF Direction Finders (A-2785)

Dear Mr. Haller:

During this work period, we have been involved in the following major activities:

(1) We have continued to collect cost data for various link types, particularly the outstation links in a telephone based network,

(2) We have developed and exercised a network design program which uses a least cost criteria for implementation. This program has been used to study implementation strategies for both telephone and satellite based systems,

(3) We have met in McLean, Virginia, with representatives of Satellite Business Systems (SBS) to obtain cost data on data links provided by their system, and

(4) We have begun to write portions of the final report.

To state project status in terms of the six defined tasks, we have essentially completed tasks one through four, task five is approximately 80% complete, and task six is approximately 50% complete.

Respectfully submitted,

Robert W. Rice, Ph.D.
Project Director

APPROVED:

R. W. Moss, Chief
Communications Systems Division

RWR:ame

A-2785

Georgia Institute of Technology
ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA 30332

February 27, 1981

Federal Communications Commission
1919 N. Street, N.W.
Room 744
Washington, D.C. 20554

ATTN: Mr. Ralph Haller
Chief, Monitoring Branch

SUBJECT: Progress Report Number 5 for the period 1 February 1981 to 28 February 1981 on Remote Control of HF Direction Finders (A-2785)

Dear Mr. Haller:

During this work period, we have completed our study of the automation of the HF DF system. The results of this study have been put in report form, and ten (10) copies were mailed to the FCC on February 26, 1981.

Our activities for the remaining thirty days of this contract will consist of: (1) preparing the required presentation of results and (2) making any modifications to the report which are requested by you during the allowed period. Work on the presentation will proceed under direction given by you in our weekly telephone discussions.

Delivery of the draft report has occurred on schedule, and at this point all other aspects of this project are also on schedule.

Respectfully submitted,

Robert W. Rice, Ph.D.
Project Director

APPROVED:

R. W. Moss, Chief
Communications Systems Division

RWR:ame

FINAL REPORT

REMOTE CONTROL OF THE FCC LONG RANGE HF DIRECTION FINDERS

By

R. W. Rice, Project Director
T. M. Mowery
C. Gilbreath–Frandsen

Prepared for

THE FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C.

Under

Contract FCC–0357

March 1981

GEORGIA INSTITUTE OF TECHNOLOGY

Engineering Experiment Station
Atlanta, Georgia 30332

1981

REMOTE CONTROL OF THE FCC LONG RANGE HF DIRECTION FINDERS

By

R. W. Rice, Project Director
T. M. Mowery
C. Gilbreath-Frandsen

March 1981

Prepared for

THE FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C.

Contract FCC-0357

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia 30332

FOREWORD

This report was prepared by the Communications Technology Division of the Electronics and Computer Systems Laboratory at the Georgia Institute of Technology under FCC Contract FCC-0357. The work described was performed under the general supervision of Mr. F.L. Cain, Director of the Georgia Tech Electronics and Computer Systems Laboratory, and Mr. R.W. Moss, Head of the Communications Technology Division. The project was directed by Dr. R.W. Rice. For the Federal Communications Commission, the contracting officer's technical representative was Mr. Ralph Haller.

Within the Commission, the particular enthusiasm and support for this work by Mr. Elliott Ours of the Field Operations Bureau is also acknowledged. The report preparation efforts of Ms. Ann Evans are appreciated.

TABLE OF CONTENTS

Section		Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF APPENDICES

1. INTRODUCTION

This report describes design work done by Georgia Tech's Engineering Experiment Station for the Federal Communications Commission. The objective of this design has been to identify means to implement an automated direction finding (DF) capability which would permit a central control facility to activate two or more remote high frequency (HF) monitoring sites for the purpose of taking a DF "fix."

The scope of this effort has included defining the structure of the DF site as well as defining the structure of the network which interconnects the DF sites and provides the mechanism for a coordinated DF capability. At the DF site, our design includes definition of the involved hardware and the associated interfaces. Where possible, commercially available hardware has been utilized to realize the required capabilities. Given the stated functional requirements for this network, little variation in structure or cost of the local DF system has been possible.

The major variable in the alternatives studied has been the structure of the communications network. The variability in the network structures manifests itself in (1) service supported, (2) system responsiveness, (3) fault tolerance, and (4) cost. Our approach to the various network structures has been to put into perspective the cost-performance relationship. This has been done by defining several reference structures which represent least-cost implementations of a given network capacity. Variations on these structures are then presented. The variations offer some additional advantage when compared with the reference structure, and the cost of this additional feature may be determined by comparison of the cost of the reference case to that of the particular structure of interest.

2. Present Monitoring/DF Operations

2.1 Washington-Based Activity

The present DF network has a primary and secondary control center. The primary center is located in the FCC's offices in Washington, D.C., and the secondary center is located at the Commission's Grand Island, NE. monitoring site. All of the CONUS (Continental U.S.) nodes in the present DF network are connected by a Private Line Teletype (PLT) circuit. A back-up communications capability using High Frequency (HF) radio is available and is based at the Grand Island site.

To understand the functioning of the present network, which is to serve as the base-line for the design effort, it is important to understand the function of the Washington control site. The Washington facility does <u>not</u> possess sufficient direct monitoring or any DF capability of its own. This facility serves primarily as an administrative entity. It is responsible for coordinating the DF network activity, and it is the point through with the results of DF activity flow to other governmental bodies both within and external to the FCC.

2.2 Review of Present Field Site DF Operations

Operation of the DF network as currently practiced begins when the need to identify the origin of a signal arises, and it appears that there are three means by which this need can arise:

(1) An FCC employee in the course of doing routine monitoring can encounter a signal, the source of which, in his judgment should be determined;

(2) An individual may call a local FCC office with either information about a distress situation or a complaint about some form of interference which leads an FCC employee to utilize the DF facility to resolve the problem;

(3) An individual, company, or government uses formal channels to contact the FCC in Washington on a matter which leads to the activation and use of the DF facility.

There are large areas of similarity for the three situations described above. The major difference is that in the third situation, monitoring/DF activity is initiated remotely (from Washington) rather than locally (at a given monitoring/DF site). In any event we shall now trace the operational activity from the point at which the local FCC operator is aware that there is a requirement for a DF fix.

The operator proceeds to activate the scanning antenna (type C or W) and then proceeds to adjust the receiver to receive the signal of interest. Activation of the scanning antenna consists of the following:

(1) turning the device on;

(2) selecting the mode of operation (lobe, null, or split mode); and

(3) selection of wideband or preselection modes.

Adjustment of the receiver consists of:

(1) tuning the receiver to the correct frequency,

(2) adjusting the receiver's bandwidth to be consistent with the signal type and/or the adjacent signal situation, and

(3) selecting the appropriate form of demodulation.

Next the operator must establish that he is observing the correct signal. Here it is assumed that the operator is responding to an external request for a bearing. In this case, the operator must be able to match selected features of the signal he is observing with those attributed to the target signal. Using the present PLT-based system, this is done as follows:

(1) The operator at the station originating the request for a fix provides a description of the signal of interest. (Table 2-1 shows the type of modulation information typically provided based upon the transmisssion type).

(2) The operator(s) at the assisting station(s) use the data provided by the PLT circuit to identify the correct signal.

(3) As the stations involved in the fix activity become "synchronized" to the same signal, each station takes a bearing on the signal. The bearing data is obtained from the scanning antenna system and consists of an angle and its complement.

(4) The bearing data are reported by the supporting stations to Washington, D.C. for plotting.

(5) Finally, the various bearings are used to determine the point of origin of the signal. This information may then be turned over to other elements of the Field Operations Bureau (FOB) for handling if the source of the signal is still not clear.

To put the communications to support this activity into perspective, we shall describe the message format which is currently used to alert the DF sites. The message format contains the following elements.

GROUP DESIGNATOR: A two character designator designating which network stations are to participate in the fix.

PRIORITY LEVEL: An indication of the relative importance of the particular problem.

CASE NUMBER: An identifier assigned by the FCC in Washington after the DF station has transmitted relevant information to that office. These numbers are consecutive for a given station over a one month period. (Usually used only for repeated fix attempts on the same signal.)

TABLE 2-1

TYPICAL HF SIGNAL TYPES AND IDENTIFIERS

MODULATION TYPE		IDENTIFYING FEATURES
AMPLITUDE MODULATION	A0	CARRIER FREQUENCY
	A1	CARRIER FREQUENCY, MESSAGE TEXT
	A2	CARRIER FREQUENCY, TONE(S), TEXT
	A3	CARRIER FREQUENCY, CARIER LEVEL, SIDEBAND(S), MESSAGE CONTENT
	A4	CARRIER FREQUENCY, SUBCARRIER FREQUENCY,
	A9	CARRIER FREQUENCY, TONE(S)
FREQUENCY MODULATION	F1	MARK FREQUENCY, TONE FREQUENCY, TEXT
	F2	CARRIER FREQUENCY, TONE FREQUENCY, TEXT
	F3	CARRIER FREQUENCY, PEAK DEVIATION, MESSAGE CONTENT
	F4	CARRIER FREQUENCY, PEAK DEVIATION

SIGNAL FREQUENCY: This is the measured/observed frequency of the signal of interest. Assuming a required frequency resolution of 10 Hz, this would be an eight (8) character string of the form XX.XXXXX.

EMISSION DESIGNATOR: This is a three (3) character identifier which categorizes the modulation type of the subject signal.

ALERT SERIAL NUMBER: An identifier assigned by each DF facility which includes the site designator, date of the month, and GMT time (9 characters). Several alert serial numbers may be assigned per case number.

DATE: At present, only the date of the month of an alert and the fiscal year is transmitted over the PLT network. A separate monthly log is maintained recording complete dates, alert serial numbers, and other relevant data.

TIME: This item identifies the time at which the request for a fix was first requested and it takes the form of a five (5) character term of the form XXXXZ.

In addition to the alert message, the PLT network provides the capability for the exchange of coordinating information. This traffic exchange is highly variable but typically involves numerous short messages of about 50 to 100 characters per message.

The actual load on DF facilities across the country must also be considered when determining an appropriate communications network.

The statistics normally available from official records reflect only formal DF activity (where a caseload number is assigned), and underestimate the amount of actual activity overall. Figure 2-1 shows the formal DF activity for the network over approximately a 10 year period.

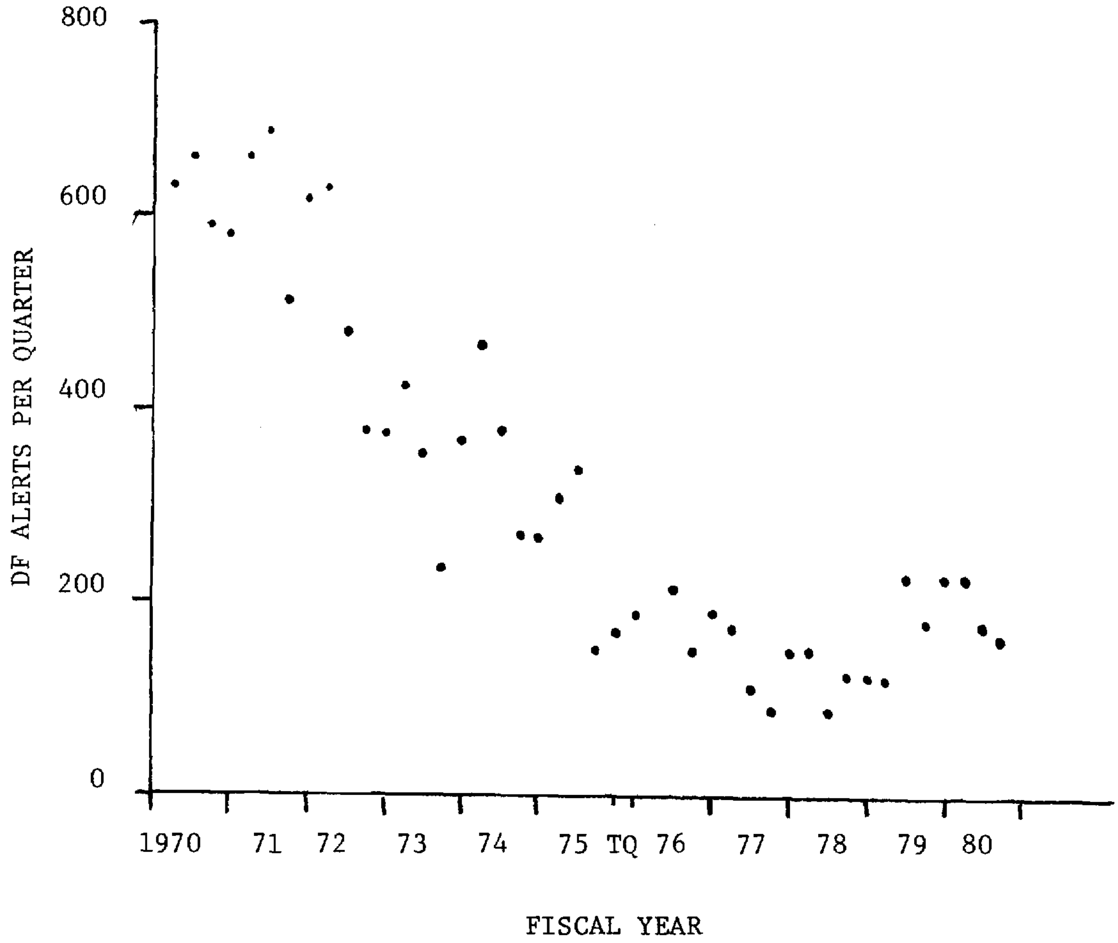


Figure 2-1 Formal DF Alert Activity by Fiscal Year

In an effort to get a quantitative understanding for specific load requirements at each site, a survey was conducted during November, 1980. The continental sites were queried by telephone; Alaska and Hawaii, through correspondence. The results of this survey are presented in tabular form in Appendix C of this report.

On the average, sites are engaged in formal and informal activity about 2 hours over a 24 hour period. However, a minimum of less than one hour and a maximum of 4 hours were also reported. This interval includes time spent in incomplete activities when no bearing was determined as well. Clearly, informal "assists," representing anywhere from 25% to 75% of the total load, introduces a significant factor.

In all cases, the audio portion of the signal is used to some extent, if not heavily, in DF activity. Generally, it is felt that the audio is quite important for signal identification and transmission. As the survey indicates, this unanimous report of the critical nature of audio in DF activity underscores the requirement by the FCC to transmit the audio portion to the control site. This latter capability appears deceptively simple and must be addressed differently, depending on the network configuration selected.

Directly related to audio transmission is the non-DF function of "speaker watch" in which all sites participate. A "speaker watch" means, essentially, that a receiver is tuned to the frequency in question. The audio is left "on," permitting the operator to listen for activity while performing other duties. Currently, each site has at least two receivers, one of which can be used for speaker watch activity. To accommodate the remote control aspect of the new system, however, one site will not be able to perform watch and DF activites simultaneously without considerable expense in duplication of equipment.

"Speaker Watches" are typically 2-3 hours in length and sites reportedly participate in some watch activity about once per 24 hour period, on the average. The maximum reported is about 3 watches per 24 hours and the minimum about once per week. It should also be noted that from time to time, speaker watches are continuous for one or more days.

As the FCC has stated that continued "speaker watch" activity should be anticipated, this aspect of site activity introduces a considerable load factor to the audio transmission requirements. So much so that the cost effectiveness of some network alternatives are impacted significantly.

Another feature having network loading implications, is that of spectrum analyzer use. Sites report moderate use of the analyzer, and the analyzer is not used typically in DF activities. It is used, however, for analysis of complex signals, for signal verification, and is reported to be very useful in the "sync-ing" process, enabling operators to be certain that they are locating the signal in question. Although used as infrequently as 10% of the time, operators stress that when needed, information from the spectrum analyzer is critical to a successful activity.

Transmitting the data from the analyzer over the network becomes important in the area of transmission speed, or analyzer data update. If the central operator can live with slow updates, on the order of 1 minute to 5 minutes, a land-line configuration is capable of supporting the required transmission speed. However, if quicker update is required, facilitating faster overall DF capabilities, then high speed channels are required such as wideband terrestrial lines or satellite channels.

The back-up HF system engaged when the PLT network fails is performing adequately, albeit slowly, to date. Reports of PLT reliability vary widely; however, on the average, sites activate their back-up HF equipment about once per week with the maximum and minimum running from twice per week to once per month. The once per week activation estimate is based upon a survey of DF site personnel described in Appendix C, and the estimated frequency of activation was in response to questions specifically discussing failure of the PLT network. It is therefore assumed that this estimate is exclusive of HF radio activation for testing purposes. The procedure is usually to activate the transmitter and then to place it on "stand by" as it often happens that the communications outage is relatively brief.

There is an advantage to maintaining the present back-up system--the equipment is paid for and essentially incurs no cost at present. However, Grand Island reports that although the present net provides adequate back-up, if the load were to increase, the equipment and current configuration would be stressed considerably. Additionally, Grand Island points out that not all sites have adequate HF transmitters and facilities for reliable back-up systems.

As to the issue of anticipated load increase, opinions vary to some extent. Experience has reflected a decline in overall DF activity. A number of those interviewed feel that the decrease will continue due to increased satellite usage. All anticipate possible increases due to "third world" activity. Mention was made of the fact that increased public awareness of the sites' enforcement role may cause some increase in load. However, the overall feeling was one of uncertainty in this area.

As to specific site problems, the one most mentioned concerns residential and industrial encroachment. This is particularly a problem at the California and Florida sites and is anticipated to be a problem in Nebraska.

3. OPERATING REQUIREMENTS

3.1 Functions to be Performed

At present, the 13 direction finding facilities utilize essentially a hybrid communications network comprised of private line teletype service (PLT) and HF radio. This configuration provides adequate service to presently manned facilities.

The anticipated system must include two independent control sites with complete remote control of direction finding equipment at the remote sites. Each control site must be able to receive either data or audio signals from one or more remote sites upon command. Although local sites will have the ability to initiate activity, control sites will have priority. Since the DF activities are anticipated to be initiated in response to requests from the Coast Guard, another government agency, or another field office, use of the present manual scanning mode is not anticipated to be necessary. However, a means of communicating an address or telephone number to report problems to the central office should be provided at each remote facility, enabling individuals to report emergencies or interference problems.

Interaction between remote facilities should be feasible. Routing such communications through the control site or through a multipoint channel is acceptable.

3.1.1 Control Site

The control facility must have simultaneous and near-instantaneous command capability of the entire network. A command distribution period on the order of 0.5 seconds is acceptable. The command instruction is estimated at 100 bytes. A set-up period to alert and activate the remote facilities must be not greater than 30 seconds, preferably on the order of 10 seconds or less. It is preferable that the data links be of the dedicated, full-time variety. Command and access time to the sites in Alaska, Hawaii, and Puerto Rico must meet these requirements.

The control site must be able to receive either data or audio upon command. Telephone-grade transmission of the audio signal is acceptable. The control site must be able to receive data or audio transmissions from at least two remote facilities simultaneously.

The control facility must have override capability to preempt any activity of lower priority as initiated by a remote site. The capability to scan for DF site status, intrusion, or fire alarms, etc., would be desirable.

The computer at the control facilities may or may not be fully redundant with automatic failover. However, an alternate control site, with completely replicated facilities, capable of all network control functions, will provide back-up control to the Washington, D.C. operation.

3.1.2 Remote Facilities

Each remote site, including those in Alaska, Hawaii, and Puerto Rico, must be alerted and activated in the time interval defined in 3.1.1. Results, however, need not be reported instantaneously. Polling for fix data by the central site may be completed over a 30 minute interval.

Each direction-finding facility must be remotely controllable by both control sites. However, an operator at any site must be able to initiate activity. That activity may be preempted by the control facility and at no time, can the remote site access the network during a priority activity.

Data loads can be anticipated to be on the order of 3000 bytes, which may include information from the spectrum analyzers (see 3.2). Audio loads may involve transmissions of several hours, continuously.

It is desirable that the controllers at the remote facilities control as much of the local equipment as possible in order to minimize the transmission load on the network. To this end, results should be stored at the remote facilities until polled by the control site.

3.1.3 Expandability

System expandability is an extremely desirable feature. At present, the PLT is used for administrative communications as well as for direction finding related functions. It is anticipated that this practice will continue with whatever new system is implemented.

Additional functions are anticipated to include security alarm scans, report generation, bulk transmission of data from other non-DF related site activities, and teleconferencing.

However, it should be stated that the primary purpose of the upgraded network is to provide remotely controllable communications capability to the DF network and that the DF functions would have priority over any other activity such as those defined above.

Overall system requirements are delineated in Appendix A of this report.

3.2 Data to be Exchanged

3.2.1 Control Site-to-DF-Site

The system must provide service at least equivalent to that provided presently. The command instruction to be received by all sites, has been estimated at 100 bytes. The total permits wide flexibility in terms of growth and modifications. Specific character allocations as per function parameters are delineated in Table B-1 of Appendix B.

The address function essentially provides bookkeeping information and alerts, through the station identifier, to the site(s) to be activated. The priority code will also include override capabilities for the control site. The function code informs the site as to the type of activity to be performed, such as direction finding, administrative, or teleconferencing.

The HF receiver would be "on" continuously. For this reason, no "activate" command will be necessary. However, an activate command will be necessary for the antenna.

A switching command to send either audio or data back to the control site is required. The ability to switch back to data once in the audio mode is also required, thereby by providing total remote control of the system.

If the data mode is selected, the remote site should be able to return upon command either basic bearing information or spectrum analyzer information. The latter will probably consist of a time averaged spectrum thereby requiring the parameters delineated in Appendix B.

Formulas for computations, printout formats, diagnostics, and the like will not be transmitted as they will be stored at the appropriate computer.

3.2.2 DF Site-to-Control Center

The control center will poll each DF site to obtain responses to commands. The minimum data return will consist of bearing information (including bearing reciprocals as is now the practice), and confidence data. Spectrum analyzer data, estimated at 1,000 characters will probably consist of time-averaged frames to aid in signal analysis, and will not be routinely requested by the control center.

Control parameters used to acquire the data requested may be returned upon the central operator's request. The operator may want to verify that the parameters used by the remote facility match those transmitted initially. The operator may further wish the return of parameters on a specific piece of equipment only (i.e., receiver, antenna or spectrum analyzer). Return of these parameters upon command is more efficient than automatic return of all information.

A command from the control site requesting the return of audio will result in the appropriate switching and the return of the audio signal through voice-grade lines. Transmission of audio will terminate and/or be switched back to data upon command.

Capability for manned as well as remote control of the DF equipment will be provided at each DF site. An operator at a remote site may initiate activity, assist another facility, or communicate with the control site. However, all such site initiated activity can be preempted by a priority activity from the control site.

4. COMMUNICATIONS OPTIONS/CHARACTERISTICS

The type of communications channel used has an impact both upon system performance and system cost. Because of this, several different channel types have been examined including telephone channels, both leased and dial-up (DDD); satellite, both the specialized common-carrier approach and the co-located earth station approach; and high frequency (HF) radio. For the sake of brevity, the various alternatives have been designated alphabetically. The designators along with a brief description of each alternative are listed below. A more detailed description of each of the alternatives may be found in Section 5 of this report.

Alternative Designator	Type of Channel Employed	Network Configuration
A	Leased, Series 1000 Telephone	Star
B	Leased, Series 3000 Telephone	Star
C	Leased, Series 1000 Telephone	Multi-drop
D	Leased, Series 1000 Telephone	Store-and-Forward Loop
E	Leased, Series 3000 Telephone	Multi-drop
F	Dial-Up Telephone (DDD)	Star
G	Dial-Up Telephone (WATS)	Star
H	Leased Satellite Transponder	Star
I	Leased Satellite Earth Station	Star
J	Leased Satellite Channel/Telephone Lines (Series 3000)	Star/Multi-drop

4.1 Common Carrier (Terrestrial)

The terrestrial common carriers offer a wide variety of services that are potentially applicable to the task of creating a DF communications network. The first major division of these services is based upon link access. In the dial network (DDD), a link is established by the user at the particular time when communications is required, the particular connection between link end-points is dynamically chosen by the common carrier, and therefore, the user is not guaranteed exactly the same channel characteristics on any two calls. Typical channel variations are generally not sufficient to be problematic for voice-type communication; however, the variations can be sufficient to make a noticeable difference in data transmissions where modems are employed which use fixed equalization. To overcome this problem, modems employing adaptive equalization are commonly used in dial networks. It should be pointed out that the adaptive modems are generally more expensive than the fixed variety.

The alternative for the terrestrial common carrier to the dial network is the private line arrangement. In this case, a permanent connection is established between two or more points, and therefore, it is not necessary for the user to place a call to establish the link between the involved points. Also, since the link is permanently dedicated to a given user, the link characteristics tend to be very stable. Here fixed equalization modems may be employed effectively.

The second major division of terrestrial common carrier service is based upon the type of channel provided. In general, the DDD network can only provide a single channel type: voice-grade. This is the conventional telephone channel which has been designed and to a degree optimized for voice communication. It typically provides approximately 3 kHz of audio bandwidth which is generally considered to result in reasonable voice quality. This same 3 kHz is also usable for digital communication and is generally the channel feature which constrains the data transmission speed. In particular, it is generally accepted that a speed of 2400 bits/second (BPS) is the effective upper-bound on transmission speed for a DDD channel.

Leased lines are generally grouped into three broad categories: sub-voice, voice, and wideband. The sub-voice channels are intended for low speed (less than 150 BPS) data communications and will not support voice traffic. These lines are known as Series 1000 lines.

The basic voice-grade line is a Series 3000 line, and its characteristics are essentially the same as those previously attributed to DDD voice circuit. In other words, this channel can alternately support voice or data with an effective upper bound on the data transmission speed of 2400 BPS.

A variety of wideband services are available; however, the service which appears to have the greatest potential for application to the problem at hand is the Series 8000 line. This line is the equivalent of 12 voice-grade lines. It may be configured in a variety of ways ranging from 12 distinct voice-grade channels to a single 56 KPBS data channel.

The important characteristics of these channels are described below.

4.1.1 Leased Lines: Series 1000

For analysis purposes, a Type 1006 line has been chosen to represent the sub-voice service category. This line supports low speed data up to 150 BPS. The other members of the Series 1000 family support noticeably lower transmission speeds at no significant reduction in cost.

The cost of service for a 1006 line has 3 components: the interexchange channel (IXC) cost, station termination cost, and the installation cost. The last item is a one-time charge, but the other items are billed for on a monthly basis. Table 4-1 summarizes these various cost elements.

TABLE 4-1

DOMESTIC COMMERCIAL TARIFF FOR TYPE 1006 LINE

		TYPE OF OPERATION	
ITEM	LENGTH (MILES)	HALF DUPLEX	FULL DUPLEX
INTEREXCHANGE CHANNEL (IXC)	0 - 100	$1.63/MILE	
	101 - 250	$1.63 + $1.31 PER MILE OVER 100	
	251 - 500	$359.50 + $0.84 PER MILE OVER 250	
	501 - 1000	$569.50 + $0.53 PER MILE OVER 500	
	OVER 1000	$834.50 + $0.32 PER MILE OVER 1000	
CHANNEL TERMINATION		$31.55	
STATION TERMINATION		$63.05	$59.40
INSTALLATION COST		$55.25*	

*PER STATION TERMINATION

It should be pointed out that the costs described in Table 4-1 are the current commercial tariffs. At present, the federal government, among others, enjoys a lower rate through the use of the so-called Telpak service. A typical cost-per-mile may be calculated using the Type 5900 (Telpak C) case. The current base capacity tariff for an interstate type 5700 line is $34.15. Since the 5700 line is equivalent to 60 voice-grade circuits, a cost of $0.57/mile is achieved for a voice-grade circuit (rates effective as of increase in June, 1980). Typically, a sub-voice channel, for example a 1006, is treated as one-half of a voice-grade channel; therefore, the cost for this circuit is $0.28/mile.

The preceding costs apply only to domestic lines. Since there are 3 stations in the DF network which are considered as foreign or non-continental US (non-CONUS) sites, the international tariffs and constraints apply. One of the most noticeable constraints for non-CONUS links is that there are a very limited number of foreign gateways; i.e., there are a restricted number of locations at which it is possible to get a direct foreign connection. Because of this, the cost of a foreign connection is the sum of the cost between the foreign location and the appropriate gateway and the cost of the domestic link between the gateway and the user's domestic site. Table 4-2 presents the link costs between the 3 outstations and selected CONUS locations. These cost figures will be used later in a cost analysis of the various network alternatives.

4.1.2 Leased Lines: Series 3000

For analysis purposes, a type 3002 line has been chosen to represent the voice-grade service category. This line can alternately support voice or data. As pointed out earlier, it is generally accepted that the maximum effective transmission speed for such a line is 2400 BPS; however, there are several companies which manufacture 4800 BPS or 9600 BPS modems for use on 3002 lines.

The cost of service for a 3002 line has 3 components: the interexchange channel (IXC) cost, the station termination cost, and the installation cost. Table 4-3 summarizes these various cost elements.

As pointed out in the previous section the Series 1000 lines, the Federal Government typically achieves a cost savings by using the Telpak

TABLE 4-2

COSTS FOR INTERNATIONAL SERIES 1000 LINKS ($/MO)

LINK		LINK TYPE	
FROM	TO	HALF DUPLEX	FULL DUPLEX
ANCHORAGE, AK.	WASHINGTON, D.C.	$2495	$2738
	GRAND IS., NE.	3096	3339
	FERNDALE, WA.	2309	2552
	LIVERMORE, CA.	2757	2757
WAIPAHU, HI.	LIVERMORE, CA.	$ 425	
	WASHINGTON, D.C.	1666	
	GRAND IS., NE.	1308	
SABANA SECA, PUERTO RICO	FT. LAUDERDALE, FL.	$1440	
	WASHINGTON, D.C.	1399	
	GRAND IS, NE.	2095	

TABLE 4-3

DOMESTIC COMMERCIAL SCHEDULE III TARIFF FOR TYPE 3002 LINE*

ITEM	LINE LENGTH (MILES)	TYPE OF OPERATION	
		HALF DUPLEX	FULL DUPLEX
INTEREXCHANGE CHANNEL (IXC)	1	$58.57	
	2-14	$58.57 + $4.86 for each mile over 1 mile	
	15	$126.61	
	16-24	$126.61 + $4.20 for each mile over 15 miles	
	25	$168.61	
	26-39	$168.61 + $3.09 for each mile over 25 miles	
	40	$214.96	
	41-59	$214.96 + $2.32 for each mile over 40 miles	
	60	$261.36	
	61-79	$261.36 + $1.77 for each mile over 60 miles	
	80	$296.76	
	81-99	$296.76 + $1.49 for each mile over 80 miles	
	100	$326.56	
	101-999	$326.56 + $ .75 for each mile over 100 miles	
	1000	$1,001.56	
	Over 1000	$1,001.56 + $.44 for each mile over 1000 miles	
CHANNEL TERMINATION	No channel termination charge provided leased lines cross state boundaries, i.e. become interstate lines.		
STATION TERMINATION		$26.30/mo. per termination	
INSTALLATION COST		$56.90 per installation point	

*Costs reflect tariffs proposed October, 1980. The rate increase was denied in the course of writing this report. For present tariff charges for 3002 lines, see Appendix E.

arrangement. It was previously shown that for Telpak C, the cost of a voice-grade (3002) channel is $0.57/ mile per month.

The costs defined in Table 4-3 are for the domestic links. Table 4-4 defines the costs for the foreign (non-CONUS) links.

4.1.3 Dial-Up Lines: DDD

Two dial network alternatives have been studied in this design effort. An approach using the conventional Direct Distance Dial (DDD) network is described in this section. An approach using the Wide Area Telecommunications Service (WATS) is described in Section 4.1.3.

The attraction of the dial network is that one pays for service on an as-used basis. Leased lines are in place 24 hours per day. If one's communications needs are fairly consistent then the lower cost-per-unit time rate associated with a leased line becomes attractive. On the other hand, if communications needs are irregular in nature, then the dial-up alternative may be financially attractive. The critical factor of the dial network configuration thus becomes the level of utilization. This issue will be addressed in Section 6. Table 4-5 shows the line costs for a Washington D.C.-based DDD network. Table 4-6 shows the line costs for a Grand Island, Nebraska-based DDD network.

4.1.4 Dial-Up Lines: WATS

At present, there are two forms of WATS which may be suitable for use in the DF network--the full business day version and the measured time version. The former has a base monthly rate which covers 240 hours/month of connect time, and all connect time beyond this amount is billed at a flat hourly rate. The measured time version has a base monthly rate which covers 10 hours/month of connect time, and all connect time beyond this amount is billed at a flat hourly rate.

A feature which both forms of WATS share is the concept of service zones. A zone is a region around the customer's service location which is accessible through WATS and is covered by the WATS agreement that the customer has with the local telephone company. In general, there are several zones defined for any CONUS customer location, and as might be

TABLE 4-4

COSTS FOR INTERNATIONAL SERIES 3000 LINKS ($/MO,)

LINK		COST
FROM	TO	
ANCHORAGE, AK.	WASHINGTON, D.C.	$3207
	GRAND IS., NE.	3921
	FERNDALE, WA.	3095
	LIVERMORE, CA.	2900
WAIPAHU, HI.	LIVERMORE, CA.	$2513
	WASHINGTON, D.C.	3953
	GRAND IS., NE.	3460
SABANA SECA, PUERTO RICO	FT. LAUDERDALE, FL.	$2226
	WASHINGTON, D.C.	2057
	GRAND IS., NE.	3054

TABLE 4-5

DDD RATES FOR WASHINGTON D.C.
BASED DF NETWORK (8 AM - 5 PM TARIFF)

POINT CALLED	RATE
ALLEGAN, MI.	55¢ + 38¢/MIN.
ANCHORAGE, AK.	79¢ + 65¢/MIN.
BELFAST, ME.	55¢ + 38¢/MIN.
DOUGLAS, AZ.	57¢ + 40¢/MIN.
FERNDALE, WA.	60¢ + 42¢/MIN.
FT. LAUDERDALE, FL.	55¢ + 38¢/MIN.
GRAND ISLAND, NE.	57¢ + 40¢/MIN.
KINGSVILLE, TX.	57¢ + 40¢/MIN.
LAUREL, MD.	30¢ + 15¢/MIN.
LIVERMORE, CA.	60¢ + 42¢/MIN.
POWDER SPRINGS, GA.	55¢ + 40¢/MIN.
SABANA SECA, P.R.	57¢ + 40¢/MIN.
WAIPAHU, HI.	73¢ + 55¢/MIN.

TABLE 4-6

DDD RATES FOR GRAND ISLAND, NE.
BASED DF NETWORK (8 AM - 5 PM TARIFF)

POINT CALLED	RATE
ALLEGAN, MI.	55¢ + 38¢/MIN.
ANCHORAGE, AK.	71¢ + 54¢/MIN.
BELFAST, ME.	57¢ + 40¢/MIN.
DOUGLAS, AZ.	55¢ + 38¢/MIN.
FERNDALE, WA.	57¢ + 40¢/MIN.
FT. LAUDERDALE, FL.	57¢ + 40¢/MIN.
KINGSVILLE, TX.	55¢ + 38¢/MIN.
LAUREL, MD.	57¢ + 40¢/MIN.
LIVERMORE, CA.	57¢ + 40¢/MIN.
POWDER SPRINGS, GA.	55¢ + 38¢/MIN.
SABANA SECA, P.R.	60¢ + 42¢/MIN.
WAIPAHU, HI.	70¢ + 53¢/MIN.
WASHINGTON, D.C.	57¢ + 40¢/MIN.

expected, the larger the coverage area, the greater the fee for the WATS line. Table 4-7 defines the pertinent zones for the two prospective control sites. Tables 4-8 and 4-9 show the rates for these two versions of WATS. Of particular interest for later analysis will be the column labeled "Breakpoint."

The measured time WATS is obviously intended to offer WATS to the low volume user. It has a lower base fee than does the full WATS, but the incremental cost for the measured service is much higher than for the full service. Therefore, there is a point at which service provided under a measured time WATS agreement will cost as much as service provided under a full WATS agreement. The value in the breakpoint column is that point in hours of connect time per month.

4.2 Specialized Common Carriers (Satellite)

An alternative to the terrestrial common carrier is the satellite-based specialized common carrier. As may be observed from the discussion in Section 4.1, the terrestrial common carrier's offerings are presently structured around the standard voice-grade channel. The satellite systems on the other hand are inherently flexible in the types of channels that can be provided, especially where an earth station can be co-located with the user's facility.

For evaluation purposes, the satellite systems have been recognized to have two major elements: earth stations and space segments. Cost data has been accumulated which will permit the economic advantages/disadvantages resulting from owning or leasing these elements to be evaluated. This information is presented in the following sections.

One of the alternatives investigated was the feasibility of sharing satellite service with another government agency. Federal entities currently employing satellites are NASA, the Department of Commerce (weather satellites), and the Department of Defense. However, none report that space is available at this time for shared use by the FCC with its present DF network load demands.

There is an effort just now being organized through the National Telecommunications Information Agency (NTIA) to coordinate the load

TABLE 4-7

WATS SERVICE ZONES FOR WASHINGTON, D.C.
AND GRAND ISLAND, NE.

ORIGINATION POINT	ACCESSIBLE LOCATIONS BY ZONE					
	1	2	3	4	5	6
WASHINGTON, D.C.	MD.		GA. ME. MI.	FL.	AZ. CA. NE. P.R. TX. WA.	AK. HI.
GRAND ISLAND, NE.			TX.	AZ. MI.	CA. D.C. FL. GA. ME. MD. WA. P.R.	AK. HI.

TABLE 4-8

WATS (OUTBOUND) RATES FOR WASHINGTON, D.C.

ZONE	FULL WATS		MEASURED WATS		BREAK POINT (HRS./MO.)
	BASE ($/MO.)	ADDITIONAL HRS. ($/HR.)	BASE ($/MO.)	ADDITIONAL HRS. ($/HR.)	
1	946	2.63	206	15.45	57.9
2	1382	3.84	230	17.27	76.7
3	1650	4.58	242	18.13	87.7
4	1729	4.79	251	18.85	88.4
5	1761	4.89	258	19.32	87.8
6	3144	8.73	337	24.18	126.0

TABLE 4-9

WATS (OUTBOUND) RATES FOR GRAND ISLAND, NE.

ZONE	FULL WATS		MEASURED WATS		BREAK POINT (HRS./MO.)
	BASE ($/MO.)	ADDITIONAL HRS. ($/HR.)	BASE ($/MO.)	ADDITIONAL HRS. ($/HR.)	
1	1472	4.09	235	17.66	80.0
2	1650	4.58	242	18.13	87.7
3	1713	4.75	248	18.61	88.7
4	1729	4.79	251	18.85	88.4
5	1745	4.85	254	19.08	88.1
6	2874	7.98	316	22.26	124.9

demands of several small agencies and have them negotiate as one buyer with the common carriers. However, the service as is now envisioned requires each agency to use the transponder space in certain allocated time intervals only. For example, a participating agency may only be able to transmit via satellite between 4 a.m. and 6 a.m. each day. Clearly, such a restriction precludes utilization of this shared satellite approach by the FCC for the DF function. However, since this is a new service still in its conceptual stages, it may be worthwhile to recheck with NTIA at the time of anticipated system implementation.

4.2.1 Leased Transponder Approach

In this approach, the common carrier will lease transponder capacity to a given user, and the user is responsible for all other system elements and functions: earth station hardware, maintenance, etc.

To be able to assign a cost to earth station equipment for this approach, it is necessary to have a reasonable idea of the required transmission capacity. As a first approximation, we have assumed that a capacity equivalent to a voice-grade circuit is required. Since much satellite communications at this time is digital in nature, it is therefore necessary to translate this voice-grade circuit capacity into an associated data transmission speed. Continuously Variable Slope Delta (CVSD) Modulation is commonly employed for voice transmission over satellite links. Typically the CVSD codecs operate at 32 KBPS. A commonly available service is a 56 KBPS capability which can be used to multiplex a 32 KBPS CVSD voice channel with a data stream with a maximum speed of 24 KBPS. This service was judged to be appropriate for the FCC's DF network; therefore, the following cost figures are for such a 56 KBPS service.

A typical satellite transponder provides 36 MHz of usable spectrum, and the cost for transponder capacity is in general proportional to the percentage of transponder spectrum occupied by the signal in question. If binary phase shift keying (BPSK) is used, the required bandwidth is 84 kHz. For quarternary phase shift keying (QPSK), the required channel bandwidth is 42 kHz. The transponder cost for these channels is presented in Table 4-10.

TABLE 4-10

COST ELEMENTS FOR A TYPICAL LEASED TRANSPONDER CAPACITY SYSTEM

ITEM	COST
EARTH STATION HARDWARE:	
REDUNDANT -	$180,000
NON-REDUNDANT -	$ 75,000
EARTH STATION INSTALLATION	$ 20,000
TRANSPONDER LEASE:	
PROTECTED SERVICE -	$1,350,000/YR.
UNPROTECTED, UNINTERRUPTABLE SERVICE -	$1,050,000/YR.
UNPROTECTED, INTERRUPTABLE SERVICE -	$500,000/YR.
SINGLE CHANNEL (42 kHz) LEASE:	
PROTECTED SERVICE -	$1,575/YR.
UNPROTECTED, UNINTERRUPTABLE SERVICE -	$1,225/YR.
UNPROTECTED, INTERRUPTABLE SERVICE -	$ 583/YR.

4.2.2 Leased (Co-located) Earth Station Approach

Another alternative available to the perspective satellite user is that of a complete end-to-end service provided by one of the specialized common carriers. In this case, the carrier assumes full responsibility for the complete communications service. As pointed out in Section 4.2.1, a variety of services are available from the satellite carriers. For evaluation purposes, the service chosen for comparison with the terrestrial alternative is a 56 KBPS capability which can support simultaneous voice and data transmissions.

The grade of service provided also influences system cost. First, one must consider whether protected or unprotected service is required. Essentially, there are three levels of service offered by common carriers. The first level, and the most costly, is the fully protected service. This service provides a completely redundant system, that is, should the transponder or satellite itself fail or be disabled, a back-up unit is available for complete and immediate back-up.

The next level of service is unprotected, uninterruptible service. No redundancy is available in this configuration. The third and least expensive level of service, unprotected, interruptible, is also non-redundant. However, the services is preemptable. Essentially, the transponder space is actually the back-up channel for another customer. Failure in the primary user's normal channel causes the secondary user's service to be interrupted by the primary user's activity. The FCC's requirement for continuity of service tends to dictate that a protected service be employed; therefore, the alternatives presented are for that level of service. It should be pointed out that an access reliability of 99% is typical for the alternatives presented. 99% reliability is the overall service projection based on reliability of equipment in nonredundant, or single-strand, earth stations. Outage is estimated at 7 hours, maximum, per month, occurring randomly. Higher levels of reliability or the order of 99.5% and 99.9% are available at higher costs. These latter levels, however, typically involve redundant, or double strand, earth stations.

Table 4-11 identifies the cost elements for the type of service described above as provided by three of the major satellite carriers.

4.2.3 Leased Transmission Approach

It is also possible to obtain transmission service from satellite carriers without having earth station equipment located at the user's site. In this case, the user typically employs terrestrial links, telephone or microwave, to connect his facility to a major earth station owned and operated as a common carrier facility by the satellite carrier. At present, this type of service is available at very few locations; therefore for this application, the satellite link would serve as a long distance trunk with the control site at one end of the trunk and one at a more remote sites tied to the other end of the trunk.

Table 4-12 presents typical costs for voice channel service between various locations served by American Satellite Company, and Table 4-13 presents similar data for service provided by RCA.

4.3 High Frequency (HF) Radio

The FCC currently uses an HF radio system as a back-up communications channel for the DF network. Experience in this and other applications has shown that such HF links are workable; however, their performance is highly variable. Described below are the basics of such a system, assuming that none of the existing HF hardware would be employed in the implementation of the new network.

High frequency (3 MHz - 30 MHz) electromagnetic propagation offers a viable alternative for system communications. HF propagation occurs in two forms: ground wave propagation and ionospheric propagation. The extent of ground wave propagation varies with the effective horizon which is a function of atmospheric conditions, terrain and frequency. Ionospheric propagation involves waves which are refracted by "excited" layers in the earth's atmosphere.

The structure of the ionosphere and its frequency dependent properties provide a means for propagation over long distances, considerably farther than the horizon. The ionosphere is composed of

TABLE 4-11

SERVICE COST FOR LEASED, CO-LOCATED 56 kBPS SATELLITE SERVICE

CARRIER	SERVICE TYPE	CENTRAL HARDWARE	REMOTE HARDWARE	SATELLITE CHANNELS
WESTERN UNION	SINGLE STRAND	$25,000/MO. (INCLUDES CHANNEL COST)	$9,000/MO. (INCLUDES CHANNEL COST)	
AMERICAN SATELLITE COMPANY	SINGLE STRAND	$10,000/MO. FOR FIRST LINK (CONUS)	$6,000/MO. FOR ADDITIONAL CONUS LINKS $7,500/MO. EACH FOR HAWAII, PUERTO RICO $8,000/MO. FOR ALASKA	
RCA	DOUBLE STRAND	$5,500/MO.	$3,500/MO. (CONUS) $5,250/MO. (ALASKA, HAWAII) $2,520/MO. (PUERTO RICO)	$1,500/MO. (CONUS) $1,500/MO. (ALAAKA, HAWAII) $2,250/MO. (PUERTO RICO)

TABLE 4- 12

TYPICAL COST FOR VOICE-GRADE CIRCUITS
PROVIDED BY AMERICAN SATELLITE COMPANY ($/MO.)

	ATLANTA	CHICAGO	DALLAS	HOUSTON	LOS ANGELES	NEW YORK	SAN FRANCISCO	WASHINGTON, D.C.
ATLANTA	--	530	530	530	780	530	780	530
CHICAGO	530	--	530	530	670	530	670	--
DALLAS	530	530	--	--	670	670	575	575
HOUSTON	530	530	--	--	575	575	575	575
LOS ANGELES	780	670	670	575	--	--	--	780
NEW YORK	530	530	670	575	--	--	780	--
SAN FRANCISCO	780	670	575	575	--	780	--	780
WASHINGTON, D.C.	530	--	575	575	780	--	780	--

TABLE 4-13

TYPICAL COST FOR VOICE GRADE CIRCUITS PROVIDED BY RCA AMERICAN COMMUNICATIONS

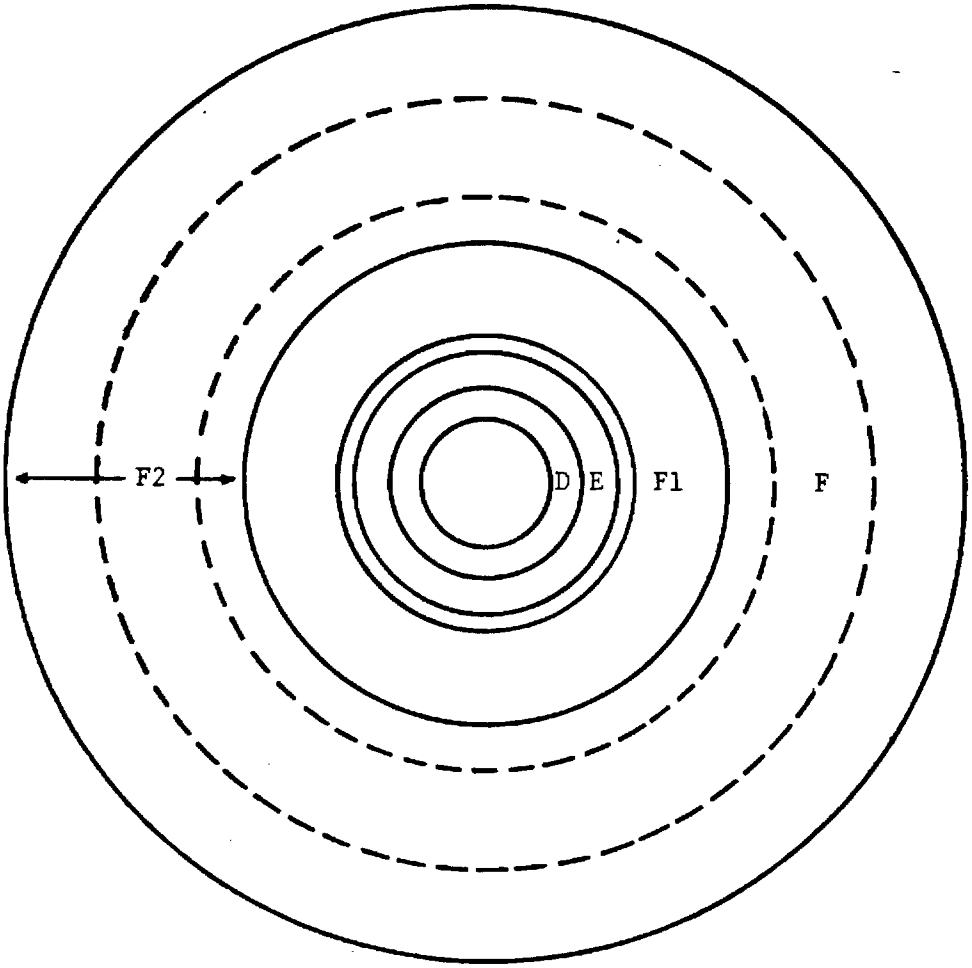
	ATLANTA	CHICAGO	DALLAS	HOUSTON	LOS ANGLES	NEW YORK	PHILADELPHIA	SAN FRANCISCO	WASHINGTON, D.C.	WILMINGTON
ATLANTA	--	700.	700.	700.	940.	700.	700.	940.	--	--
CHICAGO	700.	--	700.	700.	740.	700.	700.	740.	700.	700.
DALLAS	700.	700.	--	--	700.	700.	740.	700.	--	--
HOUSTON	700.	700.	--	--	700.	700.	740.	700.	860.	780.
LOS ANGELES	940.	740.	700.	700.	--	940.	940.	--	940.	940.
NEW YORK	700.	700.	700.	700.	940.	--	--	940.	--	--
PHILADELPHIA	700.	700.	740.	740.	940.	--	--	940.	--	--
SAN FRANCISCO	940.	740.	700.	700.	--	940.	940.	--	940.	940.
WASHINGTON, D.C.	--	700.	--	860.	940.	--	--	940.	--	--
WILMINGTON	--	700.	--	780.	940.	--	--	940.	--	--

basically four layers: D, E, F_1, and F_2, with F_1 and F_2 merging into one layer at night. Figure 4-1 illustrates the structure of the ionosphere. The D layer causes absorption (attenuation) of electromagnetic power which is inversely proportional to the square of the frequency. The E and F layers refract HF waves, and at proper angles of incidence (angles of incidence being a function of frequency) can bend the waves back to earth. It is this phenomenon that makes HF communication so attractive for long distance communication.

High frequency propagation in a point-to-point mode is highly time and frequency dependent because of the variable state of the ionosphere. At any one particular time there is only one frequency band that will support signal-to-noise ratios for intelligible communication. The maximum frequency in this band is referred to as the Maximum Usable Frequency (M.U.F.). Any frequency higher than the M.U.F. will not refract enough in the ionosphere to return to the receiving point. The lowest frequency in this band is called the Lowest Usable Frequency (L.U.F.). Any frequency lower than the L.U.F. will experience too much absorption in the D layer for adequate communication. Figure 4-2 illustrates the band of usable frequencies on daily cycles for a location near London, England.

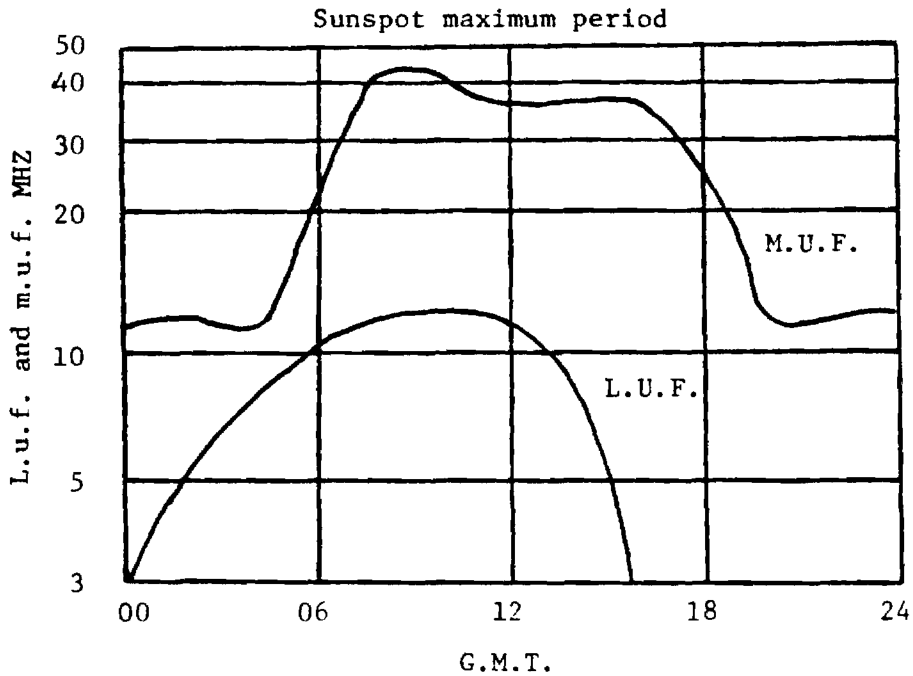
The "skip zone," an area where the HF electromagnetic energy is too low for reception, is encountered because of the finite thicknesses of ionized layers. This phenomenon occurs because there is a critical angle (dependent upon the state of the ionized layer and the frequency of the propagating signal) at which waves escape into space instead of bending back to the earth. At angles just below the critical angle, waves are bent back to earth, but only at a particular distance away. Therefore, there is a certain amount of area (skip zone) present between the upper limits of ground wave propagation and the lower limits of ionospheric refraction propagation. The "skip zone" is a function of frequency, and as a result distances involved in a particular frequency's "skip zone" can often be covered with a lower frequency.

High frequency waves not only "reflect" off the ionosphere, they also reflect off the earth (large bodies of water are particularly good reflectors); consequently, multi-hop propagation is possible. This is the phenomenon necessary for HF communication over great distances.



Layer	Approx. height and layer thickness	Effective period	Effect on h.f. waves (3–30 MHz)	Possible transmission distances by reflection from the layer	
				One hop propagation	Multi-hop propagation
D	70–100 km	Day	Absorption	h.f. waves not reflected	
E	100–140 km	Day	Refraction	Up to 2500 km	All distances except 2500–4000 km
F1	150–250 km	Day	Refraction	Up to 3000 km	Up to 3000 km
F2	250–500 km	Day	Refraction	Up to 4000 km	All distances
F	300–400 km	Night	Refraction	Up to 4000 km	All distances

Figure 4-1 Ionospheric Structure [J.A. Betts, HF Communication, American Elsevier Pub., N.Y.].



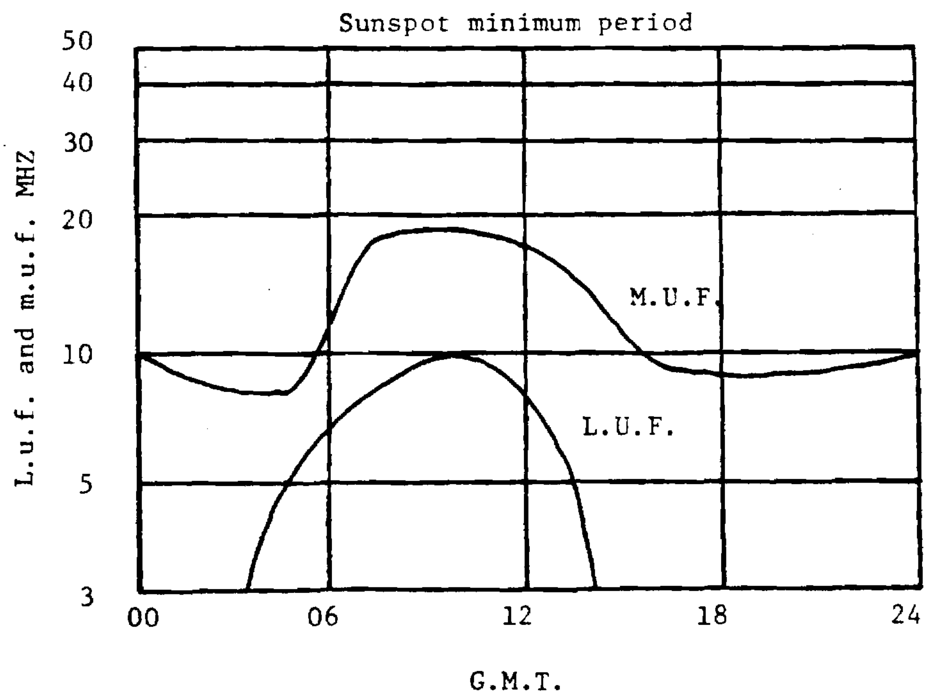


Figure 4-2 Typical Daily L.U.F. and M.U.F. Variations

The state of the ionosphere is the outstanding parameter affecting HF communication, and as a result, variations of its state can cause dramatic changes in the propagation of signals. The ionosphere varies on a daily, seasonal and sunspot cyclical basis. Knowledge of ionospheric conditions at any particular time is necessary in order to achieve a successful communication link.

In the HF radio spectrum, there is a high demand for communication channels; consequently, channel bandwidths are very narrow and the availability of channels is very low. Unfortunately, in order to have a high probability of achieving a propagation path, several channels dispersed over the HF range are often necessary.

Data rates acheivable with HF are primarily a function of bandwidth and multipath distortion. Multipath distortion, caused by different path delay times, results in fading in an analog circuit and pulse duration distortion in a digital circuit. Multipath distortion is usually only critical in a multi-hop path or in single hop cases where the frequency of operation is considerably lower than the M.U.F. In these cases, data rates are often limited to only 100 baud.

As mentioned above, the high traffic density associated with the HF band reduces the choice of modulation systems to those with minimum bandwidth requirements.

Single Sideband (SSB) modulation reduces the required bandwith by a factor of two over double sideband modulation; consequently, single sideband is a very attractive alternative in modulation techniques whenever only limited bandwidth channels are available. Reducing the bandwidth while maintaining the same information flow necessitates a factor of two increase in the data transmission rate. The major drawback of single-sideband modulation techniques is that frequency selective fading effects are more prominent.

If digital data transmission alone is desired, narrow band frequency modulation (FM) techniques can be used. Frequency diversity can be used to overcome multipath problems. This is accomplished by sending the same information at two different frequencies, where frequency separation is determined according to the average path time difference between the dominant hop modes for the circuit. This technique is, of course, accomplished at the expense of increased bandwidth requirements.

4.4 Network Control Systems

The material in Sections 5.1, 5.2, and 5.3 describes the networks which link the control centers and the DF sites together. In this section the structure of the control centers is defined. Note that the particular control center configurations are associated with specific network alternatives. A definition of the network alternatives may be found in Section 5 of this report.

Configurations for the network control centers are shown in Figures 4-3 and 4-4, and 4-13. The configuration shown in Figure 4-3 is appropriate for the low speed, data and networks such as Alternatives A, C, and D. The cost estimates for the hardware and software for such a network control center are shown in Table 4-14. The major cost variations for the different alternatives can be attributed to the differing communications requirements.

Figure 4-4 presents a network control configuration for alternate voice/data operation. This configuration is applicable to Alternatives B, E, F, G, H, I, and J. The modem identified in this structure is not a currently available commercial product. The price estimate for this device appearing in Table 4-15 is based upon: (1) the price of a similar commercial product, the Intertel M2415 modem, which sells for approximately $1000 per unit and (2) an assumed development cost of $50,000.

One other approach is available for the selecting of audio or data for the leased line cases, Alternative B and E. This method utilizes a remotely controlled switch to select the source of audio at a given location. The block diagram of such an arrangement is provided in Figure 4-5. The switch hardware for this approach costs approximately $1400 per installation, with the modem costs running approximately $1000 per installation. Thus, the combined price of $2400 per installation represents a noticeable cost savings when compared to the $3500 cost for the alternate audio/data modem previously described. The disadvantage of this approach is that it requires an operator at the control center to manually place a call to a given DF site to switch the audio on or off. For analysis purposes, the cost of the alternate data/audio modem approach will be used.

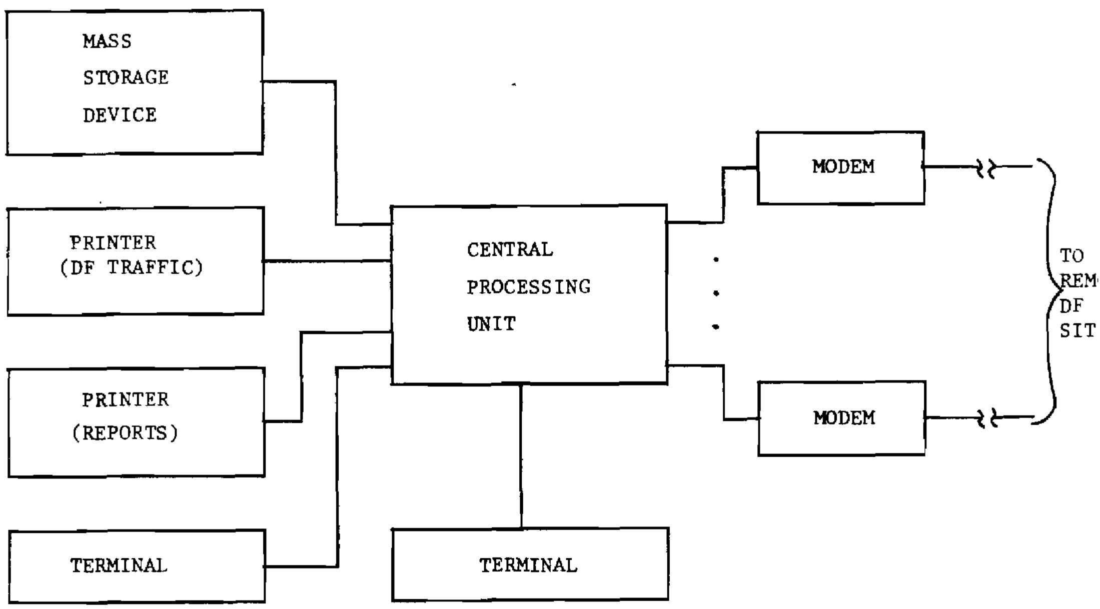


Figure 4-3 Network Control Configuration for Low Speed, Data Only Systems

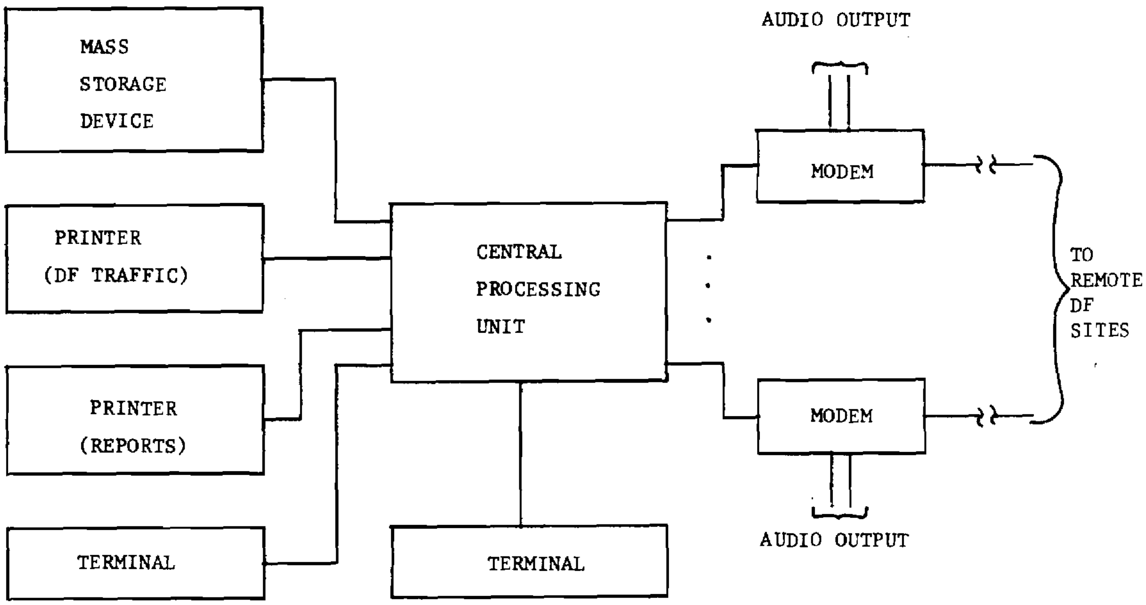


Figure 4-4 Network Control Configuration for Alternate Audio/Data Operation with Automatic Switching for Point-to-Point Configurations

TABLE 4-14

CONTROL CENTER COSTS FOR LOW SPEED, DATA ONLY NETWORKS

ALTERNATIVE	HARDWARE	NETWORK SOFTWARE
A	$47,000	$3,200
C	$40,000	$3,200
D	$40,000	$3,200

TABLE 4-15

CONTROL CENTER COSTS FOR AN ALTERNATE
AUDIO/DATA OPERATION WITH AUTOMATIC SWITCHING

ALTERNATIVE	COMPUTER HARDWARE	NETWORK SOFTWARE	MODEMS
B	$44,640	$3,200	$45,500
E	$42,400	$3,200	$21,000
F	$39,180 (3 LINES) $44,640(13 LINES)	$3,200	$10,500 (3 LINES) $45,500(13 LINES)
G	$39,180 (3 LINES) $144,640(13 LINES)	$3,200	$10,500 (3 LINES) $45,500 (13 LINES)
H (FDM APPROACH)	$42,400	$3,200	$45,500
I	$42,400	$3,200	$45,500
J	$42,400	$3,200	$24,500

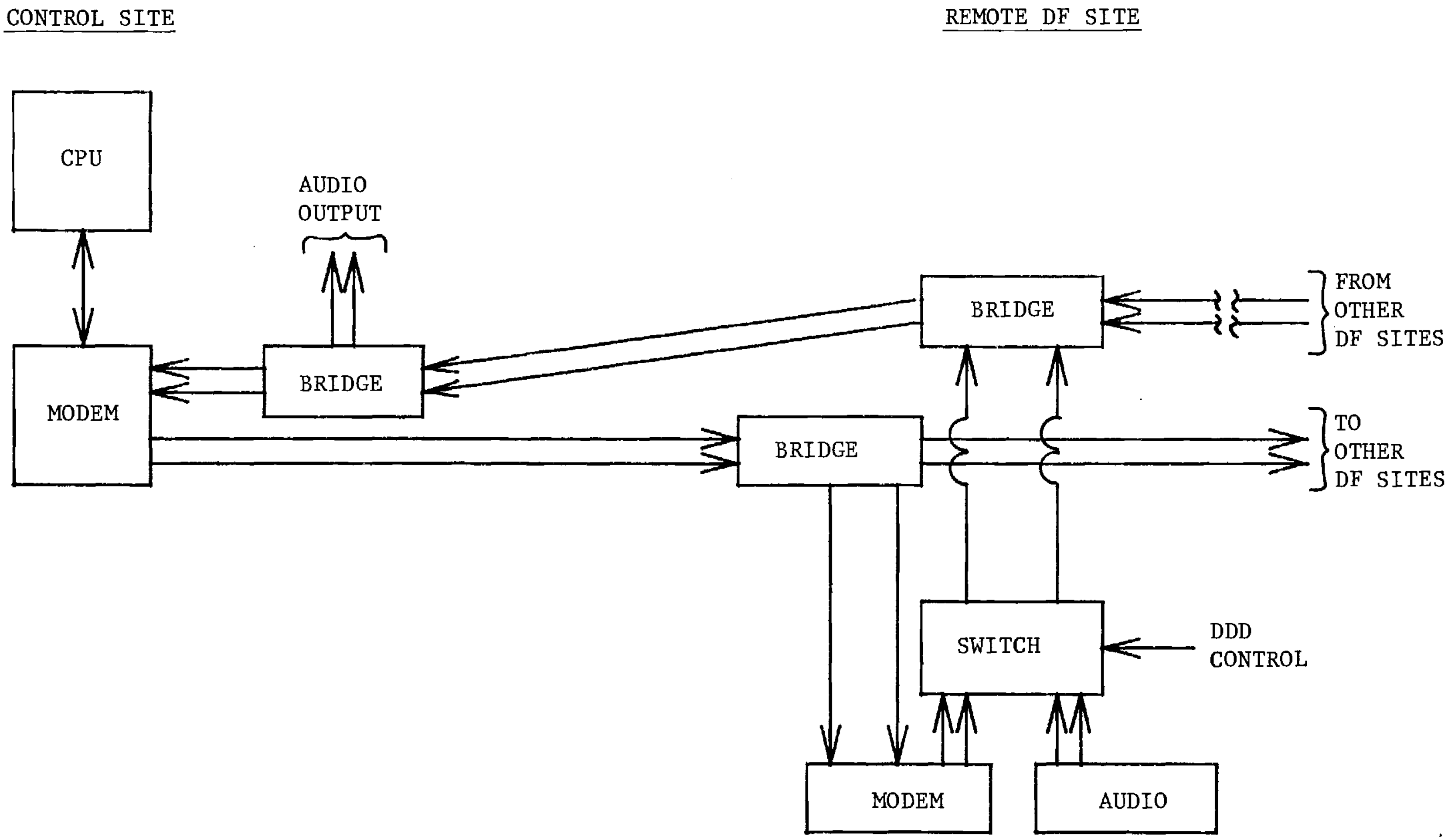


Figure 4-5 Audio/Data Selection by Remotely Controlled Switch

Alternative H offers two ways of implementing a simultaneous audio/data link. One approach employs a Time Division Multiple Access/Time Division Multiplex (TDMA/TDM) satellite link. The other approach uses a single carrier per channel (SCPC) approach with Time Division Multiplex (TDM) technique to multiplex the audio and data on a single point-to-point carrier. In both cases, the recovered audio is digitized and multiplexed with data being sent from the DF site to the control center. The costs associated with the control centers for these two methods are shown in Table 4-16, and the architecture of the control center is shown in Figure 4-6.

4.5 DF Site Control Systems

As pointed out in Section 4.4, there are three control system categories--low-speed, data-only; alternate audio/data with moderate speed data; and simultaneous audio and high-speed data. These same groupings apply to the control facility to be located at each DF site. The following material will present a local control configuration for each.

Figure 4-7 presents a local control configuration which is suitable for the low-speed, data only type network (Alternatives A, C, and D). The distinctive feature of Alternative A is that each DF site is directly connected to both Washington, D.C. and Grand Island, Ne. This is indicated in the figure by the two modems. For Alternative C, there would be only one modem, and it would be attached to multi-drop channel. In Alternative D, each site is typically connected to two other sites. Two modems are required, one connecting to the preceding DF site and one connecting to the following DF site.

The costs associated with the three low-speed, data-only alternatives are shown in Table 4-17. Notice that there is very little difference in the total hardware/software costs for these configurations.

Next consider the alternate audio/data networking schemes (Alternatives B, E, F, G, H, I, and J). It was pointed out in Section 4.4 that two approaches to the audio-data selection process have been defined. Figure 4-8 shows the local DF site configuration when the modem controlled switching is utilized, and Figure 4-9 shows the local DF site

TABLE 4-16

CONTROL CENTER COSTS FOR A SIMULTANEOUS
AUDIO/DATA TRANSMISSION CAPABILITY

APPROACH	COMPUTER HARDWARE	NETWORK SOFTWARE
ALTERNATIVE H, TDMA	$83,500	$4,100
ALTERNATIVE H, TDM	$68,200	$3,200

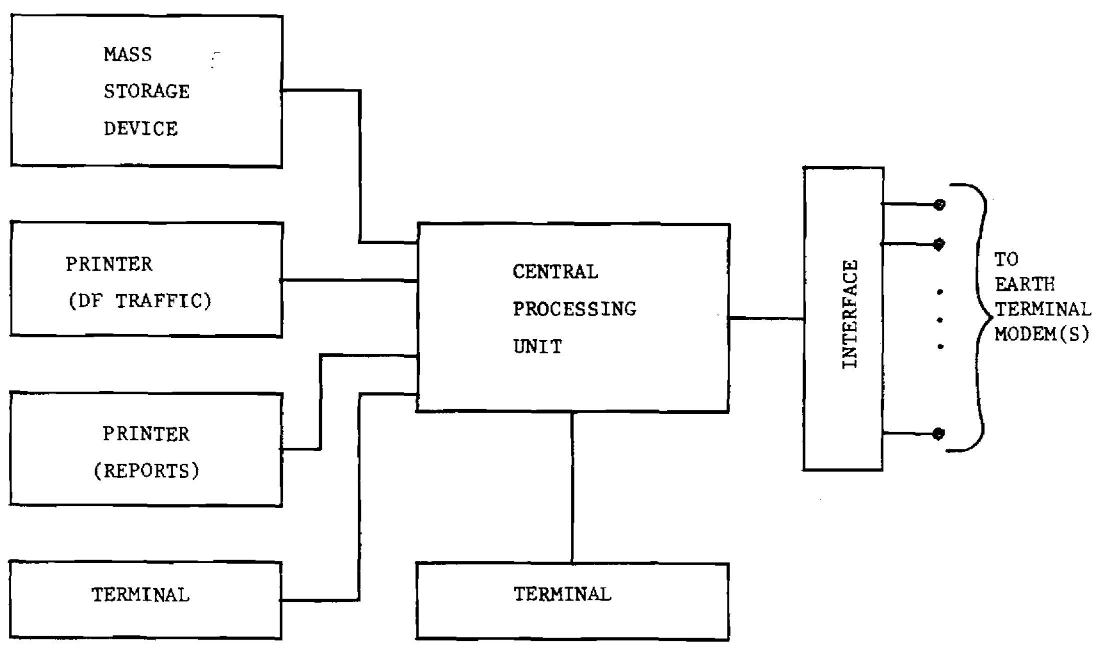


Figure 4-6 Network Control Configuration for Simultaneous Audio and Data

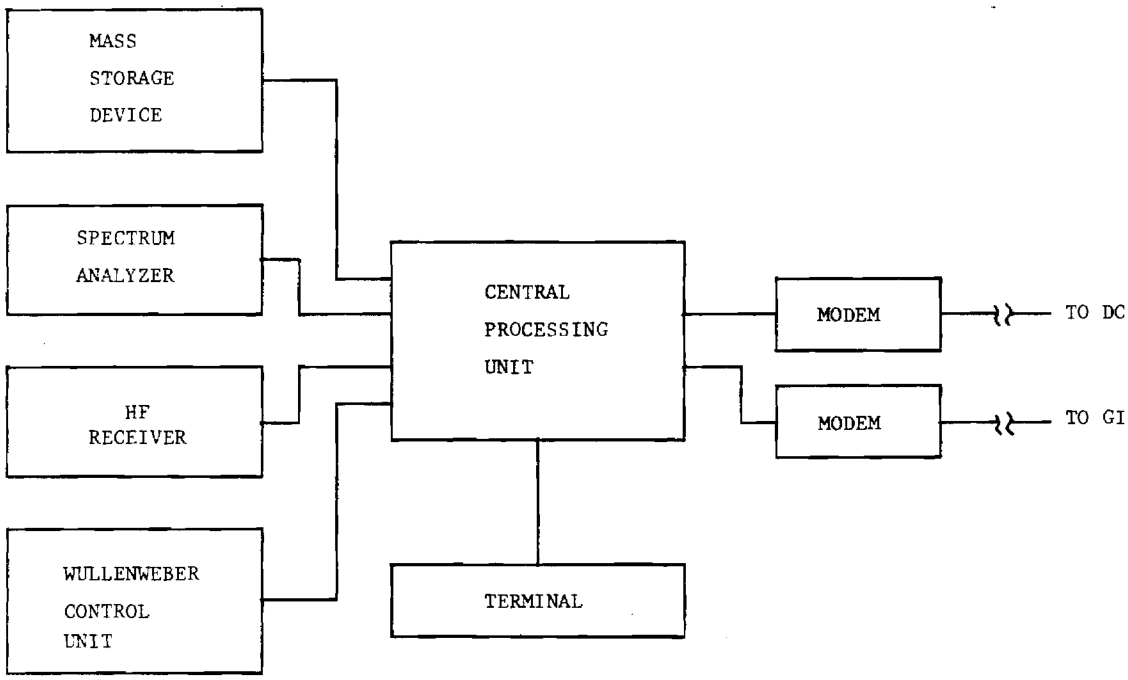


Figure 4-7 Local Control Configuration for a Low Speed, Data Only Network

TABLE 4-17

DF SITE CONTROL CENTER COSTS FOR A LOW-SPEED, DATA ONLY CONFIGURATION

ALTERNATIVE	CPU HARDWARE	NETWORK SOFTWARE	MODEMS	HF RECEIVER	SPECTRUM ANALYZER
A	$7,600	$4,000	$700	$15,000	$20,000
C	$7,300	$4,000	$350	$15,000	$20,000
D	$7,600	$4,000	$700	$15,000	$20,000

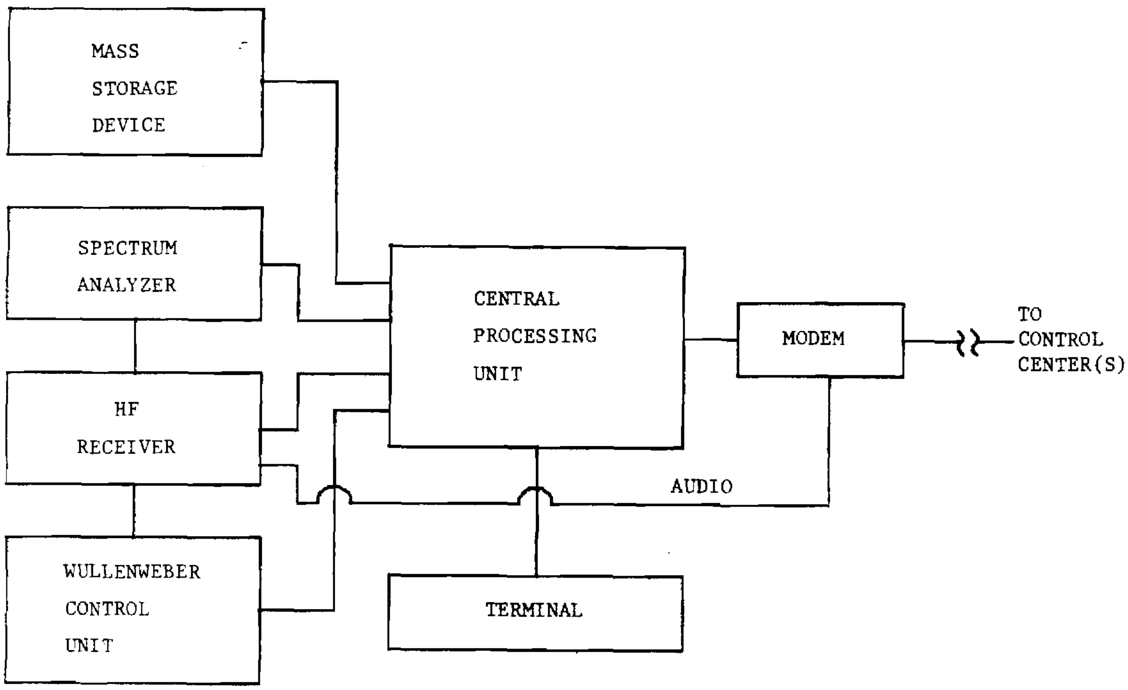


Figure 4-8 Local Control Configuration for Alternate Audio/Data Using Modem Switching

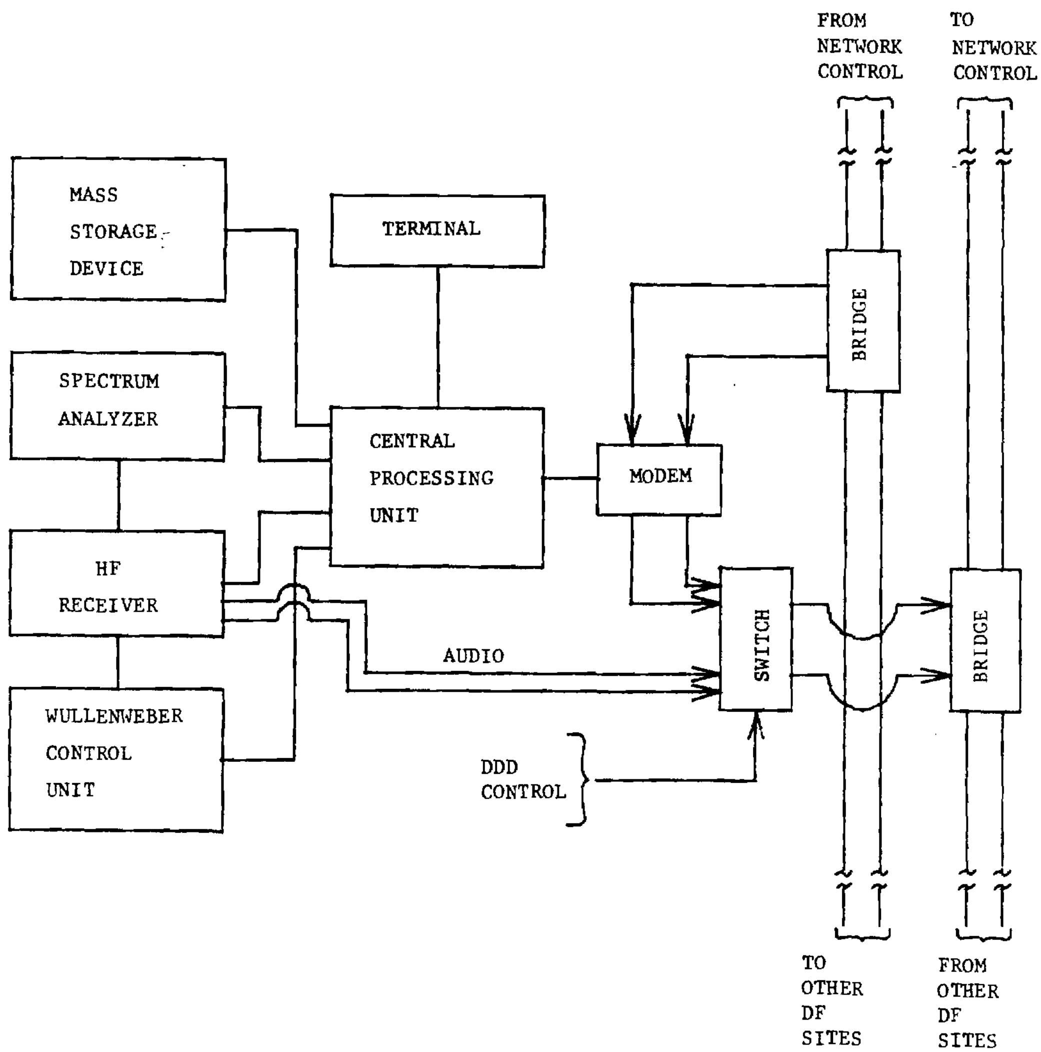


Figure 4-9 Local Control Configuration for Alternate Audio/Data Using Remotely Controlled Switching

configuration when the remotely controlled switch is employed. The cost to implement these techniques is presented in Table 4-18. As pointed out in Section 4.4, no cost distinction is made for these two techniques. The major differences are viewed as being operational in nature, and thus the choice should be made on that ground alone.

Finally, there are the alternatives which support the simultaneous transmission of audio and data. The configuration of the local DF site control system is shown in Figure 4-10. Notice that in this case the combining of the audio and data is done by first digitizing the audio using a coder/decoder (CODEC) then multiplexing the digitzed audio with the data stream from the computer. Traditionally, Continuously Variable Slope Delta modulation (CVSD) has been the audio encoding technique employed with a transmission rate of 32 kBPS. Using a TDM system such as Scientific Atlanta's DET-56 which has a transmission capacity of 56 kBPS, the system's maximum supportable data speed for simultaneous audio and data would be 24 kBPS. For TDMA systems, such as Digital Communications Corporation's DYNAC system in which each station has a burst capacity of 268 kBPS, a simultaneous data transmission of up to 236 kBPS could be supported by a single station. Such a transmission capacity far exceeds the requirements at any single station. It is therefore reasonable to consider a single station be allocated a maximum transmission capacity of 56 kBPS. Such an allocation would allow up to 4 stations to be active concurrently.

The costs associated with implementing the simultaneous audio/data capability are presented in Table 4-19. The costs estimates shown are for a maximum data transmission capacity of 9.6 kBPS. This speed was chosen as a relatively high capacity which could be achieved at reasonable cost. Additional transmission capacity is possible, but at significantly higher costs.

TABLE 4-18

DF SITE CONTROL CENTER COSTS FOR AN ALTERNATE AUDIO/DATA CONFIGURATION

ALTERNATIVE	CPU HARDWARE	NETWORK SOFTWARE	MODEMS	HF RECEIVER	SPECTRUM ANALYZER
B	$8,800	$4,000	$7,000	$15,000	$20,000
E	$7,900	$4,000	$3,500	$15,000	$20,000
F	$7,900	$4,000	$3,500	$15,000	$20,000
G	$7,900	$4,000	$3,500	$15,000	$20,000
H (FDM APPROACH)	$7,900	$4,000	$3,500	$15,000	$20,000
I	$7,900	$4,000	$3,500	$15,000	$20,000
J	$7,900	$4,000	$3,500	$15,000	$20,000

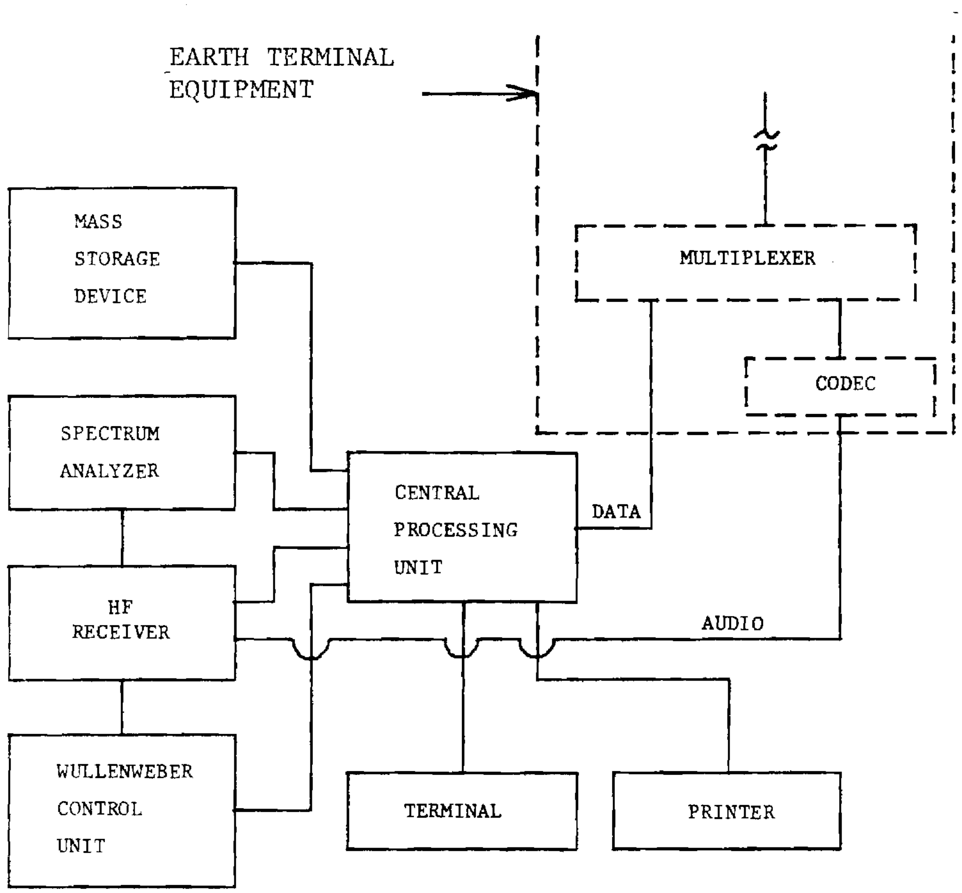


Figure 4-10 Local Control Configuration for a Simultaneous Audio/Data System

TABLE 4-19

DF SITE CONTROL CENTER COSTS FOR A SIMULTANEOUS AUDIO/DATA CAPABILITY

ALTERNATIVE	CPU HARDWARE	NETWORK SOFTWARE	HF RECEIVER	SPECTRUM ANALYZER
H (TDMA APPROACH)	$33,350	$4,600	$15,000	$20,000
H (TDM APPROACH)	$33,350	$4,600	$15,000	$20,000

5. CANDIDATE REMOTE CONTROL CONFIGURATIONS

In this section several network configurations are described which could be used to implement an automated DF network. The configurations reflect the various technologies involved, i.e., terrestrial links, satellite links, and HF radio links, as well as trade-offs between performance and cost. This section of the report defines the alternative configurations which will be evaluated technically and economically in Section 6.

5.1 Telephone Based Systems

The alternatives available for implementation of telephone based networks fall into two broad categories--private lines and direct dial. The private lines option offers a variety of line types which provide dedicated service to a particular customer. Furthermore, private lines may be arranged as point-to-point links or as multi-point links.

On the other hand, the dial network offers primarily one type of channel, voice-grade, and the channel is shared in time with a variety of users. The attractiveness of this approach lies in a cost savings that may be achieved if network utilization falls below a certain level. Two different dial-up arrangements will be considered--Direct Distance Dial (DDD) and Wide Area Telephone Service (WATS).

5.1.1 Alternative A: Star Network of Series 1000 Lines

Figure 5-1 shows the layout of this configuration. The configuration shown is actually a double star network with central nodes at Washington, D.C. and Grand Island, Nebraska. Either of these two nodes can act as network control. It should be recalled that the Series 1000 line supports low speed (<150 BPS) data only; therefore, these lines are sufficient to pass data between the various sites but the audio recovered from the various receivers can not be passed over these lines.

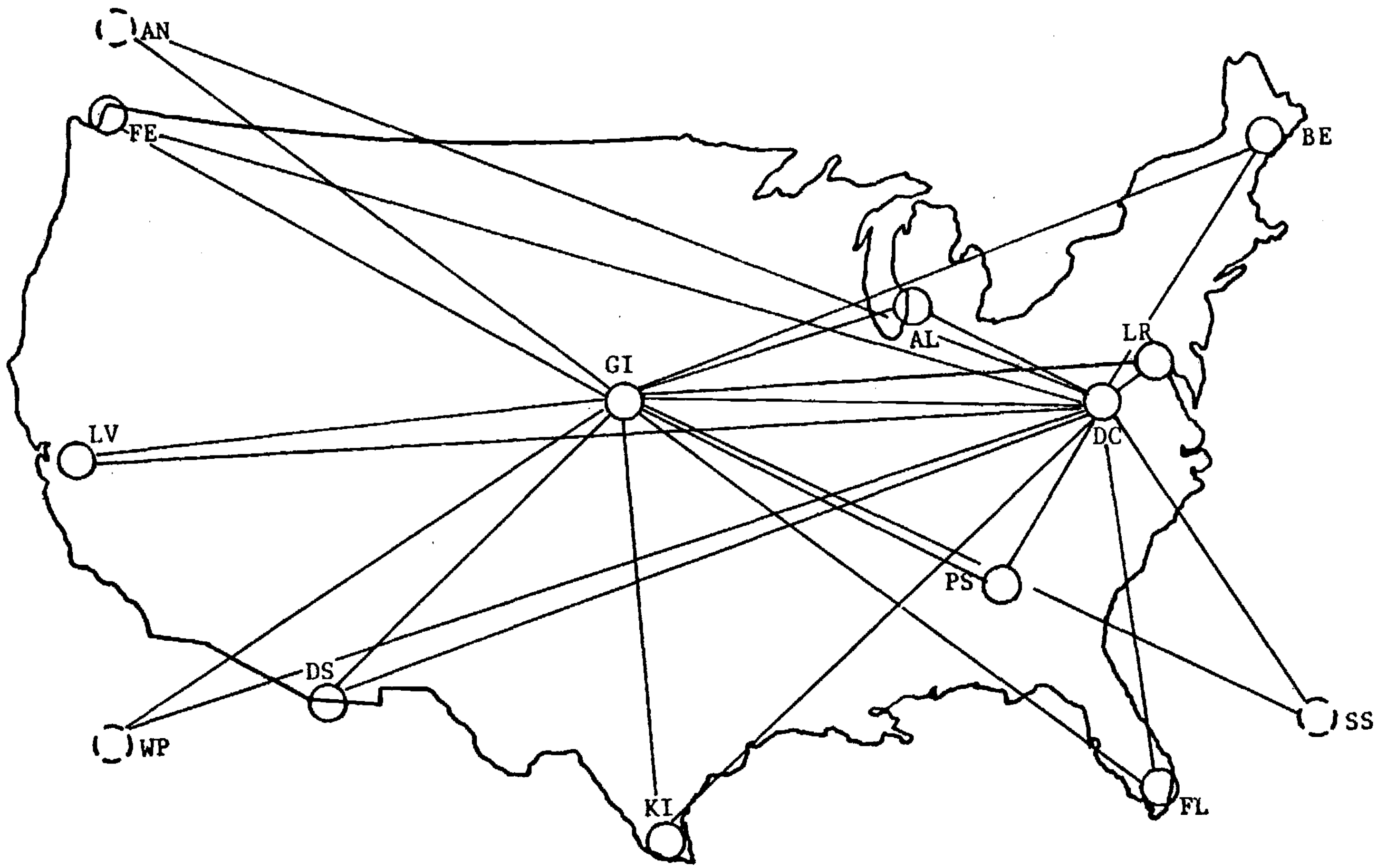


Figure 5-1. Alternative A: Star Network of Series 1000 Lines.

5.1.2 Alternative B: Star Network of Series 3000 Lines

The network configuration in this case is identical to that shown in Figure 5-1. The only difference is that Series 3000 lines are used rather than Series 1000 lines. As in Alternative A, both Washington, D.C. and Grand Island, Nebraska, can serve as network control. The additional capacity of the Series 3000 line permits the DF receiver's recovered audio to be returned to the network control sites. The bandwidth of this type of channel is approximately 3 kHz, and therefore, this could, in some instances, have a deleterious effect upon the recovered audio. It should also be pointed out that if conventional signaling equipment (modems) are used, this channel bandwidth is inadequate to permit simultaneous audio and data transmissions.

5.1.3 Alternative C: Multi-drop Network of Series 1000 Lines

The multi-drop line is an alternative to the point-to-point configuration. Its major attraction is the cost savings realized when compared with that of a point-to-point configuration. This cost savings is realized by assigning two or more tributaries per line. The fact that there is a common channel among several points is the basis for one of the central issues in this type of network--line control. Typically, the solution is to identify one of the tributaries on a given line to be the "master" for that line. All other tributaries are "slaves" and can only use the channel under the specific command of the master. In this master-slave arrangement, the master periodically polls each slave for information to be passed over the channel.

There are several strategies for configuring multi-point networks. The most basic is the so-called unconstrained configuration which implements the least cost arrangement without regard to any technical constraints which may be applicable. Figure 5-2 shows such an implementation. The configuration shown is the least cost configuration for both Washington, D.C. and Grand Island, Nebraska. Observe that when the network control is located at Washington, D.C., there are three branches emanating from the D.C. location. A communications failure in

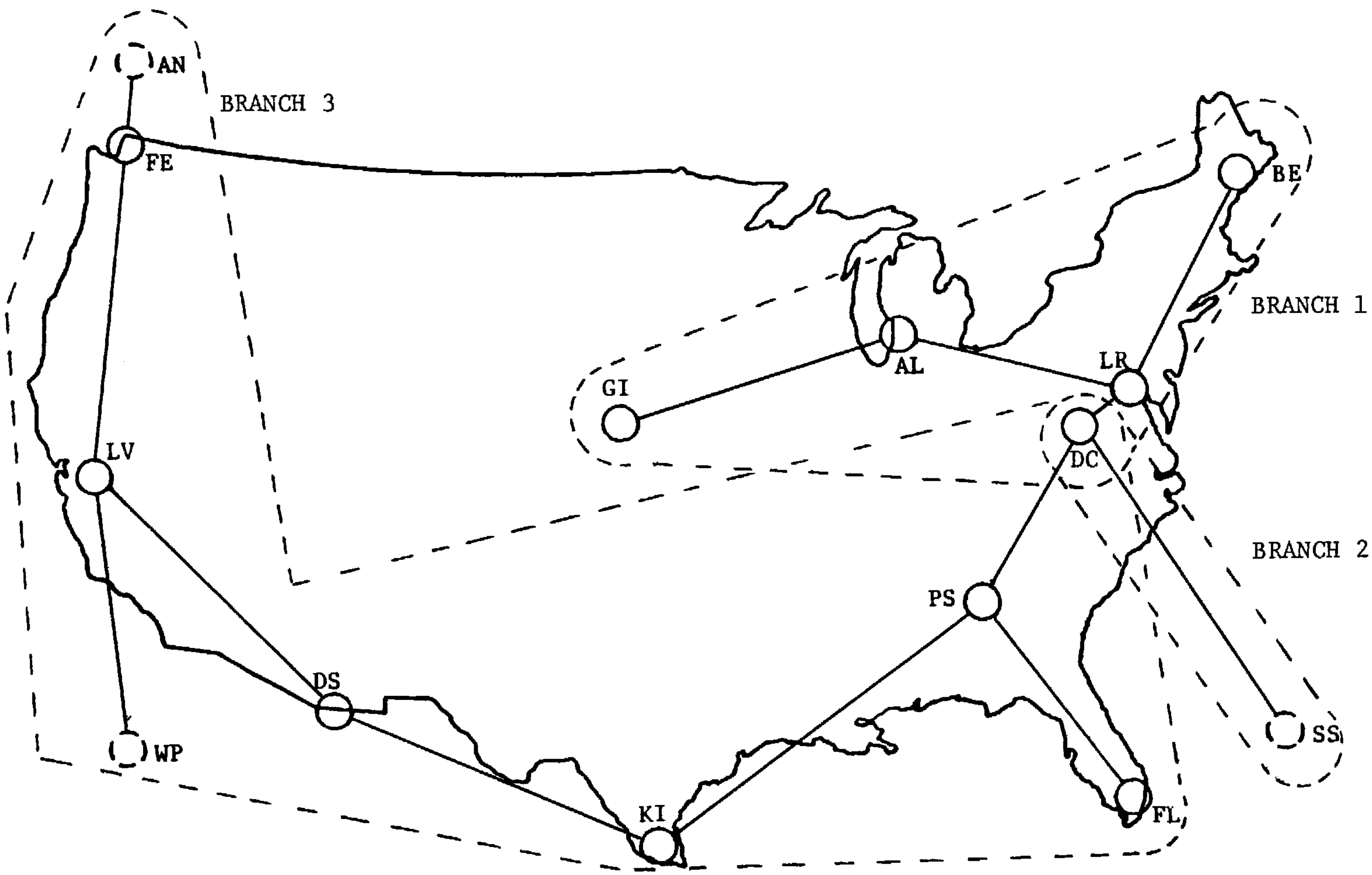


Figure 5-2. Alternative C: Unconstrained Series 1000 Multi-point Network Configuration.

any one of these branches would have a detrimental effect; however, two branches would remain leaving some capacity for coordinated DF activity.

On the other hand, the Grand Island site is attached to the other sites by only one link. A failure in this link at a time when Grand Island was serving as network control would incapacitate the network.

Another problem with the least cost configuration of Figure 5-2 becomes apparent when one observes the mileage data presented in Table 5-1.

The branches identified in this table pertain to those homing on Washington, D.C. Notice that the total path length for branch 3 is in excess of 7000 miles. It is general practice to limit the branch length for multi-point networks to 4000 miles or less. This is necessary in order for the telephone companies to be able to provide prescribed channel characteristics using their standard implementation techniques. Obviously, branch 3 is noticeably in excess of this constraint.

A similar situation exists for the Grand Island site. However, the problem is worse in this case since that site has only one branch which has an apparent length equal to the sum of all three branch lengths shown in Table 5-1.

The above interpretation assumes a tree multi-point form of operation in which commands from the master station are broadcast simultaneously to all nodes on a given branch. It is possible to use this same structure for a store-and-forward operation. If this form of operation is used, the distance constraint for a given branch no longer applies.

5.1.4 Alternative D: A Robust Series 1000 Based Store-and-Forward Network

The network described in Figure 5-2 is based upon a common channel concept for most of the stations in the network. In that approach, analog bridges are used at drop points to allow the signal to propagate to the next drop point on the line. An alternative to this which is based upon the least cost configuration is a store and forward network as shown in Figure 5-3.

To appreciate the advantages offered by the configuration shown in Figure 5-3, it is necessary to understand the store-and-forward concept.

TABLE 5-1

BRANCH ASSIGNMENTS AND LENGTHS FOR
THE UNCONSTRAINED SERIES 1000 CONFIGURATION

BRANCH: LINKS		LENGTH (MILES)
1: DC - LR		20
LR - BE		469
LR - AL		462
AL - GI		567
	TOTAL LENGTH FOR BRANCH 1	1518
2: DC - SS		1349
	TOTAL LENGTH FOR BRANCH 2	1349
3: DC - PS		478
PS - FL		520
PS - KI		780
KI - DS		661
DS - LV		704
LV - WP		2112
LV - FE		675
FE - AN		1179
	TOTAL LENGTH FOR BRANCH 3	7109

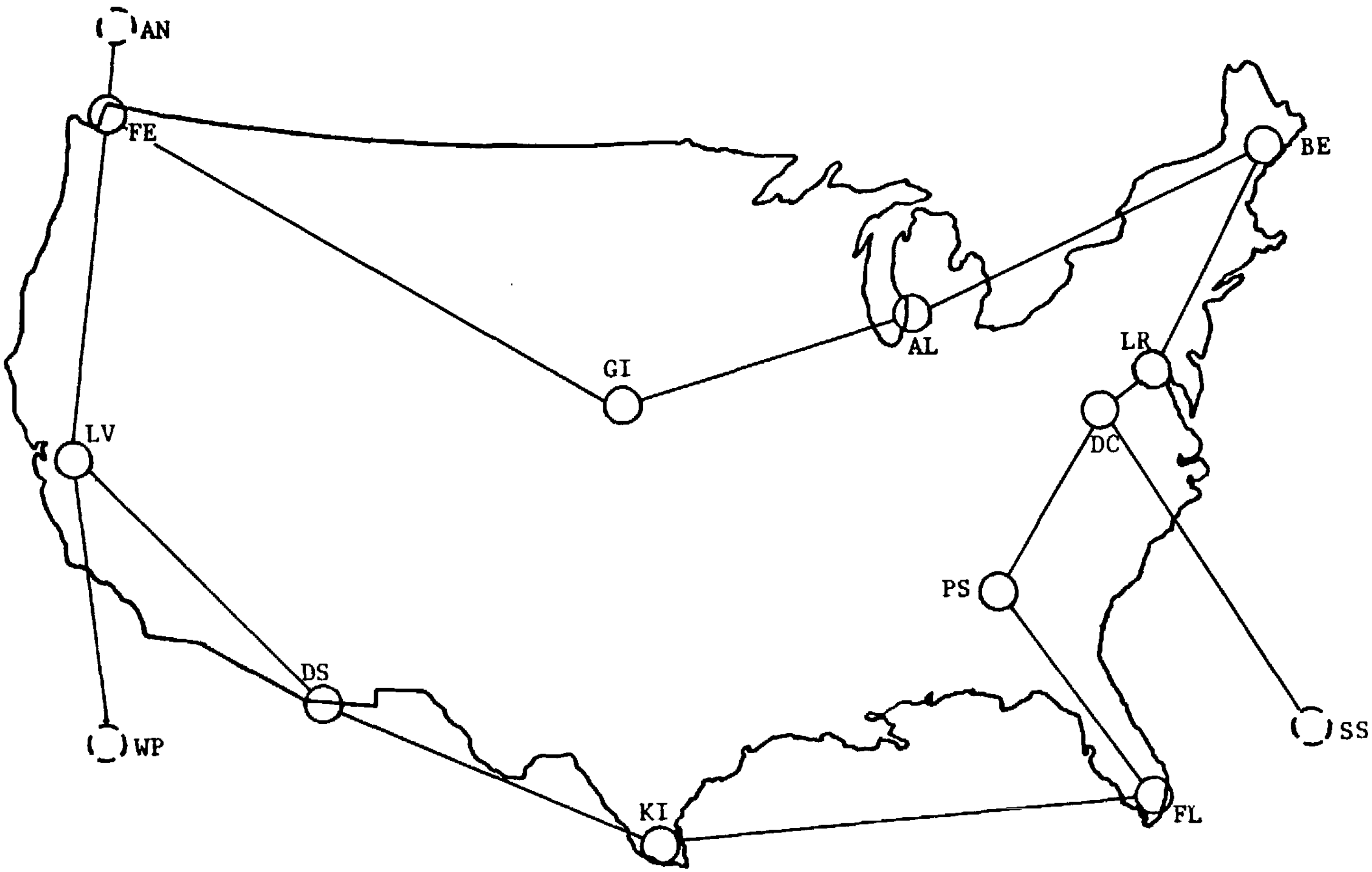


Figure 5-3. Alternative D: A Multi-Drop, Store-And-Forward Series 1000 Network.

In a store-and-forward network, a message propagates from one node to another node. At each node, the local processor "examines" the message address, and if the address is not that of the present node, the processor decides which routing will be used to forward the message to a node closer to the message's destination.

Obviously, the store-and-forward approach introduces some delay in the propagation of messages through the network since a message propagates sequentially from node-to-node rather than being broadcast to all nodes simultaneously. This same feature is a part of the strength of this type of network, however. Notice that each of the CONUS sites has at least two links connecting it to the rest of the network. This means that each CONUS site may be reached by two different paths, meaning that two simultaneous failures in the system are necessary to make any one CONUS point inaccessible.

It was mentioned earlier that there is a limit of 4000 miles on connected multi-drop channels. This specifically applies to analog channels in the multi-drop configuration and does not apply if the channel is a point-to-point configuration or if the channel is not a continuous unbroken analog path. The present case, Alternative D, is an example of a collection of point-to-point links which do not exhibit analog continuity but which collectively exceed 4000 miles in length. Since Alternative D is not a multi-drop arrangement, the 4000 mile constraint does not apply.

5.1.5 Alternative E: A Multi-point Network of Series 3000 Lines

Since the tariff for both Series 1000 and Series 3000 lines is mileage dependent, the structure for the least cost multi-point network using Series 3000 lines is identical to that shown in Figure 5-2. As pointed out in Section 5.1.3, there are some basic techincal problems with implementing the structure shown in Figure 5-2. These same problems appear in a Series 3000 implementation but in a slightly different form.

One of the primary objectives in considering the use of Series 3000 lines is the ability of such lines to support the transmission of audio. As a minimum, the intent is to make the recovered audio available at the network control site. For this to happen, a continuous analog path must exist between a given DF site and the control site. This requirment precludes the use of the digital store-and-forward technique employed in Alternative D.

In order to implement the required multi-drop analog channel, it is necessary to alter branch 3 as defined in Table 5-1. In particular, the length of this branch must be made less than 4000 miles. This can be done if the Livermore-Waipahu and Ferndale-Anchorage links are removed from this branch. One possible configuration which should solve the line length problem while at the same time providing full network access by both the Washington, D.C. and Grand Island, Nebraska, is shown in Figure 5-4. Notice that in this configuration, all of the central and western stations are routed through Grand Island. This makes the audio from these sides available at Grand Island, and the use of audio bridging at Grand Island will permit that same audio to be sent to Washington, D.C. via the identified trunk line. A similar procedure is employed in Washington to pass the audio from the sites tied to Washington on to Grand Island. The various branches of the network shown in Figure 5-4 are defined in Tables 5-2 and 5-3.

Notice that branch 5 from Washington still exceeds the 4000 mile threshold; however, only by a slight amount. Given that the link in question only involves 3 points, it is believed that satisfactory service can still be achieved.

5.1.6 Alternative F: A DDD-Based Approach

As pointed out in Section 4.1.3, the DDD network is not static like a leased line arrangement; therefore, one cannot draw a network diagram of the type provided in previous sections for leased line configurations. For a DDD-based network, the fundamental decision to be made is the number of DDD lines to be acquired. Each line can support point-to-point, alternate voice/data communications between a control center and one remote DF site. Thus, to answer the question regarding the number of DDD lines, one must be able to discuss the need to access two or more DF sites simultaneously.

Conceptually, one can obtain a valid DF-fix with bearing data from as few as two sites. In general, the precision of the fix will increase as

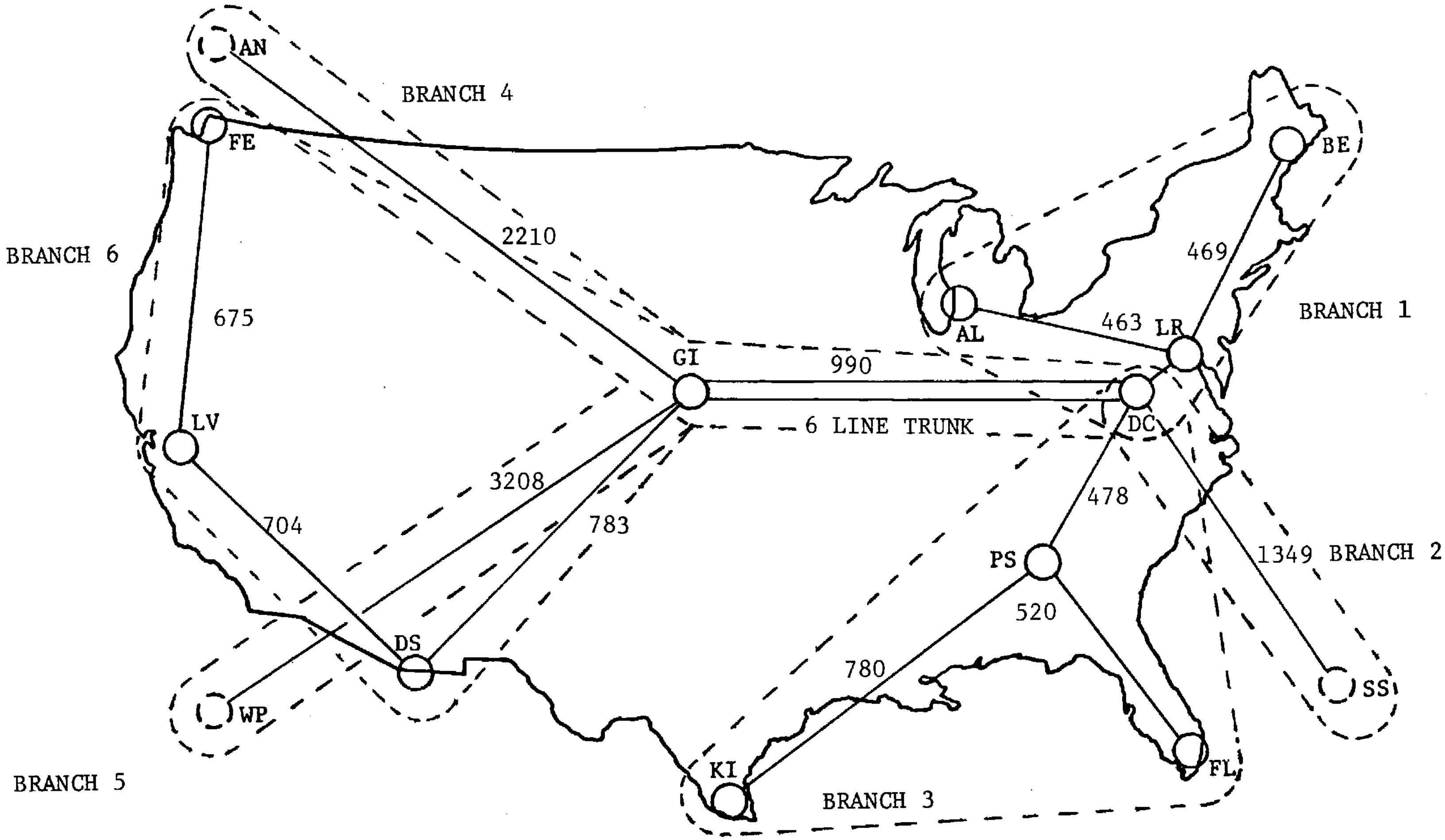


Figure 5-4. Alternative E: A Multi-point Network of Series 3000 Lines.

TABLE 5-2

BRANCH ASSIGNMENTS AND LENGTHS FOR A MULTI-DROP SERIES 3000 CONFIGURATION BASED ON WASHINGTON, D.C.

BRANCH: LINK		LENGTH (MILES)
1: DC - LR		20
LR - AL		463
LR - BE		469
	TOTAL LENGTH OF BRANCH 1	952
2: DC - SS		1349
	TOTAL LENGTH OF BRANCH 2	1349
3: DC - PS		478
PS - FL		520
PS - KI		780
	TOTAL LENGTH OF BRANCH 3	1778
4: DC - GI		990
GI - AN		2210
	TOTAL LENGTH OF BRANCH 4	3200
5: DC - GI		990
GI - WP		3208
	TOTAL LENGTH OF BRANCH 5	4198
6: DC - GI		990
GI - DS		783
DS - LV		704
LV - FE		675
	TOTAL LENGTH OF BRANCH 6	3152

TABLE 5-3

BRANCH ASSIGNMENTS AND LENGTHS FOR A MULTI-DROP SERIES 3000 CONFIGURATION BASED ON GRAND IS, NE.

BRANCH: LINK		LENGTH (MILES)
1: GI - DC		990
DC - LR		20
LR - AL		463
LR - BE		469
	TOTAL LENGTH FOR BRANCH 1	1942
2: GI - DC		990
DC - SS		1349
	TOTAL LENGTH FOR BRANCH 2	2339
3: GI - DC		990
DC - PS		478
PS - FL		520
PS - KI		780
	TOTAL LENGTH FOR BRANCH 3	2768
4: GI - AN		2210
	TOTAL LENGTH FOR BRANCH 4	2210
5: GI - WP		3208
	TOTAL LENGTH FOR BRANCH 5	3208
6: GI - DS		783
DS - LV		704
LV - FN		675
	TOTAL LENGTH FOR BRANCH 6	2162

the number of participating DF sites increases, and therefore, the upper bound on the need for simultaneous access is thirteen. A previous study of DF network activity done by Georgia Tech has shown that it is unusual to experience either extreme in practice. In particular, it is quite common to have five to seven DF sites simultaneously involved in a DF-fix.

5.1.7 Alternative G: A WATS-Based Approach

It was indicated in Section 5.1.6 that the DDD network is dynamic and does not have a rigid structure that permits one to draw a conventional network diagram. The architecture of a WATS-based system lies somewhere between the rigid structure of a leased line arrangement and the highly flexible arrangement of of DDD system. This unusual character stems from the fact that a given WATS line has connection flexibility up to the level which the user purchased for that specific line. Table 4-7 indicates this access limitation for WATS lines based in Washington, D.C. and Grand Island, Ne.

As for the DDD case, there is the question of how many lines are sufficient. As a minimum, it is assumed that one must be able to access three DF sites simultaneously, and it should be obvious from Table 4-7 that in the WATS case, one must decide which three sites are to be accessed. Since this configuration will be treated as the minimal acceptable capacity, it seems reasonable to insist that the three line configuration permit access to any three DF sites. This requirement leads to a minimal configuration consisting of two zone six lines and one zone five line at both Washington, D.C. and Grand Island, Ne.

A maximum configuration would be one which permits access to all 13 remote sites from both Washington, D.C. and Grand Island, Ne. To support this in a least-cost manner would require thirteen lines at both control sites. The required lines types are shown below.

Control Site: Washington, D.C.

Required Lines:
2 - zone 6 lines
6 - zone 5 lines
1 - zone 4 lines
3 - zone 3 lines
1 - zone 1 line

Control Site: Grand Island, Ne.
Required Lines: 2 - zone 6 lines
8 - zone 6 lines
2 - zone 4 lines
1 - zone 3 line

The cost of the two configurations identified above will be determined in Section 6.

5.2 Satellite Based Systems

There are several ways to implement a communications network which takes advantage of satellite technology, including:

(1) ownership by the user of all earth terminal equipment with that equipment located at the user's site,

(2) lease by the user of both the space segment hardware and the earth terminal equipment with the earth terminal co-located with the user's facility, and

(3) lease by the user of a communications service provided by a satellite carrier which utilizes large commercial earth stations tied to the user's facility by terrestrial links, either private or common carrier.

Each of these alternatives is explored in the following sections.

5.2.1 Alternative H: Leased Satellite Transponder Approach

Two approaches to a leased satellite transponder system will be examined. In the first approach, a single, full-duplex space link exists which serves to connect the control center to any one of the 13 remote sites. The link employed will support a single 32 kBPS CVSD voice channel with the remainder of the capacity available for simultaneous data transmission. The structure for such a network is

Figure 5-5. Alternative H: A Leased Satellite Transponder Approach.

shown in Figure 5-5. Notice that it has the shape of a star-network, but it is important to realize that it functions like a multi-drop network.

The second approach which employs leased satellite transponders has the same network structure as shown in Figure 5-5; however, in this alternative, 13 distinct satellite channels are employed to provide a dedicated channel between the control center and each remote site. Furthermore, the channels provided in this alternative are conventional analog voice frequency (VF) channels.

5.2.2 Alternative I: Leased (Co-located) Earth Station Approach

In this approach, the common carrier provides both the space segment, transponder channel, and the earth segment, the earth station hardware. The major difference between this and Alternative H is that the earth stations are owned by the common carrier. This alternative offers the variety of configurations identified for Alternative H. As in the previous cases, the two extremes will be examined to bound the cost and performance consideration. At the low end, as measured by cost and performance is the single channel shared among all users. At the high end, as measured by cost and performance, is a dedicated channel between the control centers and each DF site. The network topology for either of these cases is as shown in Figure 5-5.

5.2.3 Alternative J: Leased Transmission Approach

In this approach, major earth stations owned by satellite carriers are used as gateways for the DF network. Due to the very limited number of such gateways, the actual configuration is a combination of satellite and terresterial links. A network of such links configured using the least cost criteria is shown in Figure 5-6.

Two previously seen problems reappear in this configuration--the connectivity to Grand Island, the secondary control center, is very weak, and the multi-drop link consisting of Washington, D.C., Livermore, CA, Anchorage, AK, Ferndale, VA, and Waipahu, HI, exceeds the 4000 mile constraint considerably.

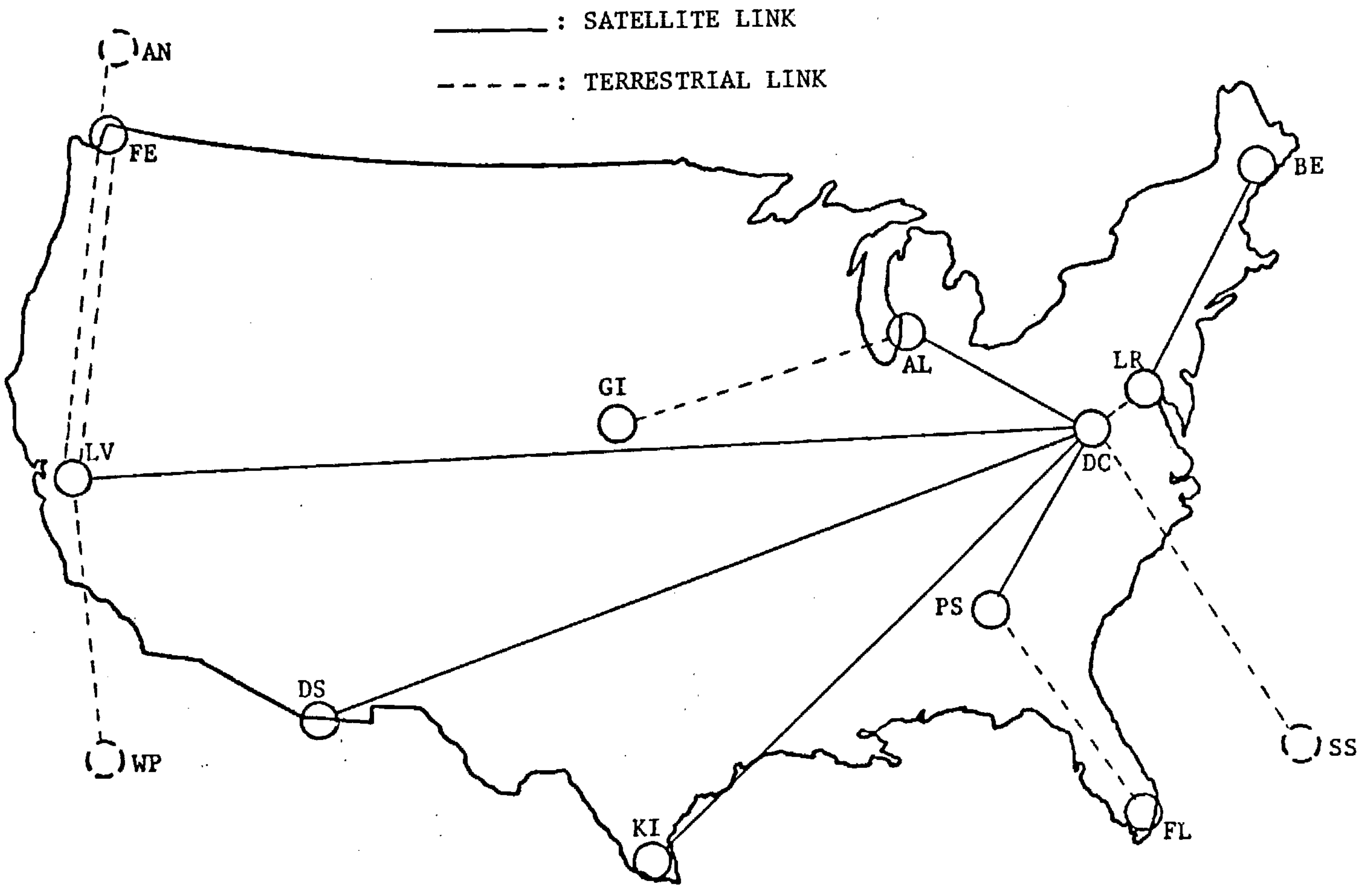


Figure 5-6. A Leased Satellite Transmission Approach.

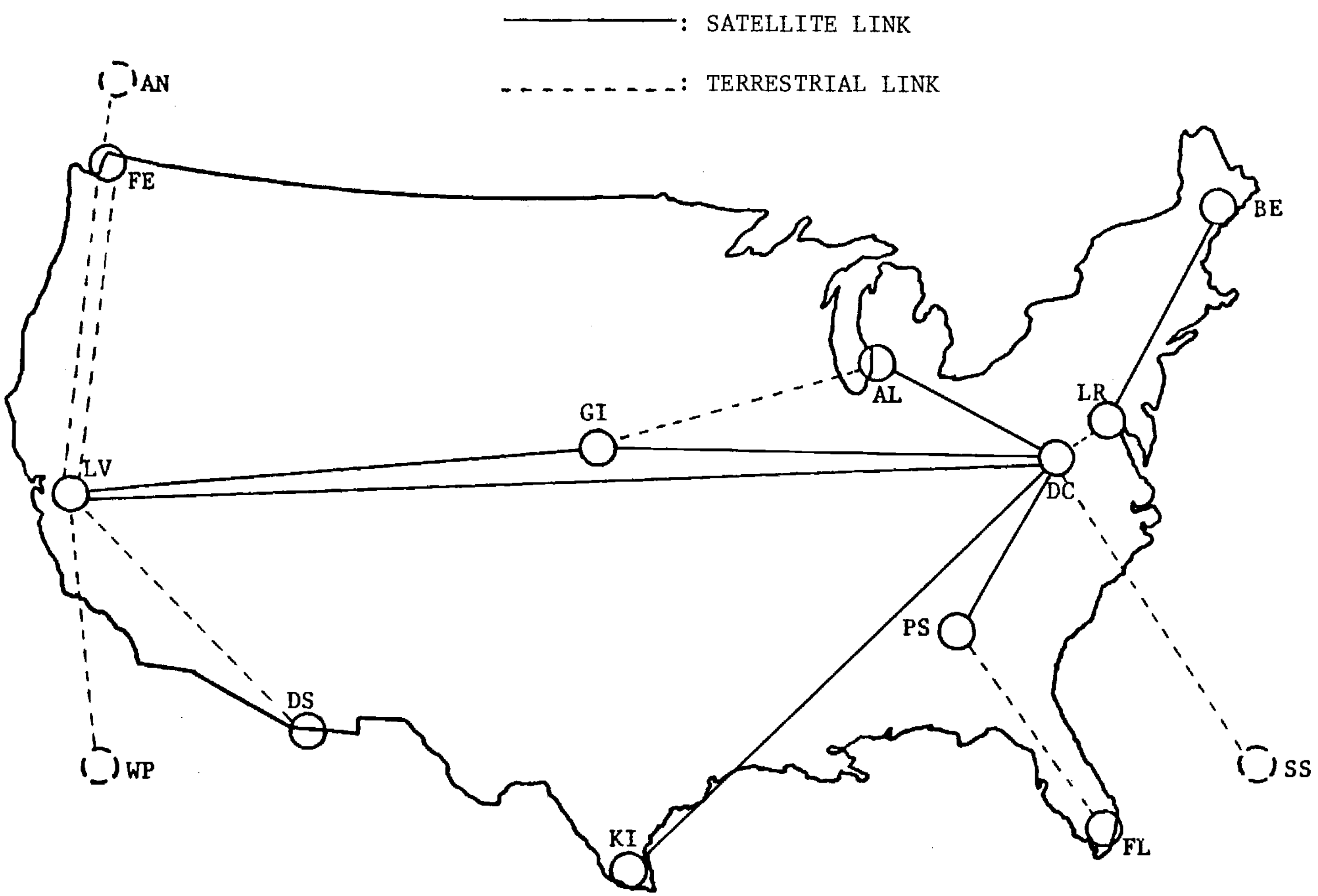


Figure 5-7. Alternative J: A Robust Leased Satellite Transmission Approach.

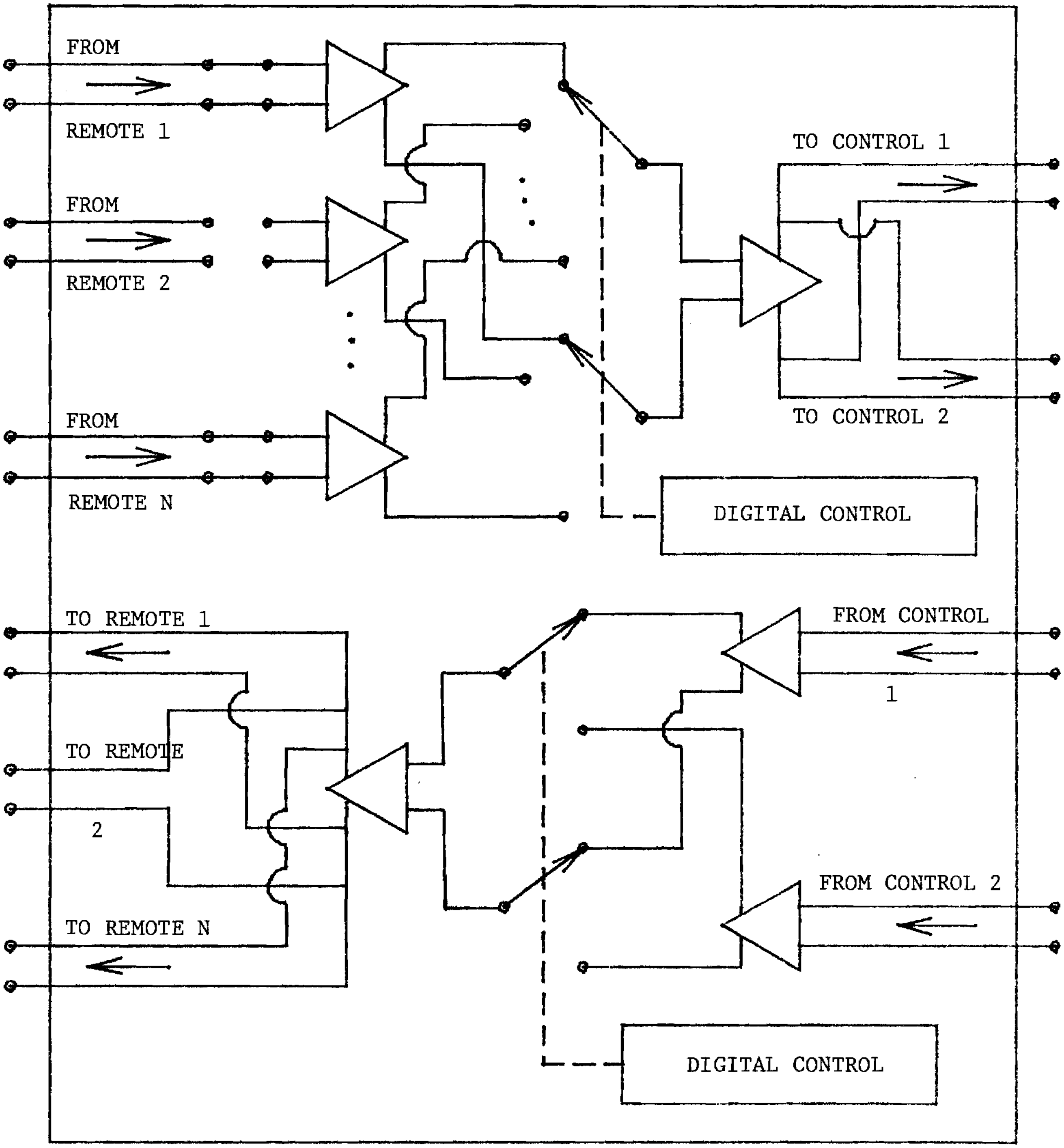


Figure 5-8. Schematic of A Digitally Controlled Analog Switch.

The configuration shown in Figure 5-7 shows one approach to solving both of these problems. An important part of this approach is the digitally controlled switch shown in Figure 5-8. Notice that this switch allows selection of both the control source and the remote line to be connected. Also notice that the path from the control point to all remotes is continuously in place and is a parallel connection. This allows the control point to communicate with all remotes simultaneously. On the other hand, the path from a given remote to the control point is connected only when traffic from the specific remote is expected. This eliminates the composite noise problem associated with a conventional nalog bridge used in normal multipoint operations. One such switch would be required at both Livermore, CA, and Washington, D.C.

5.3 Radio-Based System

In order to simplify system design and promote central control, a star network, with a central control site, is envisioned as the best alternative for handling communication requirements for the HF/DF remotely controlled system.

In a star network configuration, system software and hardware, at the outer sites, would be simplified because of the lower demands placed upon them. The outer sites would only have to communicate along one azimuth which would simplify network protocol and reduce hardware requirements (i.e. only one fixed antenna would be necessary).

In a radio-based system, distance between sites is a key factor in the determination of link reliabilities. In response to the above, the choice of a central site is often a function of its geographical location with respect to the other sites. In general, a centrally located site will approach the optimal condition in this respect. This conclusion is based upon the fact that multi-hop propagation paths can often be reduced to a minimum in a circularly distributed network, depending upon the radial distances involved.

Communication should (and practically, must) incorporate channels from various frequency bands throughout the HF spectrum. This enables a higher probability of signal reception due to the frequency dependent refractive and absorption properties of the highly variable ionosphere. The system must be able to change operating frequencies in order to achieve reasonable probabilities of communication. Remote control and on site computer control with a knowledge of the M.U.F. and L.U.F. cycles should be maintained in order to maximize the probability of communication. In this mode, frequency-independent addressing will have to be present (address in the header of the data stream). To reduce antenna and channel requirements, a half-duplex mode of communication is envisioned.

The central site will be responsible for system control and coordination since all message traffic must either be initiated from control or travel through it. A broadcast mode will be possible through the use of a neutral address header and the use of multiple antennas. As stated above, the central site should have remote control over the system for setting up frequency-sensitive (ionosphere) channels.

Software at the outer sites will have to be able to cycle through the available frequencies in conjunction with cycling at the central site in the event of total communication link loss. Software should also be able to adjust frequency assignments on stored daily and seasonal M.U.F and L.U.F. cycles for the highest probability of communication line-up. As a result (if communications break down), there should be fewer iterations of the frequency cycling process involved in synchronization.

Hardware required at the central site will include a transmitter, receiver, modem, antennas, and processing capabilities. Figure 5-9 illustrates in block diagram form the above features minus the processor. For higher reliability, back-up units should be provided (except the antennas). Transmission power should be on the order of 5 kW. Should Washington wish to control the central HF site, both the receiver and transmitter at the central location would be remotely controllable. A processor should be available for any software applications (i.e. frequency synchronization and ionospheric data). This processing capability should be handled by the already envisioned HF/DF processor. The antennas will be log periodic and half wavelength structures. The three antennas at the central site will be positioned for optimal coverage of all sites.

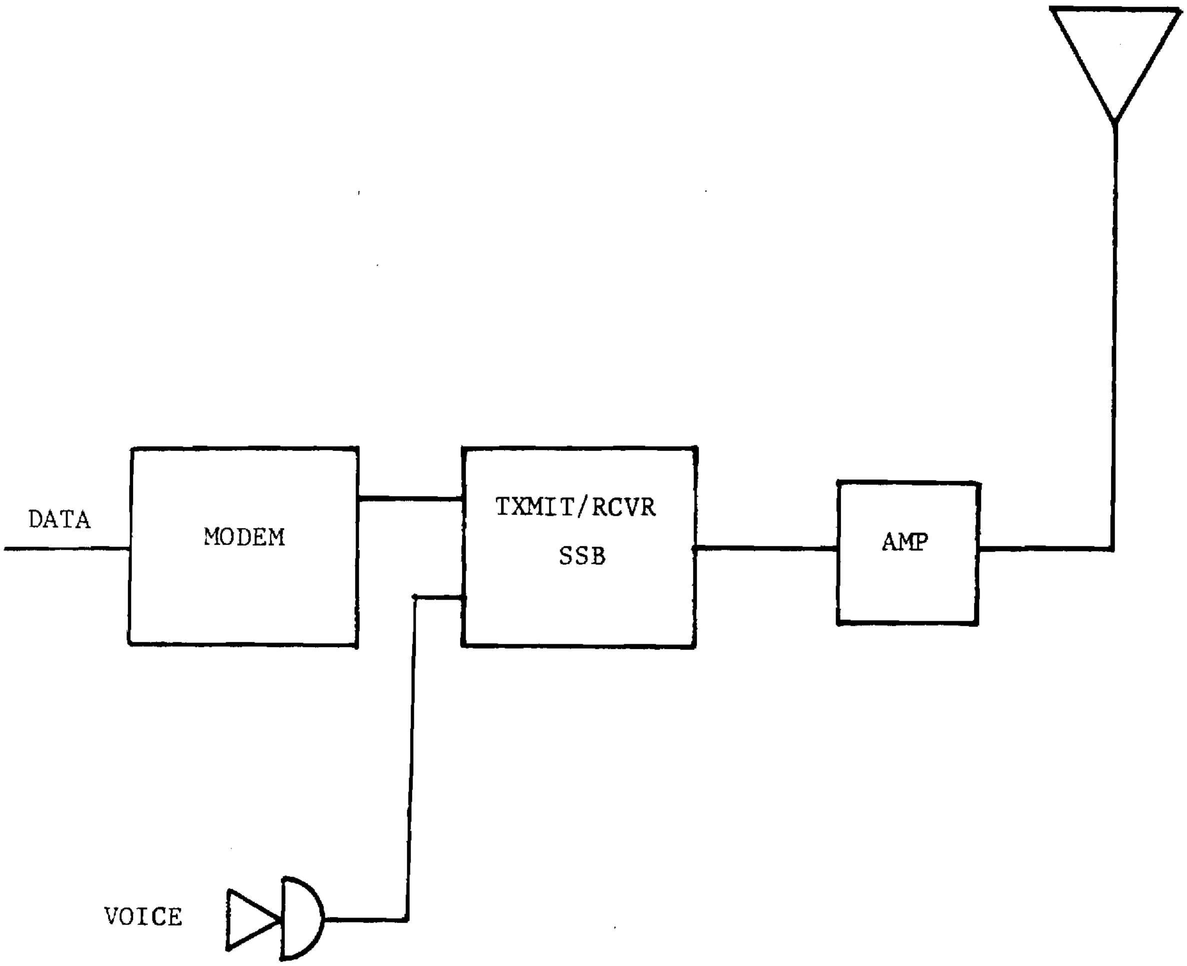


Figure 5-9 Block Diagram of HF Radio Transmit/Receive System

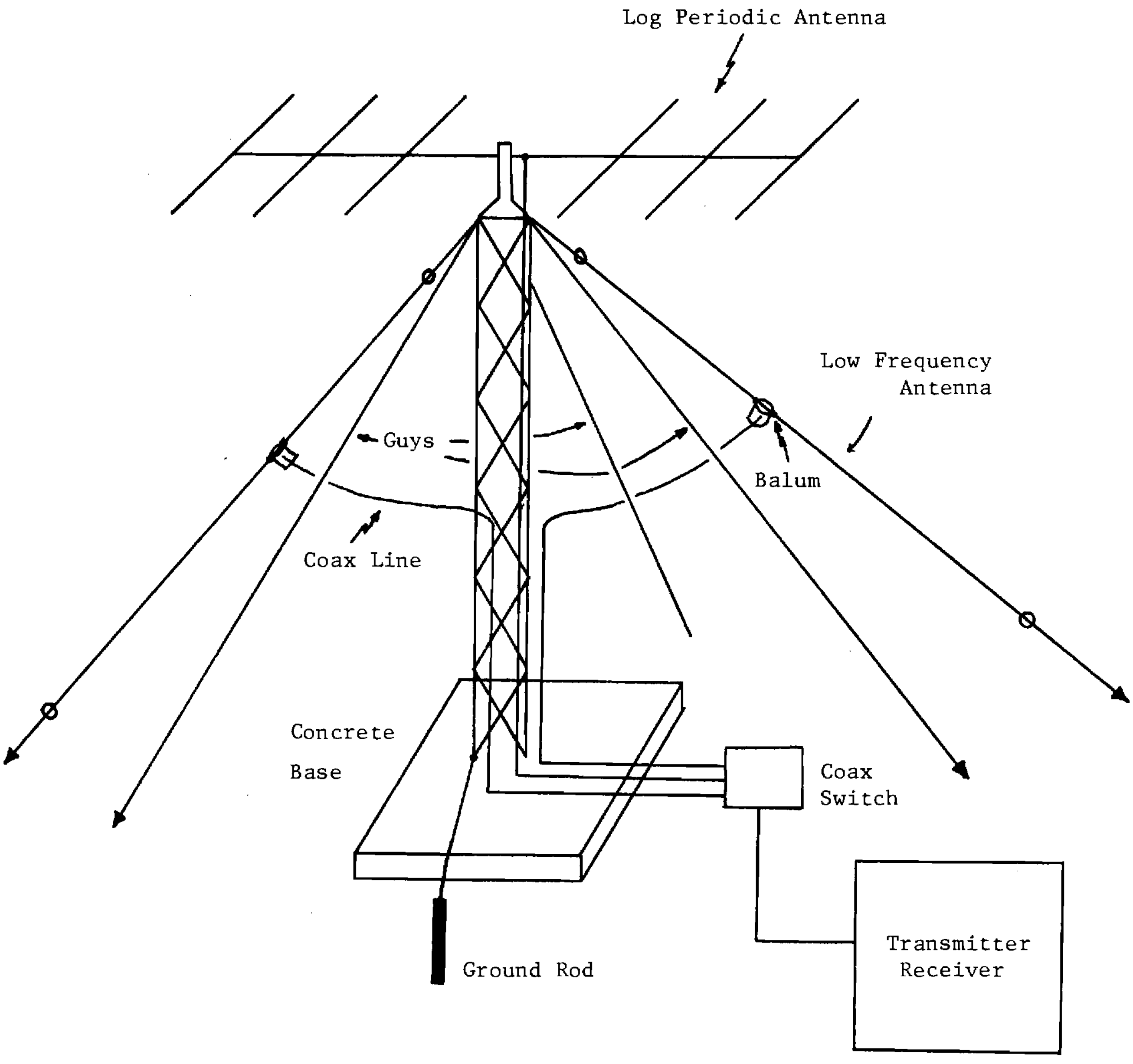


Figure 5-10 Antenna Configuration for HF Communication System

The antenna itself is efficient only from approximately 6 MHz to 30 MHz. To improve the gain at lower HF frequencies, separate copper wire antennas of the appropriate length (one-half wavelenth) for particular channel frequencies should be included. Separate coaxial feeds, a co-ax switching unit, balums, copper wire, insulators, etc. are necessary for implementing the lower frequency antennas. The entire structure will be supported by 100 ft of tower and a concrete base. The structure is illustrated in Figure 5-10.

6. SYSTEM EVALUATIONS

In this section of the design document, each of the candidate configurations identified in Section 5 will be discussed in terms of its operational characteristics, advantages and disadvantages, and cost.

6.1 Telephone Based Systems

In the following section, the technical characteristics and cost of service of the telephone based systems are presented. The discussions follow the sequence of alternatives presented in Section 5.

6.1.1 Telephone System Costs

There are two primary factors in the cost of a telephone based system: installation, and monthly lease. The installation fee is a one time charge made by the common carrier to cover the incurred expanse of establishing the desired telephone service. The monthly lease on the other hand, is the recurring cost element which continues as long as the common carrier continues to provide the service requested by the customer. It should be understood that the cost data presented in this section is intended to be used as a budgetary estimate subject to exact implementation and costs applicable when the network is implemented. It is believed that the cost data is of sufficient accuracy to permit a valid comparison between alternative services. Where significant uncertainty exists in the cost data, an effort has been made to provide upper and lower bounds on the anticipated cost.

Table 6-1 shows the costs of the various links for Alternative A and the total configuration cost. Observe that the costs for the star configuration out of Grand Island have been kept separate from the cost of the star configuration out of Washington, D.C. The purpose in doing this was to identify clearly the cost of having back-up control site capability.

Table 6-2 shows the costs of Alternative B. Again, the cost of the Grand Island links has been kept separate to identify the cost of back-up control site capability.

TABLE 6-1

ALTERNATIVE A COST DATA

LINK	IXC ($/MO.)	STATION TERMINATION ($/MO.)	INSTALLATION ($)
DC - AL	539	138.80	110.50
- AN	2738	121.80	110.50
- BE	559	138.80	110.50
- DS	1042	138.80	110.50
- FN	1162	138.80	110.50
- FL	720	138.80	110.50
- GI	829	138.80	110.50
- KI	914	138.80	110.50
- LR	32	138.80	110.50
- LV	1182	138.80	110.50
- PS	551	138.80	110.50
- SS	1399	138.80	170.00
- WP	1666	108.00	110.50
SUBTOTALS	13,333	1756.60	1496.00
GI - AL	605	138.80	110.50
- AN	3339	121.80	110.50
- BE	932	138.80	110.50
- DS	719	138.80	110.50
- FN	875	138.80	110.50
- FL	920	138.80	110.50
- KI	733	138.80	110.50
- LR	832	138.80	110.50
- LV	865	138.80	110.50
- PS	717	138.80	110.50
- SS	2095	138.80	170.00
- WP	1308	108.00	110.50
SUBTOTALS	13,940	1617.80	1385.00
TOTAL	$ 27,273	$ 3374.40	$ 2881.50

TABLE 6-2

ALTERNATIVE B COST DATA

LINK	IXC ($/MO.)	STATION TERMINATION ($/MO.)	INSTALLATION ($)
DC - AL	599	52.60	113.80
- AN	3207	52.60	113.80
- BE	617	52.60	113.80
- DS	1288	52.60	113.80
- FN	1452	52.60	113.80
- FL	840	52.60	113.80
- GI	994	52.60	113.80
- KI	1110	52.60	113.80
- LR	146	52.60	113.80
- LV	1479	52.60	113.80
- PS	610	52.60	113.80
- SS	2057	306.45	636.90
- WP	3953	52.60	113.80
SUBTOTALS	18,352	937.65	2,002.50
GI - AL	677	52.60	113.80
- AN	3921	52.60	113.80
- BE	1136	52.60	113.80
- DS	839	52.60	113.80
- FN	1057	52.60	113.80
- FL	1119	52.60	113.80
- KI	859	52.60	113.80
- LR	998	52.60	113.80
- LV	1044	52.60	113.80
- PS	835	52.60	113.80
- SS	3054	306.45	636.90
- WP	3460	52.60	113.80
SUBTOTALS	18,999	885.05	1,888.70
TOTALS	$37,351	$ 1,822.70	$ 3,891.20

Table 6-3 presents the cost data for Alternative C. Please note that this particular configuration does not make provision for a back-up control site. The particular importance of this configuration is that it is the least-cost configuration for connecting all of the involved sites. Technically, this configuration is not practical; however, it does serve as a basis for cost comparisons.

Table 6-4 presents the cost data for Alternative D. Notice that this configuration does cost more than the one presented as Alternative C. However, it must be recalled that this configuration has eliminated the technical problems associated with Alternative C and has, at the same time, provided a high degree of redundancy in both the communications channel and in the network control capability.

Table 6-5 identifies the costs associated with Alternative E. It should be kept in mind that Alternative E is a configuration using Series 3000 lines of the same type of robust network presented in Alternative D for Series 1000 lines. One of the major differences between these two alternatives is the assumed presence of audio on the links in Alternative E. The audio prevents the use of a store-and-forward type of operation which greatly enhances the data communications system's performance. The presence of analog audio also necessitates analog bridging on the multidrop lines. This form of bridging limits the number of drops per line and therefore increases the number of lines required to interconnect the sites. If it were desired to use Series 3000 lines to permit higher transmission speeds than the Series 1000 lines will support, then the configuration of Alternative D could be used with simple substitution of Series 3000 lines. This would create a high-speed, store-and-forward data network, but this network would not support audio transmissions.

As pointed out in Section 5.1.6, the most reasonable way to study a DDD network is to do a parametric study allowing for variation of average usage. This analysis began by computing the average connect time charge based upon the data in Tables 4-5 and 4-6. For the Washington, D.C. control center, the average connect charge is 58¢ + 41¢/minute. The corresponding number for the Grand Island, Nebraska, back-up control site is 59¢ + 42¢/minute. If we assume that each connection is of reasonable duration, then the connect costs approach the cost-per-unit time in the

TABLE 6-3

ALTERNATIVE C COST DATA

LINK	IXC ($/MO.)	STATION TERMINATION ($/MO.)	INSTALLATION ($)
BE - LR	543	138.80	110.50
LR - AL	538	138.80	110.50
AL - GI	605	138.80	110.50
LR - DC	32	138.80	110.50
DC - SS	1399	138.80	170.00
DC - PS	551	138.80	110.50
PS - FL	580	138.80	110.50
PS - KI	718	138.80	110.50
KI - DS	655	138.80	110.50
DS - LV	677	138.80	110.50
LV - WP	425	108.00	110.50
LV - FE	662	138.80	110.50
LV - AN	2757	121.80	110.50
TOTALS	$ 10,142	$ 1756.60	$ 1496.00

TABLE 6-4

ALTERNATIVE D COST DATA

LINK	IXC ($/MO.)	STATION TERMINATION ($/MO.)	INSTALLATION ($)
BE - LR	543	138.80	110.50
LR - DC	32	138.80	110.50
DC - SS	1399	138.80	170.00
DC - PS	551	138.80	110.50
PS - FL	580	138.80	110.50
FL - KI	806	138.80	110.50
KI - DS	655	138.80	110.50
DS - LV	677	138.80	110.50
LV - WP	425	108.00	110.50
LV - FE	662	138.80	110.50
FN - AN	2552	121.80	110.50
FN - GI	875	138.80	110.50
GI - AL	605	138.80	110.50
AL - BE	697	138.80	110.50
TOTALS	$ 11,059	$ 1895.40	$ 1606.50

TABLE 6-5

ALTERNATIVE E COST DATA

LINK	IXC ($/MO.)	STATION TERMINATION ($/MO.)	INSTALLATION ($)
BE - LR	603	52.60	113.80
LR - AL	598	52.60	113.80
LR - DC	146	52.60	113.80
DC - SS	2057	306.45	639.90
DC - GI	994	52.60	113.80
DC - GI	994	52.60	113.80
DC - GI	994	52.60	113.80
DC - GI	994	52.60	113.80
DC - GI	994	52.60	113.80
DC - GI	994	52.60	113.80
DC - PS	610	52.60	113.80
PS - FL	1398	52.60	113.80
PS - KI	836	52.60	113.80
GI - AN	3921	52.60	113.80
GI - WP	3460	52.60	113.80
GI - DS	839	52.60	113.80
DS - LV	779	52.60	113.80
LV - FN	758	52.60	113.80
TOTALS	$ 21,969	$ 1200.65	$ 2574.50

above figures. Figure 6-1 summarizes the costs for a DDD network as a function of the average connect time. For the assumed average of 2 hours of connect time per station per day, the monthly channel costs are \$19,188/month. Note that this is the cost for the network based in Washington D.C. Since it is not expected that the Grand Island control site would be active as a control point while the Washington, D.C. site is operational, this number actually represents the cost of the fully redundant control center capability.

One moderating factor on the above costs is that the numbers cited in Tables 4-5 and 4-6 are the rates applicable to the period 8:00 a.m. to 5:00 p.m. This is the peak billing period, and discounts are given during all other time intervals. In particular, a 30% discount is given between 5:00 p.m. and 11:00 p.m., and a 55% discount is offered between 11:00 p.m. and 8:00 a.m. If we assume that the DF activity is uniformly distributed over the 24 hour interval, then the average connect charges are computed as follows:

Washington, D.C. based network:
41¢(9/24) + 41¢(.7)(6/24) + 41¢(.45)(9/24) = 29¢/min.

Grand Island, Nebraska, based network:
42¢(9/24) + 42¢(.7)(6/24) + 42(.45)(9/24) = 30¢/min.

If these rates are applied to the average situation (2 hours of connect time per day per station) then the cost per month for a 13 line network is \$13,572/mo.

As pointed out in Section 4.1.4, there are two versions of WATS available: full business day and measured service. From a technical point of view, both provide the same service. To determine which form of WATS is preferred, based on cost, one must determine a level of utilization.

Our survey of DF activity has indicated that approximately two hours per day per DF site are expended in DF work. For a minimal WATS network configuration of 3 lines, the average activity per station would probably drop since the number of stations that can participate in any activity is highly restricted. The extent of this possible decline in activity

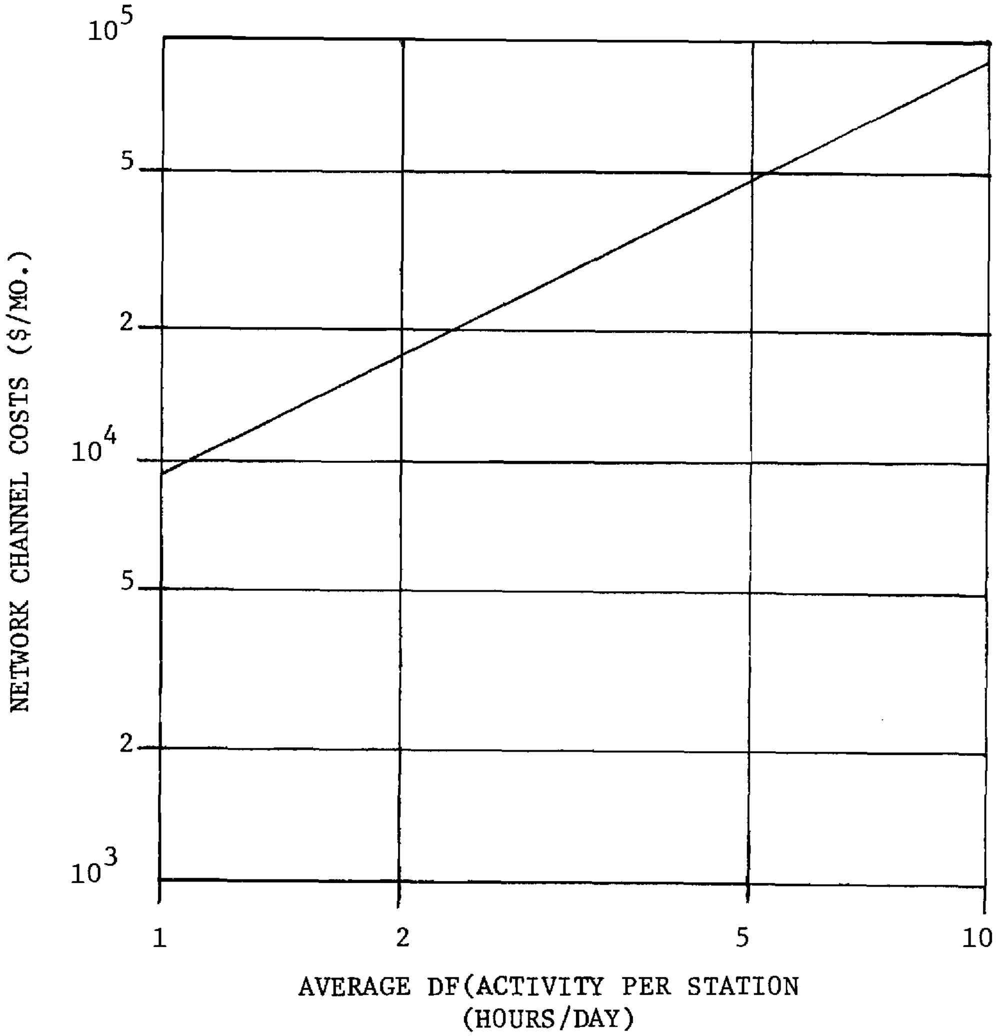


Figure 6-1 Cost for a DDD Network Based in Washington,D.C. Employing 13 Lines

cannot be reliably estimated at this time; therefore, for the cost analysis to follow, it will be assumed that the activity per DF site will remain constant at 2 hours/day.

An average of 2 hours per day per site amounts to 780 hours per month. If this amount is equally divided among three lines, the result is 260 hours per line. This level of line utilization far exceeds the breakpoints identified in Tables 4-8 and 4-9. Thus, it is more cost-effective to use the full business day WATS. The cost for a three line configuration of this type is shown in Table 6-6. Notice that a fully redundant control capacity is provided in the cost estimate shown in Table 6-6. Also notice that if both control centers are concurrently active and working in a coordinated fashion, it is possible to access six sites with this arrangement.

To evaluate the cost of the upper bound WATS configuration, we must again address the level of activity question. Using the 2 hours per day per site value for DF activity, one calculates a line utilization of 60 hours per month. Notice that this activity level favors the measured service WATS, as shown by the breakpoint data in Tables 4-8 and 4-9. The cost of the upper bound WATS configuration appears in Table 6-7. This configuration like the one presented in Table 6-6 has fully redundant control capacity.

6.1.2 Telephone System Advantages/Disadvantages

The major technical attributes at the various telephone-based networks are summarized in Table 6-8. Most of the comments appearing in this table are self-explanatory; however, the limited access comments appearing for Alternatives F and G reflect that the dial-up networks may not have a sufficient number of lines to permit simultaneous access to a specific group of DF sites.

6.2 Satellite Based Systems

The technical characteristics and associated costs for satellite-based networks are described in the following sections. The

TABLE 6-6

LOWER BOUND COSTS FOR ALTERNATIVE G

CONTROL POINT	LINE TYPE	LEASE ($/MO.)
WASHINGTON, D.C.	ZONE 6	3318.60
	ZONE 6	3318.60
	ZONE 5	1858.80
GRAND ISLAND, NE.	ZONE 6	2874.00
	ZONE 6	2874.00
	ZONE 5	1745.00
	TOTAL	$15,989.00

TABLE 6-7

UPPER BOUND COSTS FOR ALTERNATIVE G

CONTROL POINT	LINE TYPE	NO. OF LINES	LEASE ($/MO.)	TOTAL COST ($/MO.)
WASHINGTON, D.C.	ZONE 6	2	1546.00	3096.00
	ZONE 5	6	1224.00	7344.00
	ZONE 4	1	1193.50	1193.50
	ZONE 3	3	1148.50	3445.50
	ZONE 1	1	978.50	978.50
GRAND ISLAND, NE.	ZONE 6	2	1429.00	2858.00
	ZONE 5	8	1208.00	9664.00
	ZONE 4	2	1193.50	2387.00
	ZONE 3	1	1178.50	1178.50
			TOTAL	$ 32,145.00

TABLE 6-8

ADVANTAGES AND DISADVANTAGE OF TELEPHONE-BASED NETWORKS

ALTERNATIVE	ADVANTAGES	DISADVANTAGES
A	HIGH FAULT TOLERANCE FULL CONTROL BACK-UP FAST CONNECT TIME	LOW SPEED DATA NO RETURNED AUDIO
B	HIGH FAULT TOLERANCE MEDIUM SPEED DATA RETURNED AUDIO FULL CONTROL BACK-UP FAST CONNECT TIME	ALTERNATE VOICE/DATA
C	COMMON CHANNEL FAST CONNECT TIME	LOW FAULT TOLERANCE LOW DATA SPEED NO RETURNED AUDIO LIMITED CONTROL BACK-UP
D	HIGH FAULT TOLERANCE FULL CONTROL BACK-UP FAST CONNECT TIME	LOW DATA SPEED NO RETURNED AUDIO
E	FULL CONTROL BACK-UP MODERATE SPEED DATA RETURNED AUDIO FAST CONNECT TIME	LOW FAULT TOLERANCE ALTERNATE VOICE/DATA
F	HIGH FAULT TOLERANCE FULL CONTROL BACK-UP MEDIUM SPEED DATA RETURNED AUDIO	SLOW CONNECT TIME ALTERNATE VOICE/DATA LIMITED ACCESS (?)
G	HIGH FAULT TOLERANCE FULL CONTROL BACK-UP MEDIUM SPEED DATA RETURNED AUDIO	SLOW CONNECT TIME ALTERNATE VOICE/DATA LIMITED ACCESS(?)

discussions presented here follow the sequence of alternatives presented in Section 5.

6.2.1 Satellite System Costs

In this section, the costs associated with the satellite-based networks described in Section 5.2 will be determined and discussed. The analysis begins with Alternative H in which the user owns all terrestrial facilities and leases transponder capacity from a common carrier.

There are several ways to implement the network defined in Figure 5-5. One approach, which is used by Digital Communications Corporation, is to employ a Time Division Multiplexing (TDM) for the data flow at each earth station and to employ a Time Division Multiple Access (TDMA) strategy for network access. Using this technique, relatively small and inexpensive earth stations can support an impressive data flow. In particular, remote earth terminals using 4.6 meter antennas and 5 watt GASFET high power amplifiers (HPA's) can support 268.8 kBPS transmissions. In the TDM arrangement, this is the equivalent of approximately 8 simultaneous VF channels (32 kBPS CVSD). In other words, either one DF site could send back 8 audio channels, or 8 DF sites could send back one audio channel each. Of necessity, the control site in such a network must be larger. In particular, the central site(s) for this network would use 11 meter antennas with traveling wave tube (TWT's) HPA's in the 20 to 125 watt class. The costs for such a network is shown in Table 6-9.

Two additional features of the configuration are described in Table 6-9. The costs shown are for non-redundant hardware, meaning that a failure at any site takes that site out of the network until the failure is repaired. Secondly, back-up for the net control function has been provided by the provision of two central site earth stations.

As may be seen from Table 6-9, the cost of such a system has a significant initial capital investment plus a noticeable recurring cost due to the lease of the transponder. To facilitate comparison with other approaches which do not have any significant capital investment, it is desirable to distribute the initial investment over the life span of the system. If the capital investment amount were a 10 year loan at an

TABLE 6-9

COSTS FOR A TDMA APPROACH TO ALTERNATIVE H

ITEM	NUMBER	COST EACH	TOTAL COST
EARTH STATION HARDWARE REMOTES	12	$55,000	$660,000
REMOTE SITE PREPARATION FACILITY	12	$20,000	$240,000
CENTRAL SITE HARDWARE	2	$300,000	$600,000
NETWORKING SOFTWARE	1	$250,000	$250,000
TRANSPONDER LEASE	1	$300,000/YR.	$300,000/YR.
TOTAL CAPITAL INVESTMENT			$1,750,000
EQUIVALENT MONTHLY SERVICE CHARGE			$48,742

annual interest rate of 10%, then the monthly cost for this service would be \$23,742 for the hardware and \$25,000 for the transponder lease. The total monthly cost would be \$48,742 (not including user provided maintenance costs).

A second approach to the network defined in Figure 5-5 would be to use a single 56 kBPS channel which is shared in a sequential fashion by all users under the supervision of the network control station. One such system is provided by Scientific Atlanta, and the costs for that approach are presented in Table 6-10.

The capital investment for the approach presented in Table 6-10 is higher than for that shown in Table 6-9. The reason for the difference is that the system in Table 6-10 has fully redundant hardware at each site with a microprocessor-based local control unit which runs diagnostics, switches to the back-up unit if a failure is detected, and reports any failures to the network control center. If the same amortizing scheme is applied in this case as was used for the TDMA approach, then the monthly costs would be \$37,987 for the hardware and \$5,250 for the transponder lease. The total monthly cost, not including maintenance, would be \$43,237.

A third version of the configuration shown in Figure 5-5 implements a true star network with a dedicated channel for each link between the control center and a remote site. A common technique for implementing such a network is to use the FM/FDM approach. In this case, a single carrier is frequency modulated (FM) with a group of Frequency Division Multiplexed (FDM) subcarriers. Each subcarrier in the present case would represent a single VF channel. Table 6-11 shows the cost to implement a network of this type.

There are several ways to implement Alternative I. One approach would be to implement a single outbound channel from the control center to the DF sites, and have a single dedicated channel for each inbound path between the remote and the control site. Obviously, this reduces the number of outbound paths and one would expect a reduction in the space segment cost. Therefore, some cost reduction could be realized using this approach; however, it generally will not be significant. For this reason, the cost evaluation for Alternative I assumes 13 dedicated

TABLE 6-10

COST FOR A POLLED APPROACH TO ALTERNATIVE H

ITEM	NUMBER	COST EACH	TOTAL COST
EARTH STATION HARDWARE	14	$180,000	$2,520,000
EARTH STATION INSTALLATION	14	$20,000	$280,000
TRANSPONDER LEASE	3	2 @ $1500/MO. 1 @ $2250/MO.	$5,250/MO.
TOTAL CAPITAL INVESTMENT			$2,800,000
EQUIVALENT MONTHLY SERVICE CHARGE			$43,237

TABLE 6-11

COST FOR AN FM/FDM APPROACH TO ALTERNATIVE H

ITEM	NUMBER	COST EACH	TOTAL COST
CONTROL EARTH STATION HARDWARE	2	$384,500	$769,000
REMOTE EARTH STATION HARDWARE	12	$216,500	$2,598,000
TRANSPONDER LEASE	13	12 @ $1500/MO. 1 @ $2250/MO.	$20,250/MO.
TOTAL CAPITAL INVESTMENT			$3,367,000
EQUIVALENT MONTHLY SERVICE CHARGE			$45,679/MO.

links between the control site and the various remotes. The cost data appears in Table 6-12.

The configuration defined as Alternative J is a combination of satellite and terrestrial links based upon the least-cost configuration of a network which uses satellite links exclusively. The lease fee for such a network is shown in Table 6-13.

Table 6-14 summarizes the costs for all of the alternatives.

6.2.2 Satellite System Advantages and Disadvantages

Table 6-15 summarizes the advantages and disadvantages associated with the satellite-based configurations. Most of the comments are self-explanatory; however, those regarding digitized audio and periodic outage may need clarification. Most of the satellite systems considered for this application utilize strictly digital transmission schemes. This means that any audio passed over such a channel must be digitally encoded and decoded. Some methods employed for this process achieve a reduction in the required data transmission rate by assuming that human speech is the primary audio traffic of concern and customize the encoding and decoding process to take advantage of specific features of human speech. Such schemes work reasonably well as long as the audio is, in fact, human speech; however, the results can be unpredictable when the audio includes more than human speech. In this application, it is anticipated that much of the audio of interest will not be human speech; therefore, the encoding/decoding process could cause problems.

The outage comment refers to the fact that all satellite systems periodically experience an outage due to an alignment of the participating earth station, the involved satellite and the sun. Typically, this outage spans a one to two week period twice a year and ranges in duration from a few minutes to approximately one hour. Compensation for this problem normally involves having a redundant satellite which may be used when a sun outage is occurring on the primary satellite.

TABLE 6-12

COST DATA FOR ALTERNATIVE I

ITEM	NUMBER	COST EACH	TOTAL COST
CENTRAL SITE HARDWARE	2	$5,500/MO.	$11,000/MO.
REMOTE SITE HARDWARE	9 2 1	$3,500/MO. $5,250/MO. $2,520/MO.	$31,500/MO. $10,500/MO. $ 2,520/MO.
TRANSPONDER LEASE	12 1	$1,500/MO. $2,250/MO.	$18,000/MO. $ 2,250/MO.
TOTAL MONTHLY LEASE			$75,770/MO.

TABLE 6-13

COST DATA FOR ALTERNATIVE J

LINK	LINK TYPE	LEASE ($/MO.)
BE - LR	SATELLITE	1460
LR - DC	TERRESTRIAL	146
DC - AL	SATELLITE	875
DC - GI	SATELLITE	1371
DC - KI	SATELLITE	968
DC - PS	SATELLITE	678
DC - SS	TERRESTRIAL	2057
PS - FL	TERRESTRIAL	1398
DC - LV	SATELLITE	978
LV - GI	SATELLITE	1539
LV - DS	TERRESTRIAL	779
LV - WP	TERRESTRIAL	2513
LV - AN	TERRESTRIAL	2900
LV - FE	TERRESTRIAL	758
	TOTAL NETWORK LEASE:	$18,420

TABLE 6-14

SUMMARY OF COST DATA FOR COMMUNICATIONS NETWORK ALTERNATIVES

ALTERNATIVE	INITIAL INVESTMENT	RECURRING COST
A	$2881.00	$27,273.00/MO.
B	$3891.20	$39,173.70/MO.
C	$1496.00	$10,142.00/MO.
D	$1606.50	$11,059.00/MO.
E	$2574.50	$21,969.00/MO.
F	$1300.00	$13,572.00/MO.
G	$1300.00	$15,989/MO, MIN. $32,145/MO, MAX.
H	$1,750,000, MIN. $3,367,000, MAX.	$300,000/YR. $ 20,250/YR.
I	$ 000	$75,770/MO.
J	$1300.00	$18,420/MO.

TABLE 6-15

ADVANTAGES AND DISADVANTAGE OF OF SATELLITE-BASED SYSTEMS

ALTERNATIVE	ADVANTAGES	DISADVANTAGES
H	HIGH FAULT TOLERANCE FULL CONTROL RACK-UP HIGH SPEED DATA RETURNED AUDIO SIMULTANEOUS AUDIO/DATA	DIGITIZED AUDIO (?) PERIODIC OUTAGES (?)
I	HIGH FAULT TOLERANCE FULL CONTROL BACK-UP HIGH SPEED DATA RETURNED AUDIO SIMULTANEOUS AUDIO/DATA	
J	MODERATE FAULT TOLERANCE FULL CONTROL BACK-UP HIGH SPEED DATA RETURNED AUDIO SIMULTANEOUS AUDIO/DATA	DIGITIZED AUDIO (?) PERIODIC OUTAGES (?)

6.3 Radio-Based Systems

Costs along with the various advantages and disadvantages of a radio based system are discussed below. Many details of the subjects covered are present in Sections 4.3 and 5.3.

6.3.1 Costs

High frequency communication costs (individual units) are presented below in two sections: antenna hardware, and electronic hardware. Total system costs follow individual costs.

Antenna Costs:

Rohn 55G (100 ft)	$2,000
Antenna	1,000
Coax switch (electrically controlled)	75
Guy wire (1500 ft)	900
Guy anchors (3)	25
Copper wire (300 ft)	30
Baluns (2)	60
Coax (300 ft) RG-8	90
Ground rods (2-12 ft)	50
Other	150
Total	$4,380

Electronic Costs:

Transmitter/Amp	$40,000
Receiver	1,500
Modem	400
Total	$41,900

Total Costs:

14 Transmitters/Amp	$560,000
14 Receivers	21,000
14 Modems	5,600
15 Antennas	65,700
System Total	$652,300

6.3.2 Advantages/Disadvantages

The advantages and disadvntages of using high frequency propagation for communication in the remote direction finding scenario are discussed below.

The advantages include lower amortized cost, independence from communication carriers, and system cross-function (receivers could handle either the communication function or the direction finding function).

The disadvantages include the often unpredictable ionospheric fluctuations, additional software and possibly hardware processing needs, connect or set-up time delays caused by transmitter and receiver frequency synchronization searching, and data rate limitations that result from multipath interference.

In conclusion, the above disadvantages and overall lower link reliability being the major concerns, high frequency communication should not be the primary communication medium in the HF/DF network, but would provide a reasonable and economical secondary (or back-up) system.

6.4 Staffing Evaluation

One motivation for considering the implementation of an automated DF network is the possibility that the existence of such a network will permit a redistribution of monitoring site personnel. This issue is discussed in the following material.

The impact on staffing of an automated DF capability occurs at two levels - (1) manpower is made available due to the fact that local operators are not directly involved in the DF activity, and (2) flexibility in staffing assignments may be significantly increased due to elimination of the requirement for operator presence at the DF/monitoring site.

It is important to recognize that the DF site staff is involved in activities other than direction finding. The informal survey of DF site personnel which we conducted, Appendix D, indicates that on the average, each DF site is involved in approximately 2 hours per day of DF activity. This would suggest that much of the operator's time is already spent on non-DF activity. Discussions with field personnel indicate that much of the operator's time is spent in HF and VHF enforcement monitoring. It has been pointed out that the direction finding equipment is frequently used in HF enforcement monitoring; therefore, the monitoring and direction finding tasks should <u>not</u> be viewed as isolated and independent activities.

Using the estimate of two hours of DF activity per site per day, one would conclude that 9490 person-hours are expended annually in this activity. This then represents the upper bound on the amount of effort which may be transferred to any other program as a result of decreasing the manpower needs of the DF activity alone.

To evaluate the impact of an automated DF network on staff assignment flexibility, one must understand certain policy issues and have a measure of the current level of staffing influenced by the DF function. As a matter of policy, the monitoring stations are staffed twenty-four hours a day to assure that the DF network is always prepared to respond to high priority work items, such as safety-of-life matters.

In practice 5.2 work-years per year of monitoring operation time are required to keep each station open continuously, having one person on duty. For the system as a whole, all 13 monitoring sites, this amounts to an annual effort level of 67.6 person-years. It is emphasized that only a small fraction of this total effort is applied to DF problems; however, the policy decision to provide a 24 hour per day DF capability dictates that operators be physically present at the 13 sites at all times. This constitutes a constraint on staffing flexibility. For example, these same operators could be assigned to mobile monitoring tasks if it were not necessary for them to be available at the DF site to support the DF program as needed.

It is now necessary to determine the extent to which an automated DF system can enhance flexibility in staffing assignments. Consider the situation described by Figure 6-2. Notice that 1.73 person-years/year of operator effort are required at each site on each "watch." Introduction of an automated DF system would elminate the requirement that these operators be present at the DF sites. Potentially, one then has the flexibility to redistribute all 67.6 person-years of operator effort; however, there are some factors which limit in practical terms this flexibility.

Notice that only one person, an operator, would normally be on-duty at a DF/monitoring site during the evening and mid-watches. If either or both of these watches is to be closed so that the associated manpower may be reassigned, one must address the issue of station security. If in the judgement of FCC management, it is not necessary to provide physical security during the closed watches then a direct transfer of manpower is possible with no net change in staffing. If it is determined that physical security is required then the effectiveness of such redistributions is significantly reduced. The reason for this is that, in terms of effort expended, an eight hour watch served by a security guard requires the same manpower expenditure as an eight hour watch served by a DF operator. Note that the operator is capable of providing the security service; however, the guard would probably not be able to provide any direction finding or monitoring support. The possible advantage in replacing a DF operator with a security guard would stem from the salary differences for these two positions.

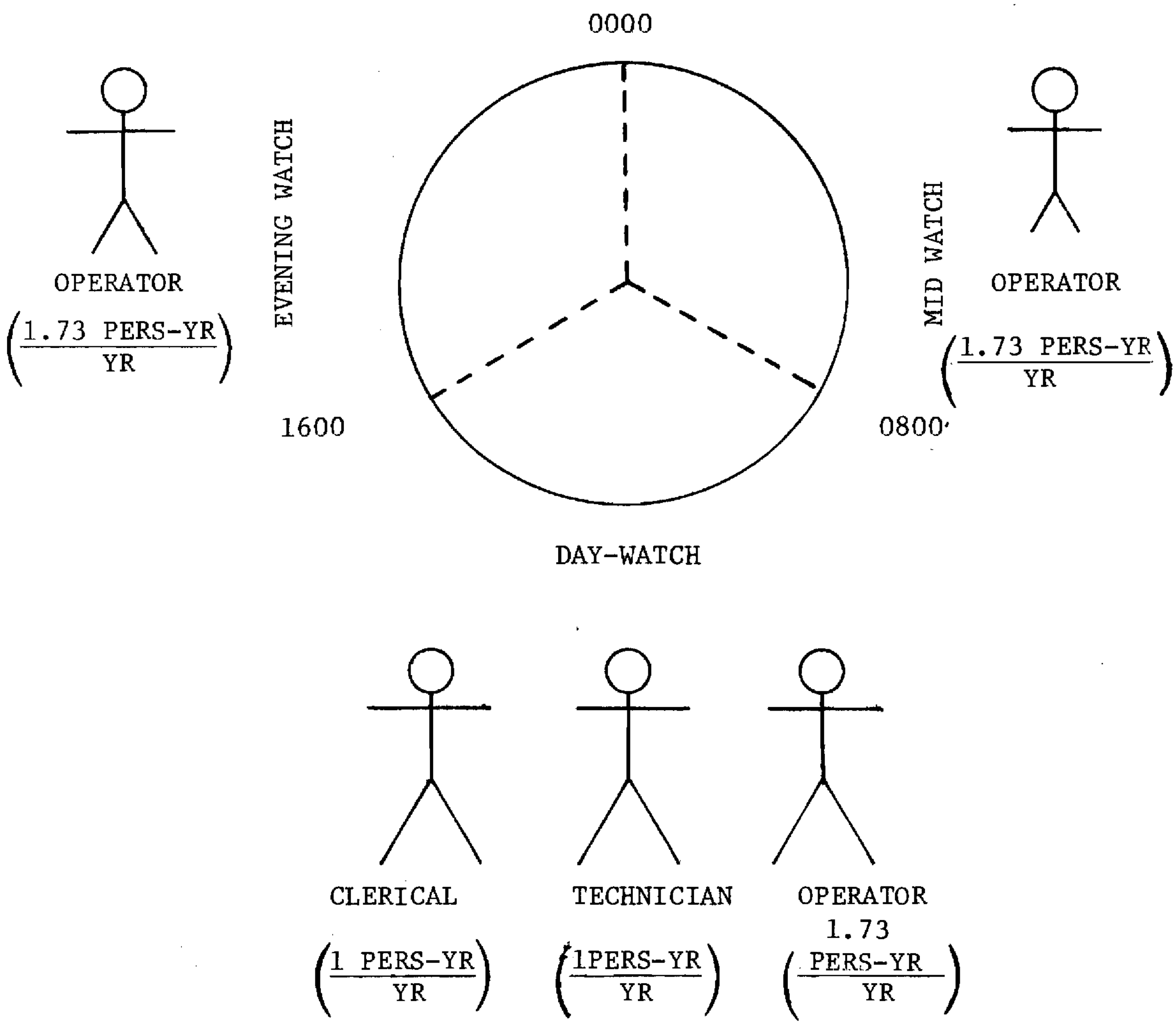


Figure 6-2. Typical DF Site Staffing.

It is possible, however, to reassign the day "watch" operators without introducing the need for security personnel since typically two other individuals are on duty during the day watch. From a technical point of view, this may be very desirable. Typically, the HF monitoring capability of a site is at a minimum during the day watch while VHF and UHF activity, which generally requires mobile monitoring, is at a peak during the day watch. This seems to be an opportunity for redistribution of effort resulting from the flexibility provided by the automated DF capability. If the day watch were closed at all 13 sites then approximately 22.5 person-years/year of effort would be reassignable.

Implementation of the automated DF network will introduce equipment for which maintenance support does not currently exist. In particular, much of the equipment associated with the automated DF network will be digital devices of varying complexity. Discussions with monitoring site personnel indicate that in general the existing maintenance personnel have backgrounds in analog system maintenance, but little if any experience with digital system maintenance. Three maintenance options appear to be available:

(1) Train the existing maintenance personnel to perform maintenance on the digital systems, or

(2) Obtain a service contract for the digital hardware where possible, or

(3) Get service performed on an as-needed basis.

There appears to be three major items in the automated DF system which will require special maintenance attention: the local computer, the digitally controlled receiver, and the controller for the Wullenwebber array. Of these, the most complex is the local computer; therefore, it is assumed that the maintenance training for the computer will allow the existing maintenance personnel to service the other items.

The cost of self-maintenance for a computer can be divided into three parts: (1) training, (2) equipment, and (3) parts. The cost to train an individual with no prior background in computer maintenance to maintain computers of the type used in the DF network is estimated to be approximately $6000 in training fees and two months of training time. This estimate is based upon the cost and duration of hardware maintenance courses offered by major computer manufacturers.

It is assumed that at present each monitoring station has a basic maintenance equipment inventory which includes items such as voltmeters, oscilloscopes, soldering equipment, assorted screw drivers, etc. In addition to such standard maintenance equipment, it is estimated that additional equipment costing approximately $15,000 will be required at each site. The two principal elements of this addition are a logic analyzer and a function generator.

The issue of the parts inventory necessary to assure a certain system availability is linked to the level at which maintenance is actually performed. Generally, three repair levels are recognized - unit, board, and component. At the unit level, the maintenance activity is directed toward identifying the unit, such as printer, terminal, magnetic tape unit, etc., which is not operating properly. An operative unit is then substituted for the failed unit. Repair of the failed unit may be done on-site, or the failed unit may be returned to a centralized repair facility.

Repair at the board or module level requires the local maintenance personnel to identify the specific printed circuit board which has failed. The defective board is replaced. Repair of the failed board may be done on-site, or the failed board may be returned to a centralized repair facility.

Repair at the component level, requires the local maintenance personnel to identify the specific components which have failed. The defective components are generally replaced locally, and the system is returned to service when the repair is completed.

The central issue in each of these cases is the acceptable down-time for the individual DF site. To consistently achieve the fastest recovery, it is necessary to provide the equivalent of unit level repair. For unit level repair, the down-time is typically a few hours, but it should be stressed that this recovery speed is attained by doubling the local hardware inventory.

If longer recovery intervals are acceptable, typically 24 to 72 hours, then a centralized repair facility can be used to reduce the spare parts inventory cost. In this case, the local maintenance personnel would be responsible for identifying the defective unit, board, or component. He would then contact the central repair facility and request immediate shipment of the required replacement. Using this approach, two or three complete back-up systems can be used to support all 13 DF sites. This approach results in a maintenance hardware overhead amounting to 15-to-23% of the hardware investment for the 13 DF sites.

The second maintenance option is that of obtaining a service contract where possible. As in the self-maintained case, there are three major hardware entities - the computer, the receiver, and the array controller. The array controller is a device developed by the FCC's ECIB; therefore, it is not likely that a commercial organization would offer to maintain that device. Self-maintenance appears to be necessary for the array controller.

Most computer manufacturers offer maintenance contracts for their products. The most common arrangement provides "next-day" service at a monthly cost of approximately one percent of the total computer hardware investment. In some cases, this type of service contract is available only within the continental U.S.; however, we have determined that at least one of the major computer vendors has service offices in Juneau, Alaska, Honolulu, Hawaii, and San Juan, Puerto Rico.

Generally, the manufacturers of the digitally controlled receivers do <u>not</u> provide service contracts for their products. This generally forces the user/owner into one of two maintenance postures - self-maintenance or as-required maintenance by the manufacturer. The self-maintenance mode has been previously described.

When receiver maintenance is provided by the manufacturer on an "as-required" basis, down-times on the order of several weeks may be expected. The estimated annual cost for this type of service is in the range of five to ten percent of the receiver's purchase price.

The third maintenance option is service on an as-needed basis. It has been pointed out that this type of maintenance will most likely be required for the array controller. It is estimated that the cost to maintain this device will be consistent with the cost of maintaining the computer. Experience suggests that the cost of "as-required" maintenance for the computer may be on the order of 0.25% per month of the purchase price. The cost of "as-required" receiver maintenance has been defined above - five to ten percent of device cost per year. It is stressed that this maintenance approach will typically lead to site down-times measured in weeks.

The maintenance cost data is summarized in Table 6-16.

TABLE 6-16

SUMMARY OF MAINTENANCE COST ESTIMATES

TYPE OF MAINTENANCE		ESTIMATED DOWN-TIME	MAINTENANCE COST ELEMENTS: TRAINING	EQUIPMENT	PARTS
SELF	LOCAL	2-4 HOURS	$6000 + 2 PERSON-MONTHS PER MAINTENANCE TECHNICIAN	$15,000/SITE	100% OF PRIMARY SYSTEM COST
	CENTRALIZED	24-72 HOURS	$6000 + 2 PERSON-MONTHS PER MAINTENANCE TECHNICIAN	$15,000/SITE	15-23% PRIMARY SYSTEM COST
SERVICE CONTRACT		24-36 HOURS SEE BELOW SEE BELOW	COMPUTER: 1% OF PRIMARY SYSTEM COST PER MONTH RADIO: NOT AVAILABLE ARRAY CONTROLLER: NOT AVAILABLE		
AS-NEEDED BY MANUFACTURER		2-4 DAYS 1-4 WEEKS 1-3 DAYS	COMPUTER: 0.25% OF PRIMARY SYSTEM COST PER MONTH RADIO: 5-10% OF PRIMARY SYSTEM COST PER YEAR ARRAY CONTROLLER: 0.25% OF PRIMARY SYSTEM COST PER MONTH		

7. CONCLUSIONS

The material in the preceding sections has described the technical and financial issues associated with implementing a remotely-controlled DF network. In this section, conclusions will be presented based upon network performance and operational capability.

7.1 Communications Considerations

A variety of requirements have been imposed on the network design, but a limited sub-set have the greatest impact. In particular, the following three requirements are judged to be the most influential:

(1) Network activation shall not require more than 10 seconds,

(2) Command distribution shall not require more than 0.5 seconds once the network has been established,

(3) Both audio and data transmission shall be supported by the network, and

(4) Site access shall be possible at any time for any site with a high confidence.

For Alternative A through E and H through J, requirement number one does not represent a significant constraint since it is readily possible to provide a set of simple and short commands which could be entered by a network control operator which would instantly activate the remote sites of interest. The major activation delay for these alternatives is associated with entry of the operation command. This is because the communications channels for these alternatives are permanently in place.

Alternatives F and G have dial-up channels, and therefore, there is an additional delay associated with call set-up. The common carriers do not routinely specify a typical call set-up time; however, one can get a feel for the set-up delay from the "abandon call timer" specification in CCITT Recommendation V.25. This specification indicates that automatic calling units should have the abandon call timer adjustable over the interval 10 to 40 seconds. This indicates that the common carriers anticipate that call set-up can routinely take 10 seconds or more. It would thus appear that the dial-up arrangements, Alternatives F and G cannot reliably be expected to meet the 10 second call set-up requirement. It is strongly recommended that the 10 second call set-up criteria be reviewed to see if it may be relaxed since Alternative F offers the least expensive means of satisfying requirement number three.

Next, consider the requirement that the command distribution not take longer than 0.5 seconds. For star networks using a single dedicated line to connect the control center and each remote site, this requirement indicates a minimum transmission speed. Our analysis has shown that the command message will be approximately 100 bytes long. To limit the transmission delay to 0.5 seconds, the transmission speed must be at least

$$\frac{100 \text{ bytes}}{0.5 \text{ sec.}} = \frac{200 \text{ bytes}}{\text{sec.}} = \frac{1600 \text{ bits}}{\text{sec.}}$$

The minimum transmission speed identified above exceeds the capacity of Series 1000 lines by approximately a factor of 11. If a Series 1000 star network is to be utilized, then a transmission delay of at least 5.5 seconds must be determined by FCC personnel to be satisfactory, otherwise, all of the configurations involving Series 1000 lines must be removed from consideration.

Those alternatives employing Series 3000 lines, Alternatives B, E, F, G, and J, are capable of supporting transmission speeds of 2400 BPS or more. Table 7-1 shows the minimum transmission speed required to satisfy requirement two. Notice that in several cases an upper and lower bound is specified for the minimum speed. The lower bound applies if the networking software has the multiple addressing capability, and the upper bound applies if a separate control message must be sent to each remote site on multi-drop channel.

TABLE 7-1

MINIMUM TRANSMISSION SPEED REQUIREMENTS

ALTERNATIVE	TRANSMISSION CAPACITY (BPS)	MIMIMUM SPEED (BPS)
B	2400	1600
E	2400	1600(LOWER BOUND) 4800(UPPER BOUND)
G	2400	1600
H (TDMA)	268000	20800
H (TDM)	56000	1600(LOWER BOUND) 20800(UPPER BOUND)
H (FDM)	2400	1600
I	2400	1600
J	2400	1600(LOWER BOUND) 8000(UPPER BOUND)

The fourth requirement stated above indicates the need for high confidence in the ability to access a given DF site. Obviously, this requirement is best satisfied by those alternatives which provide a dedicated link between the control centers and the remote DF sites: Alternatives A, B, C, D, E, H, I, and J. Alternatives F and G utilize the dial-up telephone network; therefore, the ability to establish a connection between any two points at a given time is uncertain. In most cases, the probability that such calls could be completed promptly is fairly high. Common experience indicates that the dial network does frequently experience periods of high use, and during these periods, significant delays are commonly encountered in establishing a connection. Also, experience has indicated that regional or national emergencies can significantly degrade the likelihood of promptly establishing a connection. This observation is important since a significant demand for the DF capability may exist during such periods.

Table 7-2 summarizes the responsiveness of the various alternatives to the stated requirements. Notice that Alternatives B, E, H, I, and J appear to satisfy all of the stated technical requirements. Of these, Alternative J has the smallest recurring cost as defined in Table 6-14 and would appear to be the most suitable alternative. When recurring cost is used as the ranking criteria, the alternatives in order of preference are J, E, B, I, and H.

It has been stated that Alternatives B, E, H, J, and J satisfy the stated requirements; however, each satisfies the various requirements to a different degree. All four primary requirements are important; however, discussions with FCC personnel have indicated that requirement four should take precedence over the other requirements given that the other requirements have been satisfied. Alternatives B, E, H, I, and J all provide a high degree of node accessibility assuming that all nodes and links are properly functioning. Of these approaches, only the satellite-based alternatives, H, I, and J, offer any channel or node redundancy, and of these, Alternative J is the least cost approach.

It is possible to configure a telephone-based network which can provide a high degree of access reliability at a reasonable cost. One approach is shown in Figure 7-1. The network depicted in the figure uses Series 3000 lines between the DF sites for data transmission, and two

TABLE 7-2

SUMMARY OF RESPONSIVENESS TO REQUIREMENTS
BY ALTERNATIVES

ALTERNATIVE	REQUIREMENT 1	2	3	4
A	X			X
B	X	X	X	X
C	X			X
D	X			X
E	X	X	X	X
F		X	X	
G		X	X	
H	X	X	X	X
I	X	X	X	X
J	X	X	X	X

X: INDICATES THAT REQUIREMENT IS SATISFIED

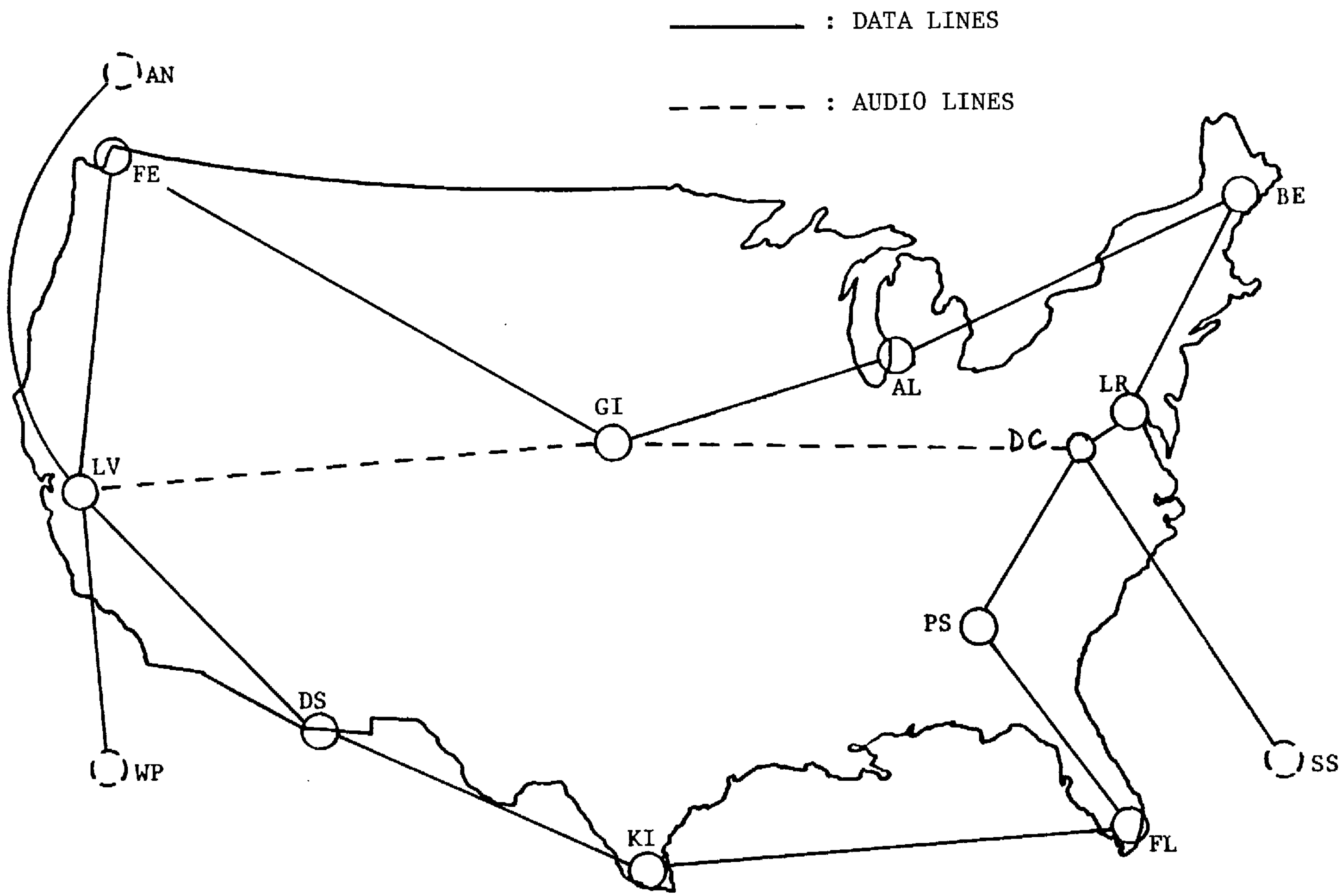


Figure 7-1. A Series-3000-Based Store-and-Forward Network.

audio links are also provided. The data lines in conjunction with the computers at each node constitute a store-and-forward network. For the configuration shown, two failures must occur before any one CONUS node is isolated. This means that no single link or computer failure can isolate a CONUS DF station.

Audio for synchronization and monitoring purposes is obtained from the HF monitoring equipment at the FCC's Washington office and by Series 3000 lines from the Grand Island, Ne. and Livermore, Ca. DF sites. Obviously more or fewer audio channels could be provided; however, the three sites selected should provide the ability to observe signals which are detectable at any of the DF sites.

The channel costs for the configuration shown in Figure 7-1 are presented in Table 7-3. Notice that the recurring cost for this configuration is \$19,098/mo. which places this approach in cost between Alternatives J and E. The hardware and software costs for the store-and-forward configurations are shown in Table 7-4. Notice that the CPU cost for the control site is typical of the control site cost for the other approaches and that the CPU cost for the DF site is slightly higher than the comparable hardware in most of the other arrangements. This extra hardware cost for the store-and-forward network is offset by the lower cost for software and modems.

From the above, we may conclude the following based on communications considerations:

(1) The networks utilizing Series 1000 lines are not able to meet two of the major requirements, command distribution within 0.5 seconds and audio distribution, and are therefore the least preferred approaches.

(2) The networks utilizing the dial-up lines, Alternatives F and G, are probably incapable of meeting the 10 second network activation criteria and their ability to achieve the required access reliability is uncertain. Therefore, they are ranked second in increasing order of preference for network implementation.

TABLE 7-3

CHANNEL COSTS FOR A SERIES-3000-BASED
STORE-AND-FORWARD NETWORK

LINK	IXC ($/MO)	STATION TERMINATION($/MO)	INSTALLATION ($)
DATA:			
BE-LR	603	52.60	113.80
LR-DC	146	52.60	113.80
DC-SS	2057	306.45	636.90
DC-PS	610	52.60	113.80
PS-FL	641	52.60	113.80
FL-KI	1119	52.60	113.80
KI-DS	747	52.60	113.80
DS-LV	779	52.60	113.80
LV-WP	2513	52.60	113.80
LV-FE	758	52.60	113.80
LV-AN	2900	52.60	113.80
FN-GI	1057	52.60	113.80
GI-AL	677	52.60	113.80
AL-BE	807	52.60	113.80
AUDIO:			
DC-GI	994	52.60	113.80
GI-LV	1044	52.60	113.80
TOTALS	17,452	1095.45	2343.90

TABLE 7-4

HARDWARE AND SOFTWARE COSTS FOR A SERIES-3000-BASED STORE-AND-FORWARD NETWORK

FACILITY	CPU HARDWARE	BASIC SOFTWARE	MODEMS	HF RECEIVER	SPECTRUM ANALYZER
CONTROL SITE	$42,560	$6,660	$4,000	NOT APPLICABLE	NOT APPLICABLE
DF SITE	$10,225	$1,525	$2,000	$15,000	$20,000

(3) Alternative E which is a multi-drop configuration of Series 3000 lines meets all of the basic communications requirements; however, the fault tolerance of this arrangement is low. It is ranked third in increasing order of preference on the grounds that the multi-drop configuration does to a degree restrict the freedom of selecting audio for transmission to the control site.

(4) Alternative B, the FDM approach to Alternative H, and Alternative J are judged to fully satisfy all of the known requirements for the DF network. These alternatives are therefore ranked fourth in increasing order of preference.

(5) The Series-3000-based store-and-forward configuration provides a high degree of access reliability at a reasonable cost. Its most noticable limitation, as defined, is in its ability to recover audio from only three sites. Should audio recovery from additional sites be required, it is a very simple matter to add additional audio lines. This approach is ranked fifth in increasing order of preference.

(6) Alternative I and the TDMA/TDM approaches to Alternative H are judged to noticeably exceed the communications requirements for the DF network.

7.2 Operational Considerations

In this section, the performance of the various alternatives will be examined in five areas which are primarily operational characteristics of the DF network. The areas to be considered are:

(1) Responsiveness to stated operational requirements,

(2) Accessibility of the DF stations to the network control station,

(3) Fault tolerance of the network,

(4) Reconfigurability of the network, and

(5) Network security.

The minimum configurations capable of supporting all of the currently defined operational requirements are those configurations which utilize Series 3000 lines, or equivalent, to provide the alternate audio/data capability. In particular, Alternatives B, E, F, G, and J are capable of supporting the operational requirements. The alternatives which support data only transmissions, A, C, and D, fall short of the stated requirements while those alternatives which support simultaneous audio/data transmissions, H and I, greatly exceed the stated requirements.

The Series-3000-based store-and-forward network meets all of the stated requirements with the exception of being able to recover audio from any of the 13 DF sites. Audio recovery from three critical locations has been provided, and in our judgement, this should be sufficient.

Obviously each of the network designs presented provides for the connecting of the remote DF sites to the control facilities. The networks presented for consideration are for the most part "sparse," i.e., the connectivity is the absolute minimum required. Failure of any one communications link will make one or more DF stations inaccessible. There are two exceptions to this.

In Alternative D, most of the remote sites are simultaneously connected to two or more communication channels. Thus the failure of any one communications channel will not isolate any of the CONUS remote sites. In particular, for the CONUS sites, it would take the failure of at least two communications links to isolate a CONUS remote station. A limited version of this capability exists for the dail-up alternatives, F and G. For the dial-up cases, if the link between Washington, D.C. and a given remote is inoperative, it is possible that the station can be activated through the dial-up connection from Grand Island, NE.

The Series-300-based store-and-forward network provides a level of access reliability comparable to that offered by Alternative D. Each CONUS location is tied to at least two other points; therefore, two simultaneous failures are necessary to isolate any single DF site.

There are various forms of fault tolerance. The above discussion has identified one type of channel fault that could have a serious impact on network operation. It should be pointed out that the satellite-based alternatives, H, I, and J, offer a degree of fault tolerance. In some cases, a double strand space segment is used; i.e., the user's traffic is either routed over two different transponders on a single satellite or possibly through two different satellites. The latter is not common for commercial applications; however, some satellite carriers do provide redundant space segment service with automatic switch-over in the event of failure by the primary satellite. Notice that this redundancy applies only to the space segment. It is up to the user to provide redundant earth terminal hardware if he feels that his application justifies the expense.

The alternatives utilizing the dial-up network, F and G, also have a degree of fault tolerance. This stems from the dynamic nature of the long distance routing used by the common carrier. As in the case of the satellite-based alternatives, the limitation in fault tolerance for the dial-up arrangements is primarily in the local loop which connects the user to his local switching center. The solution to this limitation is both simple and relatively inexpensive - obtain additional dial-up lines.

Given the critical nature of the DF function, it is concluded that a reasonable degree of network fault-tolerance is required.

There is a strong connection between the characteristics of accessibility, fault tolerance, and reconfigurability. Reconfigurability is typically required to survive network faults, and the ability to reconfigure a network is to a degree based upon node accessibility. Alternative D and the Series-3000-based store-and-forward configuration offer the greatest reconfiguration capability. In particular, for these configurations any node, station, can serve as a control node, assuming sufficient hardware capability, and no physical changes to the network are required to accomplish this. The other alternatives satisfy the minimum requirement that both Washington, D.C. and Grand Island, Nebraska, be capable of serving as network control. It is concluded that all of the alternative are suitable in reconfiguration capability.

Some of the work done by the DF network is of a sensitive nature; therefore, one must consider the issue of security. In simple terms, it may be said that none of the alternatives studied are inherently secure structures. Obviously, any transmission utilizing either satellite or HF radio links are observable over very large geographical areas meaning that ample opportunity exists for the DF network activity to be observed clandestinely. Given this, a degree of security can be achieved only by encrypting the transmissions. Devices are available for encrypting both the audio and data. The costs of such items has not been included in the hardware costs for these alternatives; however, the encryption equipment is typically quite expensive.

It is difficult to say whether the telephone-based systems offer any enhanced security over the previously discussed satellite and HF radio links. The typical philosophy is that effective observation of telephone traffic must occur at or very close to the local loop level. Obviously this would reduce the size of the geographical region in which monitoring can effectively be done, but the question remains about the actual network security. As pointed out for the satellite systems, encryption equipment is available for audio and data; however, it should be noted that the data encryption process adds noticeable transmission delays and can significantly reduce the effective data transmission speed. Regarding network security, the conclusion is that none of the identified alternatives should be viewed as secure.

8. RECOMMENDATIONS

This section of the design study presents in concise form the recommended architecture for remote control of the HF DF network.

8.1 Network Configuration

The recommended network configuration is the Series-3000-based store-and-forward network defined by Figure 7-1. As may be seen in the figure, the control and data signaling is kept separate from the audio recovered from the HF receivers at the various sites. By doing this, the control and data capabilities have been made very reliable, and there should never be a concern about blockage of control signaling by the recovered audio. Also, since all lines are leased, there should be no concern over line availability.

8.2 Control Station Configuration

The configuration of the control stations is described in Figure 8-1 and Figure 8-2. Notice that at the primary control site the HF receiver is not connected to the central proocessing unit and does not possess the standard Wullenweber array; therefore, is not considered to be a part of the direction finding capability. Also, notice the provisions for audio recovery at both the primary and secondary control sites.

The primary site has a single in-bound audio channel which can provide recovered audio from either Grand Island or Livermore. The selection of audio sources is performed by a switch located at the Grand Island site. The switch may be automatically controlled from Washington over the data links, or it may be positioned manually as a result of an instruction transmitted to the Grand Island operator over the data links. Should it be desirable to have additional audio recovery capability at the primary control site, this can be achieved by adding the required audio lines.

The audio recovery capability at the secondary control center, Grand Island, also merits additional discussion. As shown in Figure 8-2, Grand

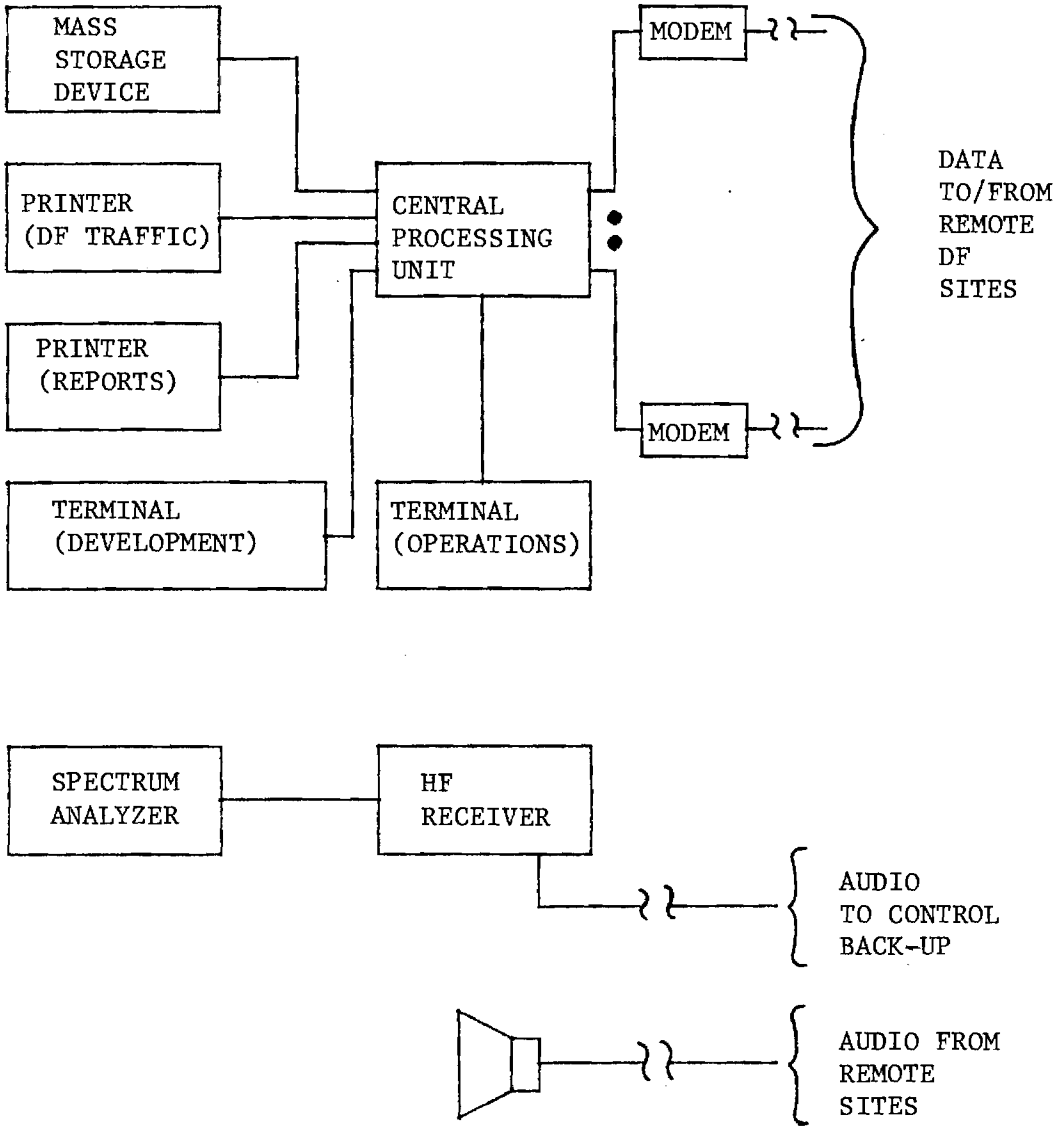


Figure 8-1. Recommended Primary Control Site Configuration

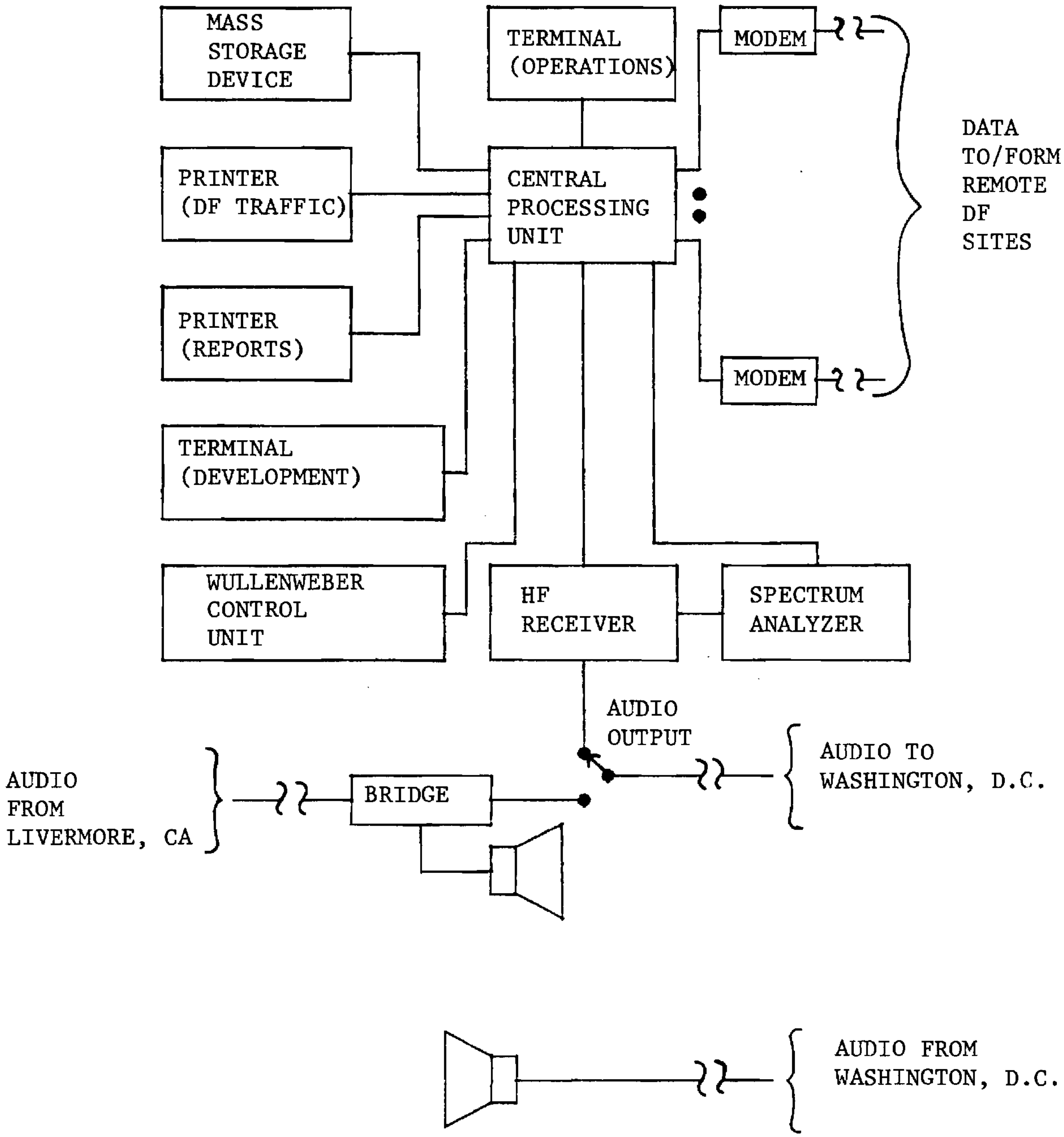


Figure 8-2. Recommended Secondary Control Site Configuration

Island has the capability of simultaneously monitoring the audio from both Livermore and Washington. The audio from Livermore is made available by an audio bridge in the Livermore-to-Washington link. Thus, Grand Island is able to monitor Livermore's audio independent of the audio switch setting chosen by Washington. The audio from Washington is delivered to Grand Island over the reverse channel associated with the link carrying audio from Grand Island to Washington. Of necessity, the majority of the Grand Island-to-Washington link employs a four-wire configuration so that there actually are two separate unidirectional channels. To maintain the separate channel arrangement, it is necessary for the local loops at both ends of the link to be implemented as four-wire lines.

8.3 DF Site Configuration

The recommended configuration of the local control system is shown in Figure 8-3. Notice that the figure shows two modems attached to the central processing unit. The configuration shown is for the CONUS sites which do in fact have two links at each DF site. For the non-CONUS sites, the configuration is the same as shown for the CONUS site with the exception that only a single modem is required.

8.4 Software

The cost estimates provided for the control center and the local DF control system includes an estimate for three major software elements: an operating system, a high-level language compiler, and a basic networking software package. What has not appeared in these costs estimates, is the cost of the application software which actually implement the functions and procedures which make the network operate in the desired fashion. It is estimated that the engineering and development costs for this applications software are approximately $400,000. This cost estimate assumes that an off-the-shelf operating system and a basic communications networking software package are utilized in the development of the required applications programs. Furthermore, it is assumed that each of the 13 DF sites uses the same

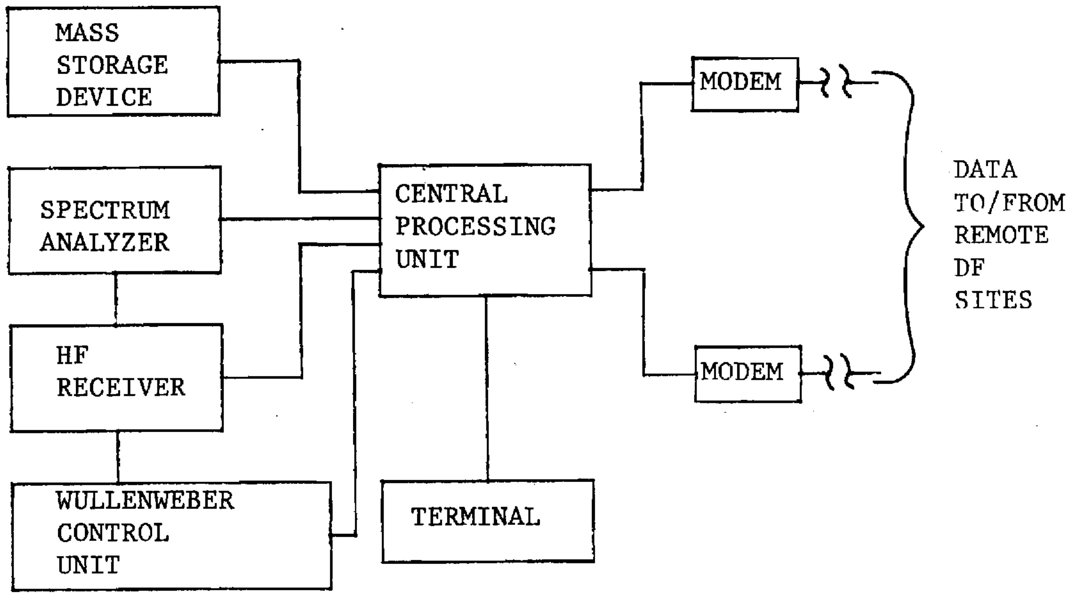


Figure 8-3. Recommended Local Control Configuration

equipment with the possible exception of a larger computer at the secondary control site. In particular, this means that each DF site uses the same receiver, spectrum analyzer, and Wullenweber array controller. Finally, it is assumed that the primary and secondary control sites have very similar configurations. In particular, it is assumed that the computer and associated peripherals at the primary and secondary sites are the same. It is not necessary for the receiver or spectrum analyzer at the primary control site to match those at the 13 DF sites unless it is desired to be able to control these entities from the secondary control site.

APPENDIX A

FUNCTIONAL DF REQUIREMENTS

System requirements may be defined according to the following categories:

(1) Network Communications

(2) Control Site Capabilities

(3) Remote Site Capabilities

(4) System Back-up

(1) NETWORK COMMUNICATIONS

The network to be implemented must be able to provide the same level of service currently afforded, at the minimum.

(1) "Set-up" time, or the interval in which the control site alerts and activates all target DF facilities, must on the order of 10 seconds or less.

(2) Command capability must be essentially "instantaneous" and simultaneous to all sites, including those in Alaska, Hawaii, and Puerto Rico. In order to facilitate this capability, the data link should be "up" continuously. Transmission speeds on the order of 0.5 seconds are acceptable.

(3) Response time may be slower; all results will be collected by the control facility in a polling procedure which may be completed over a 30 minute interval.

(4) Information to be transmitted will consist of either data requested or the audio signal from the frequency in question. Capability enabling the control site to freely

switch between the two modes and transmit either type through remote control of remote facilities must be provided.

(5) Data loads will vary from minimum requests for bearing information only to spectrum analyzer information upon request.

(6) Transmission of the audio signal can be anticipated to vary considerably, and may involve continuous transmission for 24 hours or more, particularly during a "speaker watch." It is not necessary that a remote site be able to transmit both audio from a "watch" and data or audio from an unrelated DF activity simultaneously. Transmission of the audio signal over voice-grade telephone lines is acceptable.

(7) Means to communicate between two remote sites must be provided. Routing such communications through the control site is acceptable.

(2) CONTROL SITE CAPABILITIES

(1) The control site must have complete remote control capability of all DF functions at all remote facilities, including those in Alaska, Hawaii and Puerto Rico.

(2) The control site must have override capability to preempt any activity of lower priority in the system.

(3) Computation formulas, format codes and tables should be stored at the control computer in order to lessen the information transfer load on the network.

(4) Capability to poll for intrusion and fire alarm status is desirable.

(5) Periodic frequency scanning is not required in the remote mode.

(3) REMOTE SITE CAPABILITIES

(1) Each DF facility must be fully remotely controllable by one or more control centers.

(2) Each DF facility must be able to initiate and perform DF-related activities independent of the control site(s).

(3) Network access by a remote site during an activity of higher priority must be prevented.

(4) DF site system must be able to obtain and store bearing data until a request for transmission is received from the control facility.

(5) Necessary computation formulas, tables, and format codes must be stored in the computer at the remote site in order to alleviate data loads on the network. To this end, it is acceptable to routinely control only the receiver's center frequency IF bandwidth and detection type.

(6) It is desirable to run diagnostics on remote site equipment but unnecessary to automatically transmit that information to the control site.

(7) Beat Frequency Oscillator (BFO) offset is acceptable for receiver resolution control of the audio (10 Hz minimum; 1.0 Hz desirable).

(8) The selected receiver must have an RF/IF gain control which can be stepped in reasonable and repeatable increments.

(9) The receiver should have a remotely controllable audio gain which can be used to adjust the audio level returned to the control center.

(10) Consideration of the scanner, scanner control, and communications link, other than for interface purposes, does not lie within the purview of this study.

(11) An automatic answering system should be provided at each remote facility to provide a local caller the means to report interference or emergency cases to a control facility or responsible party.

(4) SYSTEM BACK-UP

(1) The control site may or may not have a fully redundant computer system with automatic failover; however, a second, completely equipped, control facility shall be selected to provide central control back-up. This second control site shall have all the control capabilities of the first as well as complete duplication of all records, formula and relevant information in its memory.

(2) Redundant computer systems at the remote site facilities are not required.

(3) The HF radio network shall be retained as a communications back-up to the network configuration implemented.

APPENDIX B

REQUIRED DATA FLOWS

Data flow requirements are anticipated to include those functions listed in Tables B-1 and B-2 of this Appendix. Character allocations are generous, permitting considerable room for growth and modification. Total byte count as allocated in these tables is considerably less than the 100 byte estimates used in configuring the network alternatives, thereby leaving substantial room for function additions, changes and expansions.

Requirements summarized are discussed throughout the study and are addressed specifically in Section 3.2 of this report.

TABLE B-1

REQUIRED DATA FLOWS: CONTROL SITE-TO-DF-SITE

CONTROL CATEGORY	FUNCTION	PARAMETERS	CHARACTER ALLOCATION
Addressing	Bookkeeping	Date/Time	9
		Station Identifier	4
		Priority	8
		Function	10
		Case Number	4
Command Code	Receiver Control	Center Frequency	4
		BFO Frequency	3
		Bandwidth	1
		Gain Mode	1
		Detection Mode	1
	Antenna Control	Activate Command	1
		Mode Designator	1
		Sample Period	1
Audio/Data Control	Switching	Data/Audio Select	1
Data Select Code	Spectrum Analyzer	Analyzer Select	1
		Center Frequency	4
		Span	5
		Sweep Interval	1
		Bandwidth	4
		Number of Sweeps	1
		Linear/Log Scale	1
		Scale Units	1
		Scaling Function	3

TABLE B-2

REQUIRED DATA FLOWS: DF SITE-TO-CONTROL SITE

CONTROL CATEGORY	FUNCTION	PARAMETERS	CHARACTER ALLOCATION
Parameter Verification*	Addressing	(Same as Table B-1)	(Same as Table B-1)
	Receiver Control	(Same as Table B-1)	(Same as Table B-1)
	Antenna Control	(Same as Table B-1)	(Same as Table B-1)
	Spectrum Analyzer	(Same as Table B-1)	(Same as Table B-1)
Data Return**	Minimum	Bearing Data	8
		Confidence Data	1
	Spectrum Analyzer		1000

*Return is optional upon command.

**Audio return involves switching to audio signal and transmitting over voice grade line.

APPENDIX C

HF DF LOAD FACTOR SURVEY

FACILITY*	CONTACT	KEY
Allegan, Michigan	Melvin H. Hyman	(1)
Anchorage, Alaska	James E. Sutherland	(2)
Belfast, Maine	Barry A. Bohac	(3)
Douglas, Arizona	Stephen Y. Suya	(4)
Ferndale, Washington	Jack W. Bazaw	(5)
Ft. Lauderdale, Florida	James M. Feagles	(6)
Grand Island, Nebraska	J. J. Y. Hokanson	(7)
Kingsville, Texas	Oliver K. Long	(8)
Laurel, Maryland	Robert J. Douchis	(9)
Livermore, California	T. W. Van Stavern	(10)
Powder Springs, Georgia	Donald A. Taylor	(11)
Waipahu, Hawaii	Jack Shedletsky	(12)

* Sabana Seca Monitoring Facility not queried.

TABLE C-1
DF LOAD FACTOR SURVEY

QUESTION	1	2	3	4	5	6
Formal DF activity for 79/80 Fiscal year [Alerts (site generated - formal)/Bearings (formal)]						
Quarter I	7/108	5/45	198/127	10/110	12/55	28/113
Quarter II	16/148	10/72	23/134	16/85	17/62	31/140
Quarter III	9/148	8/41	12/158	0/78	14/76	11/131
Quarter IV	4/94	16/59	31/128	1/54	15/53	6/72
Total	36/498	39/217	264/547	27/327	58/246	76/456
In an average 24 hour period, time spent in:						
a. Formal DF activity	60' (1 action/3 days)	60' (1 action)	30'-40' (4 - 5 actions)	30'-60' (1 - 2 actions)	40' (2 actions)	15' (2 - 3 actions)
b. Informal DF activity	3 hours (5 - 6 short actions plus 1 - 2 lengthy actions)	30' (1 action)	1-3 hours (3 - 4 actions plus occasional extended activity)	1 hour (1 - 2 actions)	20'-30' (3 - 4 actions)	5'-10' (2 - 3 actions)
What is the nature of that load?						
a. Emergencies	5%	1%	1%	1%	>1%	>1%
b. Classified	>1%	0.1%	5%	9%	>0.5%	>1%
c. Interference, clandestine activity, administrative	94+%	98.9%	94%	90%	98+%	98+%
How often do you participate in a "speaker watch"?	Once per 24 hours, minimum.	Once per week (1 case)	3 - 4 times per 24 hours.	1 - 2 per month.	3 per 24 hours.	Once per 24 hours.

TABLE C-1 (Cont.)

QUESTION	7	8	9	10	11	12
Formal DF activity for 79/80 Fiscal year [Alerts (site generated - formal)/Bearings (formal)]						
Quarter I	2/103	2/103	24/124	14/67	30/70	8/48
Quarter II	11/89	11/89	20/125	7/53	58/186	19/85
Quarter III	6/100	6/100	23/125	24/79	86/186	16/39
Quarter IV	4/64	4/64	10/106	25/58	54/119	12/51
Total	23/356	23/356	77/480	70/257	228/561	55/223
In an <u>average</u> 24 hour period, time spent in:						
a. Formal DF activity	30' (3 - 5 actions)	2 - 3 hours (5 - 6 actions)	15' (2 actions)	15' (1 - 2 actions)	1 hour (2 actions)	60' (1-2 actions)
b. Informal DF activity	2 hours (5 - 10 actions)	~1 hour (3 - 4 actions	15' (1 action)	20'-60' (2 - 6 actions)	1 hour (10 actions)	30' (15 actions per mo)
What is the nature of that load?						
a. Emergencies	5%	>5%	1%	1%	2%	1%
b. Classified	5%-10%	1%-2%	------	(negligible)	1%	(negligible)
c. Interference, clandestine activity, administrative	85%-90%	~95%	99%	99%	97%	99%
How often do you participate in a "speaker watch"?	continuously	Once per 24 hours.	Once per week.	15 per month.	Once per 24 hours, minimum.	60' per 24 hours (3-5 actions)

TABLE C-1 (Cont.)

QUESTION	1	2	3	4	5	6
How long are the "watches"? a. Average b. Maximum	3 hours continuous for weeks	2 hrs 4 hrs (has experienced several days continuously)	(varies considerably) 12 - 14 hours	(varies considerably) 48 hours continuous	2 hours continuous for 3 days	30' - 60' 4 hours
How would you estimate your DF work load in terms of: a. Formal activity b. Informal "Assists"	25%-50% 50%-75%	75% 25%	25% 75%	60% 40%	65%-70% 35%-30%	60%-75% 40%-24%
How often does your local FCC field office request DF assistance?	4 - 6 times per year	1-2 per week	12 times per year	0	6 times per year	15 times per month
What is the nature of the cases?	Interference	Enforcement	Interference and regulation violation (clandestine broadcasts).	NA	Interference	Clandestine off-shore transmissions
Typically, how often does your site originate requests for "Assists"?	5 per 24 hour period	1-2 per week	3 - 4 per 24 hour period	18 per 24 hour period		About 15 per month
How long does it take to sucessfully complete a DF activity? a. Minimum b. Average c. Maximum	30s 5' 8 hours	--- 1.5 hrs 4 hrs	4' - 5' 7' - 8' 2 hours	3' 20' - 30' 4 hours	30s 10' - 15' 4 - 5 hours	30s 5' 15'

TABLE C-1 (Cont.)

QUESTION	7	8	9	10	11	12
How long are the "watches"? a. Average b. Maximum	(see above) (see above)	3 hours 3 days continuously	2 hours 6 - 8 hours	2 hours 4 hours	2 hours continuously for days	5' 30'
How would you estimate your DF work load in terms of: a. Formal activity b. Informal "Assists"	50% 50%	75% 25%	80% 20%	40% 60%	70% 30%	67% 33%
How often does your local FCC field office request DF assistance?	4 - 5 times per year	4 times per year	Once per year	Once per month	Once per month	8 per month
What is the nature of the cases?	Interference	Interference	(Any)	Routine interference	Amateur interference	CB 27 MHz stations
Typically, how often does your site originate requests for "Assists"?	5 - 10 per month	15 per month	1 per 24 hours	2 - 6 per 24 hours	3 - 5 per 24 hours	About 5 per month
How long does it take to successfully complete a DF activity? a. Minimum b. Average c. Maximum	60s 4' - 5' 20'	10s - 30s 3' 5' - 10'	30s 15' 4 - 5 hours	30s 10' 4 - 5 hours	30s 2' - 3' 30' - 40'	3' 30'-60"

TABLE C-1 (Cont.)

QUESTION	1	2	3	4	5	6
How important is the spectrum analyzer in your site's DF activities?	Analyzer is used significantly for signal analysis in complex emissions; it is not used in routine cases.	Analyzer used not for DF but for harmonic & spurious emission measurements on both HF and UHF, typically in use continuously for predeterminately UHF load.	Analyzer input as means of usual display is considered vital and used quite a bit.	Analyzer used for signal analysis particularly when weather conditions cause audio interference problems (contribute about 40-50% of the time).	Analyzer is used 10% of the time but when needed, is considered vital in signal analysis.	Analyzer used to some extent by some operators in signal analysis.
How important is the audio in DF activity?	Very important	Necessary, especially when more than one signal is present	Very important	Very important	Very important	Very important
How long do you typically use the audio signal in a DF activity?	For the duration of the action.	For the duration of the activity	For the duration of the action.	For the duration of the action.	Typically, initially then tune out to complete activity.	For the duration of the action.
How often does your communications link go "down"?	2 - 3 times per 24 hours.	Daily in winter	Once per 24 hours	~2 times per week	2 times per month	Once per day
For how long? a. Average b. Maximum	 10s - 30s 8 hours	 6 hrs. 36 hrs.	 1' - 5' 2.5 days	 15' 6 - 8 hours	 15' - 20' 15 - 16 hours	 1' 30'
How often do you utilize the HF back-up system out of Grand Island?	10 - 12 times per month.	(AL back-up is the phone line used to try to reestablish HF communications link or report a bearing.)	Once per week.	Once per week.	2 times per month.	1 - 2 times per month.

TABLE C-1 (Cont.)

QUESTION	7	8	9	10	11	12
How important is the spectrum analyzer in your site's DF activities?	Analyzer used by some operators in signal analysis.	Analyzer is important for emission analysis and signal verification and used frequently for those purposes; analyzer used infrequently for direct DF activity.	Analyzer used for visual signal identification by some operators.	Analyzer used significantly, mainly for complex signal analysis.	Analyzer used relatively infrequently mainly for complex signal analysis and to "sync" adjacent signals.	Analyzer used to help identify signal and is used in spurious signal analysis in interference cases (used ~ 2 hr per 24).
How important is the audio in DF activity?	Very important	Important	Not that important unless operator can't get visual.	Very important	Very important	Extremely helpful
How long do you typically use the audio signal in a DF activity?	For the duration of the action.	50% of the time, use the audio for the duration (particularly for close-in application); 50% of the time, listen initially, tune out, and complete exercise	For the duration when needed.	For the duration of the action.	Typicially, initially then tune out to complete activity.	Typically, for the duration of the alert and bearing action.
How often does your communications link go "down"?	Once per day.	Once per week.	Once per day.	15 times per month.	Once per day.	Varies; HA has 5 HF frequencies for communication.
For how long? a. Average b. Maximum	5' 8 hours	1 hour 1 1/2 days	1 hour 24 hours or more	5' - 10' 14 hours	10' 12 hours	Few hrs/wk 24 hrs
How often do you utilize the HF back-up system out of Grand Island?	2 times per month	Once per week.	Once per month.	Once per week.	Once per week.	N/A

TABLE C-1 (Cont.)

QUESTION	1	2	3	4	5	6
How long does it take to activate the back-up?	30s	N/A	30s	30s	45s	30s
What interval do you use as an outage parameter?	60s; then put back-up on stand-by.	N/A	Put system on standby upon first indication of possible failure.	Put system on stand-by upon first indication of possible failure.	About 60s, then activate back-up.	1'-2', then put back-up on "standby."
Does your site have special load demands?	Allegan is a training center which can increase the number of "assists" generated by Michigan if a class is in residence by about 20-25% per month.	AL uses HF locally as an aid for identifications of HF stations for enforcement work.	No	No	Seasonal speaker watch load (∿5%) and HF ship cases are somewhat heavy.	Substantial load from clandestine offshore transmissions.
Do you anticipate an overall increase or decrease in DF activity?	Don't know, complaint load is increasing but "assist" load is decreasing.	Does not anticipate change in load demand based on past experience.	Increase due to 3rd world impact.	Increase due to 3rd world impact and increased use by HF amateurs and ships.	Decrease in US activity as Navy is utilizing satellite instead of HF; increase from 3rd world countries.	Decrease in US due to decrease in overall HF use in favor of satellite; some increase due to 3rd world countries.
Does your site have certain problems which should be addressed?	No	No	No	No	There is a problem with West Coast fixes in that there are not really well situated sites to accurately pinpoint fixes in the Pacific.	Site should be moved due to encroachment problems caused by nearby residential and business areas; it is difficult to shelter the DF signal.

TABLE C-1 (Cont.)

QUESTION	7	8	9	10	11	12
How long does it take to activate the back-up?	(See below)	3'-4'	2'	1.5'	30s	N/A
What interval do you use as an outage parameter?	Always on "standby" to accommodate back-up net function.	2'-3' then activate back-up and put on "standby."	5' then activate back-up.	1'-2', then activate back-up.	1', then activate back-up.	N/A
Does your site have special load demands?	Provide the HF back up to the net; (activated 15 times per month for 5 min., average, 3-4 days continuously maximum); also participate in Eastern and Western nets so caseload is larger.	Participate in eastern and western nets so caseload is typically larger.	Being close to national headquarters the "assist" load is somewhat greater than what might be anticipated.	Livermore participates in two long-term amateur pirate cases which increases speaker watch load; also, site is the alternate net control for Grand Island (back-up for entire net activated 2+ times per year for about 1 hour each; back-up for Anchorage: 2 days per mo.	Centrally located and so gets more calls overall for formal and "assist" activity.	No
Do you anticipate an overall increase or decrease in DF activity?	Slight increase due to anticipated increased use of HF by amateurs and due to greater public awareness of the enforcement function. NOTE: HF back-up is adequate for present load but not for any significant increase.	Increase due to increase in number of HF users in US.	Decrease in US due to satellite usage; increase due to 3rd world impact.	Decrease in US due to satellite; increase due to 3rd world impact.	Increase due to an increase in "sensitive" caseloads.	No change anticipated in near future.
Does your site have certain problems which should be addressed?	DF equipment should be updated as Nebraska still uses Type C equipment; anticipate an encroachment problem in 5-10 years.	Not yet - encroachment is not a problem to date.	No	Encroachment is an increasing problem; may have to move site.	No	No

APPENDIX D

SURVEY OF REMOTELY CONTROLLABLE HF RECEIVERS

Table D-1 provides a comparison of the technical parameters for receivers judged to be suitable for this application. Notice that most of the available units offer 10 Hz. resolution, and a few offer 1 Hz. resolution. Cost data on the units with 10 Hz. resolution is presented in Table D-2, and Table D-3 presents the cost data for the 1 Hz. resolution units.

TABLE D-1

HF RECEIVER PARAMETERS

KEY (1)	MANUFACTURER	RECEIVERS Model	Resol.	Unit (2)	Quantity (3)	REMOTE CONTROL OPTION Model	Unit (2)	Quantity (3)	RS232 INTERFACE	OTHER Model	Unit (2)	Quantity (3)	GSA DISCOUNT	DELIVERY SCHEDULE
A	AIKEN INDUSTRIES	SR-2070	10Hz	$13,450	$12,778	Standard Opt (Sync.) 0-1 Option (Async.)	$ 500 $ 750	$ 475 $ 713	(included with remote option)	(no fine tune capability available)			6%	5: 5 mos. Bal: 3 additional mos.
B	GENERAL INSTRUMENTS	1910/GRR	10Hz	$43,000 - (custom	$44,000 house)	(standard)			(standard)	(1Hz BFO Resolution standard in design)			----	10 mos.
C	HARRIS CORPORATION	RF-550	100Hz	$14,550 (4)	-----	RF 794 RE	$11,800 (4)	------	(included with remote option)				20%	60 days
D	MAGNAVOX	R2143/BRR (ESR-701)	10Hz	$39,000	$37,000	(standard)			$10,000 one time R&D charge plus $1000 per receiver for lot purchase of 13 units	(no fine tune capability available)			---	13 mos
E	NORTH AMERICAN PHILIPS CORPORATION	RO-156	1Hz (main F)	$18,781	$18,218	RL-157 (5)	$ 8,164	------	V28 European equivalent to RS232 Interface (standard)				----	90 days
F1	RACAL	RA-6790	1Hz (main F)	$ 5,600 (6)	------	I/O cardset	$ 995	------	(included with remote I/O)				6%	90-150 days
F2	RACAL	RA-5775/6	10Hz	$12,831	50% (7)	(standard)			(standard)	MA60003A (1 Hz main tuning)	$10,000		6%	90 days
G	ROCKWELL/COLLINS	851S-1	100Hz	$12,000	------	AC 8090 cardset	$ 1,864	------	(included with remote I/O)	AC-85102 (10Hz tuning) AC-85102 (1 Hz tuning)	$ 492 $ 984	----- -----	30% 30%	120 days
H	TELLINE RADIO CORP.	RHF-04B	10Hz	$16,182	$13,140	(standard)			(standard)	(1 Hz BFO tuning is standard)			8%	4-5 months
I	TECHNICAL MATERIALS CORPORATION	GPR-110	100Hz	$ 7,200	------	(Interface)	$ 900	------	(included with remote I/O)	(1 Hz BFO tuning standard)			20%	90 days
J1	WATKINS-JOHNSON	WJ8718	10Hz	$ 5,335	$ 5,070	232	$ 1,590	$ 1,505	(included with remote option)	8718 1Hz (main)	$ 915	$875	5%	120 days
J2	WATKINS-JOHNSON	WJ8718/MFP	10Hz	$ 7,590	$ 7,215	232M	$ 565	$ 535	(included with remote option)	tuning option	$915	$875	5%	120 days

TABLE D-1

HF RECEIVER PARAMETERS (Cont.)

KEY (1)	MANUFACTURER	RECEIVERS				REMOTE CONTROL OPTION			RS232	OTHER			GSA	DELIVERY
		Model	Resol.	Unit (2)	Quantity (3)	Model	Unit (2)	Quantity (3)	INTERFACE	Model	Unit (2)	Quantity (3)	DISCOUNT	SCHEDULE
J3	WATKINS-JOHNSON	WJ8888B	10Hz	$20,035	$18,075		(standard)		(standard)				5%	120 days

(1) Candidates listed are those offering units at $50,000 or less.

(2) Prices are valid through 12/31/80 unless specified.

(3) Quantity discounts are based on lot purchase of 10-20 units.

(4) Prices are valid through 7/1/81.

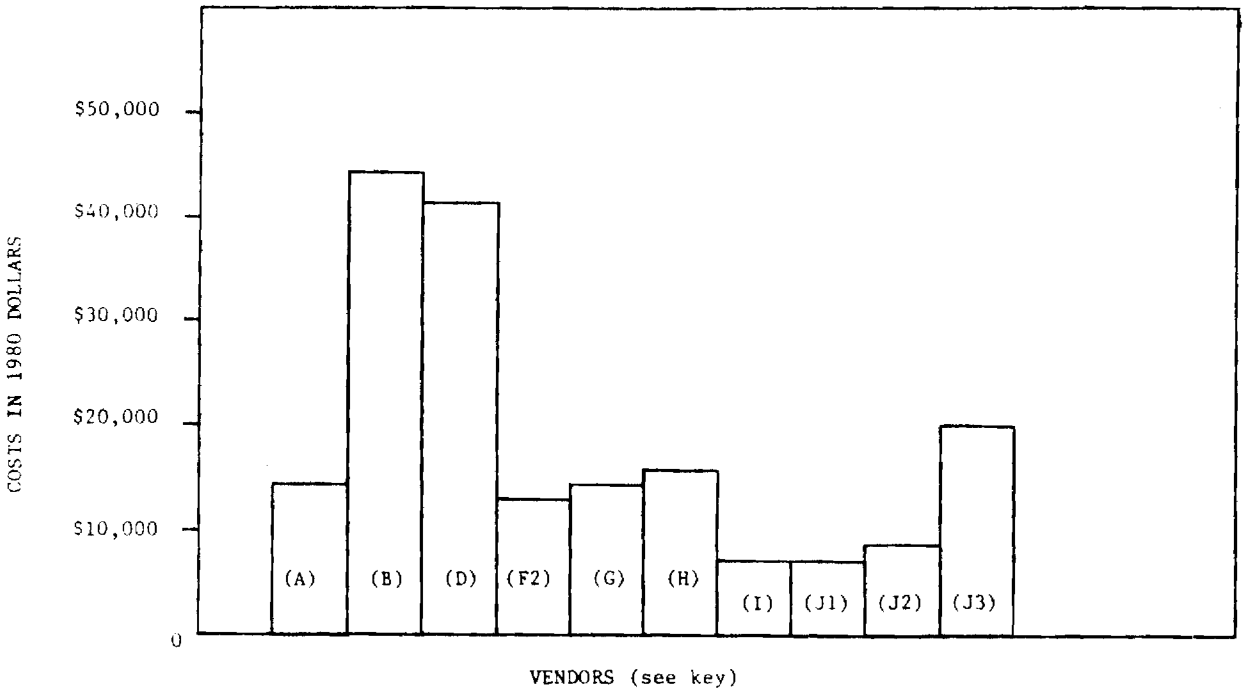
(5) To effect remote control with the Philips unit, an RL157 unit must be installed at the control site. One RL157 can accommodate up to 10 receivers; to control 13, two receivers must be installed.

(6) Price for RA6790/GM-5 unit modified as per FCC test unit requirements is $10,000 and does not include remote on RS232 interface option.

(7) RA-6775 discount is substantial as unit is no longer in production.

TABLE D-2

RECEIVER COST COMPARISON: 10 HZ RESOLUTION



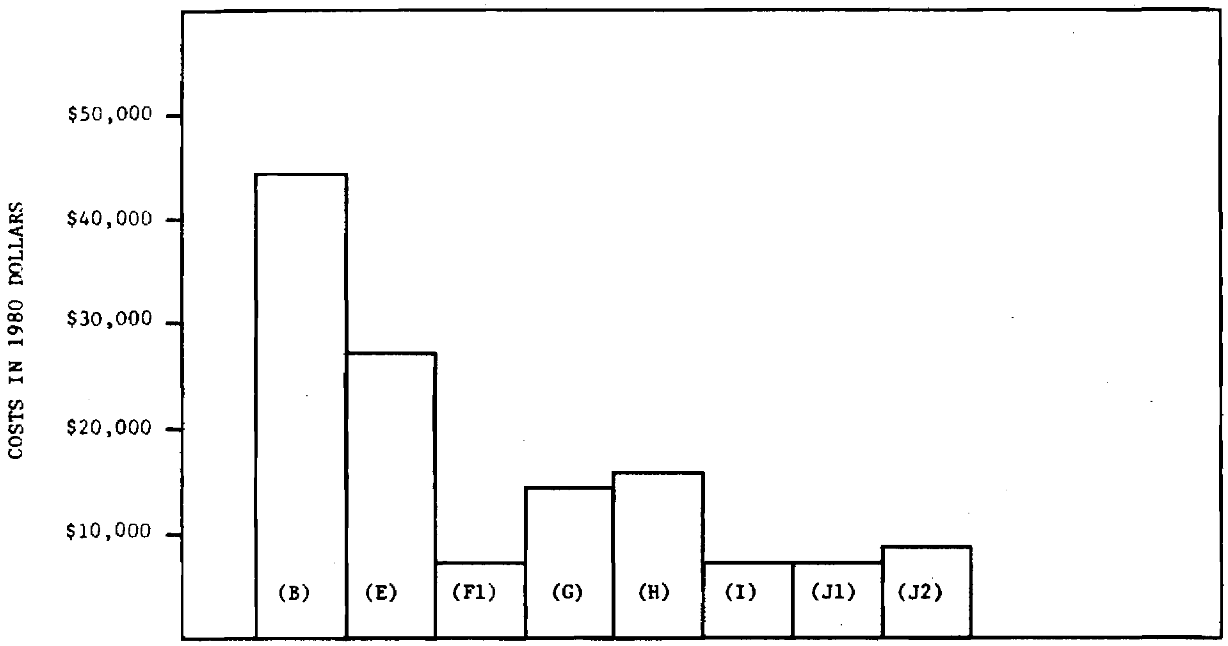
KEY *	VENDOR	UNIT PRICE **
A	Aiken Industries	$14,200
B	General Instruments	$43,000-$44,000
D	Magnavox	$41,000
F2	Racal	$12,831
G	Rockwell/Collins	$14,356
H	Telline Radio Corporation	$16,182
I	Technical Materials Corporation	$ 7,200
J1	Watkins-Johnson	$ 6,925
J2	Watkins-Johnson	$ 8,155
J3	Watkins-Johnson	$20,035

* See Table D-1 for specific unit information

** Unit prices reflect retail unit cost for receivers with remote control capability, RS 232 interface, and interface components, if required, at control site.

TABLE D-3

RECEIVER COST COMPARISON: 1 HZ RESOLUTION



VENDORS (see key)

KEY*	VENDOR	UNIT PRICE**
B (BFO)	General Instruments	$43,000-$44,000
E	Philips Corporation	$26,945
F1	Racal	$ 6,595
G	Rockwell International	$14,848
H (BFO)	Telline Radio Corporation	$16,182
I (BFO)	Technical Materials Corporation	$ 7,200
J1	Watkins-Johnson	$ 7,840
J2	Watkins-Johnson	$ 9,070

* See Table D-1 fpr specific unit information

** Unit prices reflect retail unit cost for receivers with remote control capability, RS 232 interface, and interface components, if required at control site.

APPENDIX E

CURRENT DOMESTIC COMMERCIAL SCHEDULE III RATES FOR 3002 LINE*

LINE LENGTH (MILES)	TARIFF RATES HALF DUPLEX			TARIFF RATES FULL DUPLEX
1	$ 55.71			
2-14	$ 55.71	+	$4.63	for each mile over 1 mile
15	$120.53			
16-24	$120.53	+	$3.99	for each mile over 15 miles
25	$160.43			
26-39	$160.43	+	$2.94	for each mile over 25 miles
40	$204.53			
41-59	$204.53	+	$2.21	for each mile over 40 miles
60	$248.73			
61-79	$248.73	+	$1.68	for each mile over 60 miles
80	$282.33			
81-99	$282.33	+	$1.42	for each mile over 80 miles
100	$310.73			
100-999	$310.73	+	$ .71	for each mile over 100 miles
1000	$949.73			
Over 1000	$949.73	+	$ .42	for each mile over 1000 miles

*Rates reflect Tariff 260, effective June 5, 1980. Note that rates upon which budgetaries are based in this study are approximately 5% higher than actual rates. Higher rates were based on billing schedules submitted to us reflecting a rate increase proposed in October, 1980. This increase was not approved.

NOTE: Schedule III tariffs hold for pairs of category "B" rate centers.