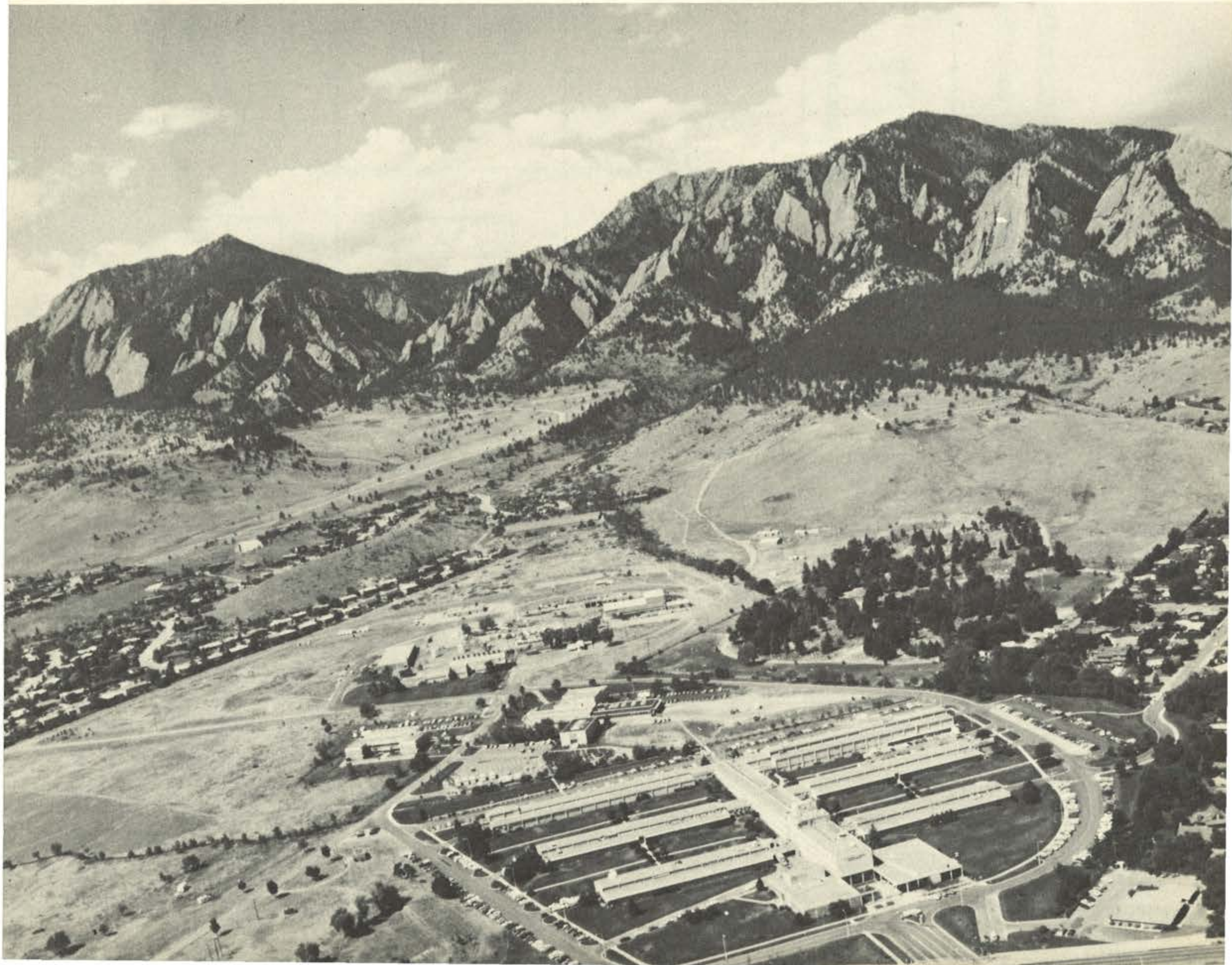
DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

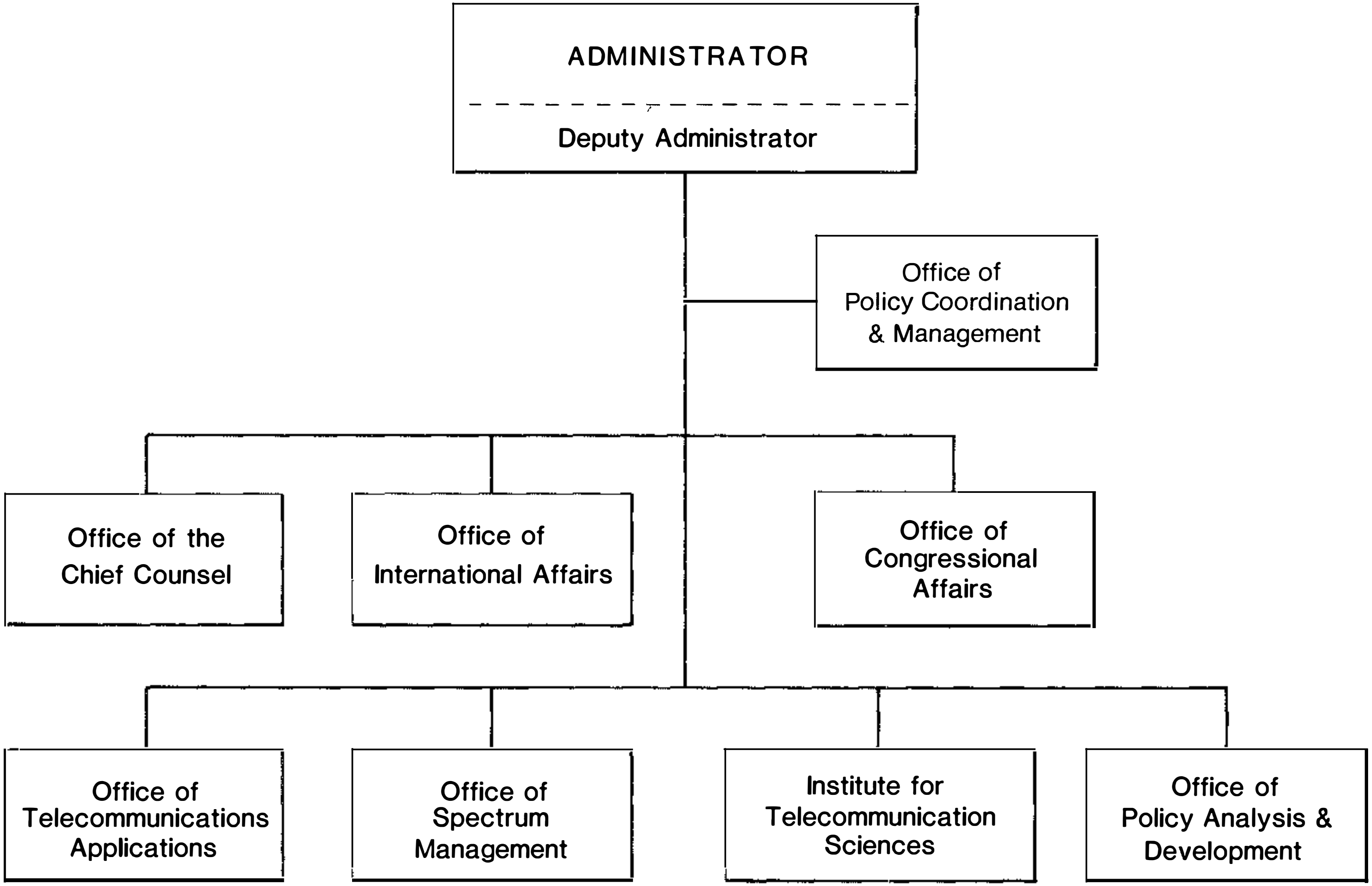
ANNUAL TECHNICAL PROGRESS REPORT 1983

For the period Oct. 1, 1982, through Sept. 30, 1983



U.S. DEPARTMENT OF COMMERCE

National Telecommunications and Information Administration



See inside back cover for ITS organization chart

ITS

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U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
David J. Markey, Assistant Secretary
for Communications and Information

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INTRODUCTION

This annual report summarizes the activities and accomplishments of the Institute for Telecommunication Sciences for the fiscal year ending September 30, 1983. It is intended to serve as a reporting mechanism to agency management, to our other-agency sponsors, and to interested members of the public.

The Institute for Telecommunication Sciences (ITS) is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. Its mission is divided into two major elements: 1) to provide direct support to the NTIA Administrator and the Secretary of Commerce and 2) to serve as a central Federal resource to assist other agencies of the Government in the planning, design, maintenance, and improvement of their telecommunications activities. The work performed in carrying out the latter responsibility is reimbursable, is relevant to national goals and commitments, cannot be readily performed by the private sector, and contributes to NTIA's goals.

In order to meet the responsibilities assigned to it by NTIA and the Department of Commerce and to meet requests placed upon it by other Federal agencies, the program carried out by the Institute falls under two broad categories: Spectrum Research and Analysis and Systems and Networks Research and Analysis.

The program of Spectrum Research and Analysis includes research directed toward development of models of radio-wave transmission applicable to optimization of spectrum use and communication system performance prediction. It also includes research directed toward developing spectrum use concepts and models that can lead to more efficient use of the spectrum resource. This is primarily related to the interactions between radio systems and the electromagnetic environment.

Radio waves are strongly influenced by the environment in which they propagate. The ITS-developed transmission models, depending upon radio frequency, consider the effects of terrain, electrical properties, shape, and surface cover; the nonionized lower atmospheric gases, meteorology, and spatial structure; and the highly-variable time and spatial properties of the ionized region of the upper atmosphere. These models provide statistical estimates of signal attenuation, dispersion, multipath, and other factors that determine the rate of information transmission and quality of systems performance. Improvements in spectrum planning techniques and ways to more intensively share the spectrum have resulted from additional information obtained from measurement and evaluation of the spectrum-consuming properties of antennas, receivers, and transmitters and from measurement of spectrum occupancy. These efforts directly relate to NTIA and FCC roles in spectrum management.

The Systems and Networks Research and Analysis program conducts studies directed toward assessing and developing domestic and international technical performance standards to facilitate competition in the provision of enhanced telecommunication products and services and to expand U.S. industry opportunities to compete in international markets. Also, technology alternatives for the development of competitive, lower cost, communication networks are investigated; and research and analysis of advanced networks for future application are accomplished.

In both program categories, significant involvement in the activities of the International Telecommunication Union (ITU) and especially, its major subdivisions, the International Consultative Committees on Radio (CCIR) and Telephone and Telegraph (CCITT), has been essential and continues a long history of active involvement by Institute staff in such activities. Work in support of these international commitments is reported within the succeeding chapters at relevant places.

In total, the work summarized in this report is intended to assist in maximizing the efficient use of the national spectrum resource, the efficient use of Government telecommunication systems, and new technology toward achieving national goals. It is directed toward incorporating technical, economic, market, regulatory, and other factors in an integrated manner into policy development in telecommunications matters and toward translating Administration policy for use in national and international arenas.

CHAPTER 1. EFFICIENT USE OF THE SPECTRUM AND EM WAVE TRANSMISSION

The electromagnetic spectrum has seen dramatic growth in demand and use since the beginning of World War II, and a great range of new spectrum-dependent telecommunication services have evolved. To provide for new and expanded use of the spectrum, two major alternatives exist: (1) to exploit new regions of the spectrum at progressively higher frequencies and (2) to determine more effective means of managing spectrum use. The National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS), conducts a program of applied research and engineering development that addresses both of these alternatives. In this chapter, some highlights of the NTIA/ITS program directly concerned with these issues are reviewed. Many of these projects draw heavily on experience from other programs in ITS, including antenna design and measurement, channel characterization and system performance, and the many propagation related efforts.

Specific spectrum engineering techniques that have been developed by ITS personnel will be discussed in the next section of this chapter. In Section 1.2, the application of these techniques for spectrum resource assessments is discussed. Section 1.3 provides an outline of the work being undertaken by the Institute to develop advanced instrumentation and spectrum measurement techniques. In Section 1.4, the work that is being undertaken to assess and predict telecommunication system performance in light of the known characteristics of the properties of the EM wave transmission medium is discussed.

SECTION 1.1 SPECTRUM ENGINEERING TECHNIQUES

The concern in this portion of the program is the development of techniques that can be used by policy makers, frequency managers, system designers, and system planners in effecting decisions regarding use of the electromagnetic spectrum for telecommunication purposes. These are techniques that address problems in optimum choice of frequencies and rational tradeoffs between limits on broad classes of equipment (limits on factors such as antenna height or power), the ability of a system to provide a required service, and the efficiency with which available spectrum is used. Techniques of this kind are extremely varied and must address a wide range of problems from the very specific (for the designer of a specific system at a particular location) to the very general (for the policy maker and regulator who must consider national or regional consequences in a single action).

Traditionally, spectrum engineering techniques have been developed to evaluate a specific situation, usually with a series of "safe" or "conservative" assumptions. The spectrum resource can be conserved by assigning specific frequencies to stations in a way that minimizes the total bandwidth required to license all applicants. In the past two years, ITS has been developing the mathematical models and computer algorithms to make such assignments. The earlier research results are being translated into practical capability in the Tradeoffs for Efficient Use of the Spectrum project. There are two useful forms of output: (1) a user-oriented, interactive computer program for making spectrum-conserving frequency assignments and (2) general principles of efficient frequency assignment that can guide the development of frequency-distance separation rules for a service.

During the past several years, we have developed computer methods for optimum frequency assignment in the Tradeoffs for Efficient Use of the Spectrum project. These efforts culminated this year in the production of user-oriented, portable software for assigning a set of stations in the minimum total bandwidth.

The program for optimum frequency assignments is called ASIGN, is written in ANSI Fortran, and is implemented on a large main-frame computer at Boulder. It is interactive and modular, with flexible input and output.

The input options include:

- a set of station locations and a set of frequency-distance rules
- a set of station locations and an associated constraint matrix
- a set of frequency-distance separation rules and a number of station locations to be randomly generated.

In each case, there may also be a number of stations with prior frequency assignments that are to be retained. The user may designate a total allocation bandwidth that will not be exceeded. If a station or stations cannot be assigned within the allocated bandwidth, the program will print a warning message, discard the station, and try to assign the remaining stations.

The program makes assignments with a number of different, nearly-optimum algorithms (an exact optimum algorithm takes an impractically long time to run on a computer) and chooses the best assignment as the optimum one. As an alternative, the user can specify one or more particular algorithms, and no others will be used.

The output of ASIGN is a list of the station locations and their assigned frequency for the optimum assignment. In addition, certain auxiliary output is available:

- the size of the initial clique (a group of stations that all mutually-constrain each other)
- tabulations of the number of stations assigned to each channel
- the stations constraining (or constrained by) any particular station.

The program will be made available to interested users for the cost of reproduction and handling. A User's Guide is being written, and will be published as an NTIA Report in FY 84. Its completion was delayed by diversion of project personnel to higher priority tasks.

The predecessor program to ASIGN was used to study the spectrum costs of adjacent-channel frequency-distance separation rules. The results were incorporated into proposed revision to CCIR Report 842. This revision has been forwarded to Geneva by the U.S. National Committee of CCIR and will be considered at the Interim Meeting in November 1983.

With the completion of the User's Guide, the project, Tradeoffs for Efficient Use of the Spectrum, will be terminated.

For several years ITS has been providing technical assistance to NTIA's Public Telecommunications Facilities Program. Principally, this assistance has consisted of estimating the number of people presently served, or soon to be served, by the various public television and radio facilities in the contiguous United States. One concern with these estimates has been that they used 1970 census figures. This has now been remedied by the acquisition of new data from the 1980 census, so that more accurate estimates are possible. For example, in 1982 it was estimated that 85.6 percent of the population could obtain service from licensed, full-service, public television stations. Using the more up-to-date information, this value changes to 84.6 percent.

In future efforts, we hope to help determine in what parts of the country outreach activities to encourage new public telecommunications would be most effective.

In support of NTIA's Minority Telecommunication Development Program, ITS has prepared a Technical Planning Service intended to help minority entrepreneurs assess the potential market of a proposed FM or TV station. This service uses a computer program to provide a quick look at the coverage area of a suggested broadcast station together with a count of the minority population living in that area. A sample of the output is shown in Figure 1-1, a map of the region proposed to be served with three estimated service contours, and in Figure 1-2, the accompanying sheet of statistics.

The Spectrum Engineering Development Support project provides analysis support to the Spectrum Engineering and Analysis Division (SEAD) of NTIA. This year, we used the optimum frequency assignment program to study the relative efficiency of land mobile radio systems with different bandwidths and different interference rejection.

Using standard FM systems and proposed amplitude-companded single-sideband (ACSB) systems as models, SEAD developed frequency-distance (f-d) separation rules for two generic systems--called the "wideband" and "narrowband" systems respectively. These f-d rules are shown in Table 1-1.

The total bandwidth required to assign frequencies to a given number of randomly-located transmitters was computed with the program for a variety of scenarios. We reached the following conclusions:

If the non-co-channel separation distances are less than about one-third of the co-channel separation distance, the number of channels, M, that are required to assign channels to N base stations uniformly and randomly located in a square with side S is given approximately by the empirical formula:

$$M = 4.19 + N(.140\ R + .722\ R^2),$$

where R is the ratio of the co-channel separation distance to the square side. This equation holds if $0.1 < R < 0.7$. Under these conditions, the narrowband systems always require less total bandwidth than the wideband systems.

We also considered cases in which the transmitters were concentrated at preferred locations, were clustered with an exponential distribution of distances from an urban center, or were located in squares with sides less than the co-channel separation distance. In all these cases, the narrowband systems required less total bandwidth than the wideband systems, although the difference was not always as great.

We considered interleaving wideband and narrowband systems by assigning wideband systems only on even multiples of 12.5 kHz and assigning narrowband systems only on odd multiples of 12.5 kHz. This arrangement automatically satisfies most of the non-co-channel f-d rules. For base stations randomly located in a square, then, the empirical formula can be applied separately to the two systems, and the total bandwith required can be computed. Interleaving the systems this way takes the same total bandwidth as segregating the systems into adjacent frequency bands.

Another spectrum planning tool with a strong potential for applications to many kinds of spectrum planning problems is referred to as Network Service and Interference Predictions. The NOAA Weather Radio Program administered by the National Weather Service (NWS) broadcasts current weather conditions and forecasts on a 24-hours-a-day basis. Recently this broadcast network has also been designated as the primary element in the national disaster warning system. In order to effectively reach their goal of 95 percent of the population of the United States with these broadcasts, NWS expanded the network by adding new stations and increased the number of transmission frequencies to seven. The network must be carefully designed in order to minimize the co-channel self-interference that may result from operating closely-spaced stations on only seven channels. To assist NWS in siting new weather broadcast stations and selecting the optimum channels to meet their objectives, the Institute has developd an interactive computer model called NETWORK.

NETWORK is designed to help NWS plan the expansion of the broadcast network by predicting the coverage that results when stations are added to or deleted from the network, or have their location or characteristics (i.e., frequency assignment, transmitter power, antenna height, etc.) changed. The NETWORK data base contains the required information about each station in the network to determine service and interference areas (see Fig. 1-3). NETWORK's editing capability allows the user to easily modify any of these station data, and

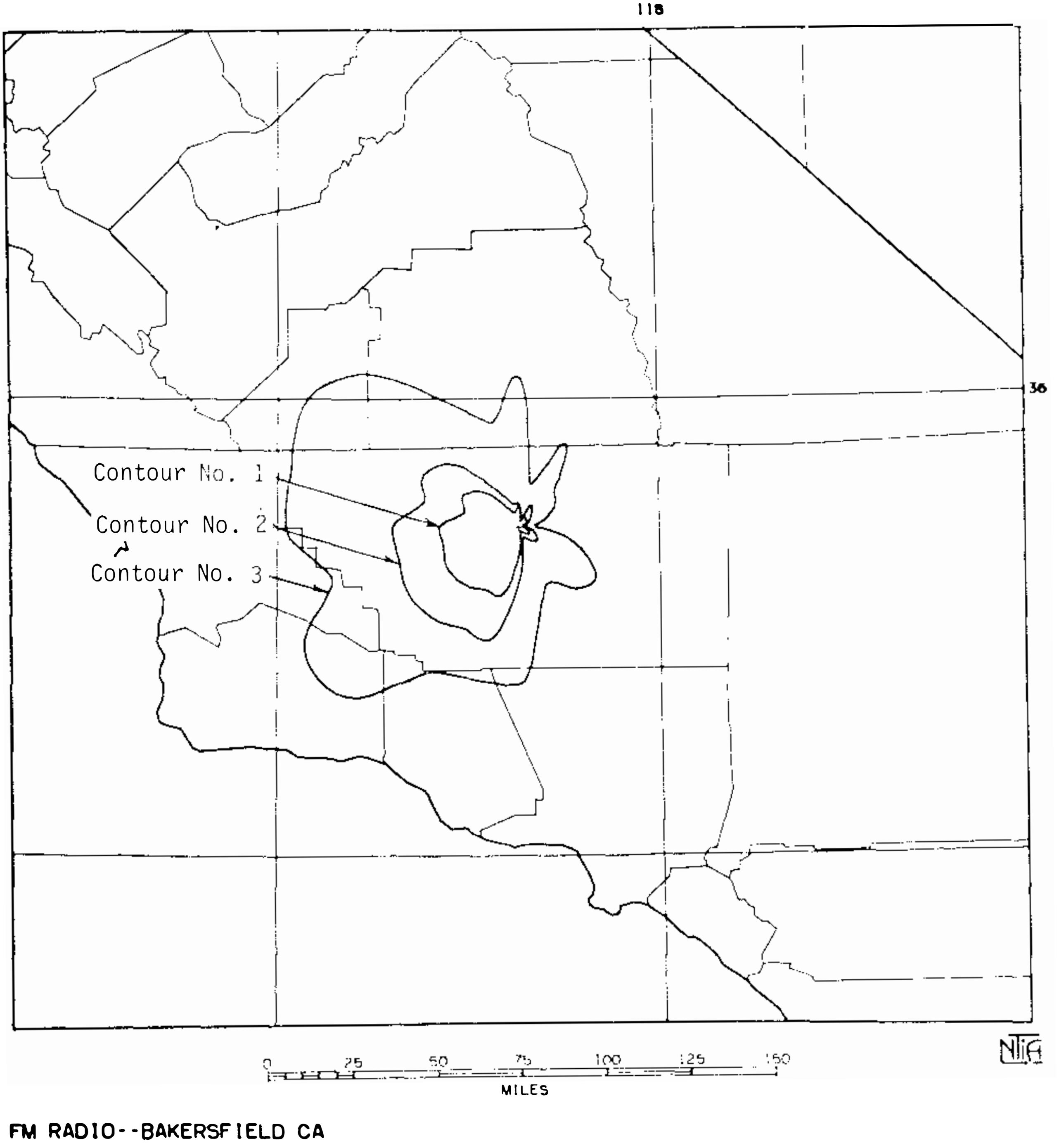
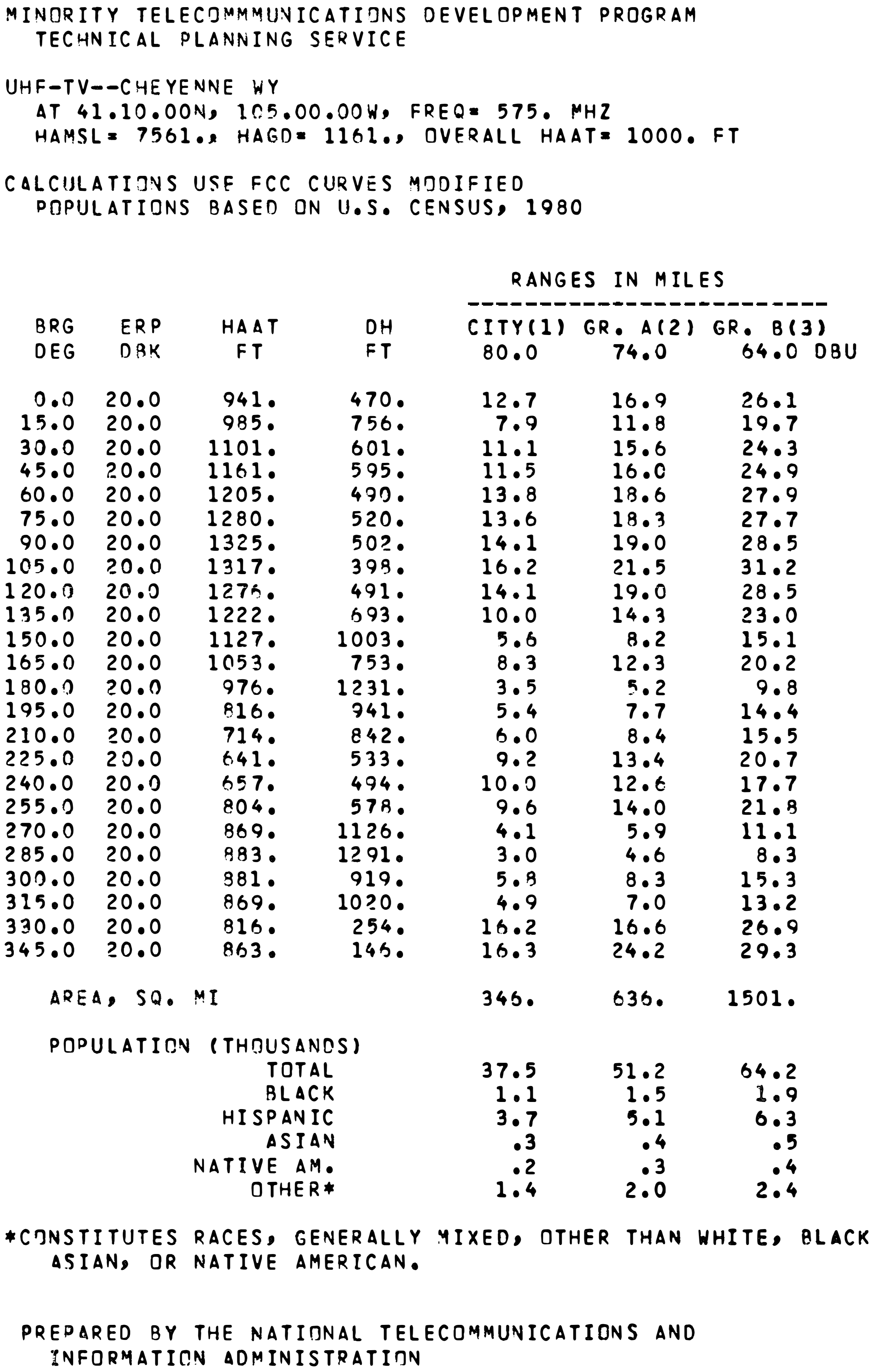


Figure 1-1. Sample output from the Technical Planning Service: three estimated contours for a proposed FM station.



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MINORITY TELECOMMMUNICATIONS DEVELOPMENT PROGRAM
  TECHNICAL PLANNING SERVICE

UHF-TV--CHEYENNE WY
  AT 41.10.00N, 105.00.00W, FREQ= 575. MHZ
  HAMSL= 7561., HAGD= 1161., OVERALL HAAT= 1000. FT

CALCULATIONS USE FCC CURVES MODIFIED
  POPULATIONS BASED ON U.S. CENSUS, 1980


                                          RANGES IN MILES
                                     --------------------------
  BRG    ERP     HAAT       DH       CITY(1) GR. A(2) GR. B(3)
  DEG    DBK      FT        FT        80.0     74.0     64.0 DBU

  0.0   20.0     941.      470.       12.7     16.9     26.1
 15.0   20.0     985.      756.        7.9     11.8     19.7
 30.0   20.0    1101.      601.       11.1     15.6     24.3
 45.0   20.0    1161.      595.       11.5     16.0     24.9
 60.0   20.0    1205.      490.       13.8     18.6     27.9
 75.0   20.0    1280.      520.       13.6     18.3     27.7
 90.0   20.0    1325.      502.       14.1     19.0     28.5
105.0   20.0    1317.      398.       16.2     21.5     31.2
120.0   20.0    1276.      491.       14.1     19.0     28.5
135.0   20.0    1222.      693.       10.0     14.3     23.0
150.0   20.0    1127.     1003.        5.6      8.2     15.1
165.0   20.0    1053.      753.        8.3     12.3     20.2
180.0   20.0     976.     1231.        3.5      5.2      9.8
195.0   20.0     816.      941.        5.4      7.7     14.4
210.0   20.0     714.      842.        6.0      8.4     15.5
225.0   20.0     641.      533.        9.2     13.4     20.7
240.0   20.0     657.      494.       10.0     12.6     17.7
255.0   20.0     804.      578.        9.6     14.0     21.8
270.0   20.0     869.     1126.        4.1      5.9     11.1
285.0   20.0     883.     1291.        3.0      4.6      8.3
300.0   20.0     881.      919.        5.8      8.3     15.3
315.0   20.0     869.     1020.        4.9      7.0     13.2
330.0   20.0     816.      254.       16.2     16.6     26.9
345.0   20.0     863.      146.       16.3     24.2     29.3

   AREA, SQ. MI                           346.     636.    1501.

   POPULATION (THOUSANDS)
                      TOTAL               37.5     51.2     64.2
                      BLACK                1.1      1.5      1.9
                   HISPANIC                3.7      5.1      6.3
                      ASIAN                 .3       .4       .5
                NATIVE AM.                  .2       .3       .4
                     OTHER*                1.4      2.0      2.4

*CONSTITUTES RACES, GENERALLY MIXED, OTHER THAN WHITE, BLACK,
   ASIAN, OR NATIVE AMERICAN.


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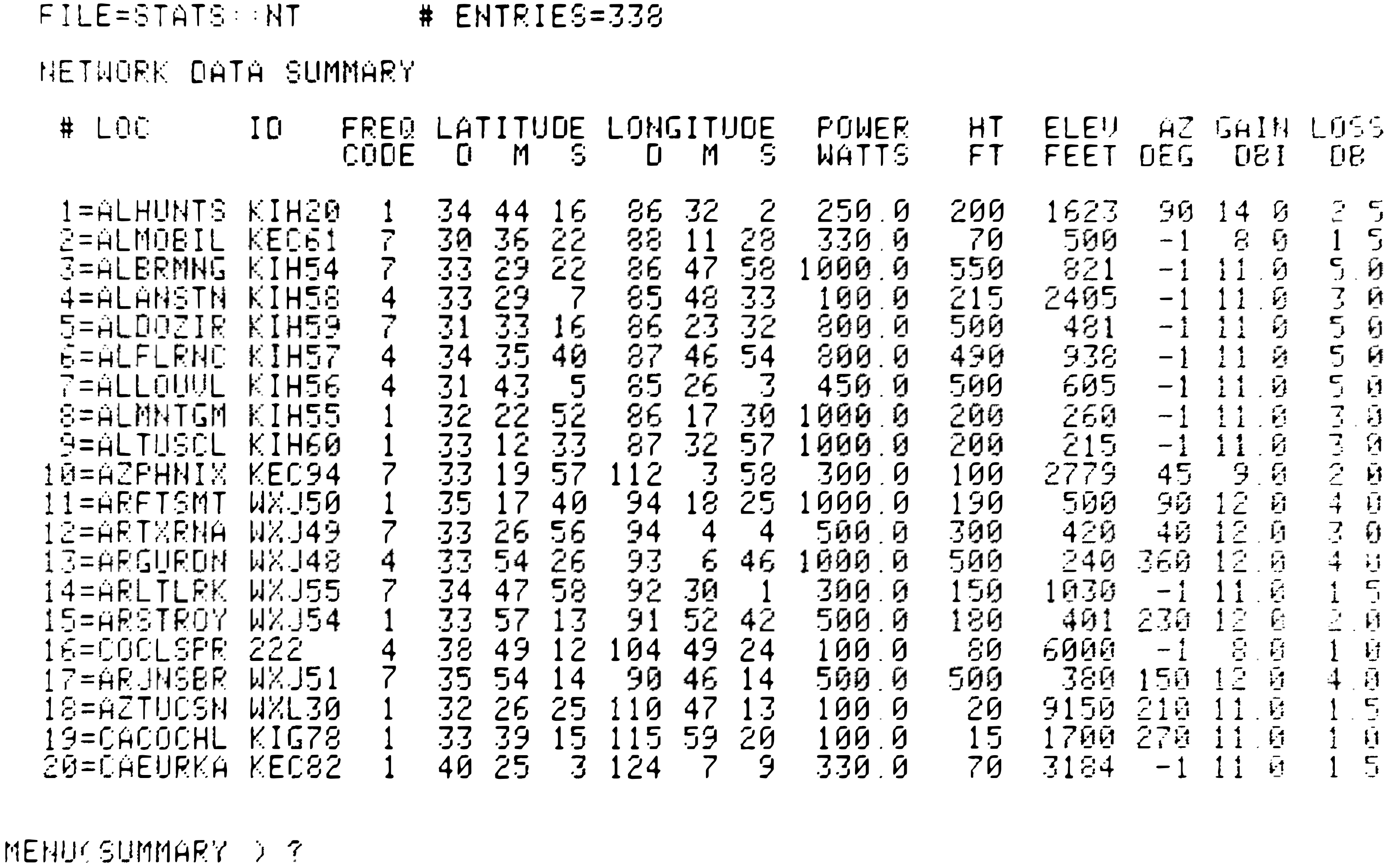
Figure 1-2. Sample output from the Technical Planning Service: statistics concerning coverage by a proposed FM station.

Table 1-1. Frequency-Distance Separation Rules for Two Generic Land Mobile Radio Systems

W: Wideband Systems - 12.5 kHz Channel Spacing
N: Narrowband Systems - 5 kHz Channel Spacing

Interaction	Frequency Separation (kHz)	Channel Separation	Distance Separation (mi)
1 W-W	0	0	110
2 W-W	12.5	1	35
3 W-W	25	2	1
4 N-N	0	0	155
5 N-N	5	1	8
6 N-N	10	2	4
7 N-N	15	3	2
8 N-N	20	4	1
9 N-N	25	5	1
10 W-N, N-W	0	0	130
11 W-N, N-W	12.5	1	8
12 W-N, N-W	25	2	1



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FILE=STATS::NT        # ENTRIES=338

NETWORK DATA SUMMARY

 # LOC        ID     FREQ LATITUDE LONGITUDE   POWER    HT   ELEV   AZ GAIN LOSS
                     CODE  D  M  S   D  M  S   WATTS    FT   FEET  DEG  DBI  DB

 1=ALHUNTS KIH20   1  34 44 16  86 32  2   250.0  200  1623   90 14.0  2.5
 2=ALMOBIL KEC61   7  30 36 22  88 11 28   330.0   70   500   -1  8.0  1.5
 3=ALBRMNG KIH54   7  33 29 22  86 47 58  1000.0  550   821   -1 11.0  5.0
 4=ALANSTN KIH58   4  33 29  7  85 48 33   100.0  215  2405   -1 11.0  3.0
 5=ALDOZIR KIH59   7  31 33 16  86 23 32   800.0  500   481   -1 11.0  5.0
 6=ALFLRNC KIH57   4  34 35 40  87 46 54   800.0  490   938   -1 11.0  5.0
 7=ALLOUVL KIH56   4  31 43  5  85 26  3   450.0  500   605   -1 11.0  5.0
 8=ALMNTGM KIH55   1  32 22 52  86 17 30  1000.0  200   260   -1 11.0  3.0
 9=ALTUSCL KIH60   1  33 12 33  87 32 57  1000.0  200   215   -1 11.0  3.0
10=AZPHNIX KEC94   7  33 19 57 112  3 58   300.0  100  2779   45  9.0  2.0
11=ARFTSMT WXJ50   1  35 17 40  94 18 25  1000.0  190   500   90 12.0  4.0
12=ARTXRNA WXJ49   7  33 26 56  94  4  4   500.0  300   420   40 12.0  3.0
13=ARGURDN WXJ48   4  33 54 26  93  6 46  1000.0  500   240  360 12.0  4.0
14=ARLTLRK WXJ55   7  34 47 58  92 30  1   300.0  150  1030   -1 11.0  1.5
15=ARSTROY WXJ54   1  33 57 13  91 52 42   500.0  180   401  230 12.0  2.0
16=COCLSPR 222     4  38 49 12 104 49 24   100.0   80  6000   -1  8.0  1.0
17=ARJNSBR WXJ51   7  35 54 14  90 46 14   500.0  500   380  150 12.0  4.0
18=AZTUCSN WXL30   1  32 26 25 110 47 13   100.0   20  9150  210 11.0  1.5
19=CACOCHL KIG78   1  33 39 15 115 59 20   100.0   15  1700  270 11.0  1.0
20=CAEURKA KEC82   1  40 25  3 124  7  9   330.0   70  3184   -1 11.0  1.5

MENU(SUMMARY ) ?
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Figure 1-3. An example showing station characteristics in the NETWORK data base.

the resulting changes in service and interference areas are then calculated and added to the data bases used to display coverage. Thus the service and interference areas plotted on the interactive terminal will always reflect the current station parameters contained in the data base. This capability allows the user to select the combination of station location and technical characteristics that will maximize service and minimize interference for the network. By revising the station data and comparing the resulting coverage predictions, the user can effectively plan the expansion of the network to obtain the desired coverage at minimum spectrum usage.

NETWORK's predictions of service coverage and self-interference areas are based on the values of field intensity calculated using the propagation loss data calculated by the Integrated Terrain Model (ITM) area prediction model. The ITM model is used to calculate basic transmission loss for a path given a particular time availability, location variability, and prediction confidence. Basic transmission loss, denoted by L_b when measured in decibels, is the coupling loss between transmitting and receiving antennas. Because random changes occur in atmospheric conditions affecting the propagation of radio waves, and small variations in antenna siting and the shape of the terrain can cause other random changes in L_b, basic transmission loss is treated as a random function of both time and space. Time availability, q_T is defined as the fraction of time during which the hourly median basic transmission loss does not exceed the predicted value L_b. For a desired signal, q_T is usually chosen to be large, and correspondingly, q_T is chosen to be small for undesired signals. The statistic location variability, q_L, must also be included since random changes in the antenna siting and propagation path cause changes in q_T. Thus the location variability is defined to be the fraction of similar paths for which there will be a fraction of time at least as large as q_T during which the hourly median basic transmission loss will not exceed L_b. The prediction confidence, Q, is a measure of how well the predicted value of L_b for a given q_T and q_L agrees with the measured data that the model is based on. NETWORK uses a prediction confidence of 50 percent; that is, the predicted L_b will be the median of the distribution of measured values for the desired q_T and q_L. This median value is sometimes referred to as the "best estimate" of the basic transmission loss for a particular case.

NETWORK calculates and displays on an interactive-graphics computer terminal areas where the service and co-channel self-interference are predicted to occur for a specified portion of the broadcast network. Service is defined using the "best estimate" of field intensity for 95 percent of the time and in 95 percent of the local area. Interference is defined using the "best estimate" of field intensity predicted to occur for 10 percent of the time in 50 percent of the local area. To store the data necessary for these predictions in a uniform manner, a 4-minute grid has been superimposed on the contiguous United States extending from the southwest corner at 24°N. 125°W. to the northeast corner at 49°N. 66°W. For every grid point, the median power density and its associated statistics for every station with 200 km of the grid point are stored. This information is automatically updated with the ITM whenever a station is added, deleted, moved, or the technical characteristics changed. Consequently, the service or interference coverage plotted always reflects the current station data.

Service or interference for the 4-minute area centered at a grid point is determined by comparing the desired signal level field intensity from the desired (closest) station with the interference level field intensity from each of the other stations within 200 km. A grid point is considered to be served by its desired station if the service level field intensity from the closest station is greater than or equal to 18 dBμ and co-channel power levels are not high enough to cause interference.

Co-channel interference is defined to occur when the field intensity from an undesired co-channel station is greater than or equal to 10 dB less than the service level field intensity from the desired station. For example, if the service level field strength at a grid point is 23 dBμ, co-channel interference is defined to occur when an undesired station on the same channel creates a signal that is greater than or equal to 13 dBμ.

Co-channel interference is only calculated for grid points that would otherwise have service from their desired station. If the point has a service level field intensity from its desired station of less than 18 dBμ, it will be considered not served even though it may have signal levels high enough to be considered service from a more distant station.

Based on comparisons of the predicted service signal levels and interference signal levels from the desired and undesired station, a coverage code is assigned to each grid point and stored in the computer for plotting coverage areas and calculating population data. These codes are updated whenever the changes to the station data base require new signal predictions. The three types of coverage codes used are as follows:

0 - not served by desired station,
1 - served by desired station,
2 - co-channel interference present.

NETWORK may be run from either a CRT interactive-graphics terminal or a hard-copy printing terminal. If a CRT graphics terminal is used, the output options available include listing stations and their characteristics, and plotting service and interference areas that may be superimposed on state or county boundaries for a selected area of the network. Figures 1-4 and 1-5 show two options of displaying the coverage and interference patterns calculated by NETWORK. The planner may interactively select the display option and the geographic area to be viewed. The plotting capability is, of course, not available when NETWORK is run from a nongraphic terminal.

A link performance analysis tool has been developed as a result of the Ground Network

ID LOCATION	FREQ
1-ALHUNTS	1
2-ALMOBIL	7
3-ALBRMNG	7
4-ALANSTN	4
5-ALDOZIR	7
6-ALFLRNC	4
7-ALLOUVL	4
8-ALMNTGM	1
9-ALTUSCL	1
39-FLPANMA	7
40-FLPNSCL	1
41-FLTALHS	1
49-GAALBNY	7
92-MSAKRMN	4
93-MSBONVL	7
100-MSMERDN	7
221-GACLMBS	1
300-ALDMPLS	4

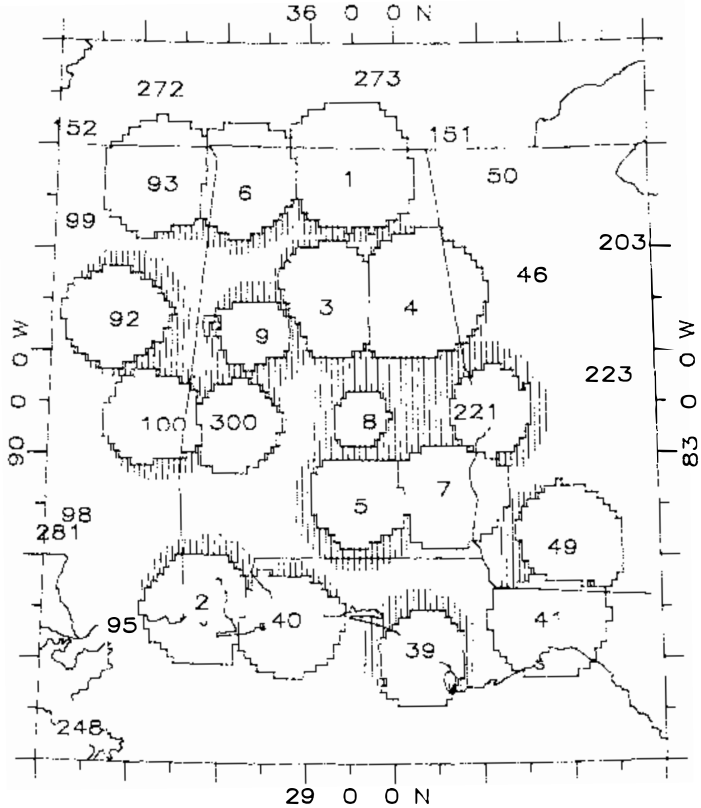


Figure 1-4. An example NETWORK plot showing coverage as polygons and interference as vertical shading.

ID LOCATION	FREQ
1-ALHUNTS	1
2-ALMOBIL	7
3-ALBRMNG	7
4-ALANSTN	4
5-ALDOZIR	7
6-ALFLRNC	4
7-ALLOUVL	4
8-ALMNTGM	1
9-ALTUSCL	1
39-FLPANMA	7
40-FLPNSCL	1
41-FLTALHS	1
49-GAALBNY	7
92-MSAKRMN	4
93-MSBONVL	7
100-MSMERDN	7
221-GACLMBS	1
300-ALDMPLS	4

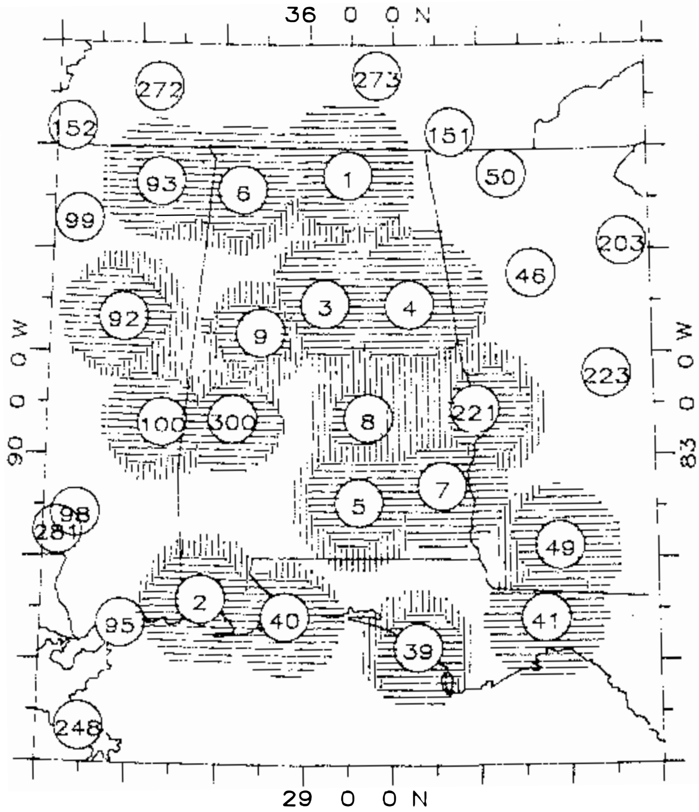


Figure 1-5. An example NETWORK plot showing coverage as horizontal shading and interference as vertical shading.

Communications project that allows a system designer or network analyzer to examine, in both a broad and detailed sense, the operation of a ground-based communication net. The model is valid over a 50 km by 50 km area, and with up to 300 nodes in the network. In the maximum size, the net would consist of 44,450 links. Using this tool, the overall parameters of the net are given in numbers of connected nodes and their connections. The designer is given the option of easily changing the network parameters (node location, antenna types, equipment types, etc.) in order to determine the effects of these changes to the network performance. The model is based on the Integrated Terrain Model (ITM) that calculates path loss from digitized topographic data. The model has choices in output of either plotting the connected links or listing the details of the link calculations. Using these outputs, the user can decide to redesign the net by any of the several options that are most cost effective. The options may be to move one or more nodes to better locations, add one or more relay nodes, adjust antenna patterns and gain, increase power, etc. The model can also be used to limit the parameters to those needed to satisfy the net requirements. This has the advantage of limiting the net interference to other users, and conserving spectrum for other uses.

SECTION 1.2 SPECTRUM RESOURCE ASSESSMENT

As a result of decisions taken at the 1979 General World Administrative Radio Conference, there will be changes in frequency allocations in certain bands for certain classes of services. In some instances, these changes could result in substantial impacts to current United States spectrum usage because of considerations such as large capital investments in equipment or specific frequency management concepts being employed under specific operational scenarios. In response to direction from the NTIA Office of Spectrum Management (OSM), the Institute undertakes Spectrum Resource Assessments to determine these impacts on particular frequency bands.

The Spectrum Resource Assessment (SRA) of the 1605-2000 kHz Frequency Band project examines the 1605-2000 kHz band to assess current and future spectrum use by both Government and non-Government services; to identify present or future compatibility problems between major users; to evaluate technically the feasibility of sharing between the services; and to recommend, where appropriate, changes to improve spectrum management procedures.

Pursuant to the allocation changes adopted at the 1979 World Administrative Radio Conference (WARC-79) and approved by the United States, Broadcasting Service will be allocated on a primary basis to the 1605-1705 kHz band in Region 2. Services now utilizing this band will either be moved into the upper adjacent band, 1705-1800 kHz, or proven to be compatible with the broadcasting service. This spectrum resource assessment identifies some compatibility problems and recommends spectrum management procedures needed to minimize the effects of these changes.

To assist NTIA in fulfilling its spectrum management missions, ITS is currently undertaking the following tasks:

- review the characteristics of existing and proposed Government and non-Government Systems within the 1605-2000 kHz band, including those that could be expected to move out of the band in response to the results of the WARC-79 and other national agreements
- review previous compatibility analyses of systems within this band
- identify and document the potential problem areas, showing potential impact on efficient use of the spectrum, and evaluate the feasibility of sharing between existing and proposed services
- review existing technical standards and channeling plans and determine the impact of state-of-the-art technology on band usage
- identify and outline specific problem areas requiring additional analysis, if any
- recommend specific changes to the existing rules, regulations, and frequency management practices, which will allow compatibility with WARC-79 changes.

A report that describes the results of this study in detail will be available in FY 83.

The effects of WARC-79 on the 1605-2000 kHz band are significant. The characteristics of the band will undergo great change in the next 5 to 10 years. The major spectrum management issues are summarized in the following paragraphs.

Radiolocation and the Broadcast Service

As an outcome of WARC-79, broadcasting will become the exclusive service in the 1605-1625 kHz and primary in the 1625-1705 kHz segments of the band in Region 2. It is very likely the United States will implement these changes by excluding other services from these bands after the Region 2 MF Conference scheduled in 1988. Exclusion of the Radiolocation Service from 1605-1625 kHz will not seriously affect the service since few systems are assigned frequencies below 1625 kHz. The problem arises when the 1625-1705 kHz allocation to the Broadcast Service is implemented and radiolocation becomes secondary in this portion of the band where most of the radiolocation assignments are presently made.

There are some kinds of radiolocation systems that require use of frequencies that are harmonically related. In the Government allocations, these are now assigned within 1650-1655 kHz and 3300.4-3310.4 kHz. Based on the analysis of this study, it is possible to assign radiolocation frequencies in both a co-channel and off-channel sharing plan on a case-by-case basis to be compatible with the Broadcast Service. This, however, assumes that the transmitters can be geographically separated far enough. Sufficient distances can be easily obtained if the broadcast assignments near this small band segment are confined to Class IV stations.

Radionavigation

The WARC-79 allocations in the 1605-2000 kHz band for Region 2 do not include allocations for the Radionavigation Service, which is principally used by Army aircraft during tactical and training missions. There are presently 215 Government assignments for radionavigation within the 1605-1750 kHz band, and the Army purchased 566 new radionavigation systems during 1981-82 with transmitters designed to operate in either of two bands, 200-535.5 kHz and 1605-1750.5 kHz.

To provide the necessary spectrum for these requirements, the proposed Ad Hoc 172 Government and non-Government allocation table has a footnote, US 240, which states: The bands 1715-1725 kHz and 1740-1750 kHz are allocated on a primary basis and the bands 1705-1715 kHz and 1725-1740 kHz on a secondary basis to the aeronautical Radionavigation Service (radio beacons).

Traveler's Information Stations (TIS)

The TIS have been allocated the 1605-1615 kHz portion of the band in the new allocation table. However, it would seem more consistent with past allocations to have TIS at the top of the AM broadcast band at 1700 kHz rather than remaining at the present 1610 kHz. This would improve frequency management by keeping the broadcast band continuous, and with only a few low-power Government and non-Government assignments around 1700 kHz, the compatibility problems may be eased. Additionally, the slightly lower value of ground wave attenuation at 1610 kHz compared to 1700 kHz favors the use of 1610 kHz for broadcasting.

The NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management contains no rules and regulations for Government use of TIS. Since there are 172 Government assignments to TIS, it may be appropriate to either make a statement to the applicability of FCC rules or to list some rules and regulations pertaining to these assignments.

Cordless Telephone and the Radiolocation Services

In the past, cordless telephones have used frequencies throughout the 1600-2000 kHz band in a more or less random manner with each manufacturer making a frequency choice. After September 1982, cordless phone manufacturers are likely to confine their frequency choices within the 1625-1800 kHz band in order to comply with a condition of an FCC waiver of FCC Rules, Part 15.7. This waiver provides a practical standard by which the manufacturer can measure cordless telephone output power. Currently, available information indicates that nearly all manufactured cordless phones do not comply with the provisions of Part 15.7 that govern the radiated field from the phones. In general, the radiated field value is much higher than the allowable value. As increasing numbers of cordless phones are sold (11 million units are predicted in 1987), the interference potential is likely to be severe. Government radiolocation receivers aboard vessels at dockside in an urban environment will be very susceptible to interference from cordless phone transmissions close by if the radiolocation transmitter is several hundred miles away.

In the Spectrum Resource Assessment of the 5650-5925 MHz Frequency Band, the 5650-5925 MHz band was examined to assess current and future spectrum use by both Government and non-Government services; to identify present and future compatibility problems between major users; to evaluate technically the feasibility of sharing between Government and/or non-Government services; and to recommend, where appropriate, changes to improve spectrum management procedures.

In the United States, 5650-5925 MHz has been a shared band with the primary allocation assigned to the Government Radiolocation Service with an industrial, scientific, and medical (ISM) allocation at 5800 ± 75 MHz. There is a secondary allocation for the amateur service. Government allocation is for military radiolocation and is used for air surveillance radar, transponder tracking and positive aircraft guidance, missile and rocket radio, and radar equipment.

At the 1979 WARC, the portion of this band from 5850-5925 MHz was reallocated to the fixed, fixed satellite (earth-to-space), and mobile services on a primary basis with radiolocation and amateur services on a secondary basis for Region 2. Interdepartment Radio Advisory Committee (IRAC) Ad Hoc 172 has recommended adding only non-Government fixed satellite services (FSS) (earth-to-space) in the 5850-5925 MHz band on a primary basis in the United States. The Ad Hoc 172 has also proposed U.S. Footnote 245, which states that the FSS is limited to international systems and subject to case-by-case electromagnetic compatibility analysis.

From a spectrum management standpoint, the major issue of this particular frequency band study is the need to accommodate the Fixed Satellite Service uplink assignment in the 5850-5925 MHz portion. At present the 5650-5925 MHz band is a Government Radiolocation Service occupied by the Army, Navy, Air Force, NASA, and DoE users along with a few manufacturers of equipment and systems used in the band by the Government. The main problem dealt with here is the interference potential of high-power radars with international communication satellites of INTELSAT-type coming into the band in the mid 1980s.

The current proposal calls for two satellite uplink terminals, probably one located on each coast within CONUS. As shown in Figure 1-6, even though the greatest density of assignments is on the coastal areas, there would be many locations where uplink terminals could be located well away from current radar sites. In addition, terrain topology could be used to minimize interference potentials between uplink transmitters and radar wideband receiver front ends.

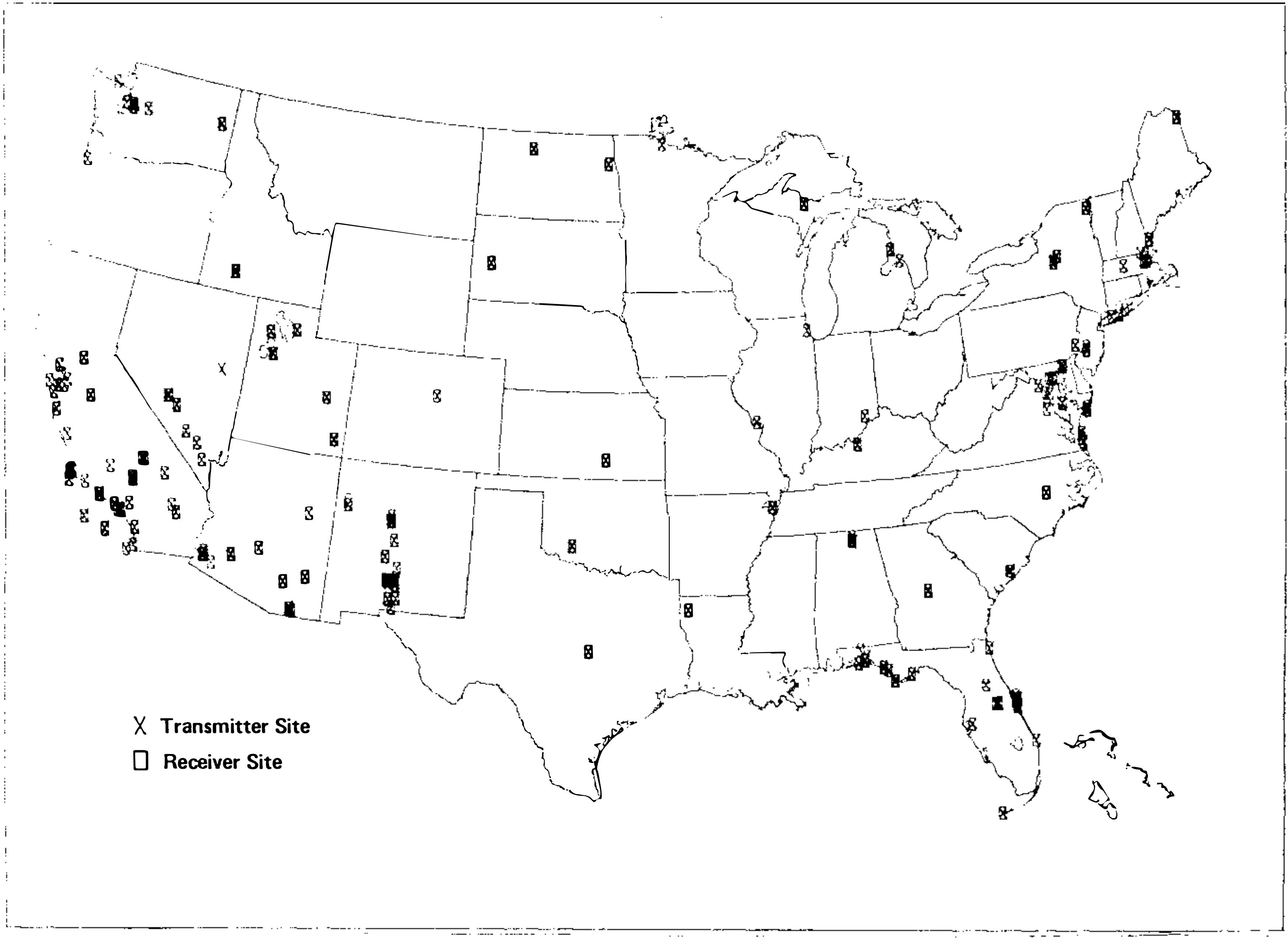


Figure 1-6. Geographic distribution of Government frequency assignments in the 5650-5925 MHz band.

There is some difficulty in assessing the mainbeam-to-mainbeam coupling problem since satellite antenna patterns are shaped to receive transmissions from almost every possible terrestrial direction. Another point of difficulty is encountered when attempting to find an agreed upon criteria or an acceptable definition of "harmful radar-to-satellite interference." One of the problems considered at present by Ad Hoc 183 of the IRAC is to develop and recommend to the IRAC spectrum management procedures that will allow implementation of the Fixed-Satellite Service in the frequency bands 3600-3700 MHz and 5850-5925 MHz consistent with the National Table of Allocations as implemented as a result of WARC-79. The outputs from this committee should be of great help to studies involving radar/satellite interference.

The NASA measurements reported in a recent CCIR document (1980) indicated that the carrier-to-interference ratio (C/I) of 11 dB to 17 dB is necessary to protect analog FM TV from incoherent interference from radar signals. The COMSAT measurements indicated that the C/I of -10 dB to 6.5 dB are required to protect FDM/FM carriers from interfering radar emissions. For analysis purposes in this report based on the types of radars involved, two values of C/I will be used to bound the problem:

C/I = 15 dB for FM/TV
C/I = -1.5 dB for FDM/FM.

Another reference point for the evaluation of interference from radar may be taken as the saturation level at the satellite receiver input. Table 1-2 gives the saturation flux density for the INTELSAT VI used in this report. For power flux densities that meet or exceed the saturation flux density of the satellite receiver, nonlinear regions of the front end may be reached and intermodulation products begin to appear at the receiver output. These nonlinear distortions may appear at frequencies other than that of the interfering signal and be demodulated into unpredictable voice channels.

Table 1-2. INTELSAT VI Communication Satellite Technical Characteristics

Earth Station Transmitter
    Power - 1 kW   ERIP 90 dBW
    Polarization - Left hand circular
    Antenna Gain - 60 dB

Satellite Transponder Receiver
    Saturation power flux density
      -79 $\mathrm{dBW/m^2/80}$ MHz beam edge
      -82.6 $\mathrm{dBW/m^2/80}$ MHz within beam

GT = -8.5 dB/k beam edge
GT = -5.5 dB/k within beam
Out-of-band Receiver Filter Response
        -30 dB at 5840 MHz
        -40 dB at 5830 MHz

The AN/FPS-16 is representative of a typical tracking radar used in the band and the most widely used at the tracking ranges in CONUS. The technical characteristics are given in Table 1-3 and will be used in the following analysis:

For mainlobe-to-mainlobe coupling

$$C/I = P_T + G_T - P_I - G_I + G_{SE} - G_{SR} - (L_T - L_I) - M + FDR \qquad (1)$$

where:
P_I = radar transmitter power, dBW
G_I = radar antenna gain, dBi
P_T = earth station transmitter power, dBW
G_T = earth station antenna gain, dBi
G_{SE} = satellite antenna gain in the direction of the earth station, dBi
G_{SR} = satellite antenna gain in the direction of the radar, dBi
L_T = path loss between earth station and satellite, dB
L_I = path loss between radar transmitter and satellite, dB
M = path loss margin for the earth station signal, dB (assumed to be equal to 1.2 dB)
FDR = frequency dependent rejection of receiver, dB.

The maximum differential path loss of two points on the surface of the earth to a satellite is 1.3 dB. $L_T - L_T = 1.0$ dB will be used in the calculations here as an approximation. For the worst case analysis, it could be assumed that the earth station is located at the 3-dB satellite beam contour and the radar is located at the beam center. Hence,

$$G_{SE} - G_{SR} = -3.0 \text{ dB} \qquad (2)$$

is a good approximation and will be used in this analysis.

Substituting equation (2) above into (1) gives

$$C/I = P_T + G_T - P_I - G_I + (-3) - (1) - (1.2) + 0$$

$$= P_T + G_T - P_I - G_I - 5.2. \qquad (3)$$

(Note, FRD = 0 for co-channel case)

Substituting values in Tables 1-2 and 1-3,

$$C/I = (30 + 60) - (60 + 47) - 5.2 = -22.2 \text{ dB}.$$

For the shipboard AN/SPS-10 type radars with less power and wider beamwidths, the calculation becomes:

$$C/I = 90 - (54.5 + 30) - 5.2 = 0.3 \text{ dB}.$$

Using the C/I criteria as discussed earlier, the AN/FPS-16 radar would then fail to meet the C/I = -7.5 dB criteria by 14.7 dB and 37.2 dB for the C/I = 15 dB criteria. The AN/SPS-10 type radars would have a safe margin of 7.8 dB for the co-channel case using the C/I = -7.5 dB criteria and would fail to meet the C/I = 15 dB criteria by 14.7 dB.

Table 1-3. AN/FPS-16 (MPS-25) Technical Characteristics

Type	Instrumentation
Frequency	$\geq$ 5650-5900 MHz
Power	1 MW peak

For the shipboard AN/SPS-10 type radars, which use a wider beamwidth, the calculation becomes:

$$C/I = 90 - (54.5 + 30) - 5.2 = 0.3 \text{ dB}.$$

Here the C/I criteria is exceeded by 24.7 dB for mainbeam-to-mainbeam coupling.

For the case of the radar sidelobe-to-satellite mainbeam interactions, the worst case will be pursued here--that involving the first sidelobe of the radar. The actual earth station antenna to be used with the INTELSAT VI was not totally specified at this writing, but the gain and patterns may be estimated from knowledge given by COMSAT Labs by private communication and ITU recommendations. The ITU Appendix 29, Annex III, gives a method for calculating radiation patterns.

Assuming the earth station antenna has a diameter of 32 m, the gain pattern of the antenna was calculated and is listed in Table 1-4. In contrast, a typical tracking radar antenna approximately 4.88 m diameter (AN/FDS-16) was calculated and the results are listed in Table 1-5.

Table 1-4. Gain for 32 m Diameter Antenna at Selected Angles off Boresight

φ°	G(dB)	Remarks
0°	60.0	Main lobe
0.12-0.33°	44.1	1st sidelobe
5°	14.5	
10°	7.0	
20°	-0.5	
40°	-8.1	
48 <φ<180°	-10.0	

Table 1-5. Gain for 4.88 m Diameter Antenna at Selected Angles off Boresight

φ°	G(dB)	Remarks
0°	47.0	Main lobe
0.84-1.07°	31.5	
5°	14.8	
10°	7.3	
20°	-0.2	
40°	-7.6	
38 ≤φ≤180°	-9.7	

For the radar sidelobe-to-satellite mainbeam coupling case, equation (3) can be rewritten in a more convenient form as

$$C/I = P_T - P_i - G_i\ (\theta) - 5.2 \qquad (4)$$

where

P_i = radar transmitter power, dBW

$G_i(\theta)$ = radar antenna gain in the direction of the satellite mainlobe as a function of pointing angle θ.

For the tracking radar case, the AN/FPS-16 radar characteristics will be used, giving for the first sidelobe

$$G_i = 2 + 15 \log \frac{D}{\lambda}\ 31.62 \text{ dBi}$$

$$C/I = 90 - (60 + 31.6) - 5.2 = -6.8 \text{ dB}$$

which exceeds the C/I criteria of 15 dB by 21.8 dB but is just within the C/I criteria of -7.5 dB by 0.7 dB.

For the minimal angle, θ, that the radar must be pointed away from the geostationary orbit position for C/I = 15 dB

$$P_T - P_i - G_i\ (\theta) - 5.2 + \theta = 15 \qquad (5)$$

$$G_i\ (\theta) = 9.8 \text{ dB}$$

$$52 - 10 \log \frac{D}{\lambda} - 25 \log \theta = 9.8$$

$$\theta = 7.9° .$$

Other interference studies involve earth station transmitter-to-radar receiver coupling, earth station-to-radiolocation transponder coupling, ISM, and Restricted Radiation Devices/Radar Interactions which are given in an NTIA Report published in January 1983. Also given in the report are the frequency-dependent rejection characteristics of the satellite that help establish how far away from the operational frequency band of the satellite a radar must operate to meet sharing criteria.

International communication satellite systems such as the INTELSAT VI series are scheduled to be operational in the 5850-5925 MHz portion of the band under study here in the 1985-86 time frame. As shown here, the interference potential to the satellite receiver systems from inband radar energy presents an incompatible situation. The earth station transmitter could also pose some compatibility problem for transponder systems in the radiolocation service sharing this portion of the band. However, only the first sidelobe provides enough energy to be a problem. Judicious placement of the earth station should minimize this problem.

Measurements by the ITS Radio Spectrum Measurement System described in the next section show this band to be heavily used by military, test ranges, and shipboard radars. However, few radars were measured above 5850 MHz. Transponders were found to operate above 5580 MHz and, as mentioned previously, would experience possible interference from the FSS. Careful selection of sites for the FSS earth station uplink will help in limited sharing by the two services. However, radars whose tracking angles may cause mainbeam-to-mainbeam coupling with the satellite would have to be power limited to 6.8 dBW radiated power to provide a C/I = 10 dB criteria and 92.3 dBW for the C/I = -7.5 dB criteria. Another option is to off-tune the radars far enough away from the 5850-5925 MHz portion of the band until some agreed upon C/I criteria are met. A combination of reduced power and off-tuning could also be used.

The project for Spectrum Resource Assessment of the 947 MHz to 17.7 GHz frequency portion of the electromagnetic spectrum addresses the uses of all Government allocations for fixed and mobile services. There are 109 distinct bands within this portion of the spectrum--44 that contain fixed and mobile services. Some of the fixed and mobile bands were combined for ease of study into 22 bands as follows:

Government Exclusive Bands

1350-1400 MHz
1710-1850 MHz
2200-2290 MHz
4400-4500 MHz
4800-4990 MHz
7125-8450 MHz
14.5-15.35 GHz

Government/non-Government Shared Bands

1427-1535 MHz
1700-1710 MHz
2290-2390 MHz
2655-2690 MHz
4500-4800 MHz
8450-8500 MHz
10.6-10.68 GHz
14.4-14.5 GHz

Non-Government Exclusive Bands

947- 960 MHz
1850-2200 MHz
2450-2655 MHz
3700-4200 MHz
5925-7125 MHz
10.55-10.6 MHz
10.7 -13.25 MHz

The Federal Communication Commission (FCC) is now examining alternative approaches to achieve more efficient spectrum use. In General Docket 82-334, the FCC has issued a Notice of Inquiry (NOI) (dated July 9, 1982, FCC 82-286, IRAC 22785) and a Notice of Proposed Rule Making (NPRM) that addresses the fixed and mobile radio services operating in the band from 947 MHz to 40 GHz. The NOI and NPRM thus far focus on regulations for only the following specific bands pertaining to this particular study between 947 MHz and 17.7 GHz:

1.99 - 2.11 GHz
6.525 - 7.125 GHz
12.7 - 13.25 GHz.

A major impetus for this FCC action is the Commission's decision on June 23, 1982, to authorize Direct Broadcasting Satellite (DBS) services in the 12.2 - 12.7 GHz band, and the need to identify spectrum for the private fixed services currently authorized in this band. Although the 18 GHz band was initially considered a likely candidate for accommodating these services to be displaced by DBS in the 12 GHz band, the Commission is now considering extensive rule changes for additional bands that are intended to achieve more efficient spectrum use through improved matching of spectrum access requirements and operating frequencies. The FCC is proposing to establish common technical standards for a pool of frequencies yet to be defined. These frequencies would be available for licensed use to a variety of eligible users--private, cable, broadcast, and common carrier entities.

The frequencies between 947 MHz and 17.7 GHz represent a very large portion of the usable radio frequency spectrum and represent a very important and valuable asset as part of this national resource. There is a need at this time to review the Government use and standards of this portion of the spectrum in light of the FCC NOI and NPRM, changes in allocations and standards proposed as a result of the 1979 WARC, changes in market demands and applications of new technologies being addressed by the FCC, and continued examination of Government spectrum requirements to assure that assigned mission functions are satisfied and that the spectrum is used efficiently.

SPECIFIC TASKS

To assist NTIA in fulfilling the mission and to assist IRAC in responding to the FCC NOI, the following tasks will be performed:

- review and document the existing and proposed uses of the bands between 947 MHz and 17.7 GHz by the Government fixed and mobile services, including those that could be expected in response to the results of the 1979 WARC and other international or national agreements
- review previous NTIA, ECAC, and other Government and private sector reports containing compatibility analysis, user needs, system descriptions, etc., of systems used in the bands between 947 MHz and 17.7 GHz
- identify and document the potential problem areas that may have an impact on the efficient use of the spectrum, and evaluate the feasibility of sharing between existing and proposed services
- identify and assess the severity of potential interference to and impact on Government systems and spectrum use that could result from the operation of those non-Government services that are under consideration by the FCC
- recommend specific changes to the existing rules, regulations, and frequency management practices that would improve overall management of the Government fixed and mobile services in the bands involved. This will include an analysis of the impacts of relaxing coordination requirements for new users of shared spectrum as suggested by the FCC.

An NTIA Report that will document the findings of the above study is scheduled to be published in April 1984.

SECTION 1.3 ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

Many forms of system design, spectrum engineering, and even tactical use of electronic systems depend on a realistic understanding of the electromagnetic environment in which the systems will be operating. Unfortunately, environmental measurements of spectrum usage are not always straightforward because of the large amounts of data needed for a reliable statistical model and because of the very detailed measurements needed to describe technical system interactions. Some of these problems can be overcome with the aid of computer-controlled measurement systems. These computer-controlled measurement systems can provide several advantages over earlier manual systems including economical measurement of massive amounts of data, real-time measurement and analysis of high-speed phenomena, and sophisticated processing of data to provide a relatively untrained operator with answers that are not otherwise obvious.

The Institute has developed a sophisticated mobile system for providing measurements of the electromagnetic environment on a detailed basis. This system, referred to as the Radio Spectrum Measurement System (RSMS) is integrated into the van shown in Figure 1-7. In FY 83, RSMS activities were divided into two major sections. Measurement Van Operations continued to provide measurements of the electromagnetic environment for various Federal frequency management projects, while major work was continued with Measurement Van Development and RSMS Upgrade to provide for an improved measurement capability in FY 84.

As in earlier years, RSMS measurements contained a mixture of directly-funded and sponsor-supported measurements. The directly-funded measurements continued to support spectrum resource assessments (SRAs) being performed in Boulder and Annapolis and other frequency management issues coming under investigation in FY 83. The SRAs (detailed in Section 1.2) are intensive studies of individual frequency bands; several of them have used RSMS measurements of current spectrum usage as a key piece of data for predicting future usage in those bands. Although RSMS measurement activities were substantially curtailed in FY 83 to allow maximum effort on the development of a new measurement system, several major sets of measurements were made. These are listed here and will be discussed more completely later:

- Denver area land mobile radio usage
- general spectrum usage measurements near White Sands Missile Range
- site survey for the Air Force
- field strength measurement verification for National Weather Service
- Power Line Carrier (PLC)
- radar close-in hazards.

The computer-controlled radio measurement system in the RSMS (Fig. 1-8) allows measurements of a selected frequency band to be made in a rapid and accurately repeated manner, as directed by the computer program being executed. Within the land mobile radio (LMR) bands, the RSMS makes usage measurements by tuning to each channel in the band and observing the presence or absence of a signal. This is accomplished at the rate of 125 channels each second; a typical LMR band with 500 channels will be measured completely every 4 s. This measurement rate can be maintained on a 24-hr/day basis, with or without operator intervention, to furnish the very large number of samples required for accurate estimation of LMR band usage.

Measurements of channel usage were made on a number of selected Government LMR bands in the Denver area. These measurements were made as part of a continuing effort to monitor crowding in the Government LMR bands. Figure 1-9 shows a representative sample of channel usage in a 1-MHz segment of the 162-174 MHz band. This graph is based on about 17,000 measurements on each channel, made over a 2-day period during the week. The data are summarized on two graphs. The upper graph shows the average and maximum signal levels received during the measurement period for each channel--using the lower and upper ends of the respective lines. The lower graph shows the percentage of time that a signal was observed in each channel. Similar data were measured for other LMR bands, using automatic measurement and analysis programs that made about 10,000,000 individual channel occupancy measurements each day and produced hourly statistical summaries of the measurements.

Two series of more general spectrum occupancy measurements were made in FY 83. The RSMS Measurements at Holloman AFB were made to help plan a new test site, and another series was made from a mountaintop site to provide usage measurements over a wider area. Each of these general occupancy surveys covered the 150 MHz to 18 GHz range, making simultaneous measurements with peak and average detectors. To be able to automatically make measurements over this frequency range, it was necessary to mount additional antennas to the RSMS antenna tower and to the rooftop antenna pedestal, resulting in a configuration shown in Figure 1-10. Three types of antennas were used for all frequencies--an omnidirectional antenna, an antenna with approximately 90 degree beamwidth, and a dish antenna with 2-20 degree beamwidth. For frequencies below 1000 MHz, only the omnidirectional and quadrant antennas were used. A set of bandpass filters and wideband, low noise preamplifiers were located near the antennas and connected appropriately as needed for the frequency band being measured. Typical noise figures of 4-8 dB at the antenna terminals were available with this configuration.

The programs used to make the measurements were designed to (1) calibrate across the whole frequency range, using noise diodes near the antennas; (2) measure across the frequency range using omnidirectional antennas; (3) measure across the frequency range using quadrant antennas; (4) measure across the frequency range using dish antennas (quadrant antennas if below 1 GHz); and (5) calibrate and start again. This program was designed to operate without requiring intervention from an operator, and data for nine days were gathered on a 24-hr/day basis.

At each frequency, measurements were made with a peak detector (for radars and other impulsive signals) and with an average detector (for cw signals). Figure 1-11 shows a typical example of data produced by this program. The "tic" marks along the right-hand edge of the graph are thresholds for the peak and average

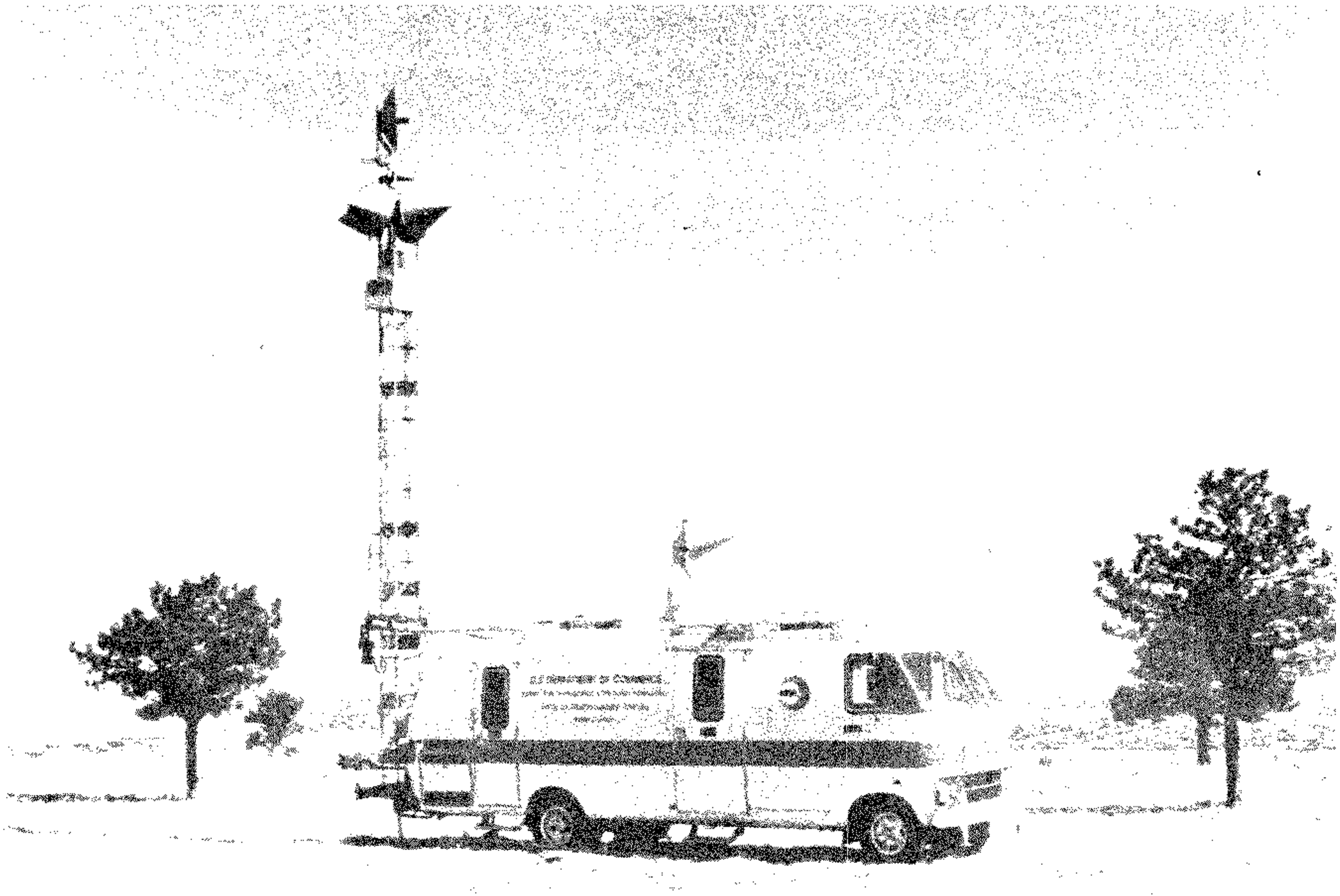


Figure 1-7. Radio Spectrum Measurement System (RSMS).

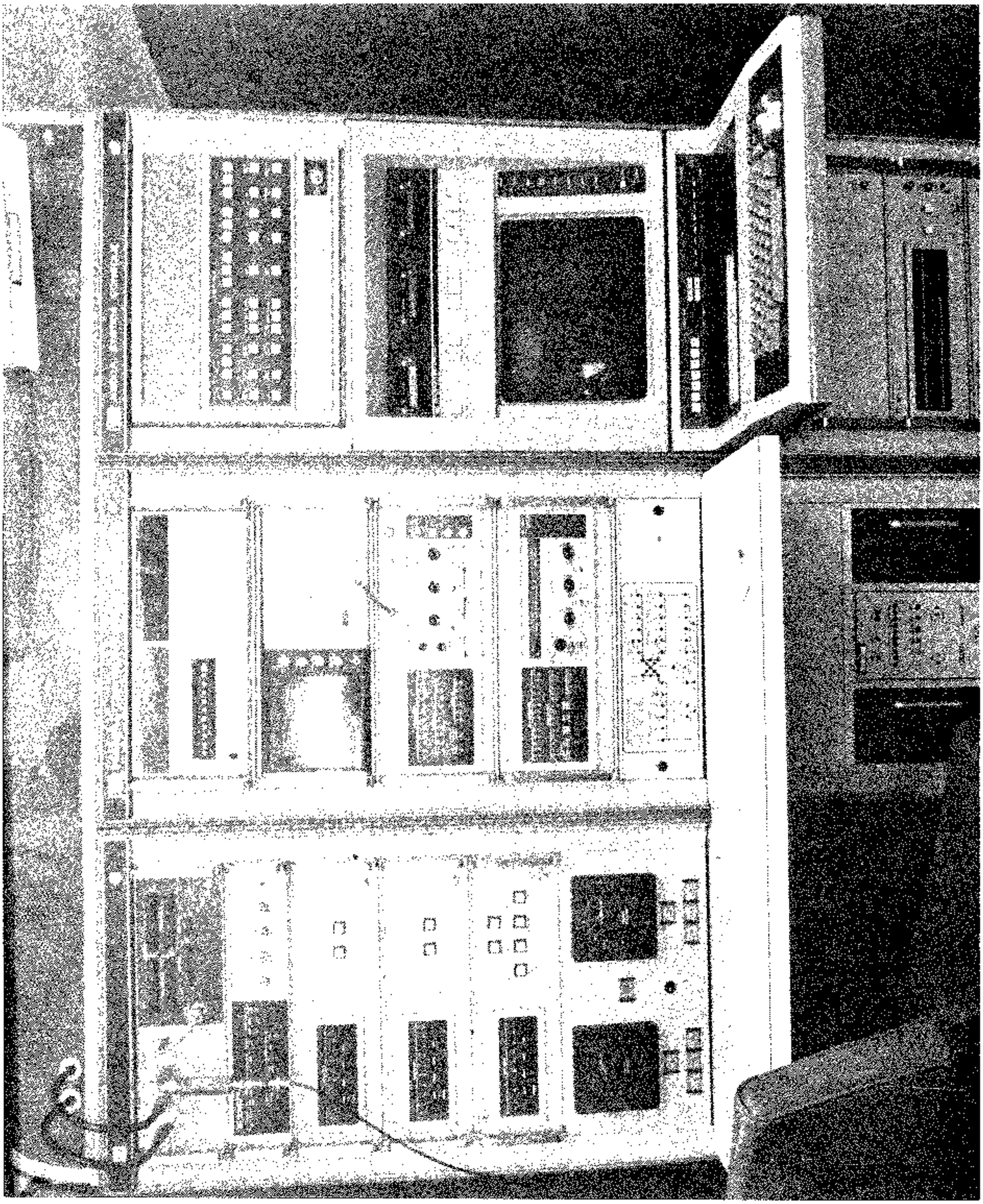


Figure 1-8. Measurement system used in RSMS.

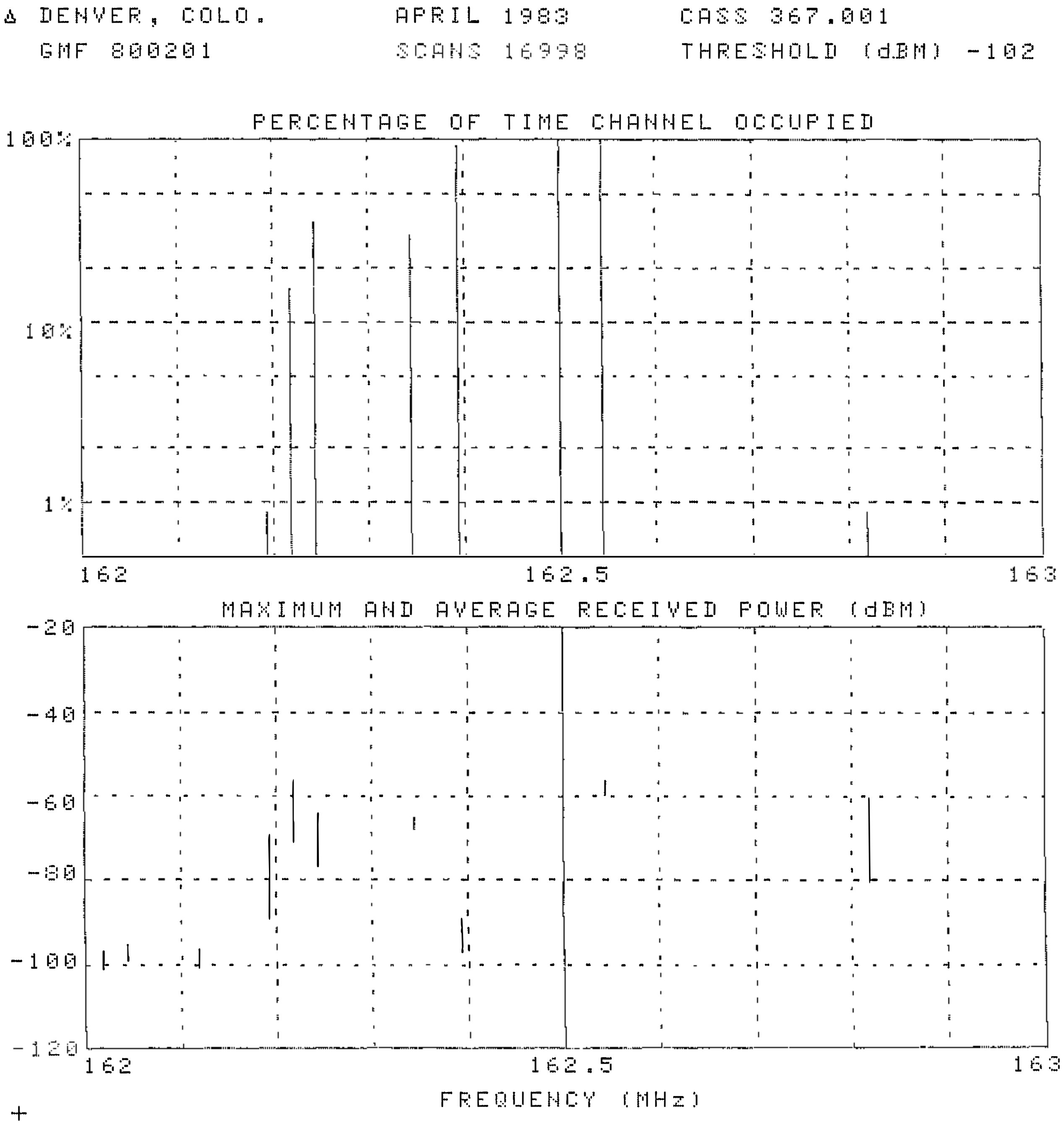


Figure 1-9. Example of LMR channel usage measurements.

Figure 1-10. RSMS configured for site surveys.

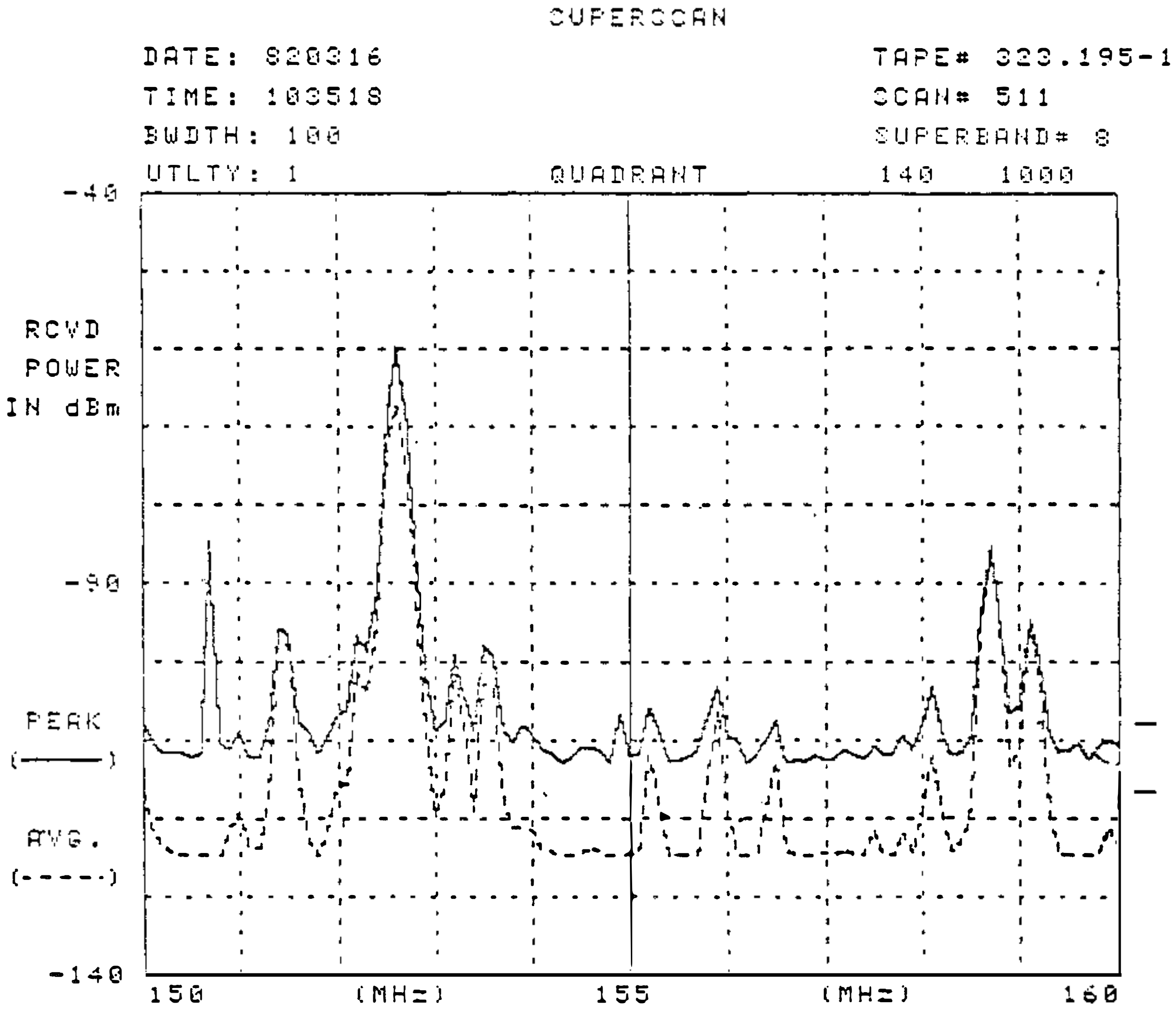


Figure 1-11. Example of site survey data.

detectors. If neither the peak nor average signals on a graph exceeds its respective threshold, the data are discarded. This real-time data sorting substantially decreased the amount of data to be incorporated into other analyses. In general, data were recorded on magnetic tape, but hard-copy output like Figure 1-11 was also produced as required.

Two different versions of the measurement programs were used--a low resolution (lo-res) and a high resolution (hi-res) version. The hi-res version provided 10 dB better sensitivity and 10 times better frequency resolution, but also required 10 times as much measurement time. The pertinent characteristics of the two versions are described in the following table:

	Lo-res	Hi-res
Bandwidth, f < 1 GHz	1000 kHz	100 kHz
Bandwidth, f > 1 GHz	100 kHz	10 kHz
No. of scans, 0.15-18 GHz	255	2500
Meas time, 0.15-18 GHz	17 min	3 hr

The measurement process resulted in thousands of graphs, which needed to be combined to permit a reasonable level of comprehension. The process of combination was done in two stages. The first stage compressed the frequency scale by a factor of 100. This "frequency compression" stage saved only the highest amplitude peak measurement and the highest amplitude average measurement from each of the original graphs. These sets of two points were combined with 99 other similarly derived sets of points and used to draw another graph which covered 100 times as much frequency range as the original graphs.

The second stage of the analysis involved combining dozens of the frequency-compressed graphs to give maximum and average values at each frequency for the peak and average detectors. Figure 1-12 shows a portion of the set of finished graphs. The upper graph shows data gathered with the peak detector; the lower graph shows data gathered with an average detector. In each graph, the upper line represents the maximum value measured and the lower line shows the average value measured. These graphs show the advantage of the measurement and analysis process used here. Although the graph covers a relatively large frequency range, the measurement sensitivity is that associated with a much smaller measurement bandwidth. Note the 10 dB better sensitivity of the average measurement graph, compared with the peak measurement data. Finally, note that the average measurement data almost completely miss the low-duty-cycle radars in the 2700-3000 MHz range.

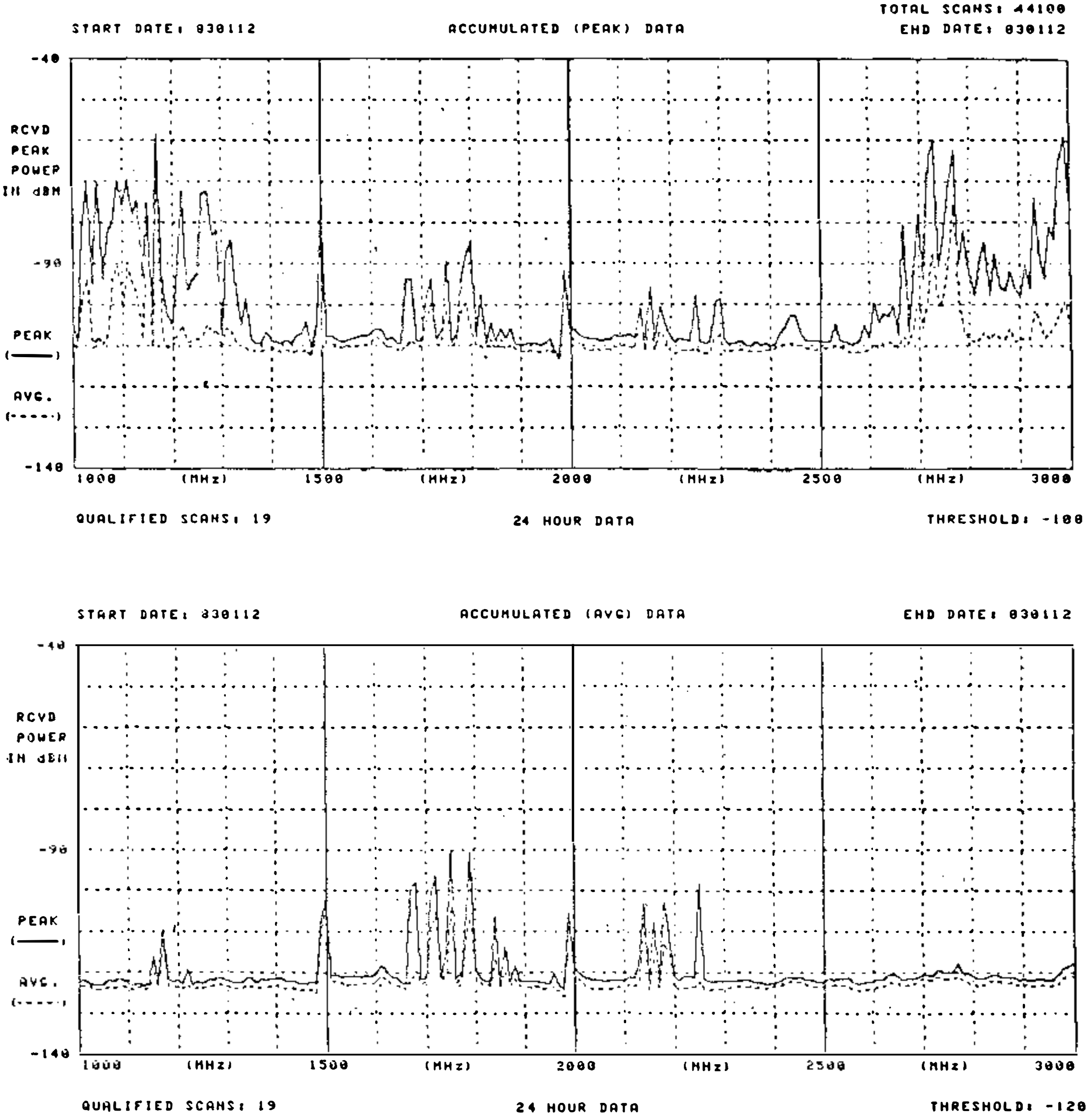
NWS Field Strength Calibrations were performed using the RSMS to calibrate some portable field strength meters for the National Weather Service (NWS). The NWS uses this portable measurement equipment to make spot checks of signal levels produced by their weather radio information transmitters, to assure adequate signal levels in areas of planned coverage. Since some initial measurements with the NWS equipment had shown substantial disagreement with predicted signal levels, it was important for NWS to know whether the measurement equipment, the tested transmitters, or the prediction process were causing the discrepancy. The RSMS was configured to make measurements in parallel with the NWS system, while driving over highways in the Denver area. The highways were chosen to give approximately radial paths from the NWS transmitter under test. During the RSMS measurements, the NWS equipment was operated in a car closely following the RSMS. Radio contact between the two vehicles allowed NWS measurements to be incorporated with the RSMS measurements on a real-time basis. When the measurements were finished, the RSMS data were compared to the NWS data, as well as being compared with predictions of received signal levels.

Figure 1-13 shows an example of the comparison for one of the segments of the measurement route. The NWS data are shown with a dashed line and the RSMS data are shown with a solid line. Predictions made for this path are also plotted on this graph and show a high degree of agreement with the measurements. The measurements shown here were made after an equipment malfunction in the NWS equipment was identified, which was believed to have caused the earlier measurement problems.

Measurements were made on power line carrier (PLC) signals in the Denver and Pueblo, CO, areas. The PLC signals are used by most electrical utilities to control and sense the status of large power line systems. These signals range between 100 kHz and 400 kHz and are transmitted along the same lines that carry high voltage electrical power. Although most of the PLC signal stays within the path provided by the electrical wires, the wires also tend to act as inefficient antennas. Because of recent plans to use the same frequency band for other various types of transmitted signals, it has become very important to establish exactly how many signals are received or transmitted by these power lines. Serious interference could be caused or experienced by PLC systems. Measurements were made at various distances from several power lines. Figure 1-14 shows a summary of one of these sets of measurements. The answers fit existing models quite closely, tending to confirm the basis for some of the spectrum management planning in this band.

Measurement operations were substantially curtailed this year to permit more effort to be committed to Measurement Van Development and the RSMS Upgrade. The present RSMS was placed into operation by ITS more than 10 years ago. Maintenance problems and an awareness of the advantages of newer systems led to an FY 82 decision to upgrade the RSMS with more modern instrumentation and computers. In FY 82, basic system design was accomplished for an upgraded RSMS. In FY 83, most of the major procurements were finished, equipment was received, construction was begun on most of the specialized measurement equipment, major software design was finished, and detailed software implementation was begun. The upgraded RSMS will be involved in the first field operations in late FY 84.

The RSMS Upgrade includes three main systems: A laboratory computer system in Boulder will



960-1215	Aeronautical Radionavigation (TACAN, 1030/1090 MHz ATCRB)
1215-1400	Radiolocation (L-Band ARSR)
1400-1427	Radio Astronomy
1427-1535	Fixed, Mobile, Space Operation
1535-1558.5	Aeronautical Mobile-Satellite, Maritime Mobile-Satellite
1558.5-1636.5	Aeronautical Radionavigation
1636.5-1660	Maritime Mobile-satellite, Aeronautical Mobile-Satellite
1660-1700	Meteorological Aids, Radio Astronomy, Fixed
1700-2300	Fixed, Mobile, Space Researcn (↓), Meteorological Satellite (↓)
2300-2450	Radiolocation, Amateur, Fixed, Mobile
2450-2500	Fixed, Mobile, Radiolocation
2500-2690	Broadcasting-Satellite, Fixed, Fixed-Satellite (↑), Mobile
2690-2700	Radio Astronomy
2700-2900	Aeronautical Radionavigation (ASR's), WX Radars
2900-3100	Radionavigation, Radiolocation

Figure 1-12. Example of combined site survey data.

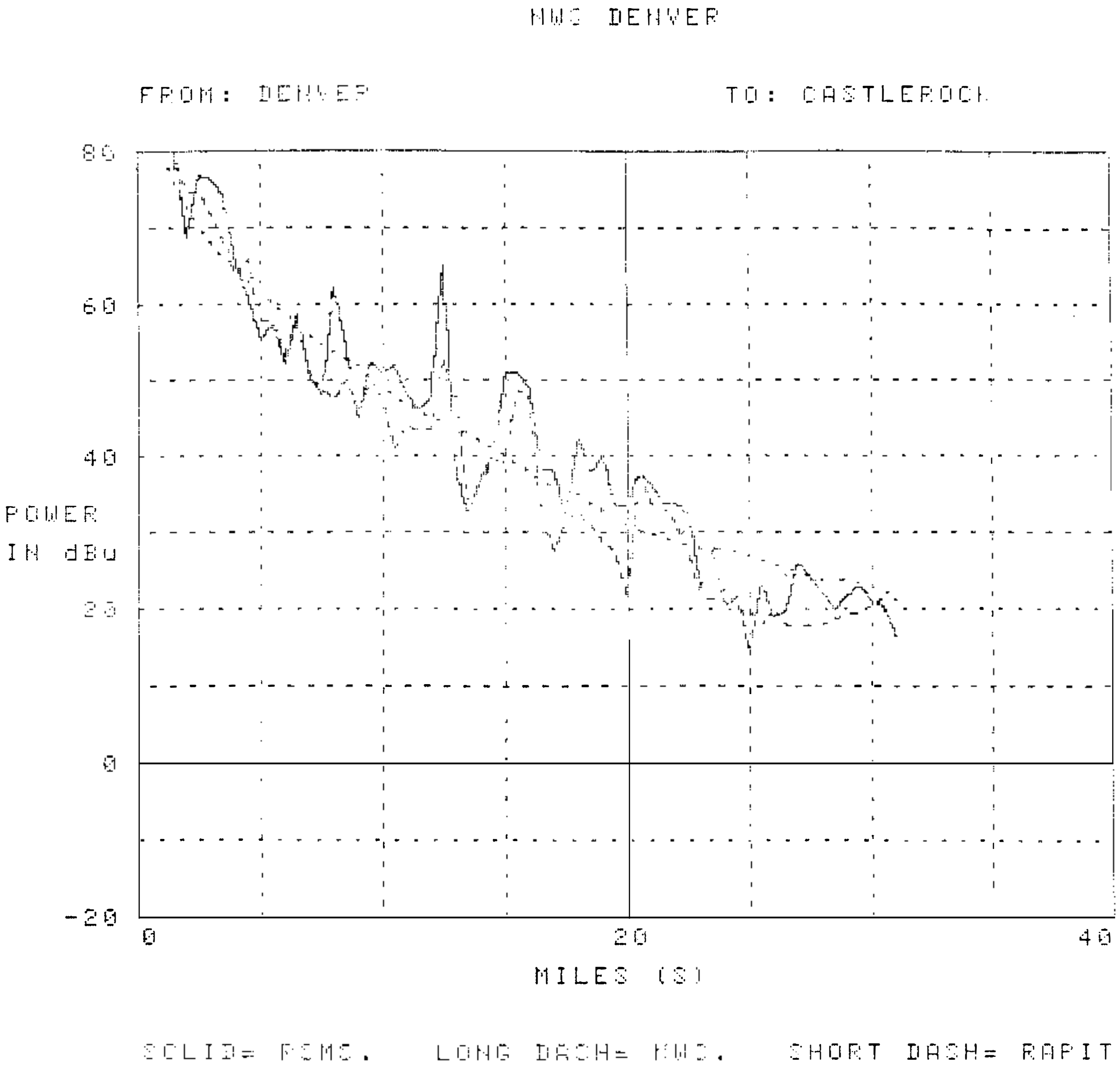


Figure 1-13. Comparison of RSMS and NWS measurements, Denver to Castle Rock.

Average differences in decibels between:

RSMS-NWS = 2.77
RSMS-RAPIT = 0.18
NWS-RAPIT = -2.5

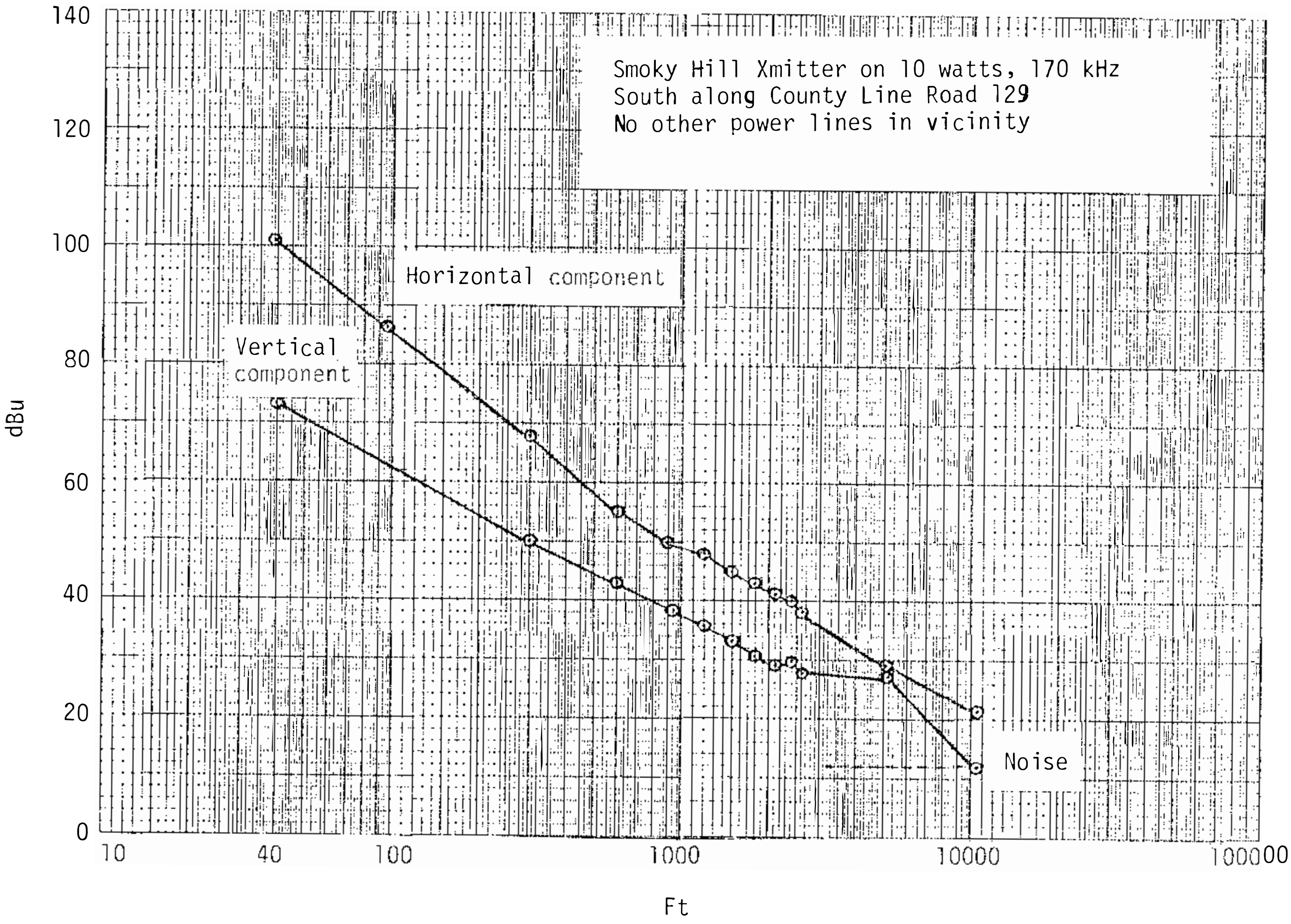


Figure 1-14. Measurements of power-line-carrier radiated signal levels.

be used for data analysis and development of measurement programs. One computer system in the RSMS will operate the "radar" measurement system. A second computer in the RSMS will operate the LMR measurement system. This will allow simultaneous radar and LMR measurements to be made at full speed. In the event of a computer failure in the RSMS, a single computer will be able to handle both measurement systems at a somewhat reduced rate.

Each of the three computer systems will use identical components except that the laboratory disc has a larger capacity. The computers will have 512 K-bytes of memory, a graphics terminal with a built-in thermal printer, a 10 M-byte or a 28 M-byte winchester disc, and a 1600 bpi 0.5 in. magnetic tape unit for data storage and transportation. The computers in the van will also have IEEE-488 bus interfaces for the measurement equipment and ADC and DAC cards to handle analog interfaces to the measurement system. Modems will be available to allow RSMS status to be remotely interrogated and to allow data to be directly transferred between the RSMS and the Boulder computer.

The radar receiver will allow measurements of signals between 10 MHz and 18 GHz with bandwidths between 10 Hz and 30 MHz. It will incorporate a number of features to ensure measurement integrity, including large-signal overload detection and auto-ranging, automatic tracking routines for the YIG preselectors, noise diode calibration, and sensing contacts on many of the rf relays. A block diagram of the radar measurement system is shown in Figure 1-15. Although this receiving system was designed especially for radar signals and incorporates pulse train separation equipment, it will be used to measure most types of signals in the 10-18,000 MHz range. Construction on the radar system is well under way and should be completed by December 1983.

A second system in the RSMS has been designed specifically to make measurements on land mobile radio (LMR) signals. The LMR receiver (Fig. 1-16) has been designed to have the special characteristics needed for efficient and accurate LMR measurements, including extreme dynamic range (as much as 140 dB without input attenuators), 250 channels/s measurement speed, very low noise sidebands, and rectangular IF filters with bandwidths of 3 kHz, 7.5 kHz, 15 kHz, and 30 kHz. Figure 1-17 shows the finished LMR receiver system. The measurement software that will be developed for this system will enable it to interleave measurements of several LMR bands as well as to change bandwidths on a channel-by-channel basis, as required.

Another measurement system developed by ITS is the AN/MSR-T4 Multiple Receiver System. The AN/MSR-T4 is a mobile, fully automatic, multiple receiver system that is to be employed by the Air Force for autonomous and/or integrated operation with ground-based radar emitters that simulate various threat signals to produce a realistic rf environment during the conduct of electronic warfare (EW) operational test, training, and evaluation (OTT&E) of equipment and aircrews at EW ranges. The primary function of the AN/MSR-T4 is to acquire, analyze, and output key operational parameters/characteristics of the radar threat(s) radiated emission profiles during EW tests and exercises. The output data are then used to (1) assess operational tests of new and improved ECM systems and techniques, (2) provide a measure of aircrew proficiency in tactics and the employment of available ECM assets, and (3) evaluate functional operational readiness of SAC and TAC aircraft.

The design of the AN/MSR-T4 is based on a prototype model developed by the Institute which, after extensive field tests, served as the basis for the production decision by the Air Force Systems Command to equip all of its worldwide EW ranges with similar models. Production was initiated in 1980 and ITS was tasked by the Air Force to provide technical support during the procurement cycle that extends over a 30-month period. The effort of ITS has been primarily technical guidance to Air Force procurement officers and engineers to ensure that hardware/software design approaches and operational strategies by the AN/MSR-T4 contractor are in compliance with specification requirements.

The Institute was also tasked to provide a Factory Acceptance Test Plan, Method, and Procedure that will be conducted by the Government to evaluate operational compliance with production requirements prior to field operational acceptance tests. This factory test is scheduled in November 1983 with completion of the first of eight production units. To conduct these tests, ITS has designed and fabricated a "laboratory type" threat/ECM simulator. This unit produces representative and realistic emission profiles of the more complex signals that will be encountered in a real-world EW environment. The simulator has an automatic time programmer that calls up different threats and ECM responses as often as once per second or any other longer period up to eight minutes. The threat/ECM parameters of pulse width, pulse repetition interval, modulations, depth of modulation, etc., and their time/frequency varying characteristics are programmed into EPROM's. The outputs are read into controlling and generating circuitry on a pulse-by-pulse basis as often as necessary to ensure the integrity of the function being generated. Special control circuitry is provided to selectively and randomly produce in the ECM signals, discontinuities, dropouts, and distortions within the generated waveforms. These intentional distortions are produced to simulate known real-world occurrences caused by propagation anomalies, multipath, clutter, and equipment under test momentary malfunctions. The waveform outputs are then fed to PIN diode modulators for modulating energy from external rf signal sources to complete the threat/ECM generation and produce the simulated signals for injection into the AN/MSR-T4 item(s) under test. The test procedure involves the simulation of threat signals and ECM signal responses that occur in a sequence of events postulating a real-world EW environment.

Other technical support efforts by ITS for the AN/MSR-T4 procurement have included (1) the derivation of data bases for radar threat emitters based on current intelligence sources

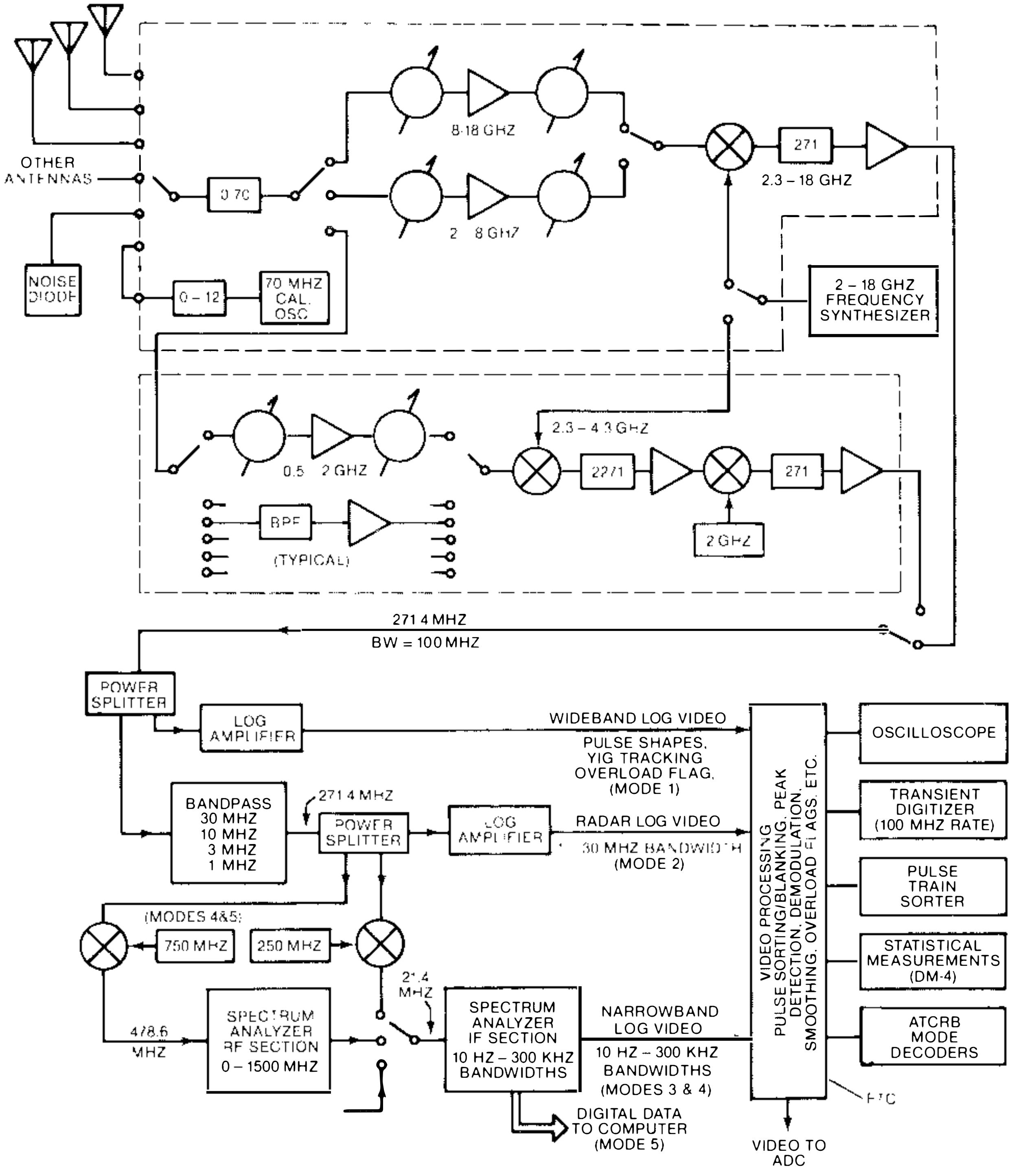


Figure 1-15. Block diagram of new RSMS radar measurement system.

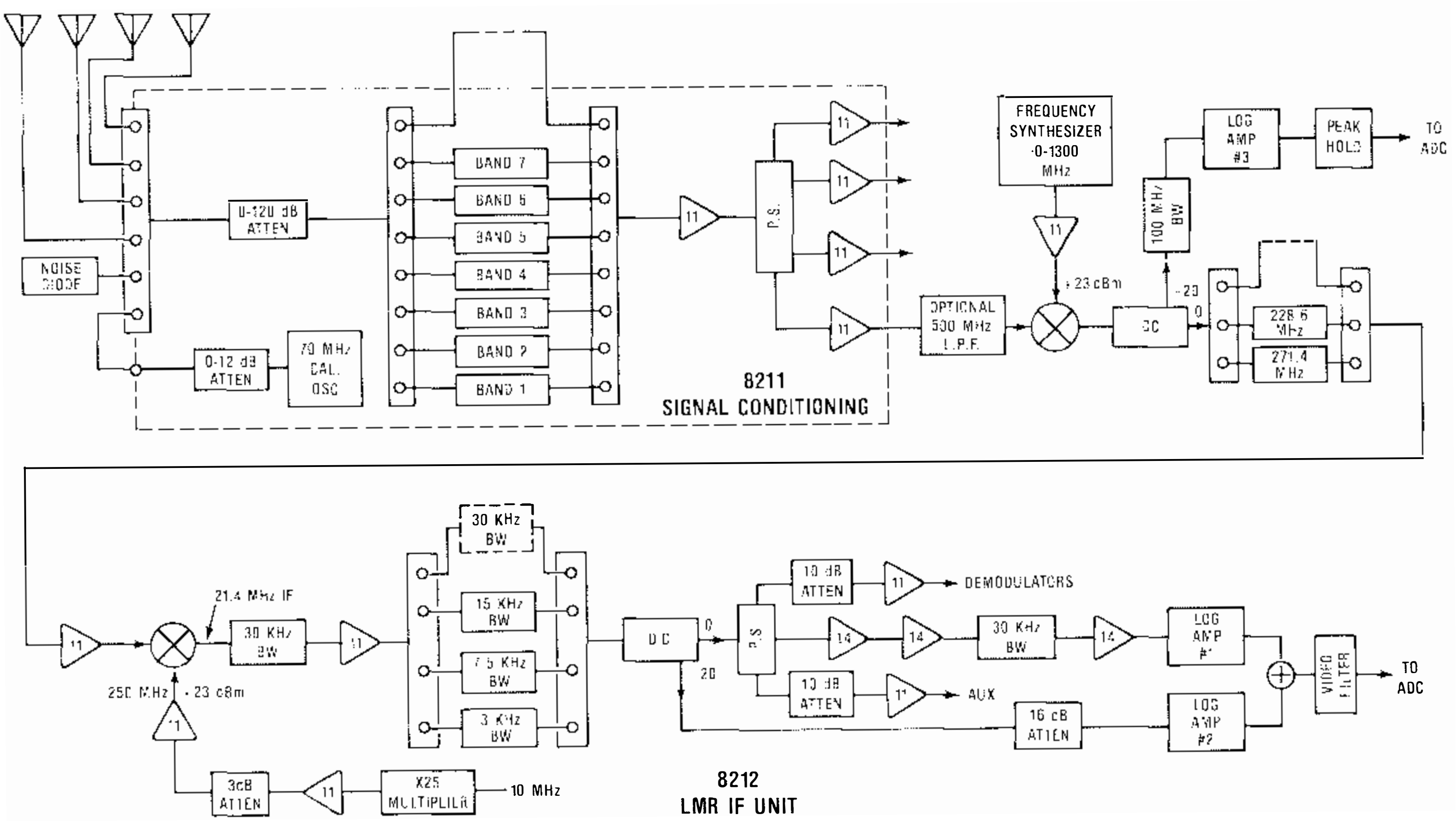


Figure 1-16. Block diagram of new RSMS LMR measurement system.

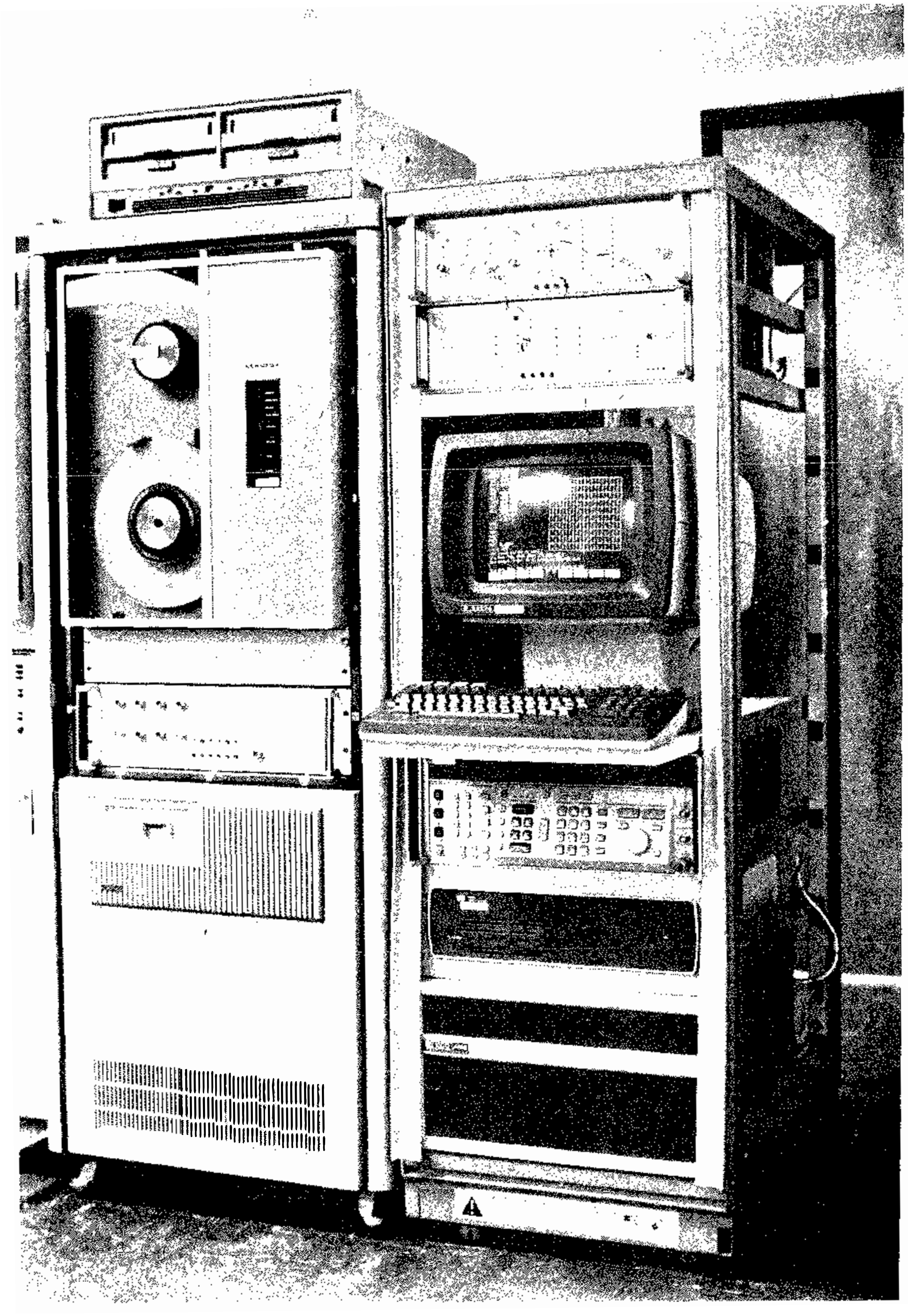


Figure 1-17. RSMS LMR measurement equipment.

and ECM performance requirements and capabilities based on current Air Force equipment and (2) a comparative analysis of the operational performance of a multiple threat emitter system currently in production/procurement versus recent intelligence estimates of actual performance. The results of these efforts are reported in classified NTIA Technical Memoranda NTIA-TM-81-58C entitled "Information and Data Base for Threat/ECM Operational Performance Evaluation During Deployment of the AN/MSR-( ), Volume I REVISED, Airborne ECM Systems--Signal Descriptions and Operational Tolerances," "Volume II: Groundbased Threat Radar Systems--Signal Descriptions and Operational SIMVAL Requirements," and NTIA Technical Memorandum NTIA-TM-82-74C entitled "Comparative Analysis of the AN/MSR-T1A Multiple Threat Emitter System Performance with the EWIR Data Base."

The data bases of radar threat emitter system operational capabilities and airborne ECM system operational capabilities are to be used as resident library files in the AN/MSR-T4 for comparison with operational measurements of actual performance during the conduct of insitu EW tests and exercises at the various Air Force ranges. The comparative analysis is then used to evaluate operational readiness of SAC and TAC aircraft, assess aircrew operational proficiency, and evaluate operational tests of new or improved ECM systems.

The Air Force also requested and ITS provided a series of EW training scenarios that would be representative of those employed by SAC and TAC forces. This was provided in an NTIA Technical Memorandum entitled "SAC/TAC Operational Scenarios for Employment of the AN/MSR-T4," dated June 1983. The report details various scenario time-line-of-events describing ground-based threat radar activity as various SAC/TAC aircraft equipped with various ECM systems perform EW mission support functions.

System Measures of Performance for the EP-3 Aircraft Sensor Update. The Institute's participation in the EP-3 Aircraft Sensor Update was to assist in the evaluation methodology for the associated ELINT and COMINT systems for the Commander, Operational Test and Evaluation Force, U.S. Navy. The Institute developed measures of performance for the automated portion of the two systems. A general review of each subsystem was conducted. The functional operation of each important segment of the system was evaluated to determine its basic contribution to the system performance and related role in meeting mission objectives.

The objective of the ELINT and COMINT systems is to provide fleet support in terms of intercepting and exploiting information obtained from monitoring the electromagnetic signals present in the aircraft environment. Each of the planned missions was reviewed to determine individual functional requirements. This was done to make certain that the proposed testing program for Combat Effectiveness Measures (CEM) and Measures of Effectiveness (MOE) would represent currently-planned mission requirements. The basic functions of signal detection, signal location, signal classification, threat assessment, and platform identification were reviewed for each planned mission for the ELINT system. The COMINT functions consisted of signal detection, signal location, and signal classification. The evaluation of each of these major functions must be accomplished during the test and evaluation program.

Given the functional requirements and specifications for the system, it is then necessary to provide the methodology for performing the measurements required to meet specified levels of confidence. This, of course, leads to statistical considerations. The estimation of the CEMs is reduced to the standard statistical problem of estimating the probability of success (or failure) in a sequence of repeated independent Bernoulli trials (sometimes simply referred to as "coin flips"). The establishment of CEMs was based on probability of detection, probability of classification, probability of determining location, probability of platform identification, and probability of determining imminent threat to the aircraft. CEMs for these specified signal sets were given exactly the same way as for any signal set, but with much higher level of importance for aircraft survival. Joint probabilities were also investigated to establish composite system performance requirements.

A proposed test evaluation program was developed. The purpose of this test program was to determine the effectiveness and suitability of the ELINT and COMINT systems in an operational environment that replicates a realistic environment when the system is operationally deployed. The data collected during these recommended tests will serve to evaluate the operational effectiveness of the ELINT/COMINT systems.

Another system, the Mobile Test and Exercise System-Radar (MOTES-R) (Figure 1-18 was developed by ITS for the Air Force as a pre-production prototype in the MSR-T1 program. It is a receiver system capable of analyzing electronic signals from airborne and ground-based radar transmitters. Upon completion of its task as a breadboard development system, it was transferred to the Electronic Warfare Center at Kelly Air Force Base, Texas. Since then it has participated in EW training exercises at Radar Bomb Scoring (RBS) sites throughout the contiguous 48 states.

The purpose of the MOTES-R Upgrade project is to incorporate state-of-the-art techniques for control by the central computer of many of the peripheral subsystems in the MOTES-R. Included in this upgrade are devices for controlling the various video, timing, and tracking data that are sent to the MOTES-R from RBS site equipment with which it is co-located, as well as controlling directional antennas.

The present mode of access and control to these peripherals is by way of a central microprocessor system employing individual parallel interface techniques. With such systems the inter-unit cabling is cumbersome and prone to failure in a system that is constantly being transported cross-country. The interface system for this upgrade is the IEEE 488 interface bus. This method is

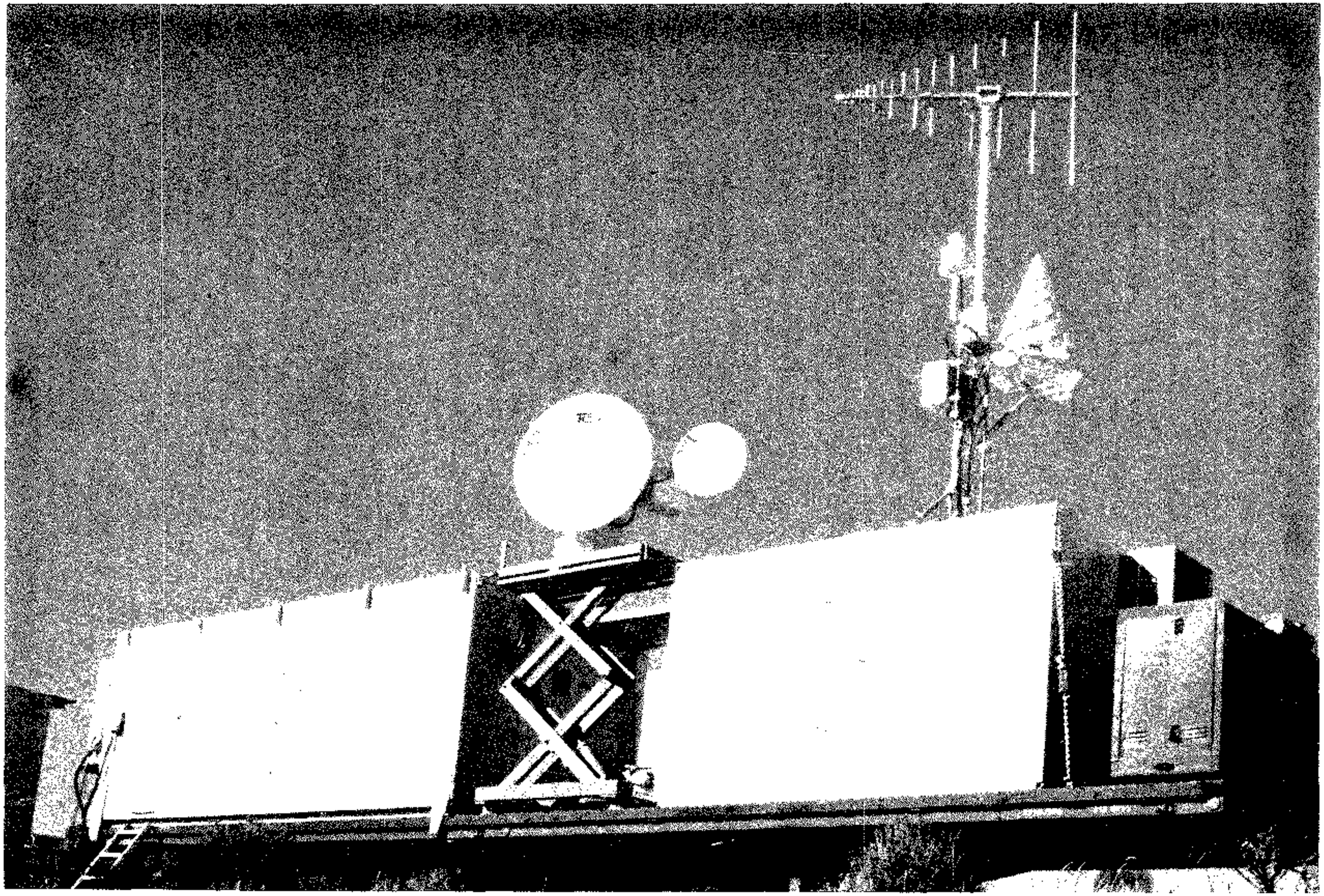


Figure 1-18. Mobile Test and Exercise System-Radar (MOTES-R).

capable of high speed communication between devices using a common set of data lines while at the same time providing reliability, flexibility, and maintainability.

In order to facilitate the serial interface requirements of the various tracking system data formats found at the RBS sites, a special RS-232 to IEEE-488 adapter was developed. Custom firmware allows the central computer operator to configure the interface adapter to accept any synchronous serial data format that might be found at the sites.

This project has been coordinated with an overall upgrade of the central computer in the MOTES-R in order to bring the system up to date in both hardware and software and prevent the system from becoming obsolete and unserviceable.

The Institute also develops specialized instrumentation in support of spectrum studies. The microwave refractometer developed by ITS is an instrument to reliably measure the refractive index of a sample of air. The refractive index of the atmosphere is composed of temperature, pressure, and relative humidity:

$$N = 77.6\ P/T + 3.73 \times 10^5\ e/T^2 \quad ,$$

where

N = refractive index,
P = atmospheric pressure in millibars,
e = partial pressure of water vapor, and
T = temperature in degrees Kelvin.

The refractometer measures the refractive index by tracking the resonant frequency of a microwave cavity. This sampling cavity is open to the air, and the air is aspirated either naturally or artificially through the cavity. Any change in the temperature, pressure, or water vapor pressure in the air will cause a change in the resonant frequency of the sampling cavity. A submultiple of this resonant frequency is recorded as the refractive index, and the rapid changes that occur when the air is aspirated through the cavity is detected as the turbulence within the media.

The refractive index is read out as absolute with 0.1 N resolution in 1 s samples and is available in digital form and analog form to be used with a chart recorder for monitoring.

The application of the microwave refractometer is to collect real-time refractive index data in a specific region or a particular path.

The radio refractive index is central to all theories of radio propagation through the lower atmosphere. The atmosphere causes a curvature of horizontally-launched radio waves, and the curvature of a radio wave is proportional to the gradient of the refractive index. The gradients of the refractive index are caused by temperature inversions, cold and warm weather fronts, and thermal effects over varying terrain.

The refractometer can be mounted at a fixed site to monitor a particular location or it can be mounted on an airplane. The airborne refractometer is the most useful in collecting real-time data over a large area because:

- The aircraft can be flown in vertical spirals to obtain refractive index vs. altitude at any point along a path of interest.
- The aircraft can be flown along a given path to determine the refractive index gradients at that particular time.
- The aircraft can be flown along a given path to determine the air turbulence.

The resulting refractive index and altitude data are used with ray-tracing programs to show the bending or trapping of the radio waves along the path, and the turbulence data are used to show the scattering effects and phase distortion of radio waves.

The AFGL Refractometer was developed by ITS in support of their microwave structure constant profile (CN^2) studies. The refractometer was configured to be used at a fixed location or as an airborne unit.

As a fixed site instrument, it can sample up to four sampling cavities. These cavities can be located on a tower at different heights so the refractive index and the turbulence can be studied close to the ground.

As an airborne refractometer it uses only one sampling cavity, and the aircraft can be flown in the areas of interest.

ITS has flown the airborne refractometer in support of many other-agency programs in the past and will assist AFGL in some of their future data collection.

SECTION 1.4 EM WAVE TRANSMISSION

The ground, the atmosphere, and the ionosphere degrade radio waves in varying degrees, depending on circumstances. It is the purpose of the EM Wave Transmission Program to study these effects and provide models to the system designer that will aid in providing more cost-effective and spectrum-efficient designs. The phenomena that cause these detrimental effects on radio systems are, in general, frequency dependent; therefore, specific studies and tests are required for specific frequency ranges and applications.

Some of the phenomena that affect radio signals and are studied in this program are:

- attenuation by atmospheric gases, rain, snow, hail, clouds, or ionization
- scattering by irregularities in the refractive index of the lower atmosphere or ionosphere
- refraction, ducting, and multipath resulting from atmospheric or ionospheric layers
- dispersion resulting from frequency dependent properties of the atmosphere, ionosphere, and earth

- scintillation of amplitude, phase, polarization, and angle of arrival resulting from turbulence and irregular structure in the atmosphere and ionosphere

- reflection, scattering multipath, and lower atmosphere perturbations resulting from terrain and man-made structures.

The effect upon any specific system of the above phenomena is not only frequency dependent, but is also dependent upon the type of service required for the specific application.

One driving force behind the EM Wave Transmission Program is the need for more spectrum space. Therefore, this program provides models, techniques, and information to aid the system designer and frequency manager in their decisions for better spectrum use. These include experimental and theoretical determinations of the properties of the radio wave transmission medium, the development and testing of models and prediction methods that characterize the performance of telecommunication systems, and applications of the knowledge and tools to specific problems besetting frequency managers and spectrum users in various Government agencies.

1.4.1 Properties of the Radio Wave Transmission Medium

Experimental determinations and theoretical estimates of the properties of the transmission medium on the performance of telecommunication systems are reported in this section. Particular emphasis is paid to those effects produced by the lower (<10 km) atmosphere.

In the project devoted toward Experimental Determination of Millimeter Wave System Effects, recent studies by ITS have indicated that if certain easily achieved design criteria are met, practical narrow-bandwidth transmission links would have few problems in climates similar to the climate of the Denver/Boulder, CO, area. Basically this entails providing adequate fade margin for line-of-sight links up to 50 km in length at frequencies up to 100 GHz, excluding the molecular oxygen absorption band around 60 GHz. At 60 GHz, the absorption is about 15 dB/km at sea level and about 12 dB/km at 1500 meters (Boulder's elevation), which restricts path lengths to no more than 3 to 4 km. However, this offers advantages such as operation of a system without the possibility of reception or detection at greater distances (covertness) and frequency reuse without mutual interference. The oxygen absorption band acts much like a band reject filter, yet bandwidths of several hundred megahertz are available without appreciable distortion in either amplitude or phase for these limited ranges.

Observations near Boulder, CO, over a 3-1/2-year period indicate that with fade margin of 35 dB in the 30 to 50 GHz band and 45 dB in the 70 to 100 GHz band, a 50 km link could maintain up to 5 MHz bandwidth with less than 10 minutes of outage per year from weather-related sources. Rain attenuation was monitored for about 2 years (1980 and 1981) on a 28.8 GHz, 23 km path with a maximum recorded rain attenuation of 26 dB. During this period, the month of May 1981 produced much above average rainfall. In July 1982, rain attenuation of slightly over 30 dB was observed for 5 minutes on a 12 km, 30 GHz path.

Very high rain attenuation is always associated with convective type thunderstorms. Convective storms produce the highest rain rates, in excess of 100 mm/hr within a cell, but seldom does the intense storm cell exceed 5 to 8 km in diameter. Therefore, the highest peak rain attenuation does not generally change significantly whether the path length is 10 km or 50 km. Rains that cover a wider area typically have much lower rain rates and the total attenuation measured during these storms is less even when extended over 50 km.

Attenuation ratios as a function of frequency were taken from data recorded at Boulder over the summer months of 1976 through 1978 for 30 and 60 GHz. Extrapolation of rain attenuation to higher frequencies is possible from these data and theoretical predictions.

No time delay spread distortion produced by forward scattering from raindrops could be detected. The main effect of rain attenuation is a reduction in signal-to-noise ratio of the link.

Next to rain, the most important mechanism observed in terms of fade depths is produced by multipath signal within the atmosphere. An atmospheric multipath occurs when a refractive layer exists at a path height that bends the signal over two routes that differ by a half wavelength. When two signals arrive at the received antenna at almost equal amplitudes, a greatly reduced received signal results from destructive phase interference. A 40 dB fade of this type was observed on a 30 GHz, 23 km link briefly (1 to 2 minutes) during a time near local sunrise. Atmospheric multipath fades of lesser depths were seen on occasion between midnight and one to two hours after local sunrise. Their occurrence might be expected to increase with frequency since the required delay path is less as the wavelength becomes shorter. Even though layers form regularly in the lower atmosphere in the Denver/Boulder area, there is usually motion within the layer of a scale size that reduces the probability of generating only two signals; or if formed, their durations are brief. This small-scale motion may prevent fade occurrence at the high frequencies.

For narrow bandwidth channels there is very little distortion associated with atmospheric multipath because the fade occupies the entire channel without appreciable amplitude dispersion.

Other fade mechanisms, such as refractive defocusing, ground multipath, beam decoupling, and scintillation occurred at various times, but the only effect on a narrowband channel is a small change in the system signal-to-noise ratio. A paper entitled "Height-Gain Studies for 23 km Links at 9.6, 11.4, and 28.8 GHz" by K.C. Allen, et al., published in the IEEE Transactions on Antennas and Propagation, Vol. AP-30, No. 4, July 1982, describes these observations.

Obtaining the required fade margin to reduce outage time to minutes per year is not difficult for a link with a few megahertz of bandwidth. A 2-foot parabolic antenna provides sufficient gain when combined with readily available low-noise receiver front-end mixer/preamplifiers and solid-state transmitter sources.

It should be noted that the climate of Colorado may be representative of a large area within the CONUS, but very humid climates will surely require trade-offs in path length and/or fade margins.

The desirable feature of millimeter waves is the inherent bandwidth capability of 2000 MHz or more. Systems developed in the United States and Japan are already approaching these bandwidths. Problems encountered with very wide bandwidth millimeter wave channels through the atmosphere are much more complex than at narrow bandwidth and require further investigation. To provide a tool for this investigation, a millimeter wave diagnostic probe that can fully describe the propagation characteristics of a wide-band channel has been developed by ITS (NTIA-R-83-128). Emphasis for the application of the probe is on high data rate digital links where the received signal characteristics are complicated by experiencing refraction, reflection, and/or diffraction, as well as attenuation enroute from the transmitter.

The primary instrumentation consists of a 30.3 GHz, 1000 mb/s coherent QPSK or 500 mb/s coherent PSK transmitter-modulator, a 2 GHz bandwidth receiver-demodulator with a 5.5 dB double sideband noise figure, and a baseband processor bit-error-rate (BER) detector. Built into this digital system is the capability of selecting a channel impulse response mode using cross-correlation of pseudo.random binary words that permit a 1/2 nanosecond time resolution in identifying time delay dispersion. A third mode provided by the probe is a spectrum of 2.5 x 10^4 coherent frequency lines for a 1 GHz bandwidth amplitude dispersion monitor. The output of the diagnostic probe describes the transfer function of the channel that can be translated in terms of BER for path lengths up to at least 50 km. At 50 km, the excess signal-to-noise ratio is 20 dB using 3-foot parabolic reflectors, for example, or 32 dB if 6-foot reflectors are used.

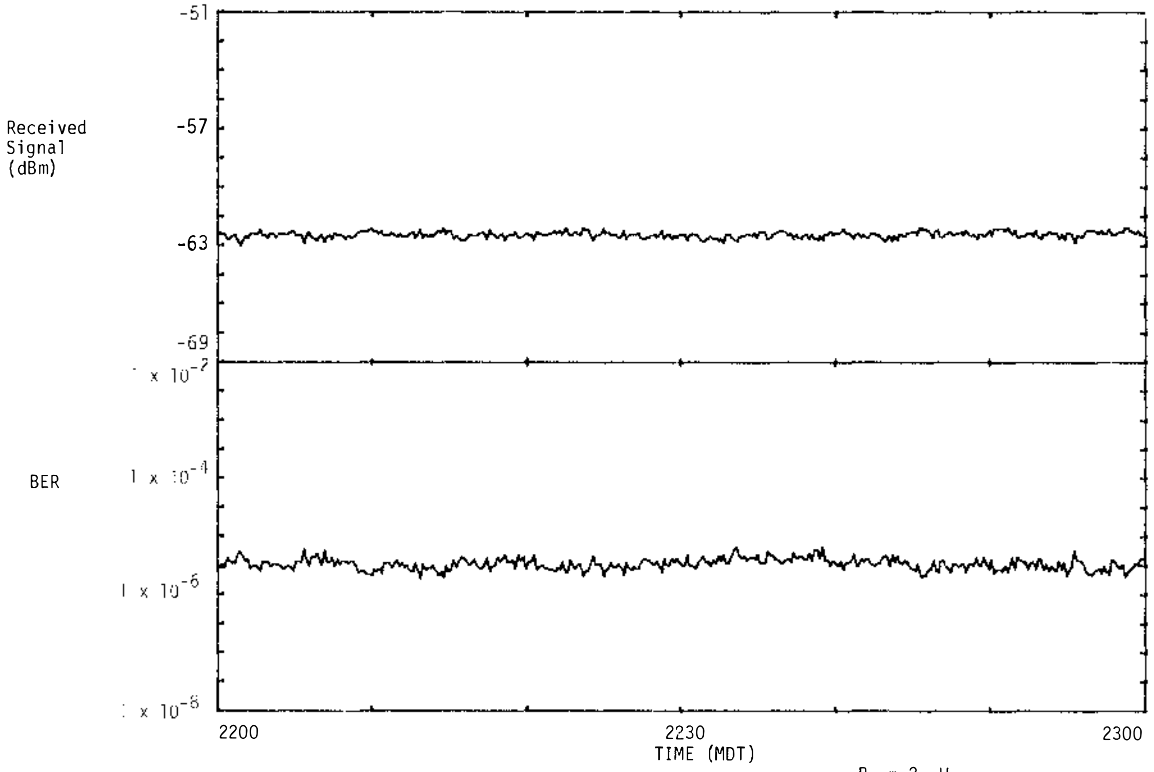
By accompanying the 30.3 GHz wideband probe with a set of narrowband coherent probes at 11.4, 28.8, 57.6, and 96.1 GHz, fades and channel distortion mechanisms can be identified and labelled according to the degree of frequency dependence. This multiple frequency probe will enable the collection of information to verify and judge theoretical propagation models and permit statistical models to be established for prediction of system performance within the 10 to 100 GHz band.

The diagnostic probe was placed on a 12 km test path. Figure 1-19 displays a plot of received signal level and BER for an atmospherically calm period when the effective transmitter power was reduced to 2 microwatts to force a readable BER. Figure 1-20 is the same path except the receiving antenna is pointed down 2 degrees. The effective transmitter power was increased to 20 microwatts to compensate for the signal lost by the antenna pointing error. In this case a multipath signal with 3.4 ns delay appeared in the impulse response of Figure 1-21. Three impulse response measurements were taken at about 30-minute intervals in Figure 1-22 showing the time variability of the multipath signal.

In January 1983, the path length was extended to 27.4 km and the effects of snow, fog, and rain were observed. A heavy, wet, snowstorm (temperatures at or above freezing) produced slightly greater signal attenuations than for a heavy, dry, snowstorm; a maximum of 5 dB in total loss was recorded at 30.3 GHz. Lower frequency channels experienced less loss with a maximum loss ratio of about 2 to 1 for the highest to the lowest frequency. No BER change was noted as a result of time delay scattering during snow. Fog attenuation was somewhat higher than expected being about 5 dB at 30.3 GHz for a maximum suspended water droplet content estimated at .5 gm/m^3, or about 100 meter daytime visibility, which occured over at least 2/3 of the path. Numerous rains permitted observations of relative drop-size distribution for a variety of seasons and storm types. A 96.1 GHz channel was added in August that allowed an estimate of drop size by comparing the attenuation ratios between frequencies. In order to develop rain models, drop-size distribution statistics are needed, and the use of 96.1 GHz has added an indicator of smaller drop-size effects that has not been previously available to verify theoretical distribution curves. Figure 1-23 shows a major rain event that occurred August 21, 1983. The reason signal attenuation and rain rate are not correlated is that the rain rate gauge is located at the receiver terminal. It was observed that the rain extended to both ends of the path but the rate varied along the 27.4 km path. It is obvious that the ratios of attenuation vary between link frequencies, and this feature relates to drop-size distribution during the storms. A scatter plot comparison of the ratio of received signal levels between the 11.4 and 28.8 GHz channels is shown in Figure 1-24. The same comparison is made between 28.8 and 96.1 GHz in Figure 1-25. Data in this form are used to calculate drop-size distribution. The top curve in Figure 1-23 indicates the change in bit error rate for the 30.3 GHz 500 Mb/s channel as a result of rain attenuation.

As the frequency of the channel through the atmosphere increases, the loss due to water vapor also increases. The actual attenuation produced by water vapor has been an uncertainty in models of the atmosphere at millimeter wavelengths. With the on-line computer and the meteorological data collected, it has been possible to precisely measure water vapor absorption, which should allow the model to be considerably improved up to 100 GHz. Water vapor absorption as high as 20 dB was seen on the 27.4 km path. A plot of measured water vapor pressure and total absorption is shown in Figure 1-26.

As part of the Vegetation Millimeter Wave Propagation project, a measurement program was

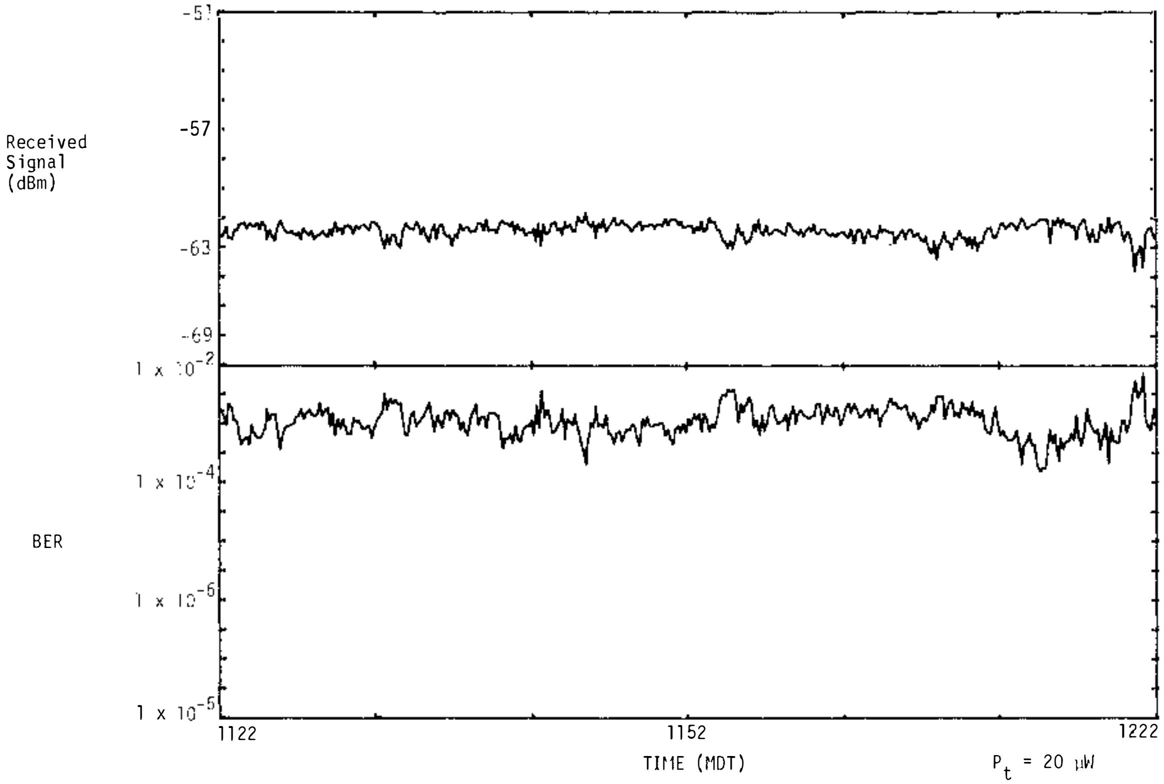


P_t = 2 μW

July 22, 1982

Receiving Antenna = 0°

Figure 1-19. A plot of received signal level and BER for a calm period on the 12 km path with the 30.3 GHz probe.



P_t = 20 μW

July 23, 1982

Receiving Antenna = -2°

Figure 1-20. A plot of received signal level and BER for the 12 km path with multipath signals present.

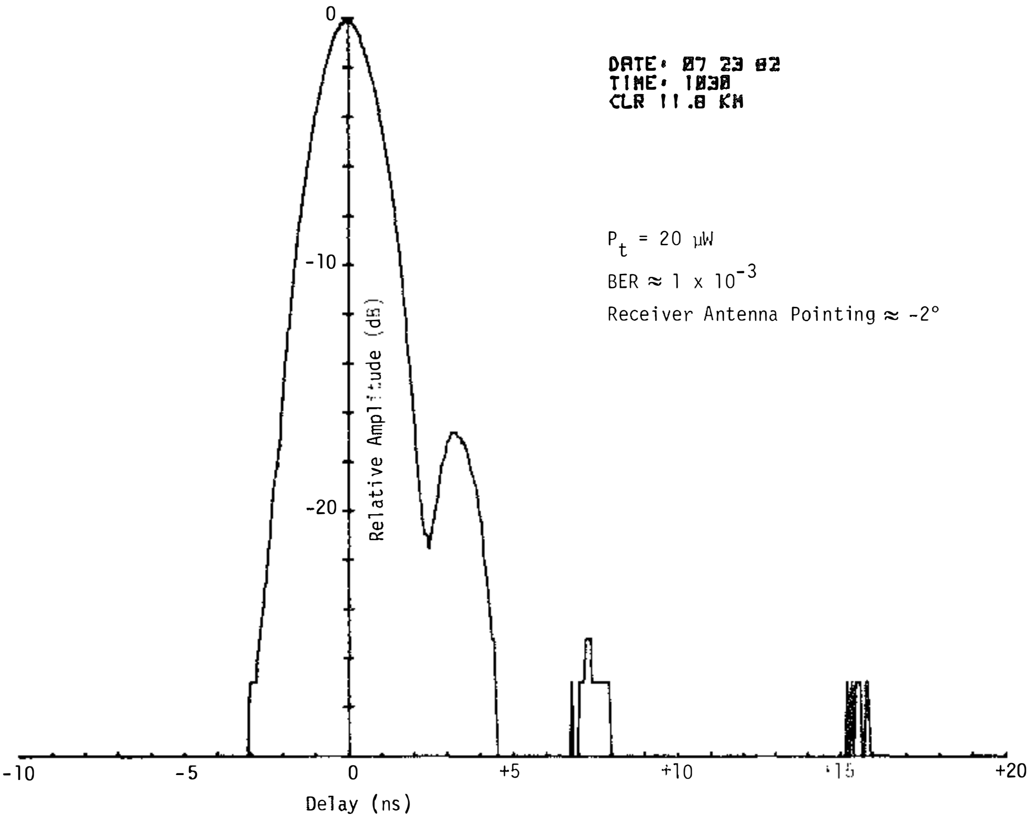


Figure 1-21. An impulse response curve showing the direct signal and a multipath signal delayed 3.4 ns.

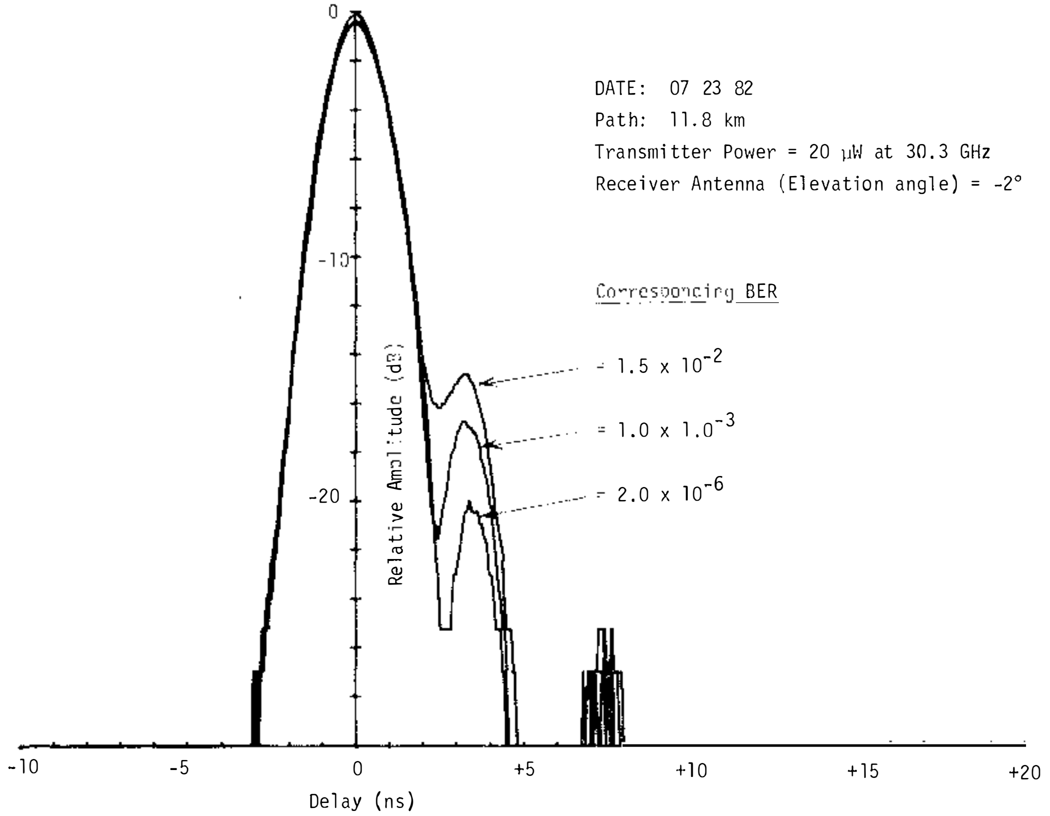


Figure 1-22. Three impulse response curves showing the effect of an atmospherically-induced phase shift between the direct and multipath signals.

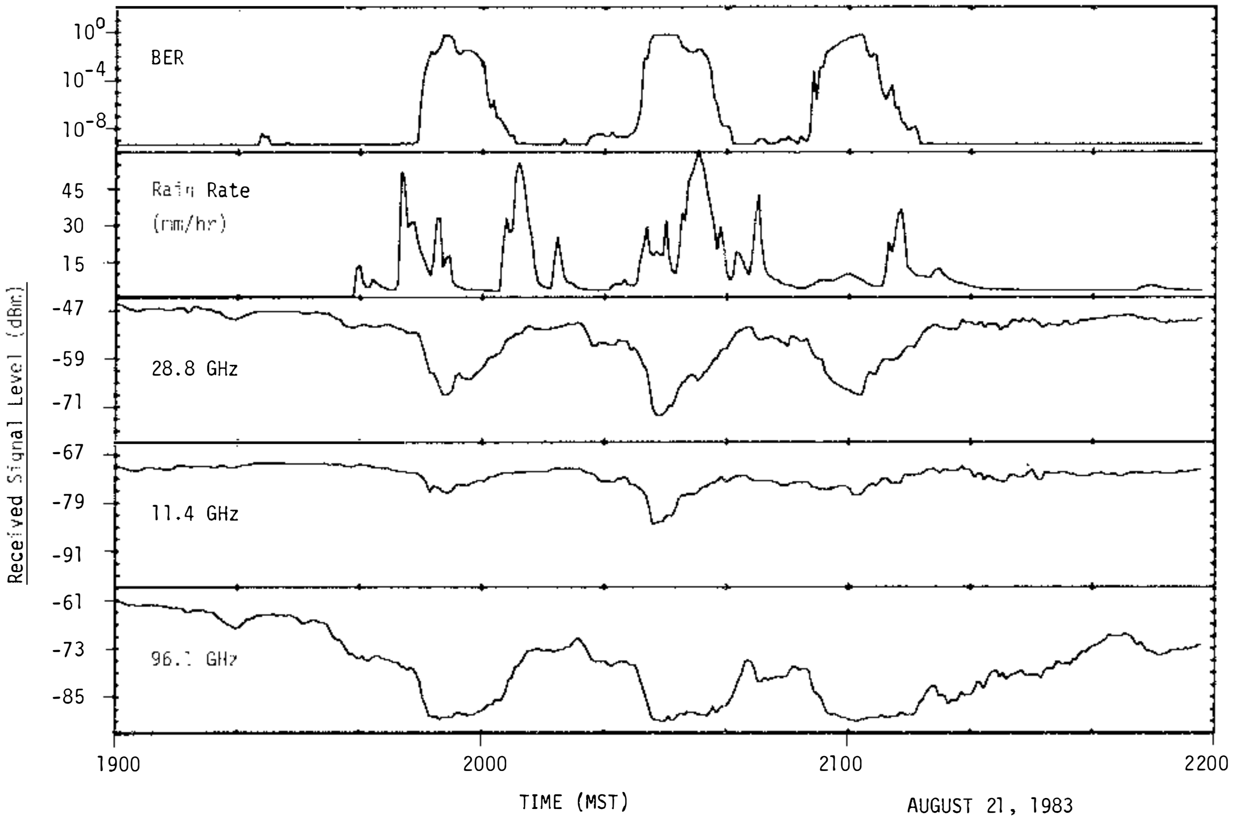


Figure 1-23. A plot of received signal levels, BER, and rain rate recorded on the 27.4 km path during a major rainstorm on August 21, 1983.

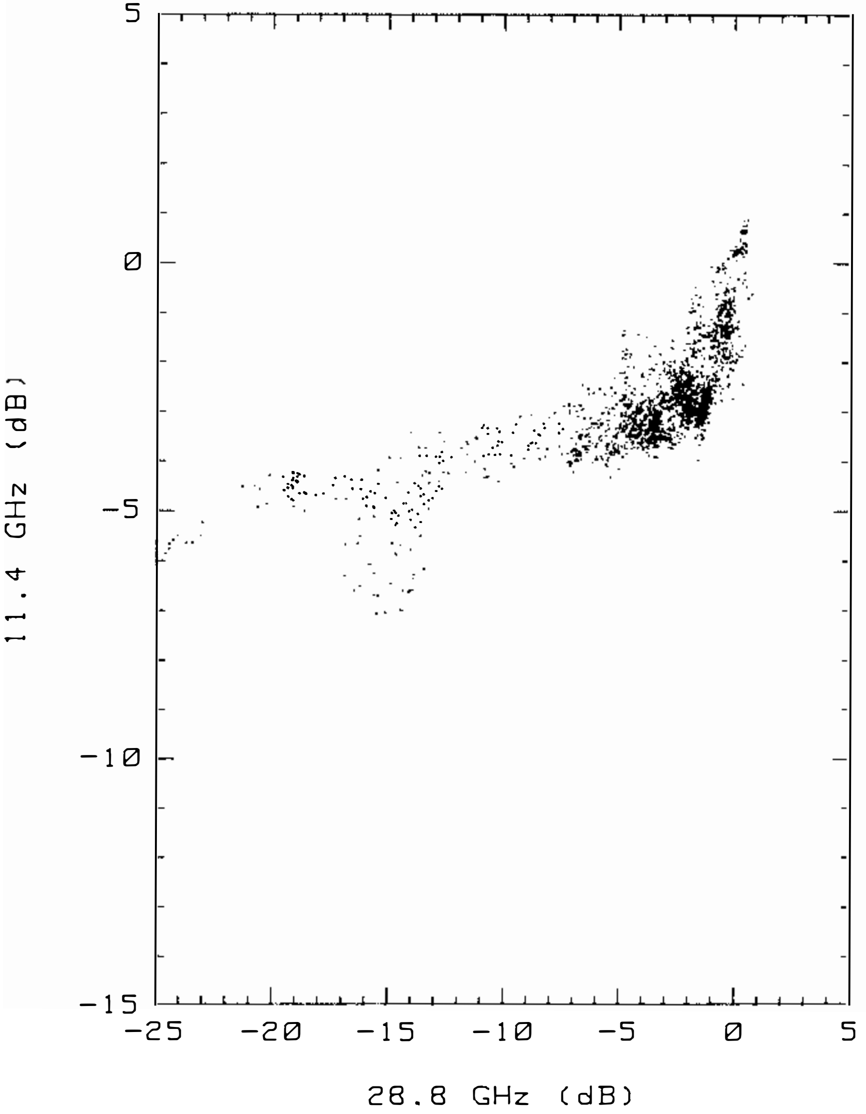


Figure 1-24. A scatter plot comparison of the ratio of received signal levels between the 11.4 and 28.8 GHz channels during rain on the 27.4 km path recorded September 19, 1983.

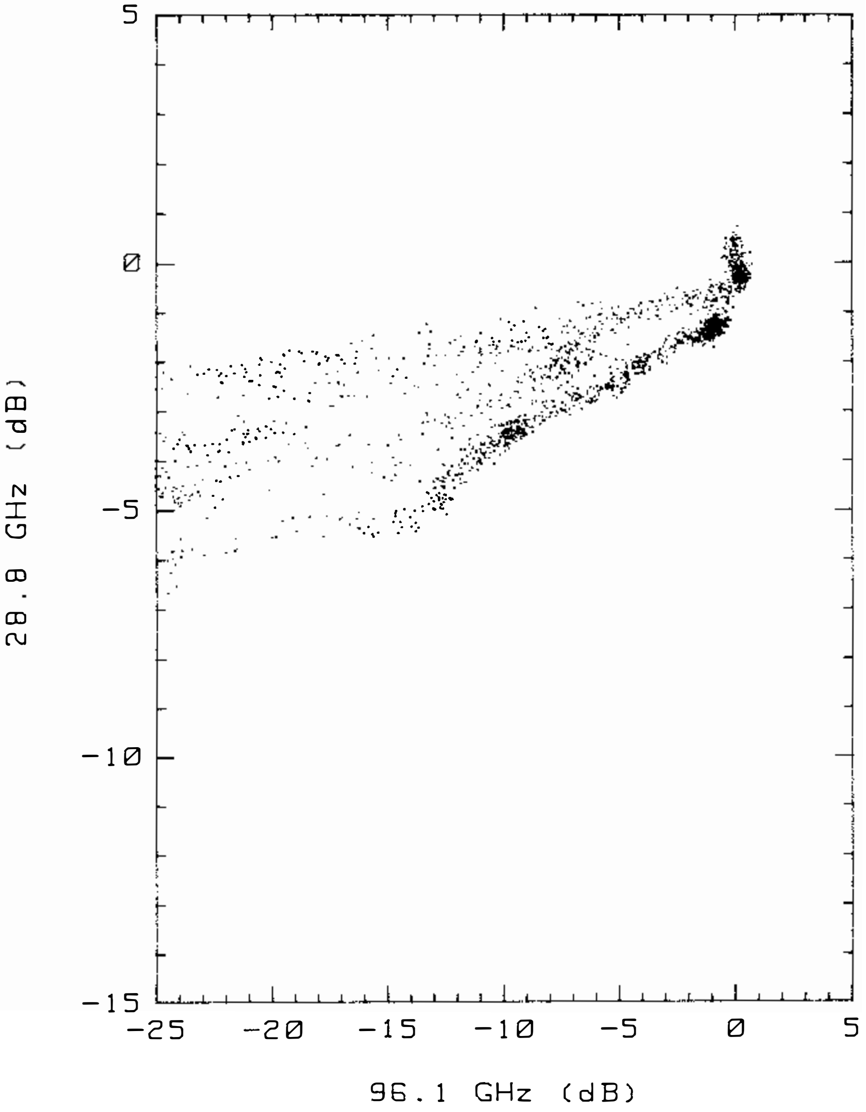


Figure 1-25. A scatter plot comparison of the ratio of received signal levels between the 28.8 and 96.1 GHz channels during rain on the 27.4 km path recorded September 19, 1983.

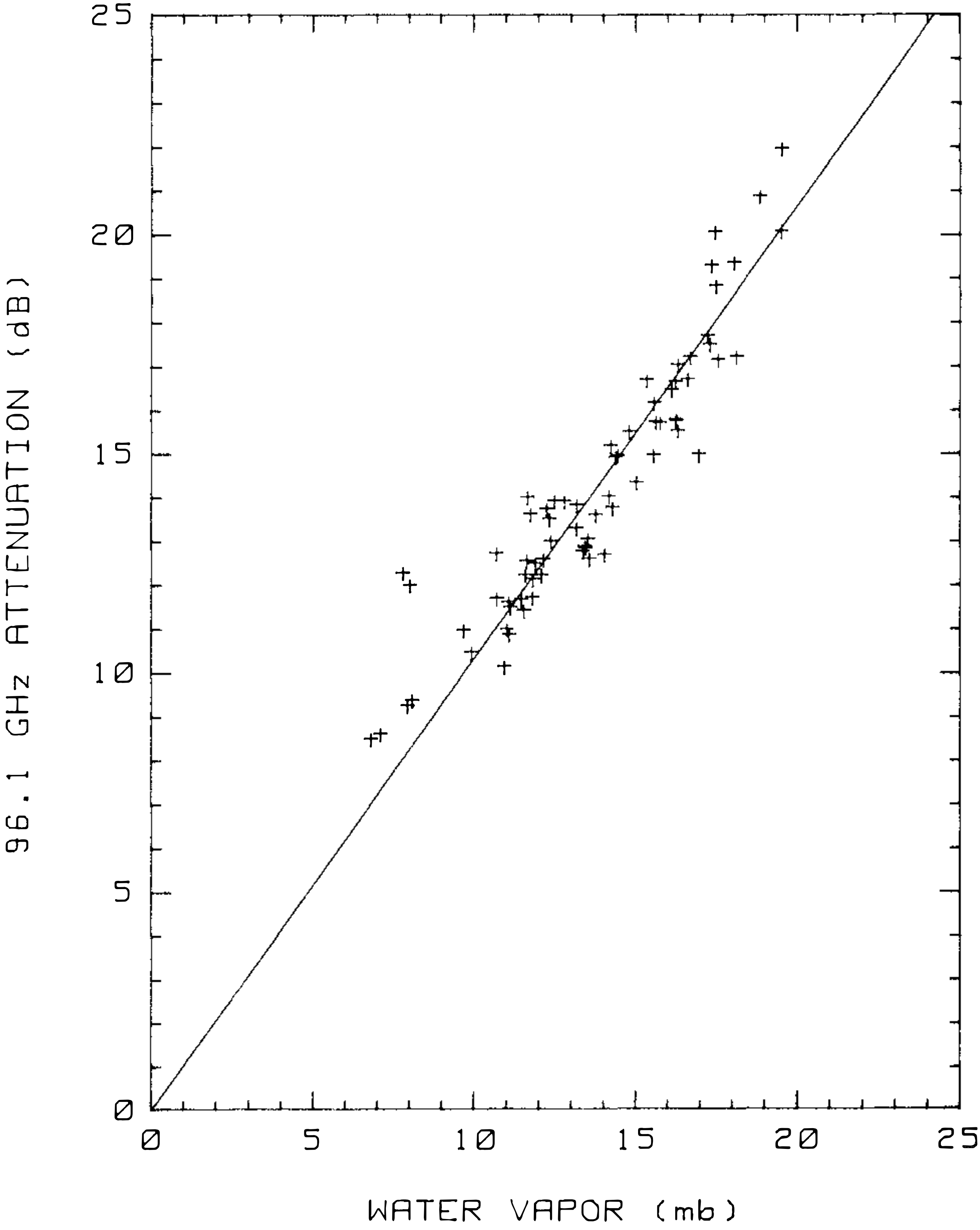


Figure 1-26. A plot of measured water vapor pressure versus total absorption at 96.1 GHz from data recorded on the 27.4 km path.

conducted in FY 81 to determine the effects on millimeter wave signals propagated along paths obscured with deciduous and conifer trees. The objective of the project was to obtain information on signal loss as well as spatial, polarization, and scattering characteristics for propagation through a variety of foliage and atmospheric conditions at 9.6, 28.8, and 57.6 GHz. Results of this work are reported in the U.S. Army Report CECOM-81-CS020-F entitled "SHF-EHF Propagation Through Vegetation on Colorado East Slope." The principal results of the FY 81 work included a measure of signal loss through vegetation as a function of tree depth, height above ground, foliage (leaves and no leaves for deciduous), antenna polarization, vertical and horizontal terminal displacement, and frequency.

In FY 82, the vegetation studies for the U.S. Army continued with emphasis on determining signal properties as a function of foliage depth in order to develop the best theoretical model for predicting link performance. In forested areas, the density of foliage was found to be nonuniform and difficult to describe in terms of depth. To remove the density variable, an evenly planted orchard would best permit a controlled measurement. Because of the tree size, foliage density, and humid climate, a pecan orchard near Wichita Falls, TX, was selected as best suited to the measurement requirements.

The first series of measurements was completed in April 1982 when the trees were in a defoliated state. In August, a second measurement series was conducted that repeated the April measurements to determine the added losses and propagation differences that occurred with leaves present. The results of these measurements are contained in U.S. Army Report CECOM-83-2 entitled "Vegetation Loss Measurements at 9.6, 28.8 and 57.6 GHz Through a Pecan Orchard in Texas." Figure 1-27 shows the vegetation loss per tree in decibels relative to the number of trees (no leaves and with leaves) on the path as a function of frequency at a 4-meter height above ground. Note that the path length increased in proportion to the number of trees, but free-space losses were normalized so that only vegetation losses are plotted. For these measurements, all paths were established by positioning the terminals (transmitter and receiver) directly in line with the center of the trunk or trunks at the 1-meter height.

The most significant finding is the rapid roll-off of loss per tree as the number of trees in the path increased. An abrupt break in the plot of vegetation loss versus number of trees can be seen in Figure 1-27. In the no leaves case, the break occurs after the 8-tree point. For the measurement with trees in leaf, the break in the curve is very pronounced after three trees. It is assumed that this break occurs when the dominant propagation mode changes from absorptive (direct signal) to diffractive. With no leaves, the small twigs and branches allow transmission through the material; but when their density becomes sufficiently great, multiple diffraction from the large number of scattering objects defines a lower loss propagation mechanism. With leaves there is a much higher attenuation per unit volume so that the transition takes place with fewer trees in the path and at a much greater loss.

Figures 1-28, 1-29, and 1-30 show a plot of vegetation loss versus foliage depth at 9.6, 28.8, and 57.6 respectively, at 4 and 6 meter heights. The average foliage depth at the 4 meters height was 9 meters, and at the 6 meters height, it was 11 meters. Curves showing predicted values from a modified exponential decay model are plotted in each figure. Because of the disagreement of measured data versus this model, a transport theory prediction method, which takes into account the scattering component, is being tested. For the transport theory predictions, the higher attenuation at short ranges are considered primarily coherent components, but at greater depths, only incoherent scattering components remain.

Because of the unusual propagation mode that occurred when diffraction scattering appeared to become dominant, directional properties of the arriving signals are most interesting. A series of receiving antenna azimuthal scans (beamwidths 4° at 9.6 and 1° at 28.8 and 57.6 GHz) are presented for all three frequencies at 6-meter terminal heights, for depths of 1, 3, 8, and 11 trees with leaves present, as shown in Figure 1-31. An unobstructed reference scan is superimposed on each data scan. These scans show a rapid loss of signal directivity, with increasing tree depth. This suggests that, after only three trees, the energy is scattered nearly equally from all the trees within the 30° scan.

Several sets of data were recorded to measure the received signal level with the transmitter moving along the perimeter of the orchard with the receiver at various locations in the orchard. One of these runs is shown in Figure 1-32 where the receiver was located at a depth of 720 meters into the orchard and midway between two rows of trees. As the transmitter transversed a 200 meter path approximately perpendicular to a line between terminals, the signal traces shown in Figure 1-32 were recorded. The highest received levels for each frequency occurred in the line-of-sight portion of the scan where greater than first Fresnel Zone clearance existed. These amplitudes are slightly less than the free-space value (0 dB) by 1 to 2 dB, but this reduced and fluctuating level is attributed to surface multipath and/or slight antenna misalignment. During these runs, the receiver antenna positioner was manually controlled, accounting for a possible pointing error and the mobile transmitter van could not perfectly maintain a constant radius arc because of terrain restrictions. Of interest are the general high signal levels when the path was non-line-of-sight considering the distance and number of trunks obstructing the path.

In the Urban Millimeter Wave Propagation project, measurements of millimeter wave propagation in urban areas have been made. The objective of the program has been to study millimeter wave propagation characteristics in a city environment with principal emphasis on the evaluation of communications link

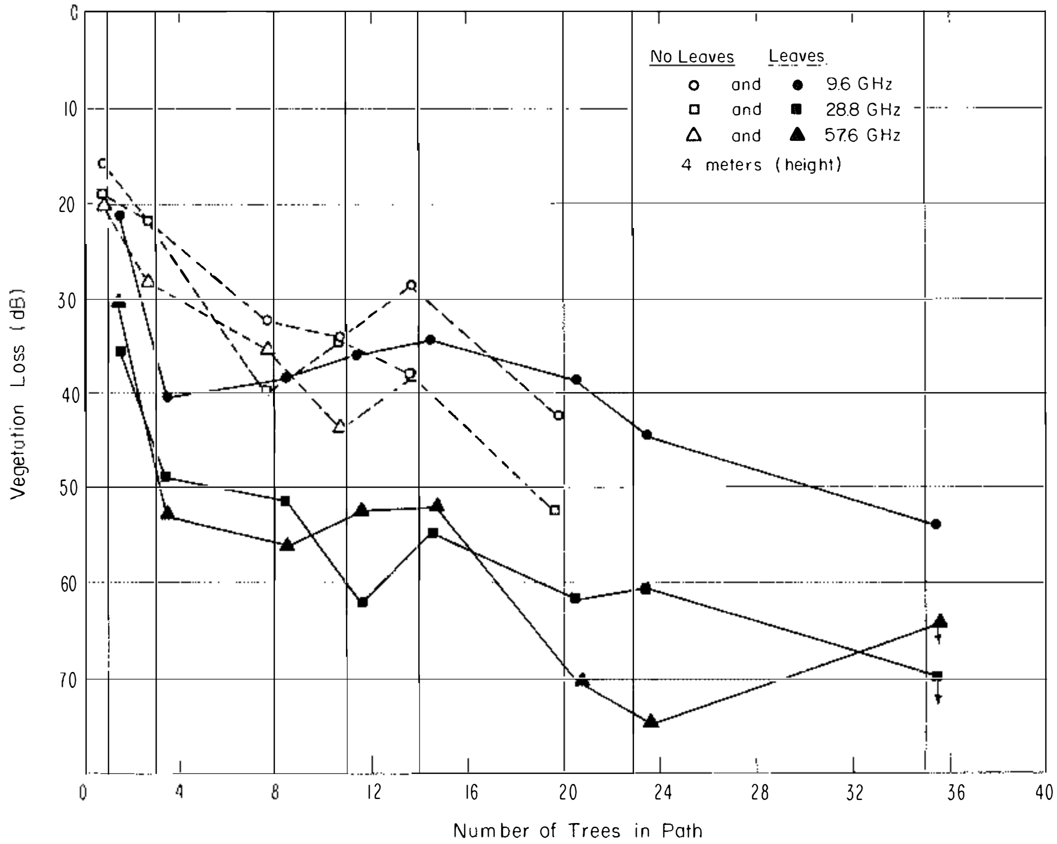


Figure 1-27. Average values of vegetation loss as a function of the number of trees in path for 9.6, 28.8, and 57.6 GHz at a 4 m height.

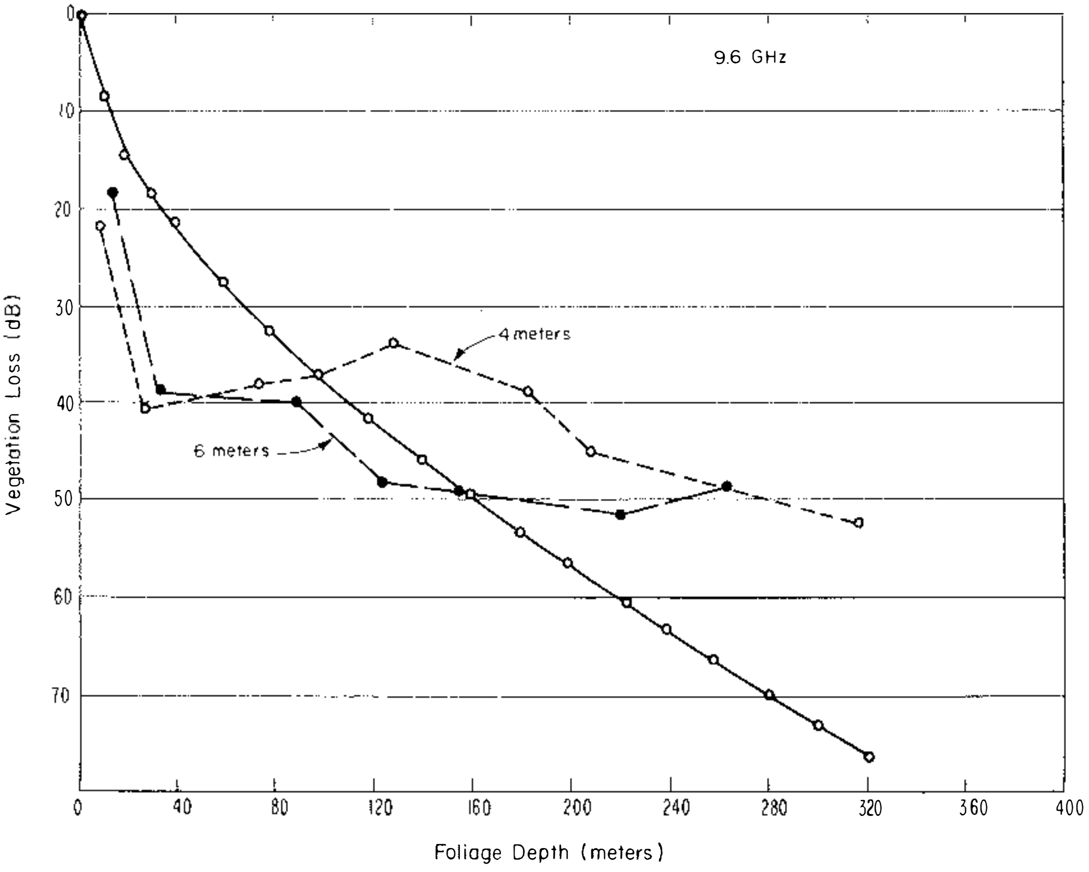


Figure 1-28. A plot of vegetation loss versus foliage depth at 9.6 GHz for heights of 4 and 6 m. The solid line curve shows values from an exponential decay model.

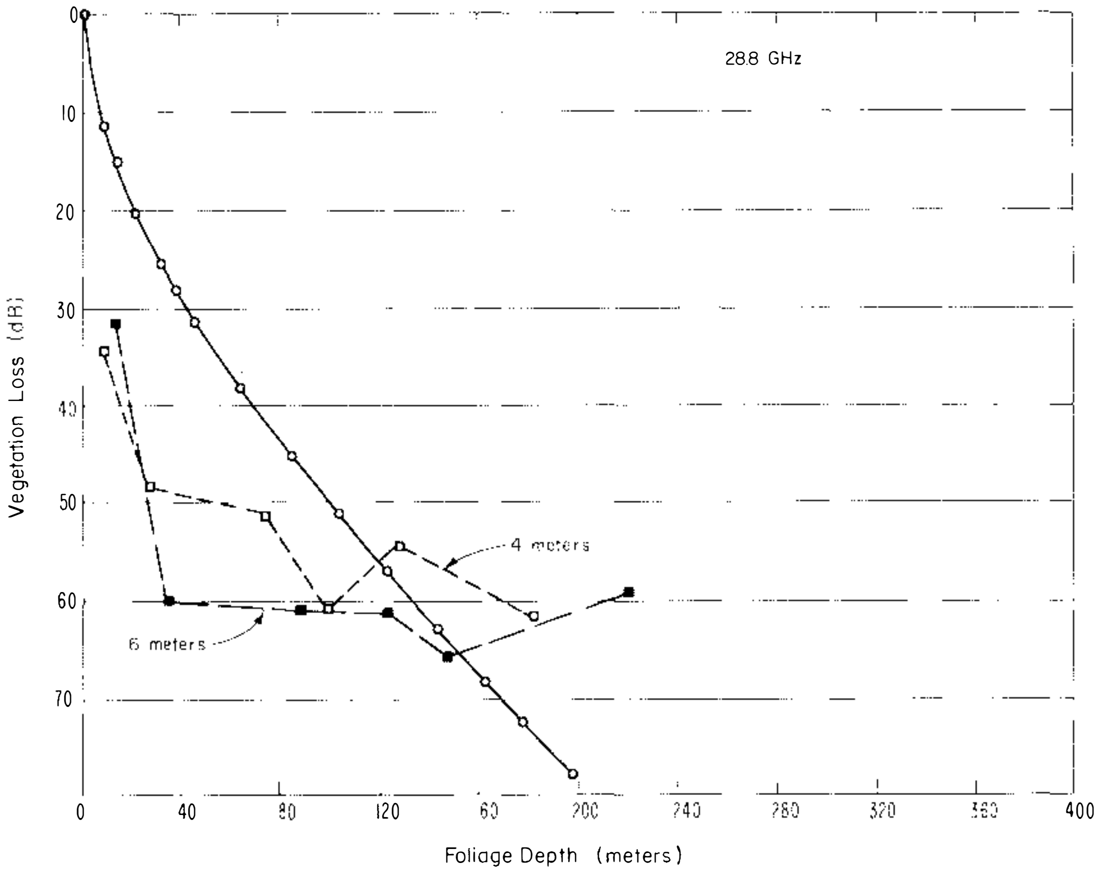


Figure 1-29. A plot of vegetation loss versus foliage depth at 28.8 GHz for heights of 4 and 6 m. The solid line curve shows values from an exponential decay model.

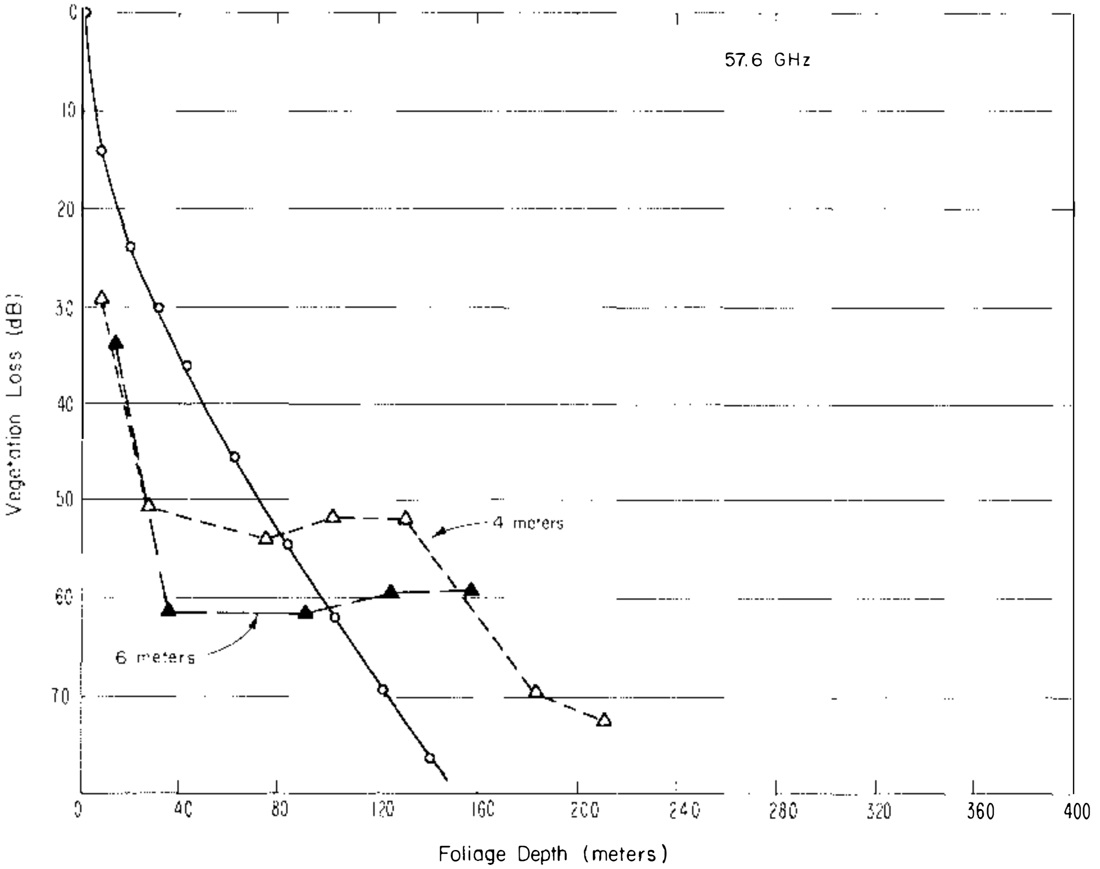


Figure 1-30. A plot of vegetation loss versus foliage depth at 57.6 GHz for heights of 4 and 6 m. The solid line curve shows values from an exponential decay model.

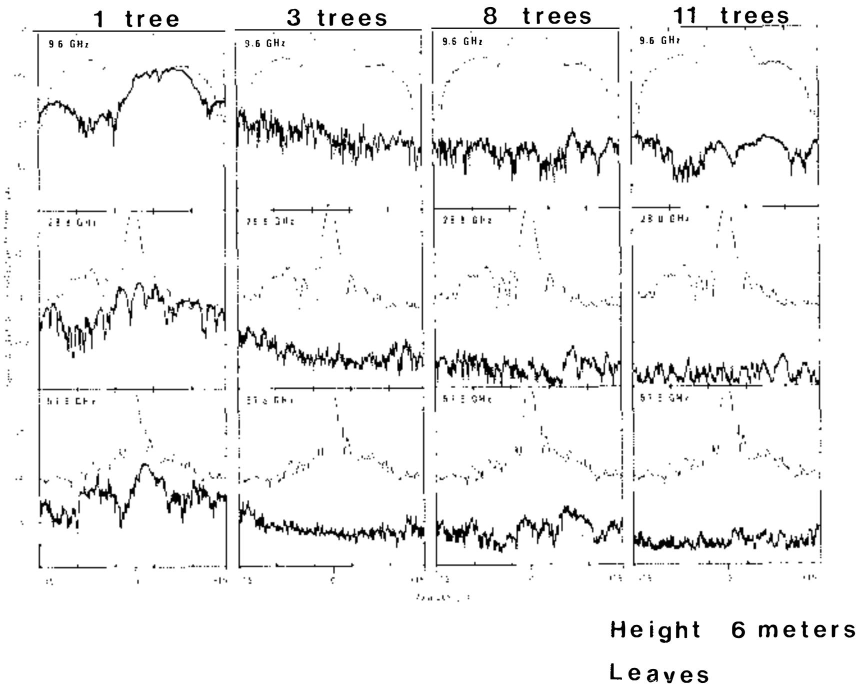


Figure 1-31. A series of receiver antenna azimuthal scans at 9.6, 28.8, and 57.6 GHz of trees in leaf at a 6 m height for 1, 3, 8, and 11 trees in path.

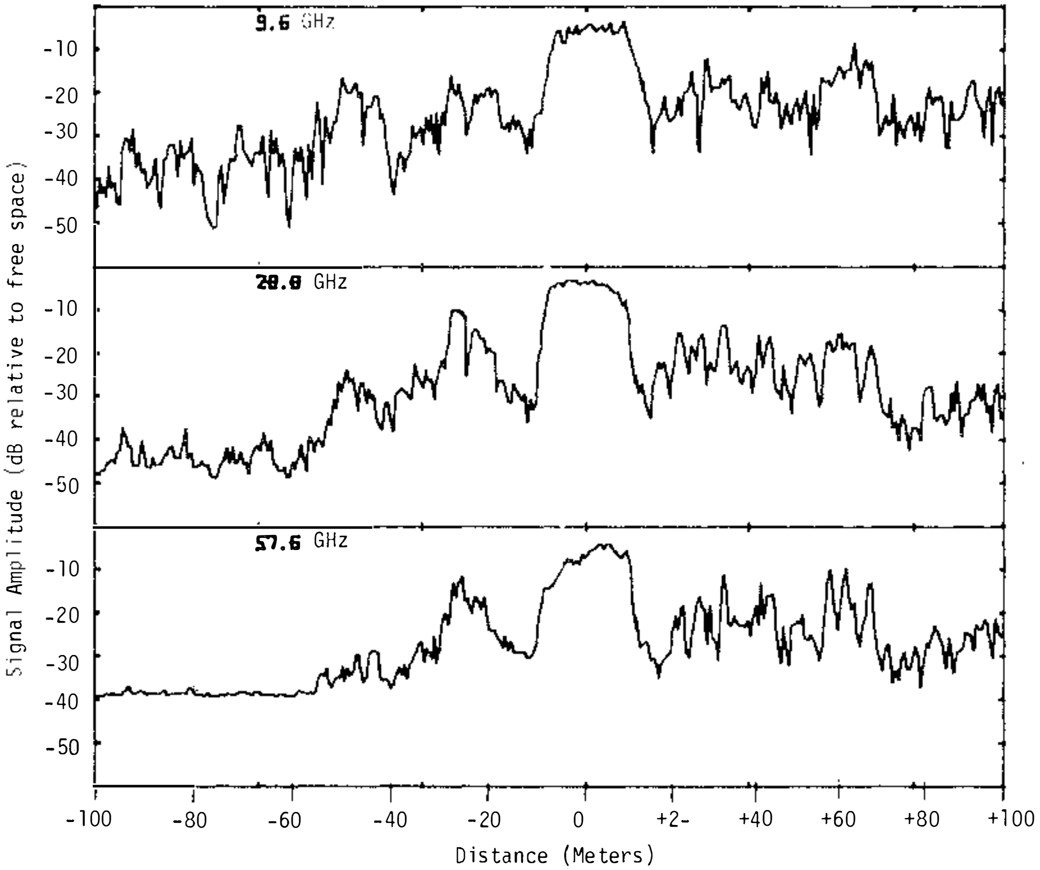


Figure 1-32. Received signal amplitudes for 9.6, 28.8, and 57.6 GHz, with the transmitter moving along an arc at the edge of the orchard and the receiver at a location 720 m into the orchard.

reliability, detectability, and usable bandwidth as a function of position of terminals.

Backscatter and oblique reflection measurements were performed on building surfaces of concrete aggregate, painted smooth concrete with protruding ribs, brick, and metal siding. Frequencies 9.6, 28.8, and 57.6 GHz were used to compare reflection coefficients for these surfaces with widely different conductivity and roughness. Data were recorded to determine aspect sensitivity of the reflected signal in a backscatter mode. To obtain a data point with known properties, a 3-foot square flat reflector was used as a reference for this type of measurement.

Signal level and multipath data were recorded as a function of distance for several runs over paths of about 1 km in the center of the Denver metro area using vertical, horizontal, and crossed antenna polarization. Figure 1-33 is a recording of one of the downtown observations with vertical antenna polarization showing signal amplitude for each frequency as a function of the transmitter terminal position as it travelled at a constant speed down the street toward the receiver terminal. This plot provides an indication of occurrence of fades resulting from multipath for this environment. Note that after the last 100 meters it was not possible to maintain antenna pointing due to maneuverability limitations of the vehicles. As a comparison, similar types of runs were recorded over paths in an open (non-urban) area to aid in separating ground multipath (asphalt road or street) from other reflecting paths. Figure 1-34 shows one such recording. The dashed line accompanying each plot is the level the signal trace would take if the terminals were in a free-space environment. The free-space trace for the 57.6 GHz rides above the recorded signal at the longer ranges because of the molecular oxygen absorption, which was not removed in the free-space trace.

A series of non-line-of-sight observations were made in urban Denver that showed substantial signals even with the terminals separated by several large multi-story buildings along the direct path. All received signals were a result of multiple reflectors and/or edge diffraction and these were most pronounced at 9.6 GHz and decreased with increasing frequency.

By means of a horizontal angle scan with 1° beamwidth receiving antennas, the angle of arrival of signals propagated down a street surrounded by buildings was plotted. Figure 1-35 displays this type of scan for two frequencies--28.8 and 57.6 GHz--and for both horizontal and vertical polarization. The signal peak occurring at 0° is the line-of-sight signal and all other signal peaks are reflected from buildings. Using the path geometry, distance between terminals, and building separation from the street, a good estimate of signal delay is possible. This delay information coupled with the multipath signal amplitude permits a calculation of channel bandwidth potential. For the case cited over a 500 meter path, using 4° antenna beamwidths, a 25 mb/s link could run with little intersymbol interference.

To determine the effects of multipath signals on a digital communication link operating in an urban environment, the impulse probe (NTIA-R-83-128) was set up on a controlled multipath link. Data were taken on a 250 meter folded path with dual reflectors (one fixed and one movable) using the 30.3 GHz, 500 mb/s coherent BPSK probe to compile data on multipath effects on bit error rate (BER). Figure 1-36 contains a plot of contributions to BER by S/N variations and intersymbol interference as a function of the time delay of a multipath signal relative to the direct signal normalized to bit duration. For this plot, the direct-to-multipath signal ratio (R_1/R_2) is 7 dB taken for the ratio of bit energy to noise (E_b/N_o) of 14 dB. With no multipath present and a 14 dB S/N ratio, the BER is 5 x 10^{-7}. At zero multipath delay, the change in BER is due only to S/N changes with an average BER of about 1.5 x 10^{-6}. This average BER is greater than the no multipath case because fades of 5.1 dB and enhancements of only 3.2 dB occur for a R_1/R_2 of 7 dB. Since a psuedo-random sequence bit generator is used to produce the data stream, the amplitude variations diminish as the multipath delay extends to 1-bit duration. Hence, the error changes due to S/N diminishes as shown by the narrow hatch-lines, "BER due to S/N only." Delay times greater than 1-bit duration theoretically produce no changes in BER due to S/N because no amplitude variations occur as a result of the multipath signal.

Errors due to intersymbol interference for this controlled multipath case (Fig. 1-36) are shown to diverge from zero delay, where a BER of 5 x 10^{-7} is that for a no multipath state. This indicates that there is no intersymbol interference contribution at zero multipath delay relative to the direct signal. As the multipath delay increases, the maximum and minimum contributions from intersymbol interference are shown by the broad spaced hatch-lines extending to coincide with the total contribution of errors at a delay time equal to 1-bit duration. Part of the errors attributed to intersymbol interference are the result of the composite of the direct signal and multipath signal producing a phase shift in the reconstructed carrier. The reconstructed carrier is manually phase adjusted to provide a zero reference to the phase detector in the demodulator for recovery of the baseband signal. This composite signal phase shift is cyclic at the rf rate and the resulting phase error accounts for most of the maximum-minimum BER excursions.

The BER due to a multipath signal is dependent on the channel S/N and the strength of the multipath signal. For a direct-to-multipath signal ratio of 8 dB, Figure 1-37 shows measured and extrapolated values of BER as a function of S/N compared to a curve showing system performance without a multipath signal. All values plotted are for a case where the multipath signal delay is 1-bit duration or greater. The measured points using the passive reflectors to produce controlled multipath are indicated by the small circles on the figure. These points include minimum, average, and maximum BER as a result of the multipath signal being continuously varied in delay time over several rf cycles.

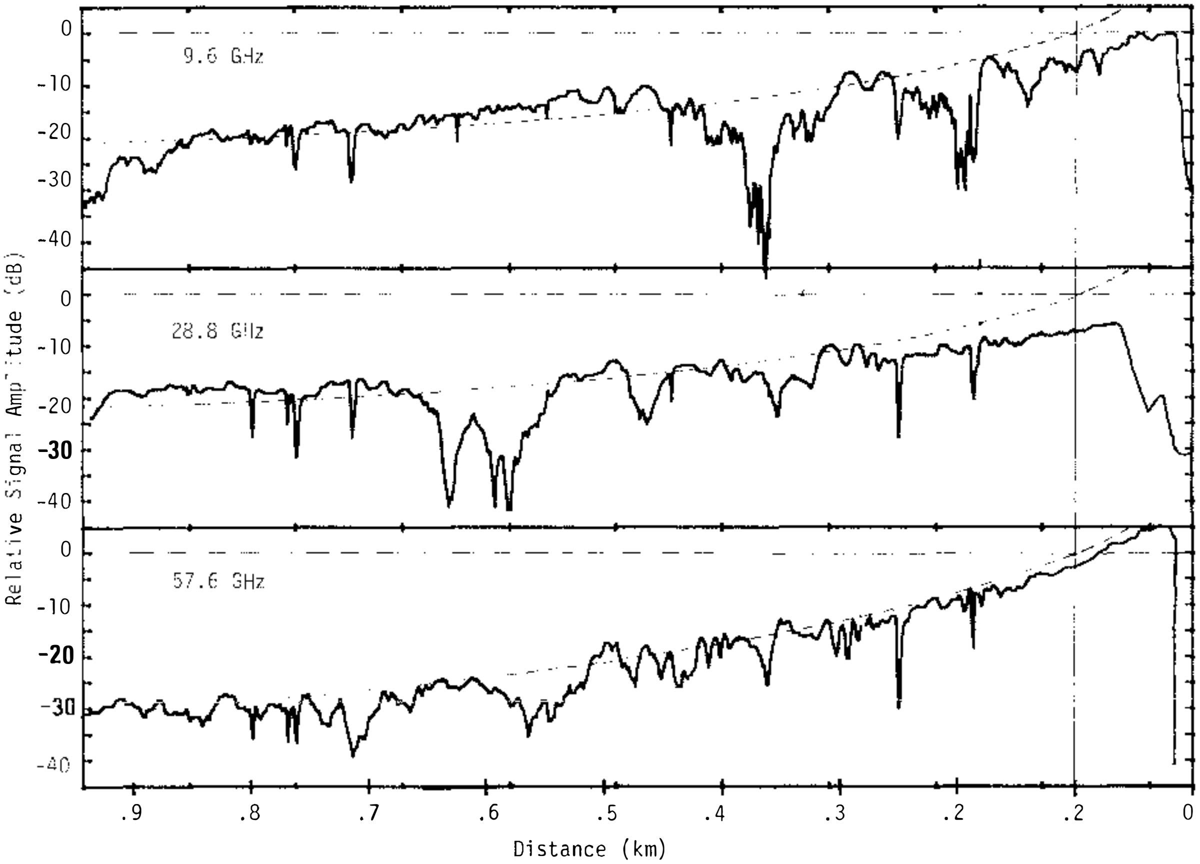


Figure 1-33. Signal amplitudes recorded as a function of distance between the transmitter and receiver along a street in the Denver metro area.

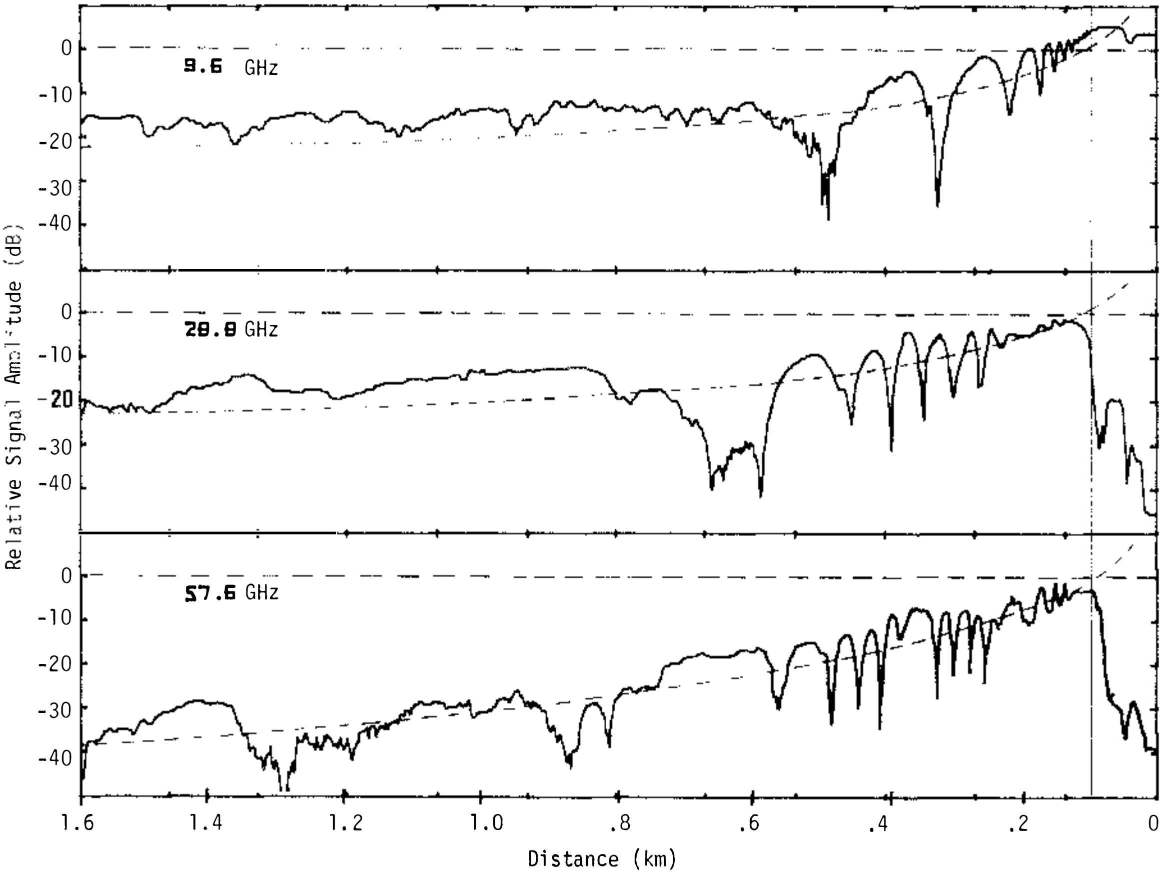


Figure 1-34. Signal amplitudes recorded as a function of distance between the transmitter and receiver along an asphalt road in a rural area.

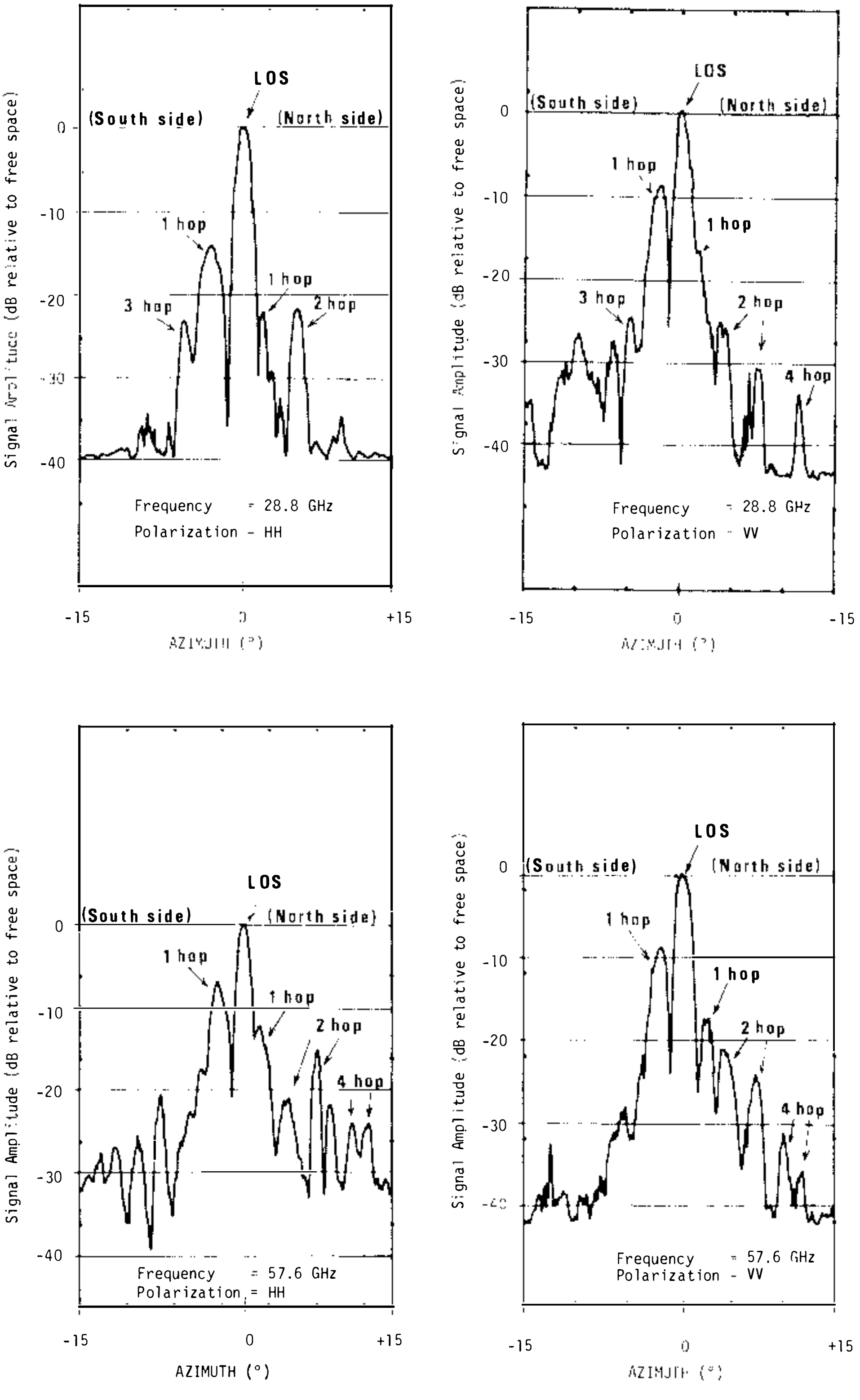


Figure 1-35. Signal amplitude as a function of azimuthal scans for horizontal-horizontal and vertical-vertical antenna polarizations at 28.8 and 57.6 GHz. These recordings are for a 485 m path down a street in the Denver metro area and show the effect of reflections from buildings.

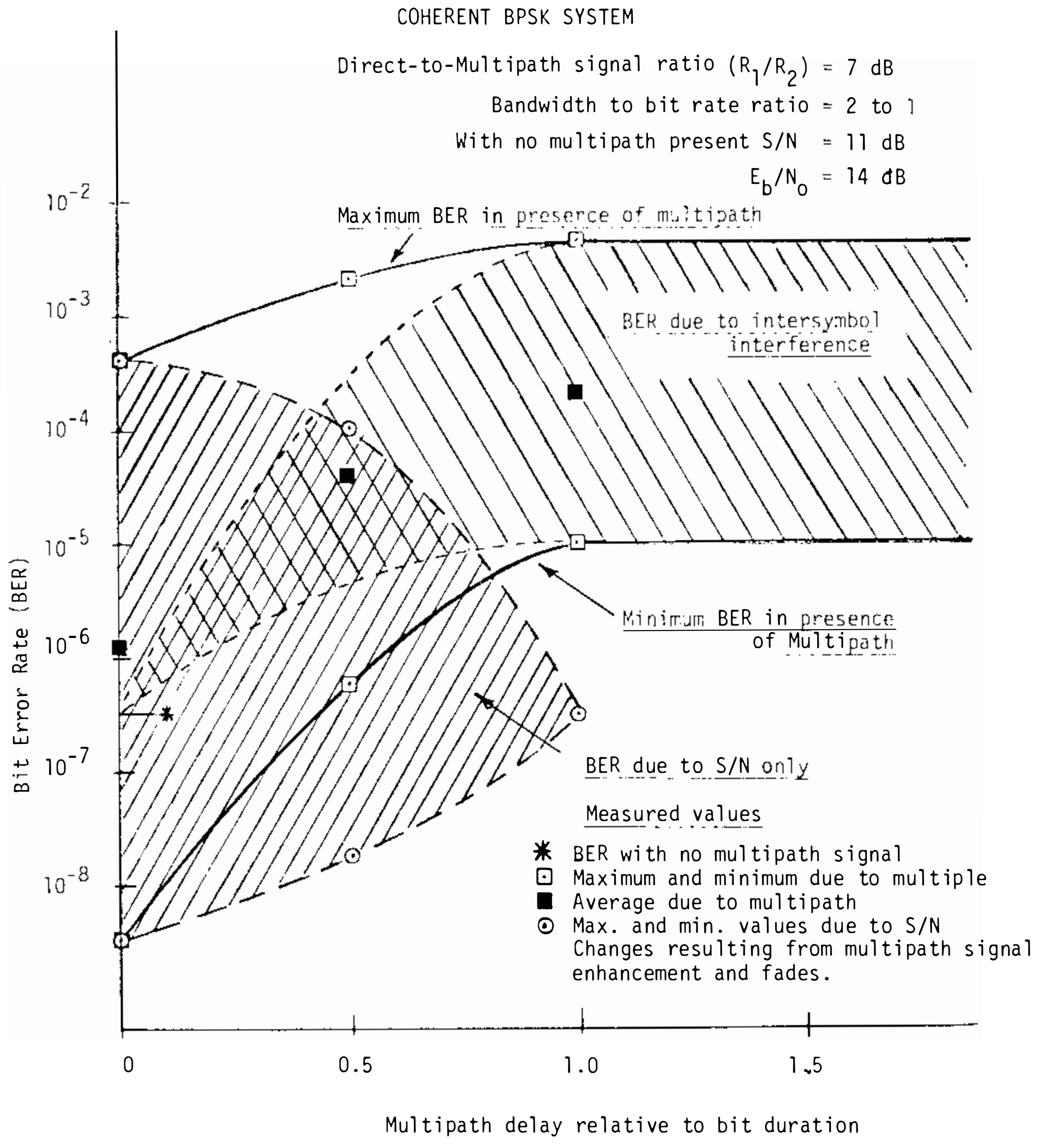


Figure 1-36. BER in the presence of multipath signals due to intersymbol interference for a S/N of 11 dB and a direct-to-multipath signal ratio of 7 dB.

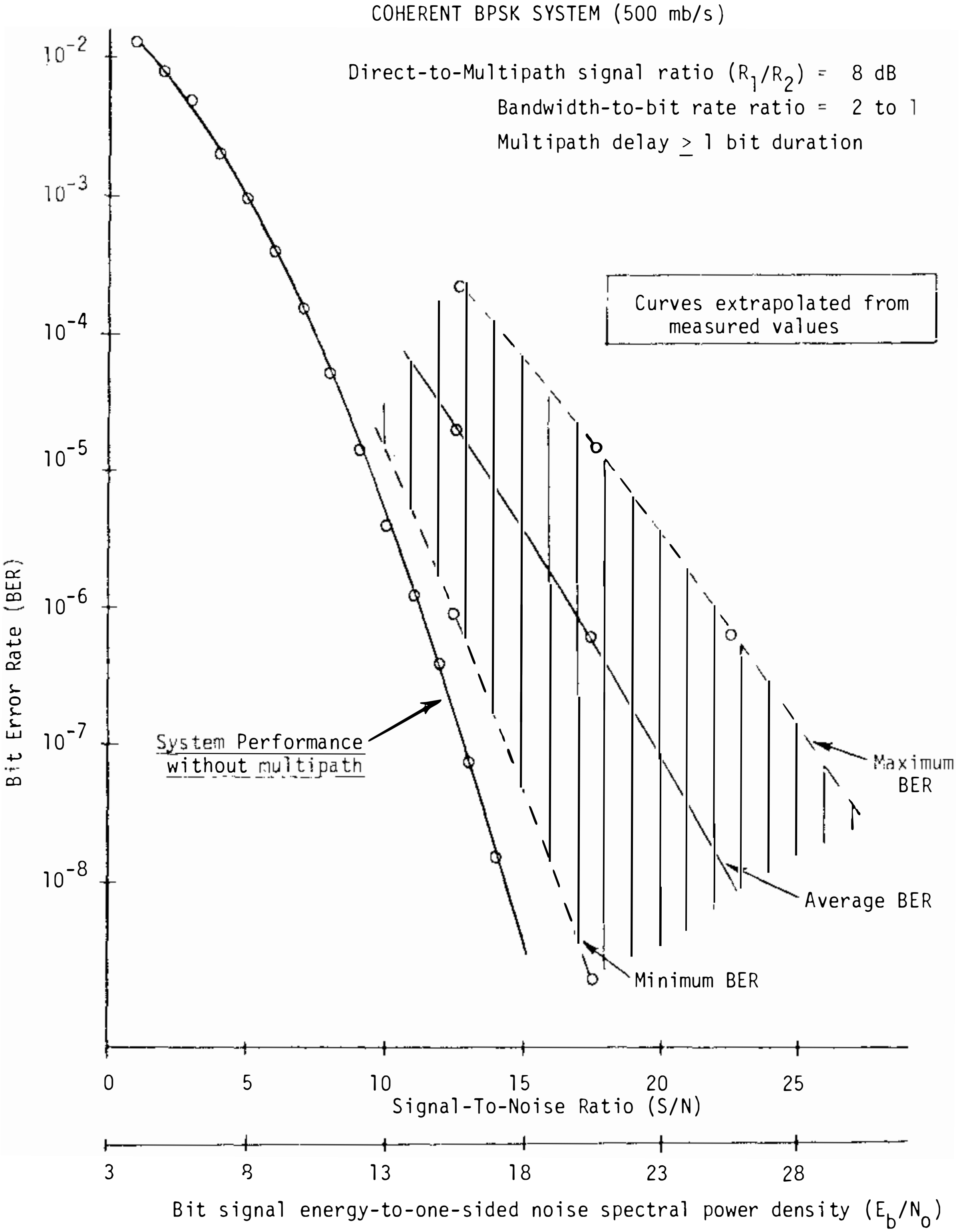


Figure 1-37. BER as a function of S/N for a direct-to-multipath signal ratio of 8 dB for multipath delays greater than 1 bit duration.

Bit error rate versus S/N curves are extrapolated from measured data for three different ratios of direct-to-multipath signal level in Figure 1-38. An estimated scale of R_1/R_2 starting at 7 dB and extending to ∞, which is the no multipath state, is included for the case where the multipath delay time is 1-bit duration or greater.

Multipath signals in a high data rate channel have a serious effect on data transfer rates due to increased errors. This treatment of multipath involving a single discrete signal does not usually represent an actual path where several components of multipath may occur or numerous scatters may exist. However, the measurements made for this analysis will provide an order of magnitude of channel degradation for the conditions that may be encountered in an urban environment.

The results of this project are contained in a report to the sponsor, U.S. Army Report CECOM 83-3 entitled, "Urban Millimeter Wave Propagation Studies."

With the current high interest in millimeter waves, there is a need for a reliable model to predict average loss and delay effects of the atmospheric propagation medium from easy-to-obtain meteorological data. Such a model would find considerable practical application through conversion of generally available climatologies into transfer characteristics of a radio path. Water in both vapor and liquid states is the major deterrent to an unrestricted exploitation of millimeter wavelengths. For the ITS propagation model, moist air is characterized for the frequency range 1 to 300 (1000) GHz as a nonturbulent propagation medium. The medium is treated as an ensemble of molecules and particles in which spectral features of water vapor, oxygen, suspended water droplets (hydrosol), and precipitation constitute the main absorbers.

The spectroscopic data base consists of:

- resonance information for 30 H_2O lines between 22 and 987 GHz
- resonance information for 48 O_2 lines between 49 and 834 GHz
- a continuum spectrum due to >2000 H_2O lines above 1000 GHz
- a continuum spectrum due to nonresonant O_2 and pressure-induced N_2 absorption
- a suspended water droplet (haze, fog, cloud) attenuation term
- a simple rain attenuation model.

The data base is applied in two computer programs to calculate and to plot specific attenuation α (dB/km) and dispersive delay β (ps/km) throughout the neutral atmosphere.

Program 1 covers the lower atmosphere (0 to 30 km) and requires the input data: pressure P, temperature T, relative humidity RH, cloud water concentration W, and rain rate R. A typical graphical output is illustrated in Figure 1-39.

Program 2 addresses isolated line behavior over the height range 30 to 100 km, wherein the geomagnetic field strength H is an additional input parameter due to the Zeeman effect of the O_2 molecules. Each oxygen line splits proportional with H into numerous sublines, which superimpose to form a Zeeman pattern spread over a megahertz scale.

A program was outlined to develop a performance model for fixed terrestrial millimeter wave communications systems operating in the 10 to 100 GHz frequency range. Radio path distances up to about 100 km and signal bandwidths of several gigahertz are feasible. The key performance parameter for both analog and digital systems is the signal-to-noise ratio realized at the receiver. Fade margins for this ratio need to be established for systems to tolerate propagation losses caused by adverse weather and obstacles in the path (see general example in Fig. 1-40). The role of the model is to relate path distance, system parameters, and occurrences of various propagation losses, most notably those due to rain, in order to establish the link availability.

The modeling strategy will be to ensure "ease-of-operation" and viable trade-off options for optimum performance. The model architecture will be structured to permit updating in a facile manner with emphasis on link security and other special requirements for applications by the U.S. Army. Future desired modifications of the initial version are identified, and it is strongly suggested that the phase of development toward an ultimate model be paralleled by extensive field tests. Multiple-frequency experiments should be capable (1) of detecting deep fades (potential outages) over 0.1 to 10 minute periods and (2) of operating at high digital data rates (0.1 to 1 Gbit/s) so that missing data for testing and verification of the model become available.

Absolute attenuation rates and refractivities due to water vapor and moist nitrogen have been measured in the laboratory at 138 GHz, 300 K, pressures up to 1.5 atm, and relative humidities up to 100 percent. The computer-controlled measuring system comprises a millimeter wave resonance spectrometer (0.15 km effective path length) and a humidity simulator. Several shortcomings of earlier measurement attempts have been rectified. The data (Fig. 1-41) are interpreted as a water vapor continuum spectrum consisting of two terms, namely strong self-broadening (H_2O-H_2O) plus foreign-gas-broadening (H_2O-N_2) contributions.

The new results have implications for modeling atmospheric EHF window transparencies and for revising established H_2O line broadening theory. The water vapor continuum is modeled by

$$N''_c = (c_1 e p \Theta^{y} + c_2 e^2 \Theta^{y^*}) f \times 10^{-6} \qquad \text{ppm}$$

where p is the partial dry air pressure, p=P-e. The coefficients are chosen according to the following scheme:

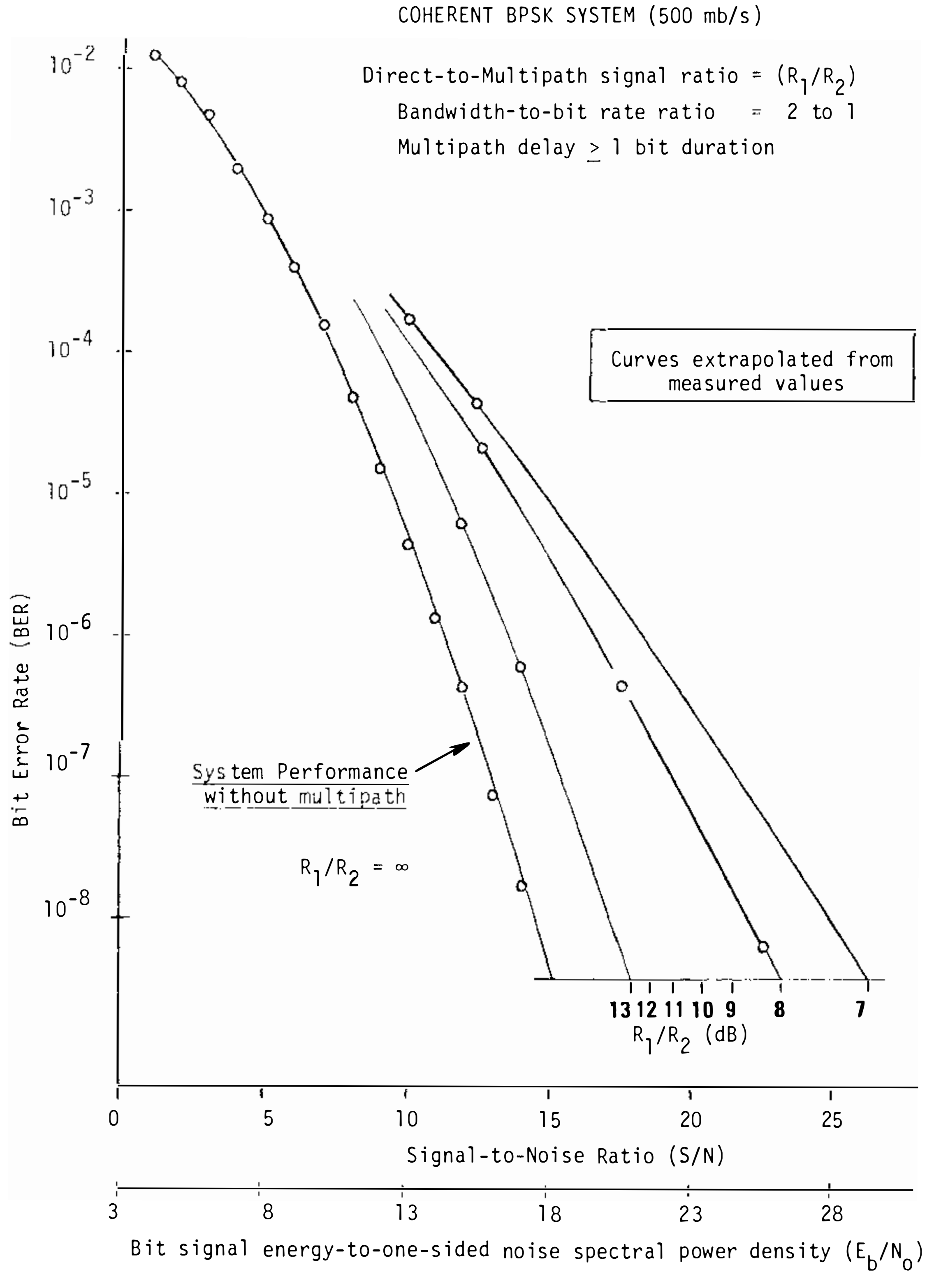


Figure 1-38. BER as a function of S/N for direct-to-multipath signal ratios (R_1/R_2) from 7 to 13 dB for multipath delay greater than 1 bit duration.

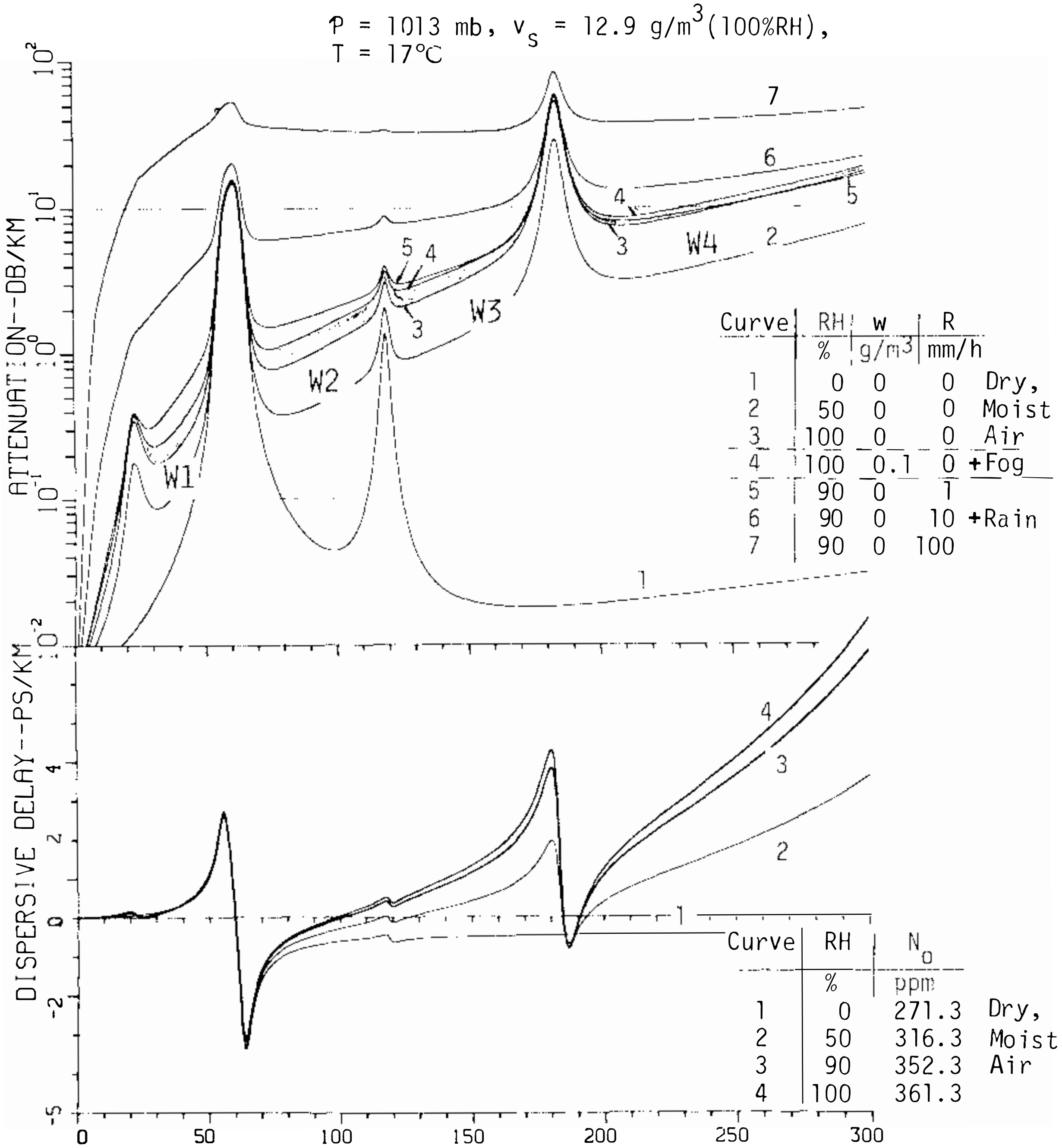


Figure 1-39. Specific attenuation α (dB/km) and dispersive delay β (ps/km) for humid air at sea level (RH=0 to 100%). Also shown is fog attenuation for a liquid water concentration w=0.1 g/m^3 (about 300 m visibility) and rain attenuation for the rates R=1, 10, and 100 mm/h. The nondispersive refractivity is N_o.

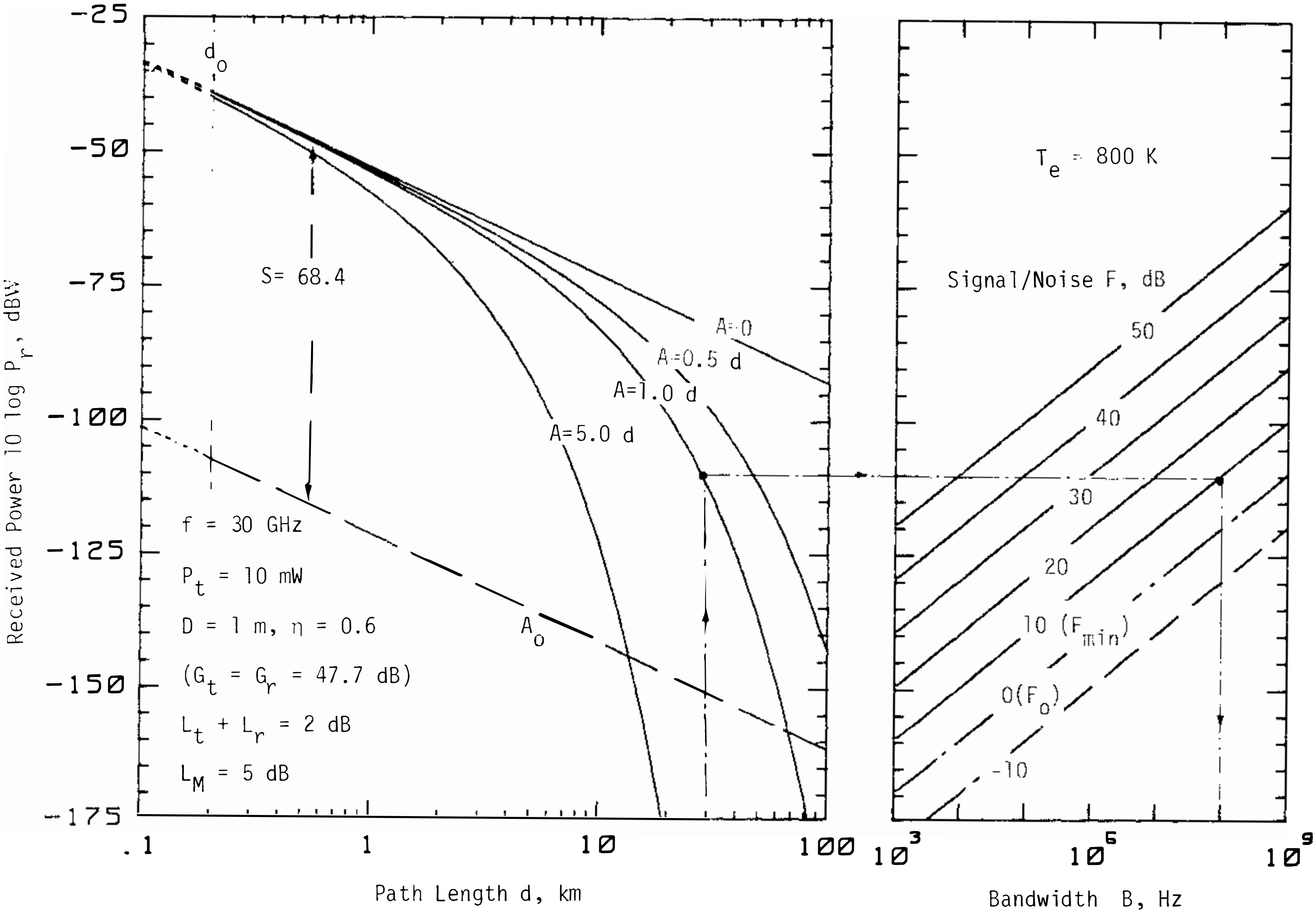


Figure 1-40. Received average power level 10 log P_r and signal-to-noise ratio F for a line-of-sight communications link operating at 30 GHz. Various propagation losses A=αd and bandwidths B are assumed. Example: d=30 km, A=30 x 1 dB, F_{min}=10 dB, B≤100 MHz.

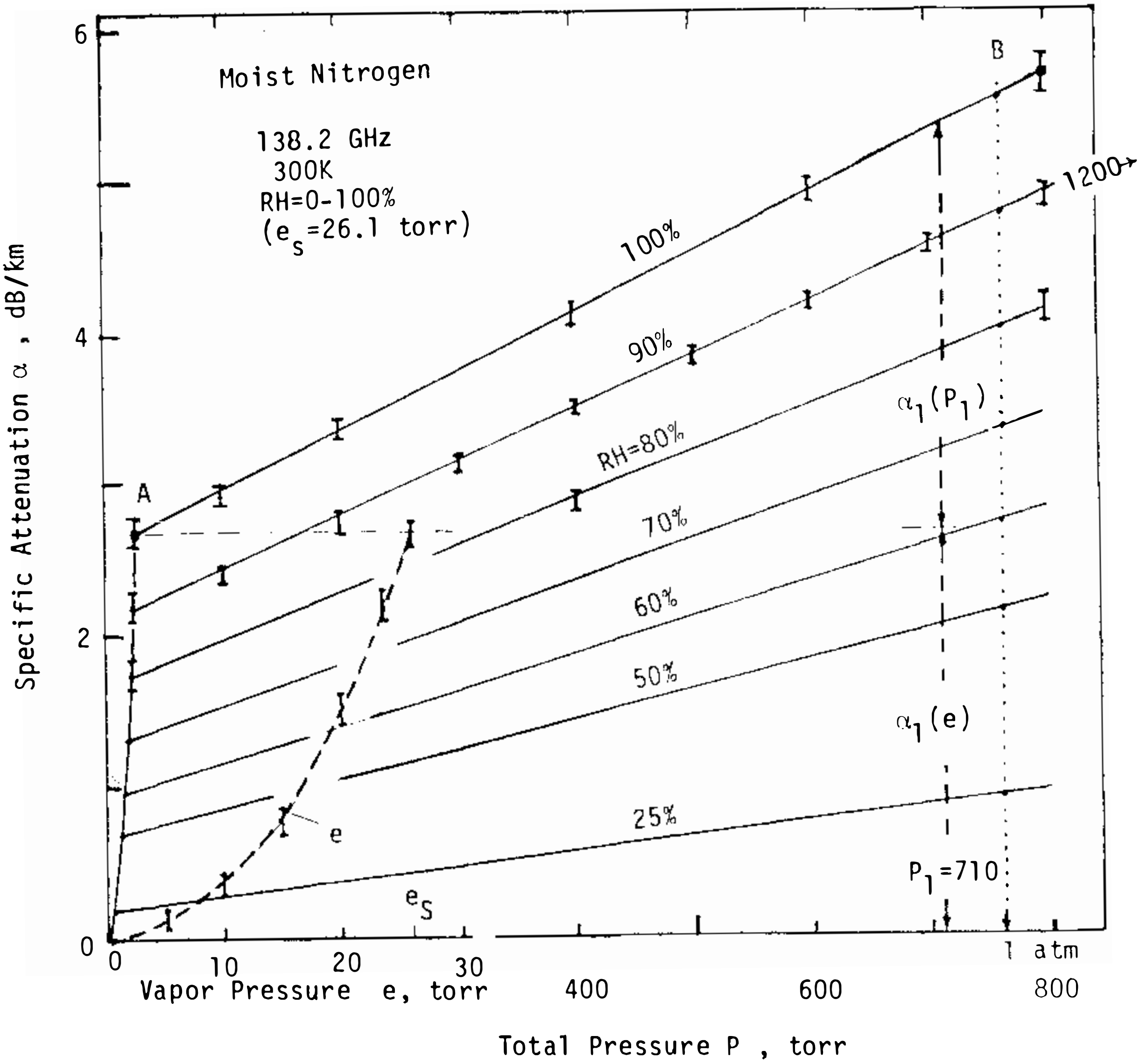


Figure 1-41. Pressure dependence of specific attenuation α due to water vapor (e) and moist nitrogen (P) measured at 138.2 GHz and relative humidities from RH=80 to 100 percent.

	c_1	y	c_2	y^*
Old	1.90	3.1	0	[illegible]
New	1.40	2.5	54.1	3.5 .

Table 1-6 compares the results of the old and the new continuum for the case of predicting zenith attenuation A(dB) through a model atmosphere.

Except for a strong self-broadening component ($\propto e^2$), no additional anomalous behavior was observed contrary to findings by other workers--not even at saturation (RH=100%).

In our case, we could clearly identify anomalous absorption behavior (e.g., unusually high rates, extreme temperature dependencies, hystereses in pressure and temperature cycles) as being instrumental, that is, condensation effects on the millimeter-wave active parts of the spectrometer. Considerable effort had to be expended before the instrument produced consistent, reproducible results.

Practical implications of the new, though preliminary, EHF water vapor continuum to propagation modeling are not too serious. Up to relative humidities of RH≈60 percent, essentially the widely used empirical Gaut-Reifenstein continuum is confirmed. At higher humidities, increases over the GR continuum (by a factor 1.5 at RH=100%) and a nonlinear dependence on absolute humidity are predicted.

Before the millimeter wave portion of the radio spectrum can be used efficiently for earth-satellite communications, means of accurately predicting the attenuation of millimeter waves propagated along an earth-satellite path are needed. A high reliability communication link should not suffer outages more than a few percent or fractions of a percent of the year and, therefore, must be designed to tolerate levels of attenuation that are only rarely exceeded.

Rain has long been known to be the cause of the high levels of microwave attenuation exceeded small fractions of the year. Estimates of the cumulative distribution of attenuation due to rain are used to predict the amount of time an earth-satellite microwave link will experience outages.

As radio frequency increases, the attenuation due to clouds increases. Although cloud attenuation is negligible at microwave frequencies, it can become quite large for millimeter waves.

The Millimeter Wave Cloud Attenuation project at ITS was directed toward determining whether rain still dominated the cumulative distribution of attenuation at small percentages of the year or if cloud attenuation must be included to predict the performance of high reliability millimeter wave communication systems.

The attenuation due to rain producing clouds was investigated, and a model developed to predict the cumulative distribution of cloud attenuation based on the cumulative distribution of point rain rate. In Figures 1-42 and 1-43, cumulative distributions of attenuation due to rain and rain producing stratus and cumulus clouds are shown for 30 and 90 GHz respectively. It can be seen that at 90 GHz cloud attenuation contributes to the total cumulative distribution of attenuation at percentages of the year when rain attenuation dominates at lower radio frequencies. The model indicates that cloud attenuation dominates the total cumulative distribution of attenuation for frequencies above 140 GHz.

The ITS cloud attenuation model can be used to improve predictions of the cumulative distribution of millimeter wave attenuation for small fractions of the year. Further development of the model is needed for more accurate predictions. Attenuation due to nonprecipitating clouds and the geographical variability of the liquid water content of clouds should be included in the model.

Raindrop-size data taken in four macroscale climatic zones (Zones A, B, C, and D) have been examined. The examination shows considerable disparity in drop densities in the small drop sizes, but reasonable agreement when larger (greater than about 1 mm) drop diameters are considered. An existing drop-size model can be fitted to much of the data for the larger drop sizes; however, the model parameter N_o shows a large variation, and it is apparently not related to rain rate. There is a paucity of data for arid and cold climates; fortunately, there is a larger data base for the more populated tropical and humid temperate climates.

On the basis of the macroscale subdivision of the world's climates, the drop-size distribution data in the four climatic zones were used to develop zonal coefficients for the specific attenuation-rain rate relationship:

$$\alpha_z(f,R) = a_z(f)R^{b_z(f)} \pm \text{S.E.}, \qquad (1)$$

where $\alpha_z(f,R)$ represents a zonal (z) average specific attenuation that is related to rain rate, R, by statistical regression techniques applied to given zonal data at a given frequency, f. The values $a_z(f)$ and $b_z(f)$ then represent coefficients derived from the regression fits, and S.E. is the "standard error of estimate."

Tables 1-7 through 1-10 show the results of the regression fits for Zones A through D, respectively. The first column of these tables shows frequency, the second column shows zonally evaluated regression results, and the third column shows some results that are often recommended in the literature. The resulting coefficients do little to resolve any confusion that might exist in the millimeter wave region as to which set of coefficients is truly meaningful. The results continue to indicate the random behavior of attenuation on a climatological basis, implying an existing need to assess variability and statistical bounds on any kind of relationship used for prediction purposes. As well, there is indicated a need for either a more consistent and meaningful climatological classification structure or more data within the zonal classifications used in this effort--or both.

Table 1-6. Comparison of Zenith Attenuation A(dB) Predicted for a Synthetic Atmosphere (30°N, July) by Employing the ITS Millimeter Wave Propagation Model with Old (Gaut-Reifenstein) and New Water Vapor Continuum Absorption

Model Atmosphere 30°N, July

```
RAY PATH ANGLE:  0.00 DEGREES FROM ZENITH
INTEGRATED THROUGH MODEL ATMOSPHERE:  P0 = 101.35 KPA, T0 = 301.15 K,
31 HEIGHT LEVELS, H = 0 TO 30 KM,
INTEGRATED WATER VAPOR        V = 52.685          70.247  MM,
ELECTRIC PATH LENGTH          LE = 2627.16        2739.02  MM.

      FREQUENCY(GHZ)        ATTENUATION(DB)          ATTENUATION(DB)
          30.00              .59       .64            .72       .88
          35.00              .63       .70            .74       .96
          40.00              .79       .90            .91      1.21
          45.00             1.13      1.26           1.27      1.64
          50.00             2.13      2.29           2.29      2.76
          55.00            28.16     28.35          28.36     28.92
          60.00           148.98    149.21         149.09    149.75
          65.00            23.87     24.14          24.16     24.94
          70.00             3.19      3.51           3.49      4.39
          75.00             2.42      2.78           2.75      3.78
          80.00             2.36      2.77           2.72      3.91
          85.00             2.48      2.95           2.89      4.22
          90.00             2.69      3.20           3.14      4.63
          95.00             2.94      3.52           3.44      5.11
         100.00             3.23      3.87           3.79      5.64
         105.00             3.58      4.29           4.20      6.24
         110.00             4.07      4.84           4.75      6.99
         115.00             5.47      6.31           6.23      8.67
         120.00            11.89     12.81          12.73     15.39
         125.00             5.38      6.39           6.31      9.19
         130.00             5.51      6.59           6.52      9.64
         135.00             5.92      7.09           7.03     10.40
         140.00             6.43      7.68           7.66     11.28
         145.00             7.03      8.37           8.41     12.29
         150.00             7.75      9.19           9.32     13.47

                             OLD       NEW            OLD       NEW
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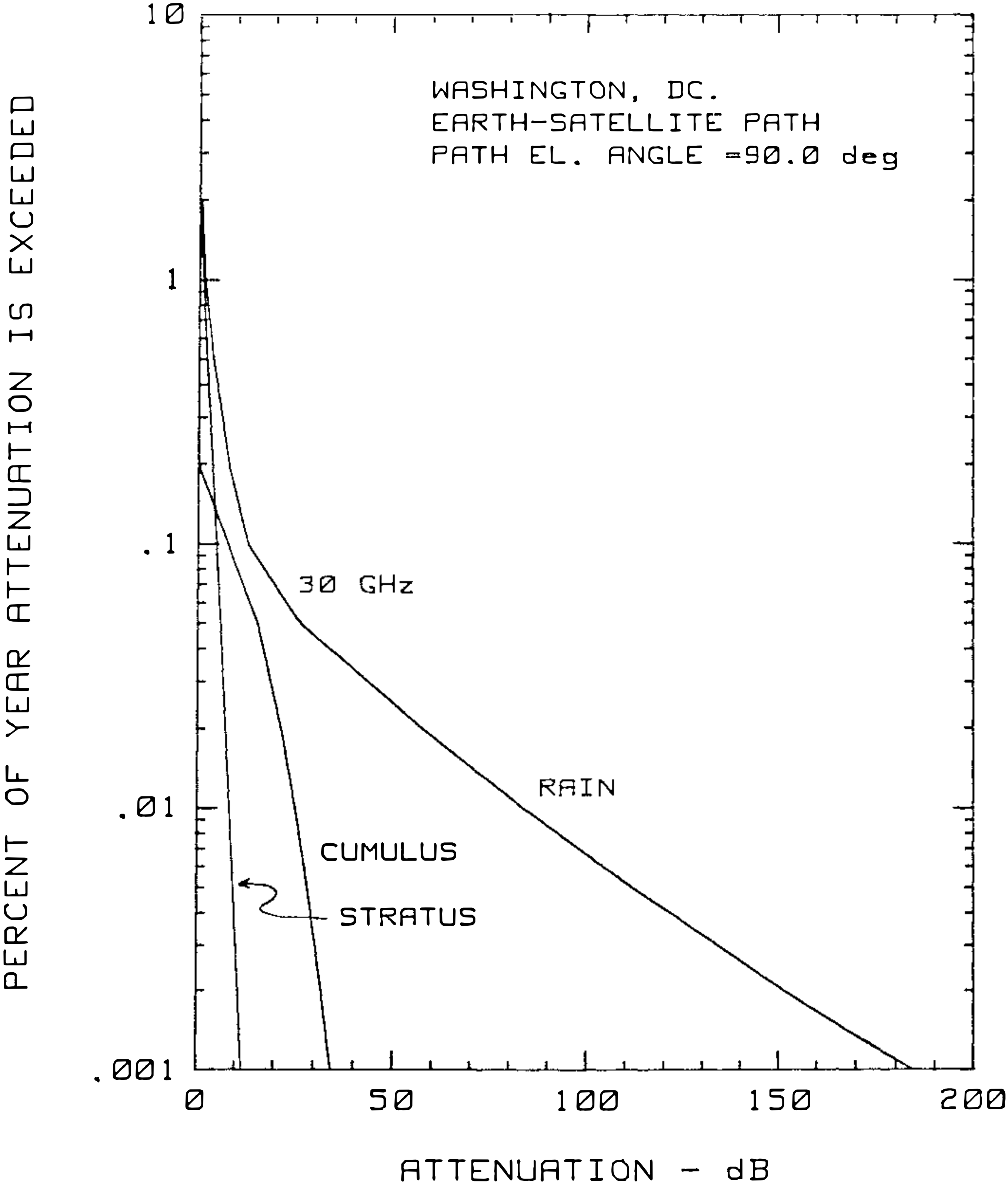

Figure 1-42. Predicted attenuation distributions for 30 GHz due to rain and precipitating stratus and cumulus clouds for a zenith path at Washington, DC.

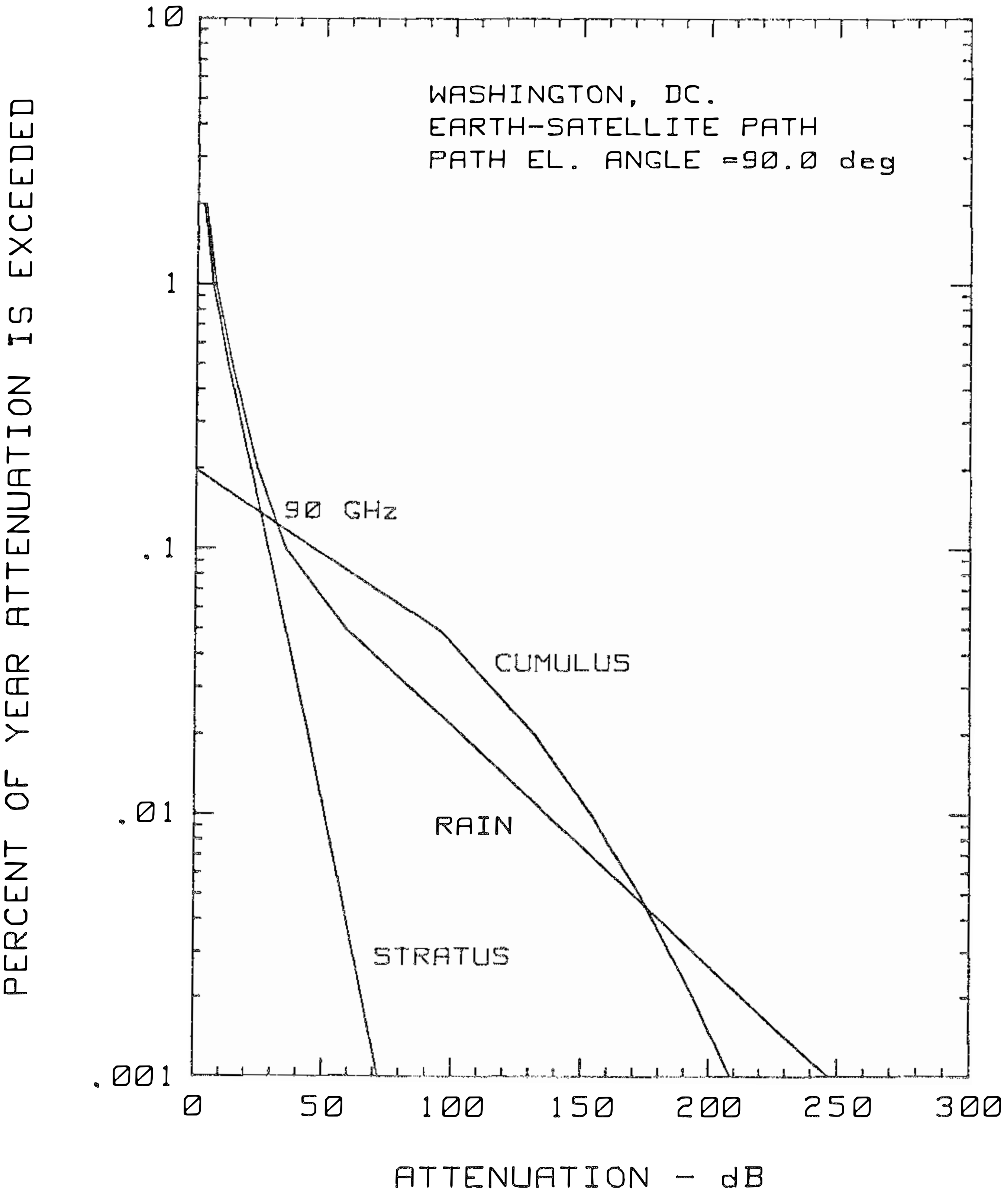

Figure 1-43. Predicted attenuation distributions for 90 GHz due to rain and precipitating stratus and cumulus clouds for a zenith path at Washington, DC.

The real conclusion of this effort, that use of any of the modeled specific attenuation-rain rate relationships should be pursued with considerable caution at millimeter-wave frequencies, will perhaps stimulate endeavors to acquire more and meaningful rain attenuation/rain description data with the intent of providing usable prediction relationships.

Table 1-7. Coefficients for Zone A of the Relation in Equation (1)

Frequency (GHz)	Evaluated from Eq. (1)			Commonly used Coefficients	
	$a_z(f)$	$b_z(f)$	S.E.	a(f)	b(f)
10	4.72×10^{-3}	0.899	0.300	1.36×10^{-2}	1.150
30	8.66×10^{-2}	0.735	2.06	0.186	1.043
60	0.331	0.611	4.17	0.801	0.851
100	0.637	0.515	5.21	1.48	0.730
300	0.956	0.423	5.34	2.24	0.614

Table 1-8. Coefficients for Zone B of the Relation in Equation (1)

Frequency (GHz)	Evaluated from Eq. (1)			Commonly used Coefficients	
	$a_z(f)$	$b_z(f)$	S.E.	a(f)	b(f)
10	6.44×10^{-3}	0.937	0.09	1.36×10^{-2}	1.150
30	1.14×10^{-2}	0.814	0.91	0.186	1.043
60	0.424	0.748	0.74	0.801	0.851
100	0.802	0.665	1.37	1.48	0.730
300	1.19	0.575	1.67	2.24	0.614

Table 1-9. Coefficients for Zone C of the Relation in Equation (1)

Frequency (GHz)	Evaluated from Eq. (1)			Commonly used Coefficients	
	$a_z(f)$	$b_z(f)$	S.E.	a(f)	b(f)
10	7.74×10^{-3}	1.224	0.64	1.36×10^{-2}	1.150
30	0.125	1.015	3.52	0.186	1.043
60	0.444	0.855	6.09	0.801	0.851
100	0.806	0.737	7.16	1.48	0.730
300	1.16	0.623	7.23	2.24	0.614

Table 1-10. Coefficients for Zone D of the Relation in Equation (1)

Frequency (GHz)	Evaluated from Eq. (1)			Commonly used Coefficients	
	$a_z(f)$	$b_z(f)$	S.E.	a(f)	b(f)
10	1.42×10^{-2}	1.149	0.57	1.36×10^{-2}	1.150
30	0.237	0.875	1.61	0.186	1.043
60	0.816	0.690	2.93	0.801	0.851
100	1.41	0.578	3.84	1.48	0.730
300	1.88	0.490	4.04	2.24	0.614

The Rice-Holmberg (RH) model for predicting rain rate annual distributions makes use of an intermediate parameter known as the "thunderstorm ratio," β. In the RH model, the purpose of β is distinction between convective and stratiform types of rainfall. The thunderstorm ratio was originally defined as

$$\beta = \beta_o\left\{0.25 + 2\exp\left[\frac{-0.35\ (1 + 0.125M)}{u}\right]\right\}, \qquad (2)$$

where

$$\beta_o = 0.03 + 0.97\exp[-5\exp(-0.004M_m)]. \qquad (3)$$

In (2) and (3),

M = the average annual precipitation in millimeters,

u = the average annual numbers of days with precipitation greater than .01 in (.25 mm), and

M_m = the maximum monthly precipitation in 30 consecutive years of record, in millimeters.

Formulas (2) and (3) have two unfortunate aspects. First, they generally require a calculator to use. Second, and more important, they require the only use of M_m in the RH model calculations. The value M_m is very difficult to obtain on a worldwide data basis, which often greatly reduces (sometimes to none) the number of RH model results that can be calculated in a given part of the world. There is, however, an alternative. If we define the thunderstorm ratio as the ratio of u', the annual number of days with thunderstorms to $D_{.01}$', the annual number of days with precipitation greater than .01 in. These data have much greater worldwide availability. The statistical measures of u' and $D_{.01}$' are their means, u and $D_{.01}$, and their standard deviations s_u and $s_{D.01}$.

Figure 1-44 shows a contour map of the rain rate, $R_{.01}$, expected to be exceeded 0.01 percent of an average year, derived from β, and Figure 1-45 shows the same map derived from $u/D_{.01}$ instead of β. Both maps are for the United States. The most notable difference in the two maps is the diminution of $R_{.01}$ in the Pacific Northwest on Figure 1-45 as contrasted with Figure 1-44 and respectively higher $R_{.01}$'s in the Great Basin on Figure 1-45. Figures 1-46 and 1-47 contrast $R_{.01}$s derived from β and $u/D_{.01}$, respectively, for Southwest Asia. Here the most notable feature is the greater data availability of Figure 1-47 compared to Figure 1-46. In some areas of the world, the u/D method is the only feasible approach to data contouring because of a nearly total absence of β information. Figure 1-48 for the Republic of Korea (South Korea) and Figure 1-49 for Central America show contour maps of $R_{.01}$ derived from u/D where this is the case.

Table 1-11 shows an analysis and summary of the comparison of observed rain rate distributions from 20 usable data locations with predicted results from the RH model using the β and $u/D_{.01}$ thunderstorm ratios. The only likely significant comparison of data distributions with the prediction distributions is

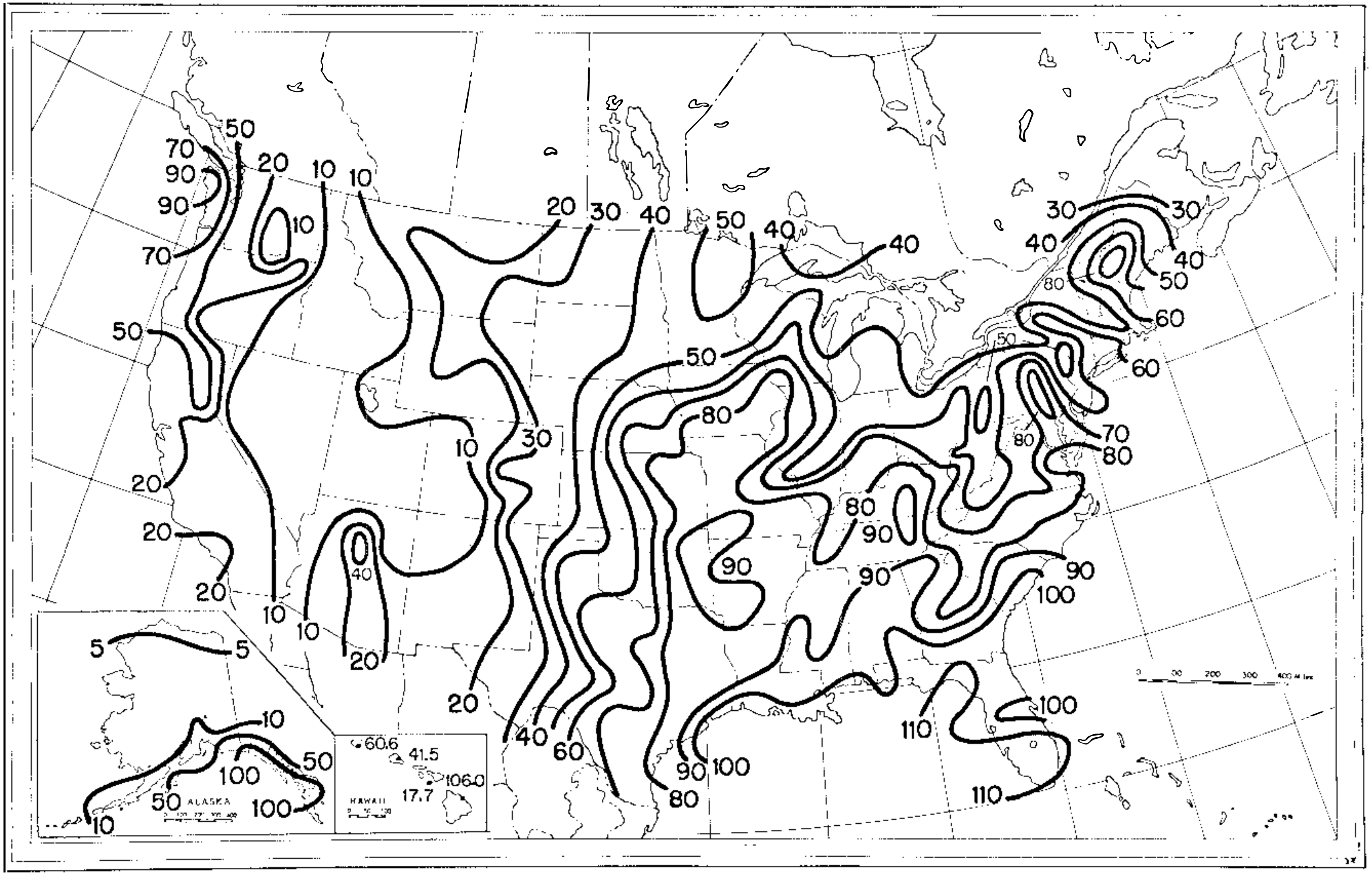

Figure 1-44. Rain rates, R_{01}, expected to be exceeded 0.01% of an average year in the United States, derived from the thunderstorm ratio, β.

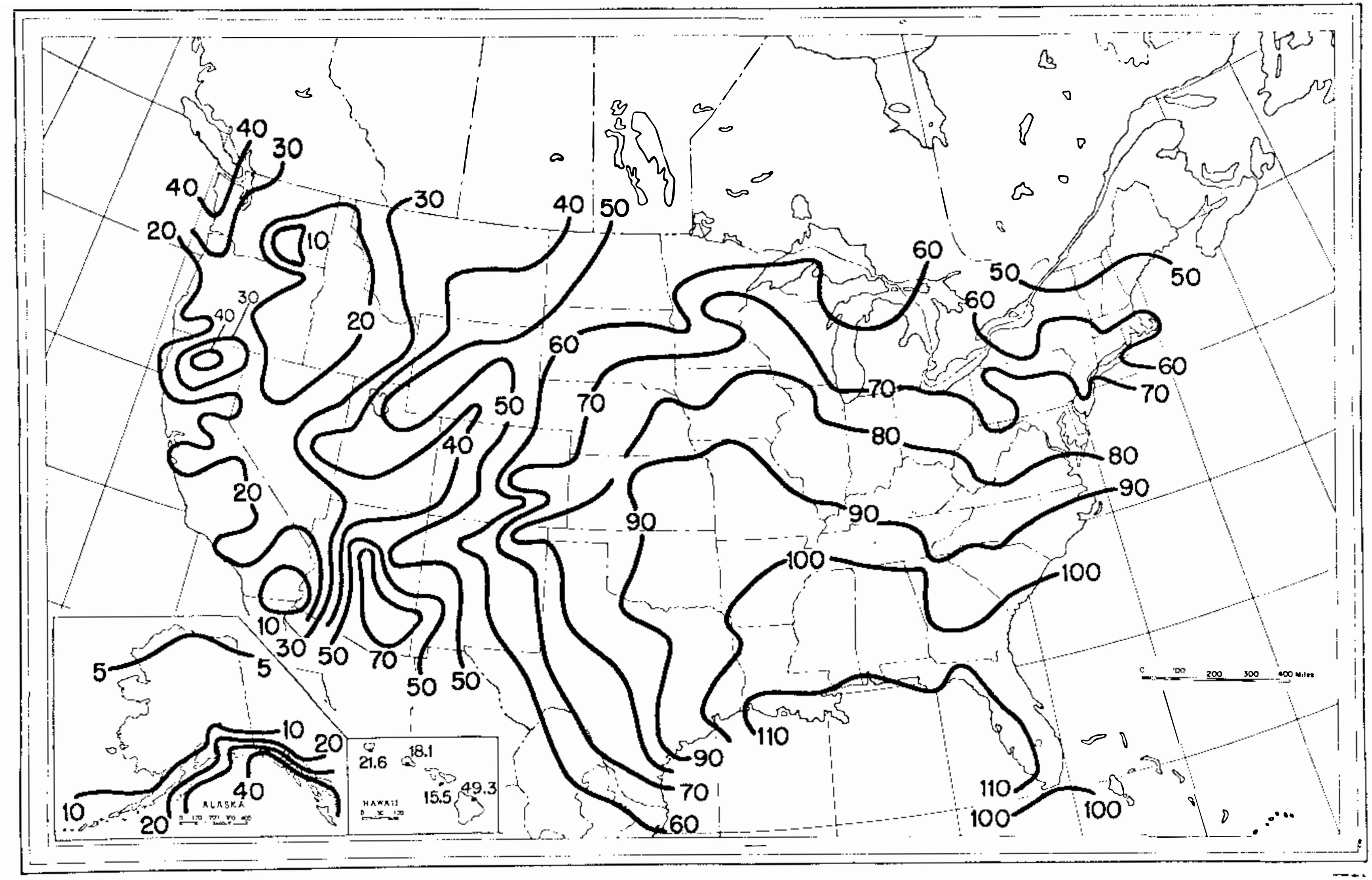

Figure 1-45. Rain rates, $R_{.01}$, expected to be exceeded 0.01% of an average year in the United States, derived from the thunderstorm ratio, $U/D_{.01}$.

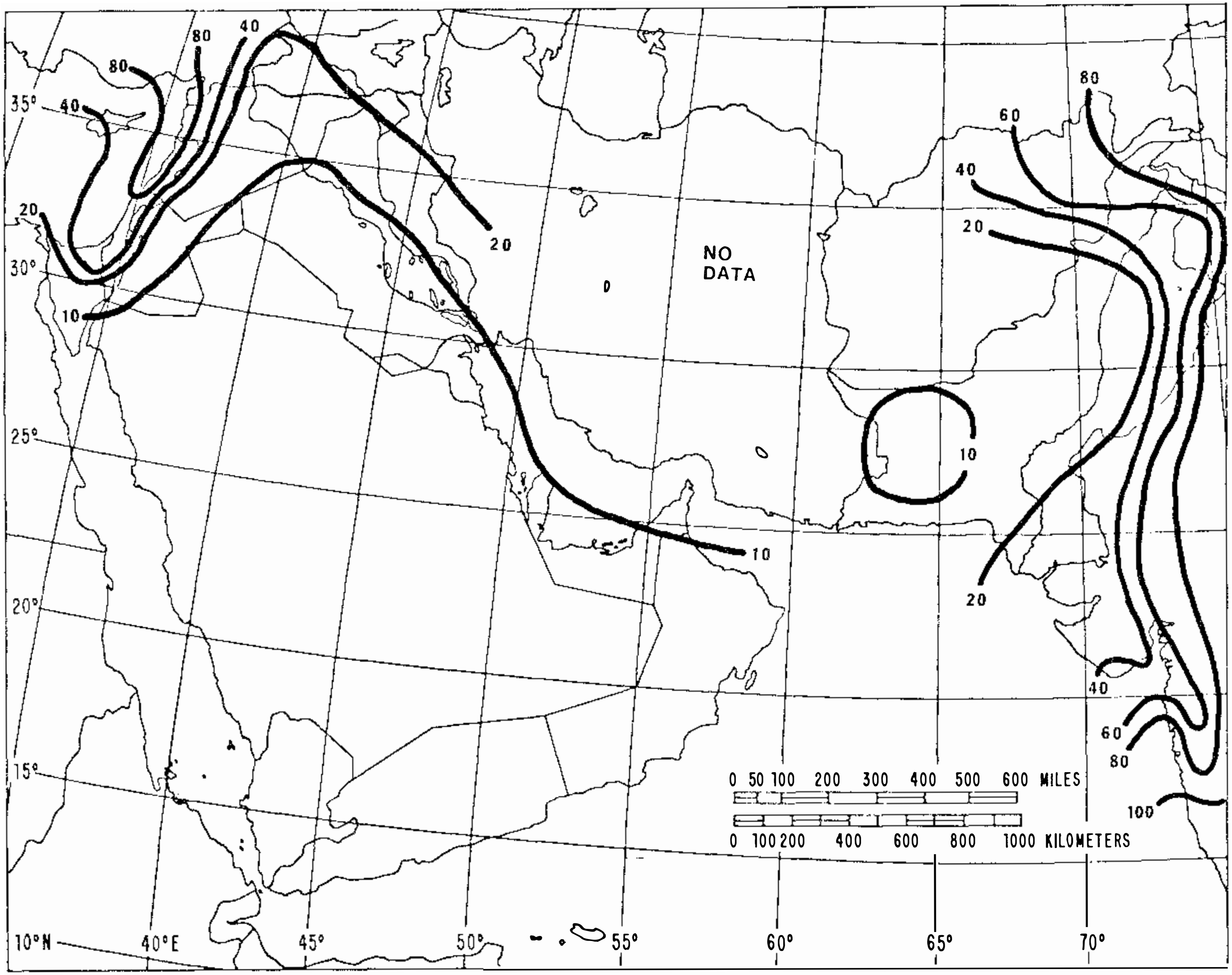

Figure 1-46. Rain rates, $R_{.01}$, expected to be exceeded 0.01% of an average year in southwest Asia, derived from the thunderstorm ratio, β.

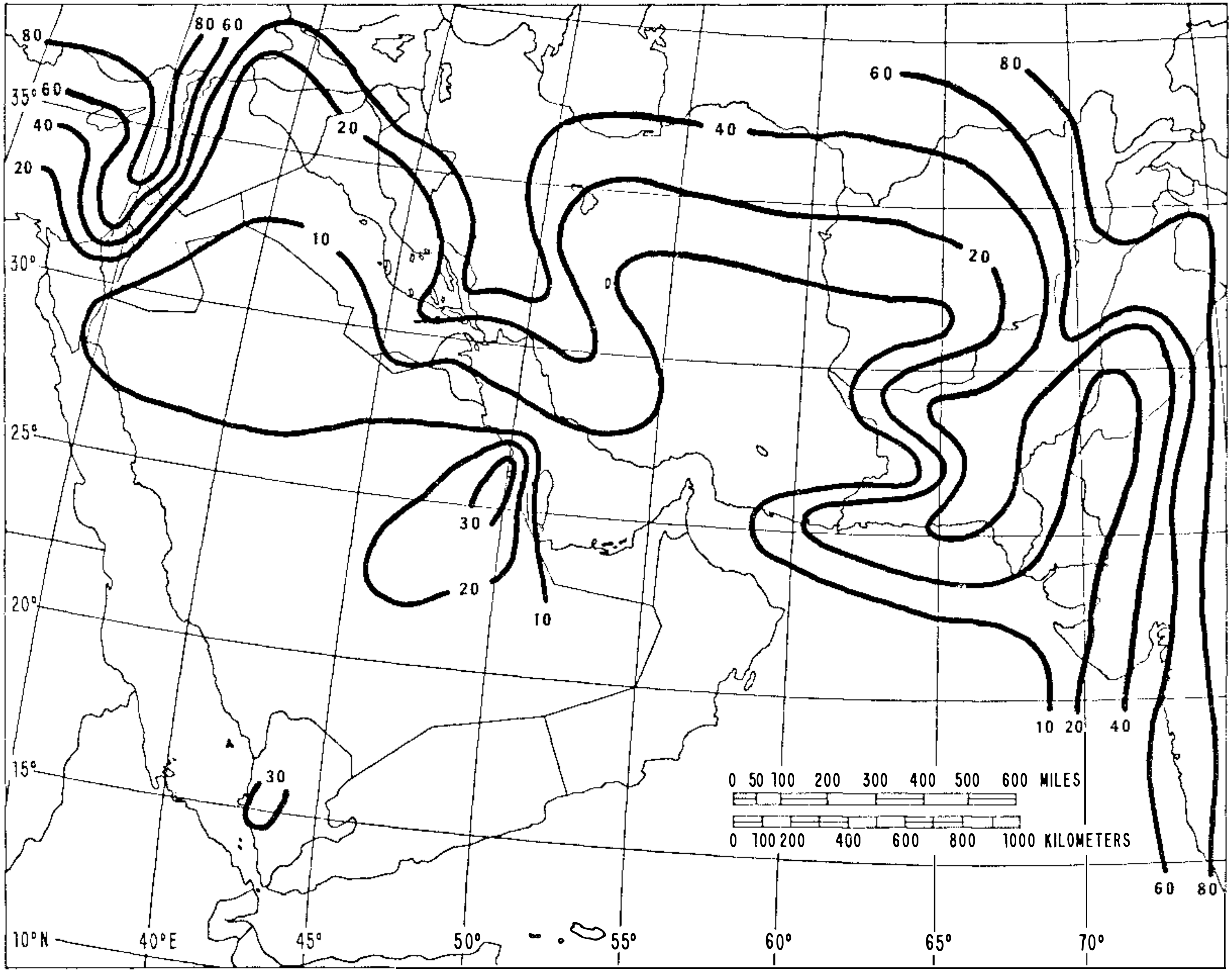

Figure 1-47. Rain rates, $R_{.01}$, expected to be exceeded 0.01% of an average year in southwest Asia, derived from the thunderstorm ratio, $U/D_{.01}$.

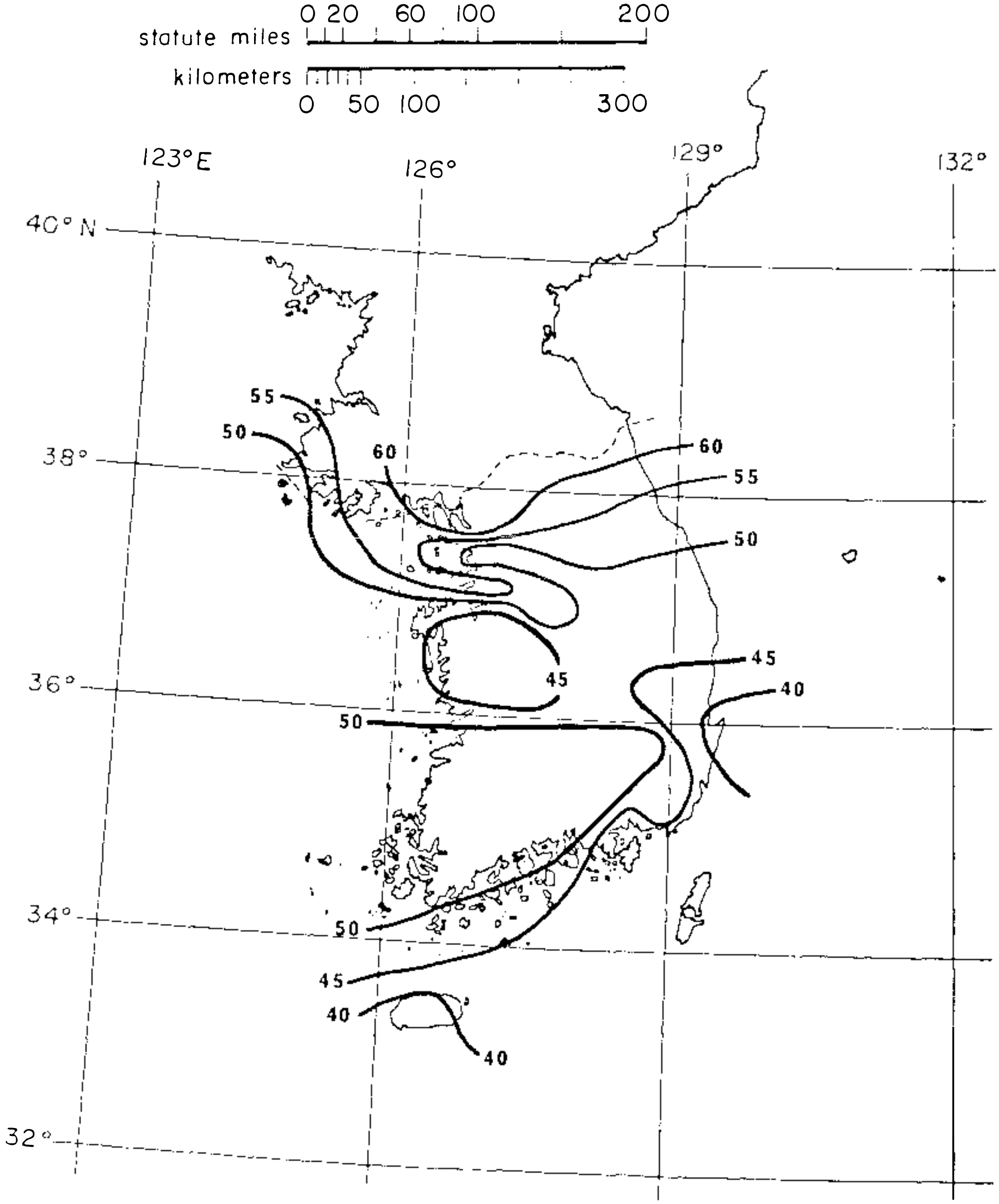

Figure 1-48. Rain rates, $R_{.01}$, expected to be exceeded 0.01% of an average year in the Republic of Korea, derived from the thunderstorm ratio, $U/D_{.01}$.

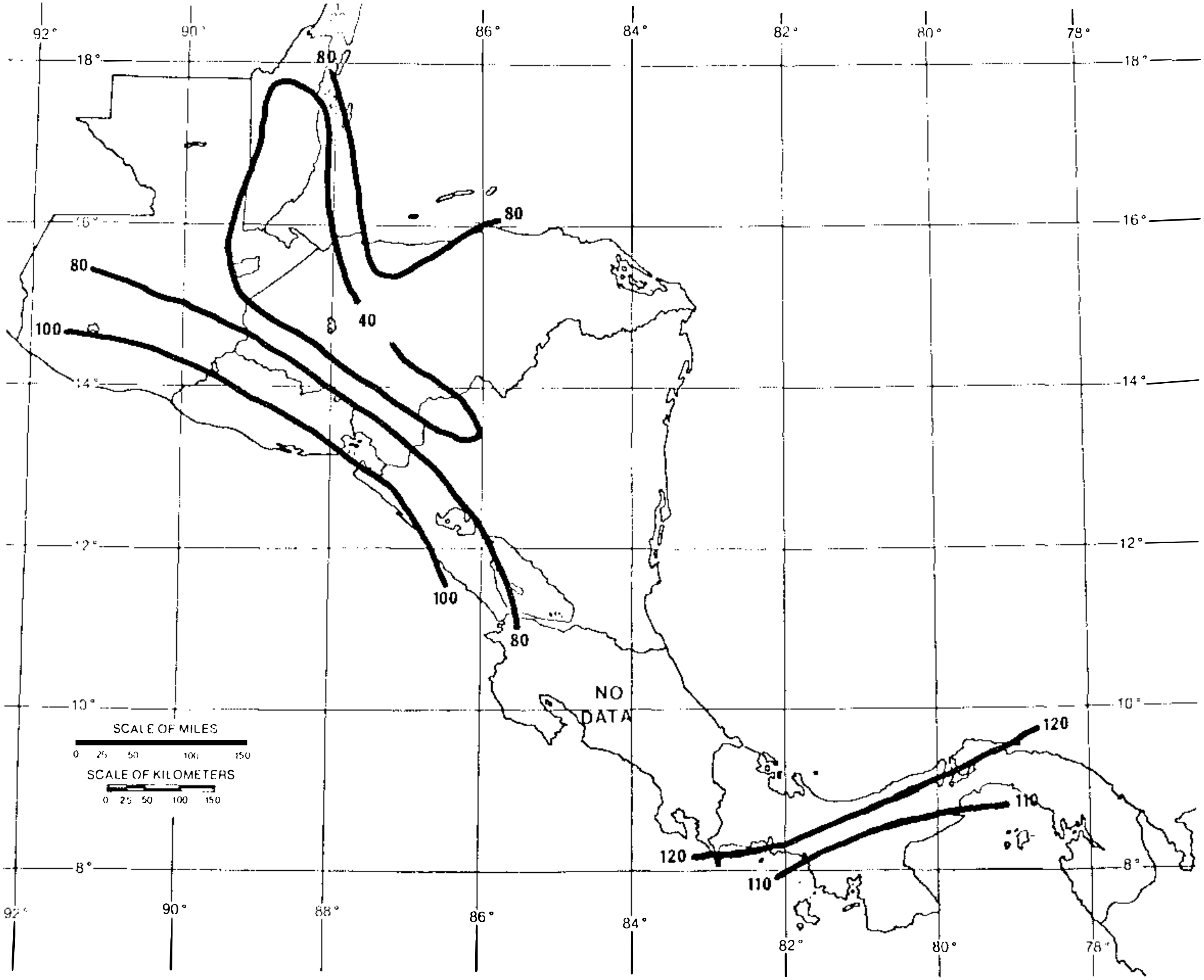

Figure 1-49. Rain rates, $R_{.01}$, expected to be exceeded 0.01% of an average year in Central America, derived from the thunderstorm ratio, $U/D_{.01}$.

Table 1-11. Absolute Value of Observed Rain Rate Deviation, ΔR, Outside Predicted 0.5 and 99.5 Percent Confidence Limits Using the Two Thunderstorm Ratio Estimating Procedures in the RH Model

Observing Station i	Data Period	Gauge Integration Time	$\lvert \Delta R_i \rvert$ at 1% Exceedance Level (mm/hr)		$\lvert \Delta R_i \rvert$ at 0.1% Exceedance Level (mm/hr)		$\lvert \Delta R_i \rvert$ at 0.01% Exceedance Level (mm/hr)		$\lvert \Delta R_i \rvert$ at 0.001% Exceedance Level (mm/hr)		Assigned Weight, W_i
	(years)	(min.)	β	$U'/D'_{.01}$	β	$U'/D'_{.01}$	β	$U'/D'_{.01}$	β	$U'/D'_{.01}$	
Miami, FL	1	1	0	0	0	0	0	0	0	0	1
Island Beach, NJ	1	1	0	0	0	0	0	0	0	2	1
Franklin, NC	1.25	1	0	0	0	0	0	20	-	-	1.25
Wallops Island, VA	4	0.03	0	0	0	0	13	0	-	-	4
Stockholm, Sweden	2	1	0	0	0	0	14	7	1	3	2
Stockholm, Sweden	2	1	0	0	0	0	0	0	19	21	2
Atlanta, GA	20	5	0	0	0	0	0	0	1	0	20
Majuro Atoll, Marshall Islands	1	1	0	0	2	9	0	15	0	0	1
Palmetto, GA (near Atlanta)	2	5	-	-	3	0	0	0	15	12	2
Paris, France	13	1	-	-	-	-	0	0	0	4	13
Tokyo (Takematsu), Japan	1	?	0	0	0	0	0	9	-	-	1
Tokyo (Kashima), Japan	1	?	0	0	0	0	14	0	-	-	1
Woody Island, Alaska	2.83	1	0	0	0	0	0	0	32	0	2.83
Paris (Montsouris), France	10	1	-	-	-	-	0	0	0	4	10
Paris (Gometz), France	1	1	-	-	0	0	0	0	49	56	1
Rio de Janeiro, Brazil	3	1	-	-	-	-	8	0	59	37	3
Blacksburg, VA	3.67	?	2	1	0	0	0	0	4	21	3.67
Tokyo (Shakujii), Japan	1	?	-	-	0	0	0	24	0	43	1
Tokyo (Sakai), Japan	1	?	-	-	1	3	0	33	3	30	1
Darmstadt, FRG	0.83	5	0	0	0	0	0	0	13	21	0.83
Average Departure, $\lvert \overline{\Delta R} \rvert$			0.10	0.05	0.13	0.17	1.62	1.65	6.02	6.94	

based upon whether the data distribution lies inside or outside the 0.5 and 99.5 percent prediction levels. This is the type of comparison made in Table 1-11. In order to put these comparisons on a quantitative basis, the absolute value of the departure, ΔR_i, outside either the 0.5 or 99.5 percent prediction value of a given observing station, i, was assessed. Zero departures were assigned if the observed distribution lies inside the predicted confidence limits. Four exceedance percentiles, 1, .1, .01, and .001 were checked in the analysis, as shown in Table 1-11. Note that the average departure, $\overline{|\Delta R|}$, in the last row of Table 1-11 gives no significant indication whether the β or the u/D prediction approach in the RH model is superior.

1.4.2 Models and Performance Prediction Methods

The direction of use of the frequency spectrum resource has generally been upward in frequency in recent years, primarily because of the relative availability of bandwidth, and the requirement of digital systems for wider bandwidths. This has led to considerable interest, both here at NTIA and elsewhere, to the usage potential of microwave and millimeter wave systems. The lower atmosphere, sometimes called the troposphere, has a considerable influence in this frequency region if existing and/or intended systems must communicate through the atmosphere. However, the surrounding terrain and even the ionosphere can exert an influence as well.

The objectives of Southern California Propagation Study addressed the somewhat lower VHF and UHF frequency ranges. These objectives were to develop plans for the measurement of VHF and UHF propagation loss, particularly under ducting conditions, and to design, fabricate, and install automated special-purpose propagation measurement and data acquisition equipment. The design was completed and four automatic propagation measurement systems were built; three were deployed in the San Diego area. Each of the systems will measure 10 signals in the frequency range of 60 to 900 MHz for about 1-1/2 years. The systems, being microprocessor controlled, proceed through an hourly cycle of self-calibration, sequential data collection, and data analysis and storage. Data summaries are printed locally, and all raw data along with the summaries and overhead information are recorded on magnetic tape. The Federal Communications Commission will collect the data tapes once per month for further analysis. The ultimate goal of the project is to develop statistics on the incidence of ducting propagation conditions at VHF and UHF in the Southern California environment.

Phase I of this project provided the FCC with an overview of the propagation phenomena involved, recommendations as to the type and amount of data needed to accomplish the overall project objectives, and descriptions and cost estimates of the equipment needed. In consultation with the FCC staff, the Institute has provided the FCC with the following specific items of information:

- a review of the propagation phenomena involved that is based on available theoretical and empirical studies and interference reports
- recommendations as to paths, recording sites, and transmitting sites required to obtain needed data
- recommendations as to signal sources
- recommendations as to desirable data sampling rates, amount of on-site data reduction, and statistical parameters to be recorded for reduced data
- recommendations as to meteorological data needed and sources.

This information was presented in an informal report to the FCC entitled "Planning for the Measurement of Propagation Phenomena in Land Mobile Frequency Bands in Southern California," dated June 2, 1980.

The objective of Phase II was to develop the design of both the receiver and the receiver control/data collection system (RCDCS) to the point where the procurement of supplies and equipment could begin and then to procure some of those supplies and equipment. Figure 1-50 is a photograph of one of the automatic propagation measurement systems.

Phase III of the project provided for the final assembly, testing, and deployment of the three systems in the San Diego area. The sites are as follows:

Site 1. Point Loma

- on Naval Ocean Systems Center property
- 32°40'03"N., 117°14'36"W., 15 m/msl (above mean sea level)
- very close (100-200 m) to the Pacific shore

Site 2. La Mesa

- on the premises of the FCC field office in La Mesa
- 32°46'08"N., 117°01'43"W., 150m m/msl
- about 15 km inland from the shore

Site 3. Cowles Mountain

- at the "head-end" of a cable TV company
- 32°48'45"N., 117°01'50"W., 475 m/msl
- about 20 km inland from the shore.

The choice of signals to be monitored at each location took into account a variety of path characteristics and, of course, the availability of signal sources. Table 1-12 gives only the frequencies of the sources to be received at each of the three receiver sites. These sources are of two types: television signals (only the video carrier is measured) and test

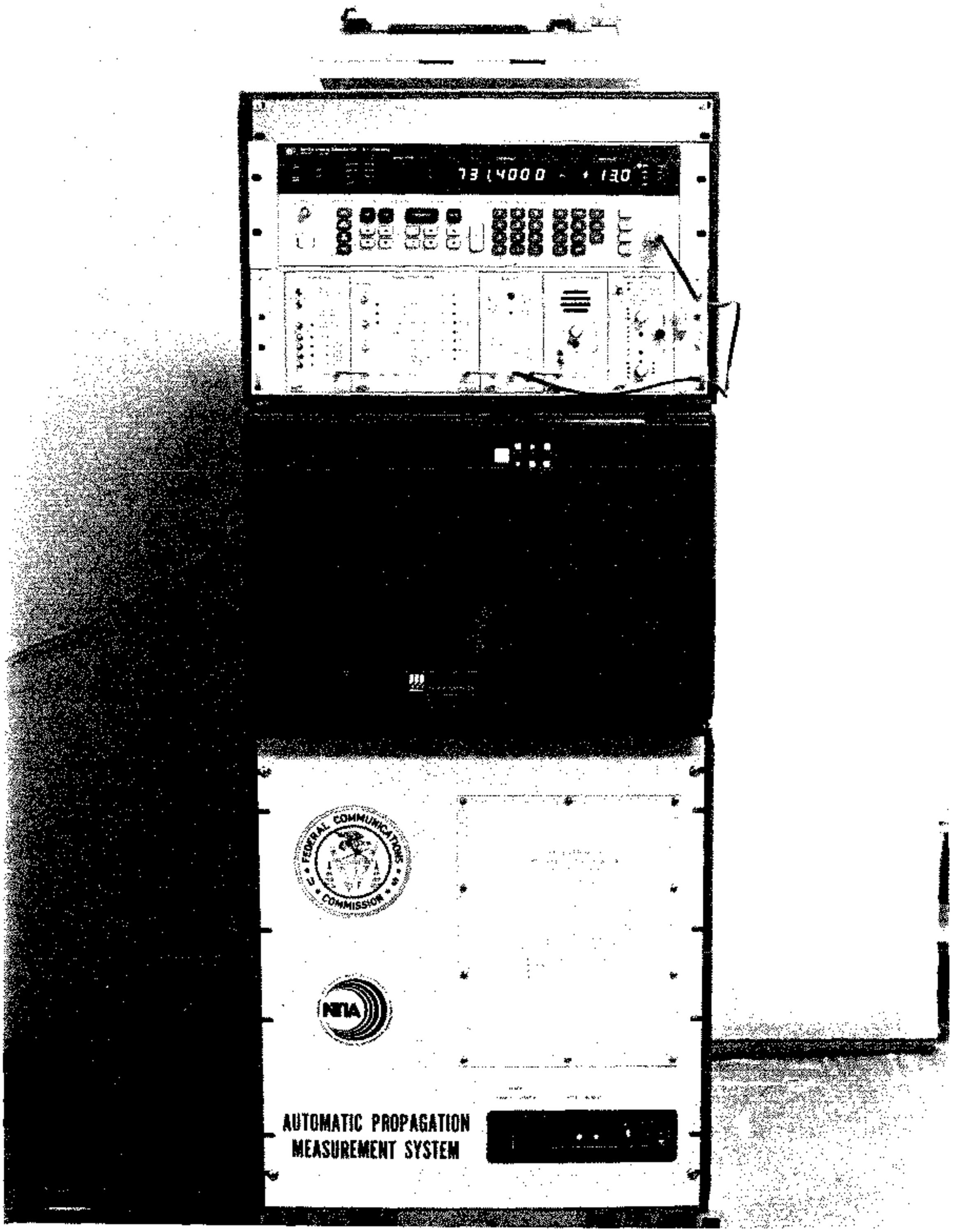

Figure 1-50. The Automatic Propagation Measurement System. Three of these are being used in the Southern California Propagation Study.

signals installed for this experiment. The last three sources listed in the table are the test sources. Nearly all of the sources are located in the Los Angeles area.

Table 1-12. Receiver Site Measurement Frequencies

Site 1 (MHz)	Site 2 (MHz)	Site 3 (MHz)
61.25	741.25	61.25
175.25	175.25	175.25
497.25	519.25	519.25
735.25	735.25	735.25
531.25	531.25	531.25
687.25	687.25*	687.25
741.25	687.25*	487.25
418.00	418.00	418.00
869.00	869.00	869.00
869.50	869.50	869.50

*This signal will be received using both horizontal and vertical polarization.

The other important path parameters associated with this selection of sources and receiver sites are terrain type, source height, and path length. Of the paths chosen, some are almost entirely over water or land (several each); most are a combination of land and water. The source height ranges from 20 m/msl to over 1800 m/msl. The path length ranges from as low as 15 km (one case) to a typical value of about 150 km, to as high as 330 km.

Phase IV of the project provided for maintenance and repair of the systems, the development of detailed system documentation, and preliminary "ducting-incidence" model development. The first task listed is self-explanatory; some repair work and a trip to the San Diego area were needed. The system documentation is the collection of all the design information, such as schematics and specifications, and manufacturers' literature. The documentation includes a full, annotated listing of the computer software. Two copies of the documentation package were given to the FCC.

Some of the reduced data is presented in Figure 1-51, which shows hourly median received signal level and hourly interdecile range for October 1981 at the La Mesa receiver from four sources. The K59AL to La Mesa path is a 24 km line-of-sight path. The KABC and KWHY to La Mesa paths are 188 km in length with a single horizon near the La Mesa receivers. The KOCE to La Mesa path is 159 km with two horizons (one mid-path and the other near the La Mesa receiver). Note the large diurnal change on the last path with nearly a 40 dB swing in received signal level. The variation for the month is approximately 50 dB. The hourly interdecile range exceeds 20 dB in some cases. The mechanism for the large change in these examples is presumably ducting. Data reduction on additional months is proceeding.

Using the data, we are exploring the correctness and pertinence of existing models such as that reported by the CCIR and planning to devise new, more extensively applicable models. One approach, for example, is to consider a standard set of possible atmospheres, to compute for each of them the consequent field strengths, and then to combine the results into a statistical distribution according to the statistical incidence of the atmospheres in the region of operation.

Another aspect of the ITS VHF/UHF modeling effort is the Extended Range Communication project. The basic concept is that a message is sent as a short burst of information. The message is first stored in a local memory device, and the system waits until a communications link to the intended receiver can be established. When propagation conditions are sufficiently good, the message is quickly transmitted. The basic concept here has been known before; this is how a meteor-burst communications system works. The new aspect in this study is the application of the burst concept to terrestrial (groundwave or troposcatter) radio propagation at VHF and UHF.

Several protocols for establishing the required link are possible. One that comes immediately to mind is presently used in the "meteor burst communication" systems that make use of the intermittent appearance of meteor trails in the ionosphere. In such a system, when a "master" station wishes to receive a message, it "polls" one or more sending units by periodically transmitting a command signal. When a sending unit receives one of the command signals, it can assume there exists a suitably placed meteor trail and that propagation conditions are satisfactory. It immediately transmits its message before the meteor trail has had time to disperse.

There are two main aspects to this project. One is to develop a meteor-burst model and then to implement it as an interactive computer program. The other aspect is to study the feasibility of using burst transmissions in situations where the usual modes of radio propagation are operating. There are several parts to this feasibility study: field measurements to demonstrate the principle, an examination of how to use the received signal statistics, computations of the range extension, and suggestions for future work. These topics will be discussed in the paragraphs below beginning with the meteor-burst model.

A communication channel can be established by reflection from one or more of the billions of meteor trails formed daily in the earth's atmosphere between 80 and 120 km. This channel will function in the frequency range of 30 to 120 MHz and for terminal separations of 200 to 2000 km. Typically, a meteor trail with the right geometry to provide reflection will be available every few to tens of seconds and will last a portion of a second. Although these signal durations and waiting times would be unacceptable for analog voice, digital information requiring a low throughput can appear to be almost continuous to a user. One benefit of a meteor-burst communication system is that transmissions are relatively secure because there is only a small probability that a second receiver would have a simultaneous and properly oriented trail.

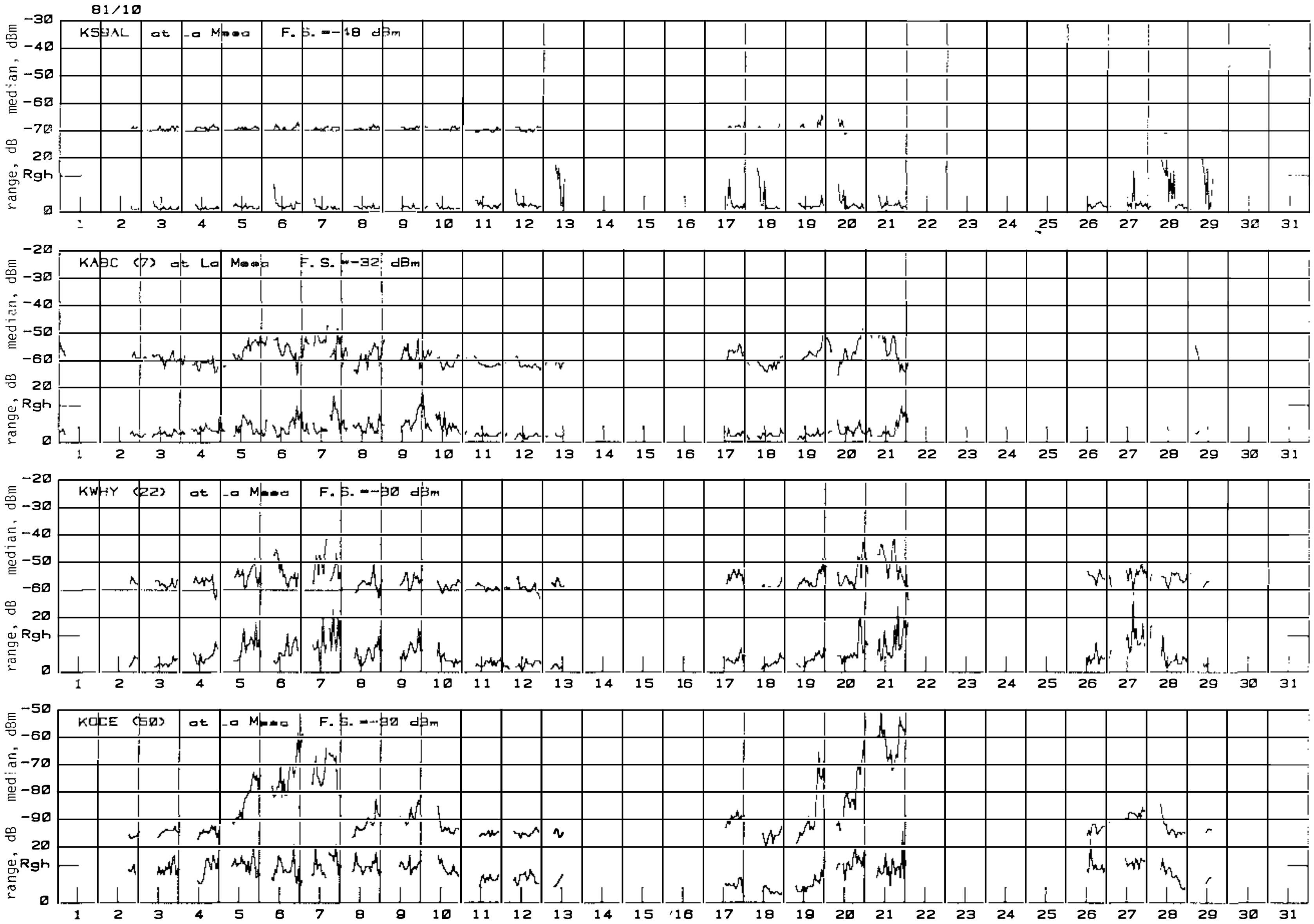

Figure 1-51. Measured values of hourly medians and hourly interdecile ranges for signals in suspected ducting environments.

The Institute has developed a Meteor Burst Communications Model, which is a user-interactive computer model. The model predicts the waiting times required to complete the transfer of messages from a master station to a remote station as a function of the frequency, transmitter, and receiver characteristics, system protocol, distance, time of year, and time of day. This model can also predict the waiting times for a network of stations, e.g., a master, a remote, and two relays, each with its own user-defined system parameters. Figure 1-52 shows the model input and output for a transmitter and receiver separated by 1300 km. The first section of the figure lists the input parameters that were entered by the user; the second section lists the computed values and gives a table of the waiting times for seven message lengths. This length is the duration of a complete message transfer rather than for an interrupted channel. For example, at 2000 bits per second and 7 bits per character, a 200 ms message would contain about 60 characters or roughly one line of text. As can be seen in the table of waiting times, with a 99 percent reliability, the one line of text will be received within 15 s in the morning and within 24 s in the evening. Radio system designers can use this model to develop system and siting parameters for meteor-burst communications systems.

Work so far on the feasibility study has shown that the burst transmission concept is probably most useful in the land-mobile service where one can take advantage of the well-known propensity for signal levels to vary significantly as a mobile unit moves. The usual system is designed with a large fade margin to counter this variability. A system employing burst transmission can dispense with this fade margin and perhaps even operate on the negative side where it anticipates higher than average signal levels. We estimate that the signal advantage would be between 20 and 40 dB and that the system range might be extended by a factor of 1.5 to 3.

There is, of course, a price to pay for the range extension. Usually a given message will not be sent immediately but will need to wait while the mobile unit moves to a suitable location. The distance required to find this location we call the "waiting distance." It is a random variable related to the autocorrelation function of received signal levels. Preliminary measurements indicate that to gain the advantages given above, the system would need to wait, at most, 5 to 10 km before 90 percent of the messages would have been sent.

The measurements mentioned above were made in the Boulder, CO, area at the nominal frequency of 50 MHz. The configuration of one fixed and one mobile terminal was used. Some of the data has been used to compute the location variability, and there are limited examples of some time variability.

The needs for future work fall into two areas: a better understanding of "low-percent" data for the usual propagation mechanisms (i.e., troposcatter) and some study of unusual propagation mechanisms (i.e., off-path reflection or ducting). The first aspect could be approached by determining the weaknesses of existing propagation models. The ultimate terrestrial burst-transmission system or model should allow for some adaptability in system protocol. This would allow the use of the system in a wider range of conditions.

In the past several years, the telecommunications community has experienced a renewed and critical emphasis in virtually all areas of command, control, and communications. Recent advances in meteor burst communication systems have shown this means of communications is simple, reliable, and cost effective at times when this availability of conventional systems is questionable. This has been proven by the Department of Agriculture's SNOTEL system and the Alaskan meteor burst communications system. Figure 1-53 depicts the meteor-scatter communications channel environment.

The performance of a meteor-burst link is usually defined as the waiting time required to transfer a message between two stations at a specified reliability. A second index of performance is the average words per minute that can be transferred over a period of time. The critical system parameters that will influence performance are operating frequency, data rate transmitter power, antenna gain, receiver threshold, system protocol, separation distance, time of year, and time of day.

A user-interaction computer model ("Meteor Burst Communications Model," by Haakinson, NTIA Report 83-116) was developed to predict the reliability of such a system.

The Meteor-Scatter Propagation Study was an initial investigation into a series of current meteor scatter system tests to determine if the data collected could be useful in verifying or updating this model. Evaluation of the test and data acquisition plan indicated that the available data would not be sufficient to completely verify the model. Enhancements to present test plans were proposed for future tests in order to provide all the required data. A letter report was submitted to the project sponsor with the details of these recommendations in anticipation of further testing in the near future.

Until this year, Boundary Studies were conducted under the auspices of NTIA and coordinated with NSA under the Communications Protection Program. The Communications Protection Program was originated with Presidential Directive (PD-24) to provide protection to sensitive civilian and Government information that was not related to national security (DoD). Since the Communications Protection Program (NTIA) was terminated at the end of FY 82, NSA decided to extend support for the continuation of the Boundary Studies portion of the Communications Protection Program.

The major objective of the Boundary Studies is to determine a meaningful threshold distance to which common carrier microwave systems can be received. Specifically, the question that must be answered is: which transmitters can be received by an unauthorized receiver system? In order to answer this question it should be noted that the receiver may well be content to have usable reception much less

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                      METEOR BURST COMMUNICATIONS

(a)                         INPUT PARAMETERS
                            ----- ----------
                                         MASTER  REMOTE
    FREQUENCY                             30.0    30.0 MHZ
    TRANSMIT POWER                        30.0    30.0 DBW
    TRANSMIT LINE LOSSES                   2.0     2.0 DB
    TRANSMIT ANTENNA OPTION               GAIN    GAIN
    TRANSMIT ANTENNA GAIN                 15.0     7.0 DBI
    RECEIVE ANTENNA OPTION                GAIN    GAIN
    RECEIVE ANTENNA GAIN                  15.0     7.0 DBI
    ANTENNA CIRCUIT LOSSES                 0.0     0.0 DB
    RECEIVE LINE LOSSES                    2.0     2.0 DB
    RECEIVE NOISE FIGURE                  10.0    10.0 DB
    IF BANDWIDTH                           2.0     2.0 KHZ
    REQ'D PRE-DETECTION S/N RATIO          3.0     3.0 DB
    LOCATION DESCRIPTION           QUIET RURAL    QUIET RURAL
    MESSAGE TRANSFER                   MULTIPLE BURST MODE
    SYSTEM OVERHEAD PER BURST             83.0    83.0 MS
    USER-DEFINED MESSAGE LENGTH                   75.0 MS
    DISTANCE BETWEEN MASTER AND REMOTE          11318. KM
                                                7034.2 S MI
    COMPUTED SYSTEM NOISE POWER         -120.8  -120.8 DBM
    MONTH OF OPERATION                           MAY

(b)                         OUTPUT PARAMETERS
                            ------ ----------

        POWER FACTOR = TRANSMIT POWER - TRANSMIT LINE LOSSES
                       + ANTENNA GAINS - (SYSTEM NOISE POWER
                       + REQD SIGNAL-TO-NOISE RATIO)

        THE MASTER-TO-REMOTE LINK POWER FACTOR = 197.8 DB
        THE REMOTE-TO-MASTER LINK POWER FACTOR = 197.8 DB
        THE WAITING TIME CALCULATIONS ARE BASED
        ON THE SMALLER POWER FACTOR.

        THE AVERAGE METEOR BURST DURATION =         .1 SEC

            COMPLETE MESSAGE TRANSFER BY MESSAGE PIECING
                         ON MULTIPLE BURSTS

   LOCAL                               WAITING TIMES NOT EXCEEDED
   TIME                                 FOR 99.00% OF THE TIME
  MIDPOINT                             FOR THE GIVEN MESSAGE TIME
  BETWEEN       AVERAGE       USER-
   MASTER      INTERVAL      DEFINED
    AND          BETWEEN         75    50   100   200   400   800  1600
   REMOTE       BURSTS           MS    MS    MS    MS    MS    MS    MS
  --------      --------     ------------------------------------------
                  (SEC)         (SEC) (SEC) (SEC) (SEC) (SEC) (SEC) (SEC)

       0           5.2           42    40    44    53    67    91   137
     200           4.5           37    34    39    46    58    81   120
     400           4.3           35    33    37    44    56    77   116
     600           4.9           40    37    42    49    63    88   130
     800           6.0           49    46    51    60    77   107   158
    1000           6.9           56    53    58    70    88   123   183
    1200           8.3           67    63    70    84   107   148   221
    1400          10.9           88    84    95   113   141   197   292
    1600          13.3          109   102   113   134   172   239   359
    1800          13.3          109   102   113   134   172   239   359
    2000          10.8           88    83    91   109   141   193   288
    2200           6.7           54    51    56    67    86   120   179
```

Figure 1-52. Meteor-burst communication model input parameters (a) and output parameters (b).

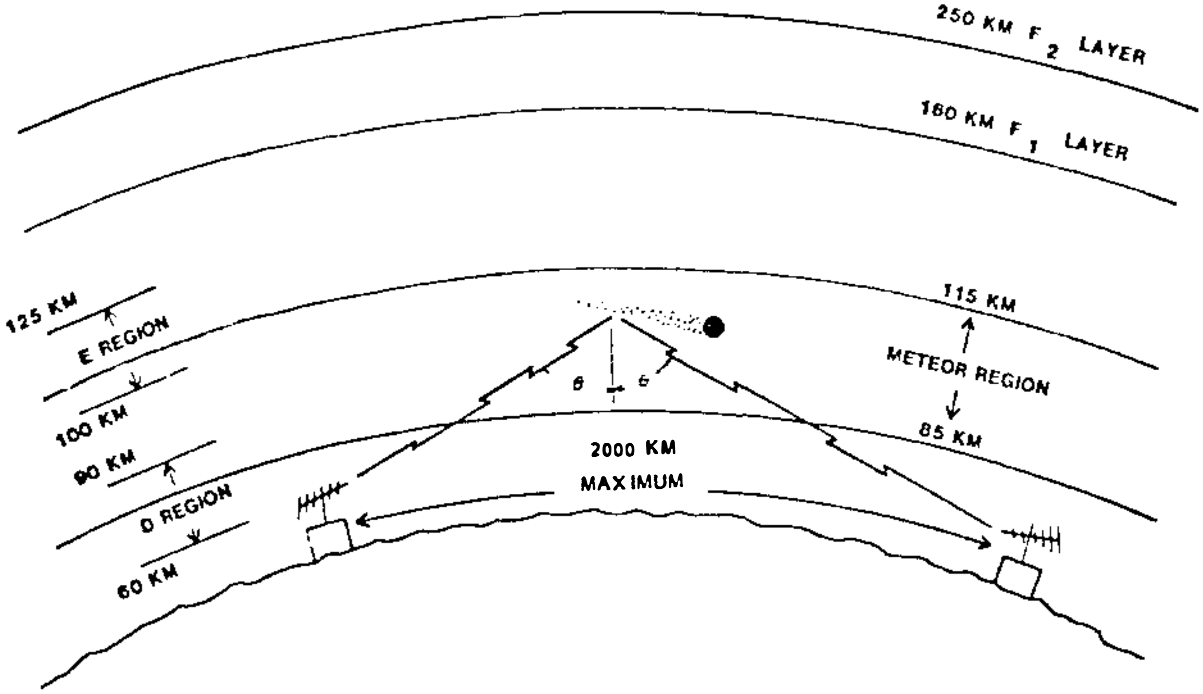


Figure 1-53. Meteor-scatter communications channel environment.

than 100 percent of the time and also may accept reception for only one-half of the conversation (this occurs when one end of the transmission link is not receivable because of obstructions such as topography or buildings in the receiver's path). In order to predict when usable signals will be available. it is necessary to obtain the antenna type of expected antenna gain pattern for 360°. This is necessary since the likelihood of a receiver being located in the main beam is relatively small. Then it is necessary to obtain the path profile from topographical data to determine extent of path blockage. Also, special propagation models are needed to accurately assess the propagation losses that occur under less-than-desirable conditions. Finally, an assessment needs to be made regarding the unauthorized receiver station characteristics, which includes antenna (size and type), receiver sensitivity, and minimum signal-to-noise requirements.

The Institute has developed a Multiple Knife-Edge Diffraction model that will calculate microwave propagation attenuation for up to ten obstacles in any given path. The Multiple Knife-Edge Diffraction model utilizes a generalized residue series formulation for the propagation of electromagnetic waves over a sequence of smooth and rounded obstacles, which can be treated as knife-edges at microwave frequencies. The resulting expression is in the form of a multiple integral. This expression is transformed into a series representation through the use of repeated integrals of the error function in the report by L.E. Vogler, "The Attenuation of Electromagmetic Waves by Multiple Knife-Edge Diffraction," NTIA Report 81-86, October 1981. The solution and computer implementation constitutes a significant breakthrough in propagation analysis of multiple diffraction propagation problems. The model has been used to compare predictions with propagation measurement and has resulted in good agreement. Comparisons were made with previously written double and triple knife-edge programs again with very good agreement. This model will serve as an excellent means of determining propagation losses for microwave frequencies.

A composite large-scale computer program has been developed at ITS that utilizes the Multiple Knife-Edge Diffraction model, the analytical expressions for common carrier antenna patterns, and computer data base that provides topographical information for selected areas in the United States. This information, coupled with transmitter and receiver antenna heights and types, transmitter power levels, receiver sensitivity, and distance between transmitter and receiver provides a very versatile propagation analysis tool that meets all the special requirements of calculating communication boundaries. This computer program can be readily adapted to a wide variety of applications and, since it is automated, large numbers of propagation paths can be readily analyzed.

Some earlier Boundary Studies used only two antenna types--Western Electric KS-15676 and the CCIR standard parabolic antenna. This necessitated determining two separate boundaries on the assumption all transmitters used only one type of antenna at a time. The new Boundary Studies only determine one boundary for a given frequency band. This resulting boundary is based on the antennas that are actually in use. The two studies considered this year include the reanalysis of two areas and two frequency bands that had been characterized previously by the earlier boundary studies. The ITS computer program and analysis capabilities were provided to the sponsor during this fiscal year (FY 83).

In the HF portion of the spectrum, the Ionospheric Communications Analysis Prediction Program (IONCAP) is the most recent of the prediction programs developed at ITS. The computer program is an integrated system of subroutines designed to predict high-frequency sky-wave system performance and analyze ionospheric parameters. These computer-aided predictions may be used in the planning and operation of high-frequency communication systems using sky waves.

In the initial planning, or in the modification of many communication systems, there may be an appreciable delay between the circuit planning and the actual circuit construction or modification. This is of particular importance for high-frequency circuits with marked time and geographic variations in optimum frequency, required power, and system performance.

Predictions of ionospheric characteristics and techniques for using these characteristics are available and may be used to anticipate the performance of HF communication circuits and thereby provide the lead time for necessary equipment selection, frequency selection, and frequency and time-sharing arrangements.

Specific modeling efforts included in the IONCAP program are:

- A complete, explicit electron density profile. While this function is not measurable, the integration of the profile to give an ionogram is. These prediction ionograms have been checked against measurements.
- For oblique ray paths, Martyn's theorem has been corrected for a curved ionosphere. The correction was derived to assure agreement with full ray tracing using the same electron density profile.
- Explicit sporadic-E modes have been added to the program. The model is composed of subparts that have been derived from and tested against measurements over the past 30 years.
- A revised median loss model has been created. The same basic equation is used, but an additional term is added for E modes, and a revision of the collision frequency term for modes with reflection heights within the absorbing region added. Also, a deviative loss term is added to high angle modes (these are also an addition to the program). The revision as well as the total loss equation was compared to field strength measurements.

- An MUF model has been added that directly calculates the values rather than searching for the correct value. The complete electron density profile is used. The distribution of the MUF over a specified month for each possible layer is now included.
- The distribution of transmission loss has been extended to vary with each operating frequency and with each type of mode. This allows the extension of statistical system performance upward in frequency.
- Some modifications to the antenna models have been made, the most significant being for vertical antennas that are electrically short.
- The complete set of models for long paths, as described above, have been added.

A major effort is currently in progress to replace all of the antenna models used in the IONCAP program.

The IONCAP program or calculations using the program are available from the Institute. The program has been supplied to several foreign and domestic government agencies and to the private sector.

For the past three years a substantial effort has been devoted to the development of antenna models and a program code to be used with the IONCAP program. The major intent is to create an antenna package to be used with the HF sky-wave predictions. This HF Antenna Simulation project permits the analysis of antenna models using two logical subdivisions:

1. the exterior (radiation) problem, which deals with the interaction of the antenna with the propagation medium; and
2. the interior (circuit) problem, which deals with the interaction of currents, voltage, etc., within the antenna system itself.

The work during this year consisted of finalizing the subprograms for traveling wave antennas and writing the final report on the theory and use of the antenna module. The report includes the general theory of sky-wave antenna patterns, the derivation of the models for each antenna type, the use of the computer program, and advice on the use and limitation of each particular antenna type. Comparisons of computed patterns with published patterns are given where available. The report entitled "Computation of Linear Communication Antennas" is expected to be published by the end of 1983.

The report is intended to be documentation of antenna models intended for use with the HF sky-wave propagation prediction program, IONCAP. It is not intended to be a general antenna design guide or user's handbook. The major elements of this report are:

- the derivation of all radiation pattern equations and comparison with published equations if available
- the clarification of the use of the radiation resistance equations and reference to their source
- the clarification of the normalization of the reflection coefficients and their use with the ground reflection factors
- the simplification of the models for use with the prediction program and the resultant stability of the computer code.

In an effort to increase the usefulness of computerized HF prediction programs for system applications, ITS has developed a ground-to-air prediction program that incorporates ground-wave propagation as well as sky-wave propagation. The program is described in detail in NTIA Report 83-131 entitled "An Air-to-ground HF Propagation Prediction Model for Fast Multicircuit Computation," by Stewart et al. The computer code has been optimized to permit rapid calculation of ground-wave and sky-wave field strengths. The calculations are performed using, as a basis, the ground-wave program developed by Les Berry and described in OT Technical Memorandum 78-247 entitled "User's Guide to Low-Frequency Radio Coverage Programs" and the sky-wave program referred to as HFMUFES that is described in the report ERL 110-ITS 78 by Barghausen et al.

The general approach to increasing the operating speed of the HF predictions program HFMUFES is to precalculate as many ionospheric parameters as possible for a given area of interest. The ionospheric parameters such as foF2, h'F2, fOES, etc., are precalculated for a grid of points that encompasses all the path control points. Then, for any communications link whose control points fall inside this grid, a linear interpolation is done to get the ionospheric parameters. This eliminates the necessity for evaluating large numerical series and reduces the cost of calculating communications path performance.

The initial ground-wave model required a rather large memory assignment, and execution time for a given communications link was unacceptable. To achieve the program size and speed, the following procedure was developed. Loss curves were plotted in the range of 2 MHz to 30 MHz for 0 km to 2000 km. These plots were made for antenna heights from 1 m to 50 km, a fixed antenna type (vertical), and ground constants (conductivity = .005 MHO/meter, dielectric constant relative to free space - 10.0).

Numerical equations were fit to the plotted curves and the coefficients of these equations were placed in a subprogram for evaluation. For a given antenna height, frequency, and distance, a linear interpolation between coefficients is done, and the resulting coefficients are evaluated for the ground-to-air loss.

Because of the heavy reliance in HF propagation prediction programs on numerical coefficients to represent the ionospheric parameters, ITS constantly seeks ways to improve the accuracy of the coefficients. As part of the Ionospheric Mapping project, a new set of coefficients to represent the global variation of the F2-region critical frequency, foF2, has been developed. These coefficients have been derived by combining observed monthly median values of foF2 with theoretical values of foF2 derived using the time-dependent continuity equation for ions and electrons in the ionosphere. The method used to derive the new coefficients and a description of the use of the time-dependent continuity equation to generate theoretical values of foF2 has been described in detail in a January-February 1983 Radio Science paper entitled "Improving ionospheric maps using theoretically derived values of foF2" by Rush et al. Coefficients have been determined for each month from July 1975 through June 1976 and July 1978 through June 1979. The 1975/1976 coefficients can be used to derive global values of foF2 that are representative of solar minimum conditions. The 1978/1979 coefficients are used to derive global values of foF2 that are representative of solar maximum conditions. Figures 1-54 and 1-55 illustrate the global variation of the median value of foF2 derived from the coefficients for September 1975 and September 1978 at 0600 hours universal time. Currently ITS is studying how these coefficients can be used to predict the appropriate values of foF2 throughout the entire solar cycle.

HF Propagation Study/Tactical Operation Chart Procedures. For several years, ITS has provided support to the U.S. Army Communications Command-Electronics Engineering Installation Agency (USA/CEEIA) in technical areas pertaining to HF propagation and numerical simulation of HF propagation system performance. In addition to providing technical assistance, ITS has accepted specialized studies in support of USA/CEEIA objectives and operational requirements. In particular ITS has developed and/or implemented specific analytic techniques to assist USA/CEEIA in the development of operational and analytical procedures.

The study undertaken was directed toward the development and implementation of processors that generate tactical operation charts from the IONospheric Communication Analysis and Prediction Program (IONCAP). The project supports the operational requirements of the U.S. Army Communications Command by providing specific methodology to the Communications Engineering Directorate (CED) Propagation Engineering Division (PED). This methodology allows CED/PED to supply the 5th Signal Command with detailed tactical charts of propagation predictions for HF communication paths in Europe and specific tactical charts of propagation predictions for the Special Forces Burst Communications System.

One task of this project was to develop and implement processors that generate tactical operation charts from the IONospheric Communications Analysis and Prediction Program (IONCAP) as a unique representation of maximum usable frequency (MUF) and frequency of optimum traffic (FOT) dependent of path length and the lowest usable frequency (LUF) dependent of path length, emission type, and transmitter power. These predictions will be generated every two hours. This task requires the development of a specialized input processor, output processor, and interface to the IONCAP program. The methodology developed in this task provides the ability to generate detailed tactical charts of propagation predictions for the U.S. Army 5th Signal Command.

Another task of this project was to develop and implement processors that generate tactical operation charts from IONCAP as a unique representation of reliability and multipath probability dependent of time and frequency. These predictions are generated for each hour (UT) and at discrete frequencies from 2 MHz to 30 MHz. This task requires the development of a specialized output processor and interface to the IONCAP program. The methodology developed in this task provided specific tactical charts of propagation predictions for the U.S. Army Special Forces Burst Communications System.

Army AG and ISD Books. The U.S. Army, in its tactical operations, makes extensive use of high-frequency communication. To assure this communication, it is desirable to be able to select the proper operating frequency at any time in many geographic locations for the specific equipment involved. This selection process has been assured by "Intermediate and Short Distance Sky-Wave Propagation Charts." Improvements in the performance of sky-wave systems as a result of recent operational experience with over-the-horizon radars permits a revision of these propagation charts to reflect these propagation prediction improvements. A revision of the "Intermediate and Short Distance Sky-Wave Propagation Charts" has been undertaken for the U.S. Army. The revised charts involve 33 different geographic areas covering most land masses. The predictions are provided in 33 volumes, one volume for each of the areas shown in Figure 1-56.

The Maximum Usable Frequency (MUF), the Optimum Traffic Frequency (FOT), and the Lowest Usable High Frequency (LUF) are presented for six seasonal intervals, for each hour of local time, six distance intervals, and for solar activity extremes of a normal solar cycle. Figures 1-57 and 1-58 are examples of the ISD sky-wave propagation charts.

In addition to the tactical operations, sky-wave propagation information is required to assure the proper frequency selection for communications between aircraft and the base stations. This sky-wave propagation information has been provided as "Air/Ground Sky-Wave Propagation Charts for Selected Worldwide Stations." These charts have been prepared for 55 air-base stations to essentially provide worldwide coverage.

The maximum frequency expected to be available for sky-wave propagation on at least 50 percent of the days (the MUF) is predicted for each ground station in a series of eight pages of charts. The charts are divided into tables that correspond to the 32 sectors as shown on the example map in Figure 1-59. Each table shows the MUF for various increments of distance at each even hour of Greenwich Mean Time (GMT) and at the solar activity extremes of a normal solar cycle, i.e., at solar activity indices of sunspot numbers 10 and 110. The seasonal variation of the MUF is shown in a series of charts, each for a 2-month interval.

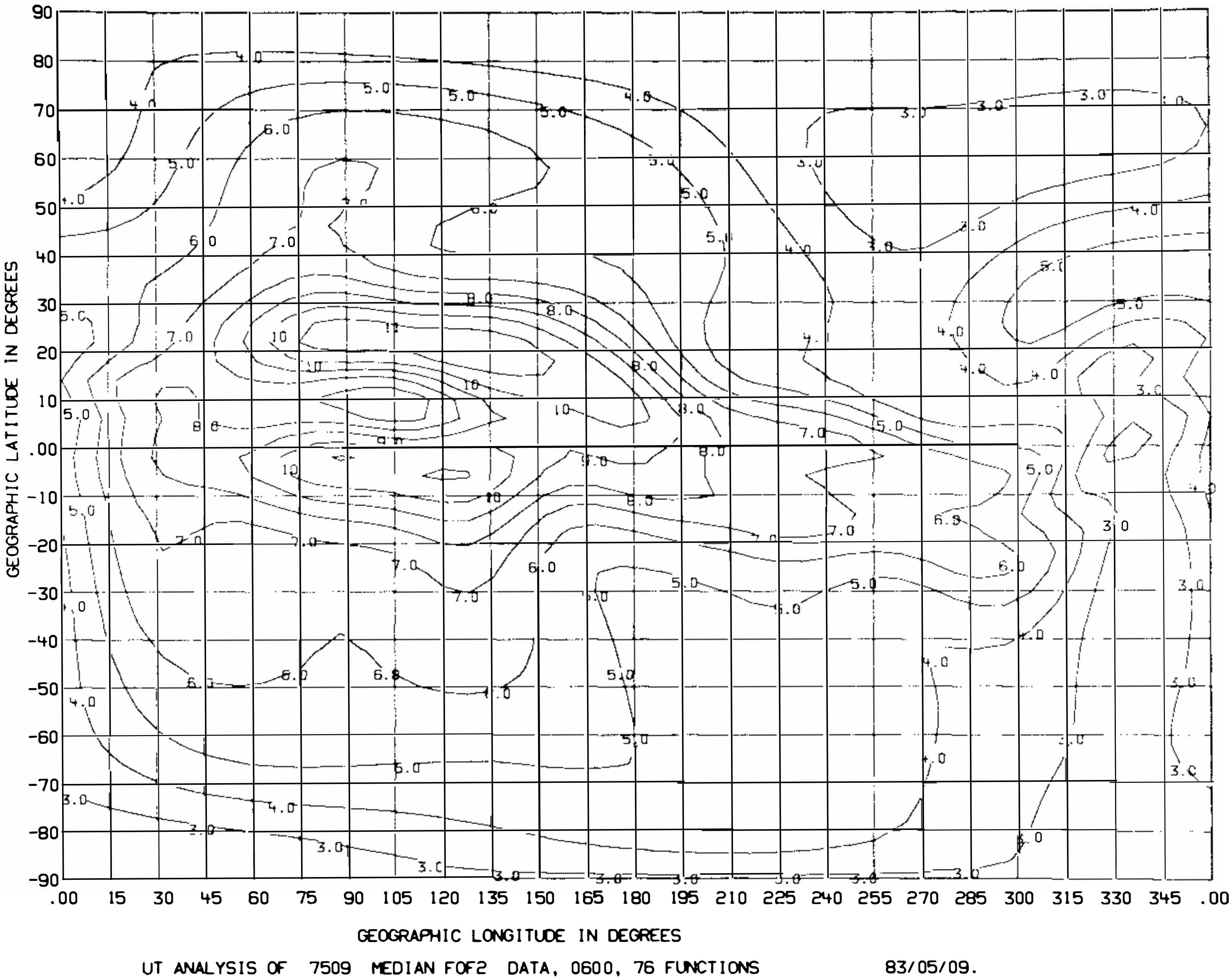


Figure 1-54. Contours of the Monthly Median Values of foF2 (in MHz) at 0600 UT for September 1975.

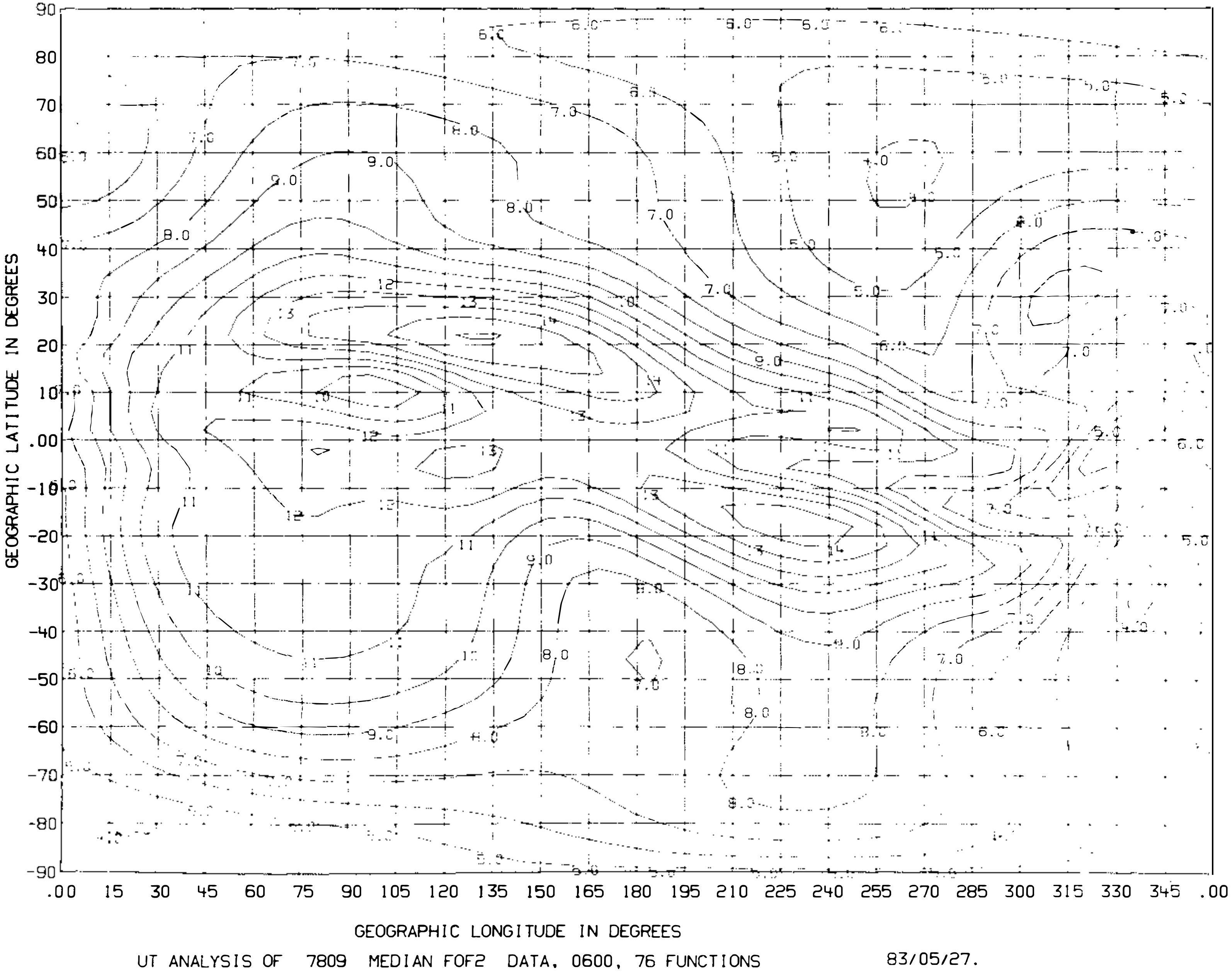
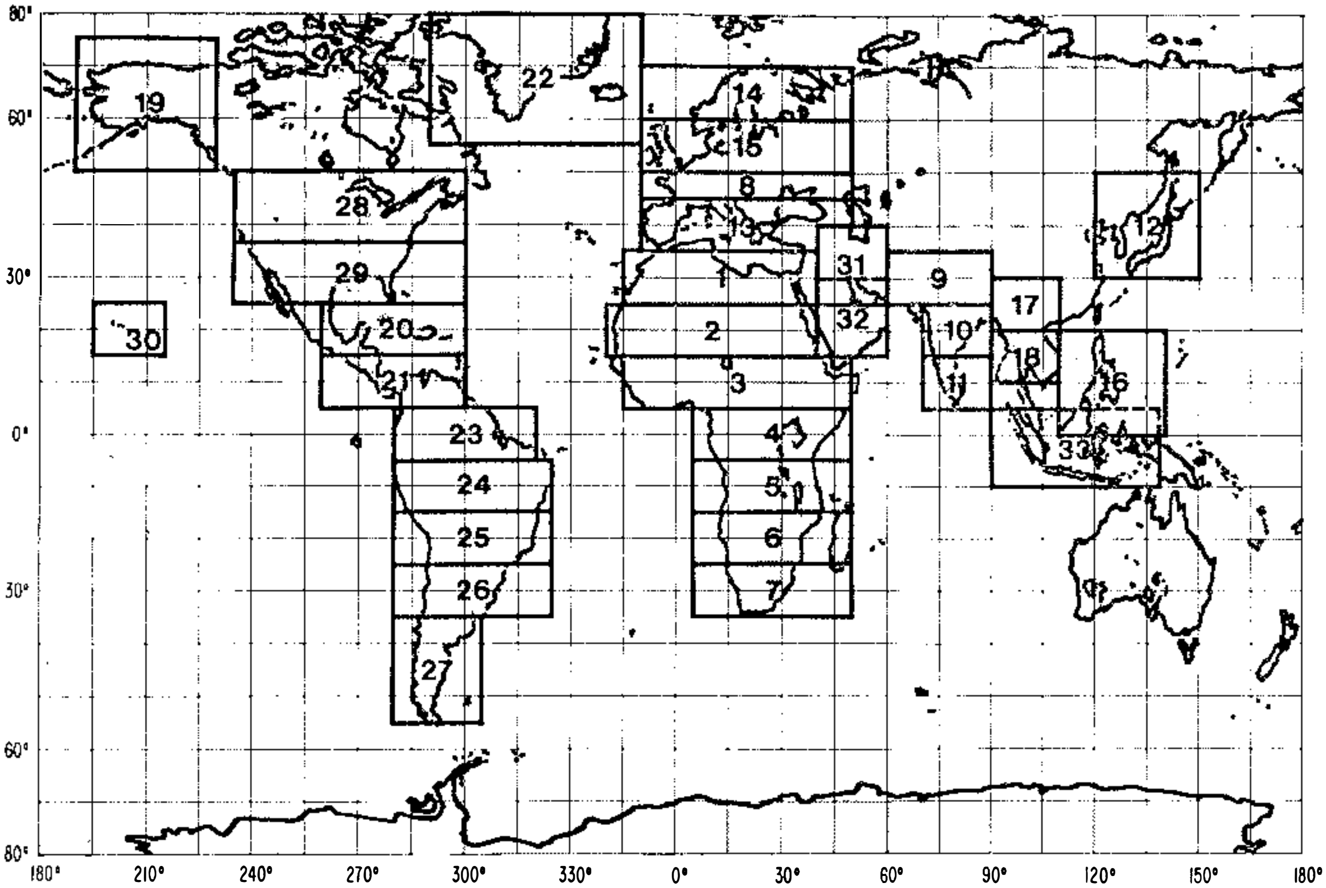


Figure 1-55. Contours of the Monthly Median Values of foF2 (in MHz) at 0600 UT for September 1978.



1. AFRICA I
2. AFRICA II
3. AFRICA III
4. AFRICA IV
5. AFRICA V
6. AFRICA VI
7. AFRICA VII
8. CENTRAL EUROPE
9. INDIA I
10. INDIA II
11. INDIA III
12. JAPAN-KOREA
13. MEDITERRANEAN
14. NORTH EUROPE I
15. NORTH EUROPE II
16. PHILIPPINES
17. SOUTHEAST ASIA I
18. SOUTHEAST ASIA II
19. ALASKA
20. CARIBBEAN I
21. CARIBBEAN II
22. NORTH ATLANTIC
23. SOUTH AMERICA I
24. SOUTH AMERICA II
25. SOUTH AMERICA III
26. SOUTH AMERICA IV
27. SOUTH AMERICA V
28. UNITED STATES I
29. UNITED STATES II
30. HAWAII
31. IRAN
32. SAUDI ARABIA
33. INDONESIA

Figure 1-56. ISD book geographic areas.

MAXIMUM USABLE FREQUENCIES (MUF)

OPTIMUM TRAFFIC FREQUENCIES (FOT)

JANUARY FEBRUARY

	160 KM. (100 MI.)				400 KM. (250 MI.)				800 KM. (500 MI.)				1200 KM. (750 MI.)				1600 KM. (1000 MI.)				2400 KM. (1500 MI.)			
	SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110	
LT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT
01	4.2	3.3	5.1	3.9	4.7	3.7	5.5	4.3	6.3	4.9	7.1	5.6	8.0	6.3	9.0	7.0	9.7	7.5	10.8	8.4	12.3	9.6	13.8	10.7
02	4.4	3.0	4.9	3.4	5.0	3.4	5.4	3.8	6.7	4.5	6.9	4.8	8.6	5.8	8.7	6.1	10.4	6.9	10.4	7.3	13.1	8.8	13.2	9.3
03	4.4	2.9	4.8	3.4	4.9	3.3	5.2	3.7	6.6	4.4	6.6	4.6	8.4	5.7	8.3	5.8	10.2	6.8	9.9	7.0	12.9	8.6	12.7	8.9
04	4.0	2.6	4.5	3.1	4.4	3.0	4.8	3.4	5.8	3.9	6.0	4.2	7.5	5.0	7.5	5.2	9.0	6.0	8.9	6.3	11.4	7.6	11.4	8.0
05	3.6	2.4	4.2	3.0	4.0	2.7	4.5	3.2	5.3	3.5	5.7	4.0	6.7	4.5	7.1	5.0	8.1	5.4	8.5	5.9	10.3	6.9	10.8	7.6
06	4.0	3.4	5.2	4.6	4.4	3.9	5.6	5.0	5.9	5.1	7.2	6.4	7.6	6.6	9.0	8.0	9.1	7.9	10.8	9.6	11.7	10.2	13.8	12.3
07	5.1	4.4	7.5	6.7	5.8	5.0	8.3	7.4	7.8	6.8	10.8	9.6	10.1	8.8	13.8	12.3	12.3	10.7	16.6	14.8	15.7	13.6	21.2	18.9
08	6.3	5.5	10.1	9.0	7.2	6.2	11.2	10.0	9.9	8.6	14.9	13.3	12.8	11.1	19.1	17.0	15.5	13.5	23.8	20.5	19.8	17.2	29.5	26.3
09	6.9	6.8	11.6	10.3	7.9	6.9	12.9	11.5	10.9	9.5	17.1	15.2	14.2	12.4	21.9	19.5	17.3	15.0	26.5	23.6	22.0	19.2	34.0	30.2
10	7.2	5.4	11.9	10.6	8.2	6.1	13.1	11.7	11.2	8.4	17.3	15.4	14.5	11.3	22.1	19.6	17.6	13.4	26.6	23.7	22.5	16.9	34.2	30.5
11	7.5	5.6	11.9	10.6	8.4	6.3	12.9	11.4	11.3	9.0	16.6	14.8	14.5	12.1	21.0	18.7	17.5	14.3	25.3	22.5	22.5	16.9	32.6	29.0
12	7.8	5.9	11.9	10.6	8.7	6.5	12.8	11.4	11.5	9.3	16.2	14.4	14.7	12.5	20.2	18.0	17.7	14.7	24.3	21.6	22.8	17.1	31.2	27.7
13	7.9	5.3	11.8	10.5	8.8	6.6	12.6	11.2	11.6	9.1	15.8	14.1	14.8	12.3	19.7	17.6	17.8	14.5	23.6	21.0	22.9	17.2	30.3	27.0
14	8.0	6.1	11.5	10.3	8.8	6.8	12.4	11.0	11.8	9.1	15.5	13.8	15.0	11.6	19.4	17.2	18.2	14.0	23.2	20.6	23.3	17.9	29.7	26.5
15	8.1	6.2	11.3	10.1	9.1	7.0	12.2	10.8	12.1	9.3	15.3	13.6	15.6	12.0	19.1	17.0	18.8	14.5	22.9	20.4	24.1	18.5	29.4	26.1
16	8.1	6.2	11.1	9.9	9.1	7.0	12.0	10.7	12.3	9.5	15.3	13.6	15.9	12.2	19.2	17.1	19.2	14.8	23.0	20.5	24.6	18.9	29.5	26.2
17	7.3	5.6	10.7	9.6	8.4	6.4	11.7	10.4	11.5	8.9	15.1	13.4	14.9	11.5	19.0	16.9	18.0	13.9	22.8	20.3	22.9	17.7	29.3	26.0
18	5.9	4.7	10.0	8.3	6.8	5.4	11.0	9.1	9.4	7.4	14.3	11.9	12.2	9.7	18.1	15.0	14.8	11.7	21.8	18.1	18.8	14.9	27.9	23.1
19	4.5	3.6	9.0	7.5	5.2	4.1	9.9	8.2	7.1	5.6	12.8	10.6	9.2	7.3	16.2	13.5	11.1	8.8	19.5	16.2	14.1	11.2	24.9	20.7
20	3.7	2.9	7.8	6.5	4.2	3.3	8.5	7.1	5.6	4.4	10.9	9.1	7.2	5.7	13.8	11.4	8.7	6.9	16.5	13.7	11.1	8.7	21.1	17.5
21	3.5	2.8	6.8	5.7	3.9	3.1	7.4	6.1	5.1	4.0	9.4	7.8	5.5	5.1	11.7	9.7	7.8	6.1	14.0	11.6	9.9	7.8	17.9	14.8
22	3.6	2.8	6.3	4.9	4.0	3.1	6.8	5.3	5.1	4.0	8.5	6.7	5.4	5.0	10.6	8.3	7.7	6.0	12.7	9.9	9.8	7.6	16.2	12.6
23	3.8	3.0	6.0	4.6	4.2	3.3	6.4	5.0	5.3	4.2	8.1	6.3	6.7	5.2	10.2	7.9	8.0	6.3	12.1	9.5	10.2	8.0	15.5	12.1
24	4.0	3.1	5.5	4.3	4.4	3.4	6.0	4.7	5.8	4.5	7.7	6.0	7.3	5.7	9.6	7.5	8.8	6.8	11.5	9.0	11.1	8.7	14.7	11.5

Figure 1-57. ISD book propagation chart example of MUF/FOT.

CARIBBEAN I

LOWEST USEFUL HIGH FREQUENCIES (LUF)

JANUARY FEBRUARY

1/2 WAVE HORIZONTAL DIPOLE 10 METERS (33 FEET) HIGH TRANSMITTING AND RECEIVING

B,C,D,E,F INDICATE RELIABILITY OF FREQUENCY IS ONLY 80-90, 60-80, 40-60, 20-40, OR 0-20 PCT.

	-1-		-2-		-3-		-4-		-5-		-6-		-7-		
	10	110	10	110	10	110	10	110	10	110	10	110	10	110	
LT						160 KILOMETERS		(100 MILES)							LT
02	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	02
04	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	04
06	2.3	2.8	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	06
08	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	08
10	2.3	4.5	2.0	3.4	2.0	2.8	2.0	2.6	2.0	2.0	2.0	2.0	2.0	2.0	10
12	4.2	5.1	2.7	4.6	2.3	3.7	2.0	3.5	2.0	2.9	2.0	2.7	2.0	2.6	12
14	2.5	5.5	2.0	3.6	2.0	3.2	2.0	2.7	2.0	2.5	2.0	2.0	2.0	2.0	14
16	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	16
18	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	18
20	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	20
22	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	22
24	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	24
LT						400 KILOMETERS		(250 MILES)							LT
02	2.2	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	02
04	2.9 B	3.2 B	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	04
06	3.7 B	4.4	2.6	2.8	2.0	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	06
08	3.2	4.2	2.7	3.6	2.1	3.2	2.0	2.7	2.0	2.5	2.0	2.0	2.0	2.0	08
10	5.4	6.4	4.5	6.0	4.0	5.6	3.5	4.9	3.2	4.7	2.8	4.3	2.6	3.9	10
12	5.5	6.7	5.4	6.6	4.9	6.5	4.5	6.0	4.0	5.6	3.7	5.3	3.3	4.7	12
14	5.2	6.4	4.8	6.3	4.2	4.7	3.7	4.6	3.3	4.6	3.0	4.6	2.8	4.4	14
16	3.3	4.3	2.7	3.7	2.2	3.4	2.0	2.8	2.0	2.6	2.0	2.2	2.0	2.0	16
18	2.3	2.7	2.0	2.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	18
20	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	20
22	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	22
24	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	24
LT						800 KILOMETERS		(500 MILES)							LT
02	4.3 C	4.6 C	4.1	3.9	3.0	2.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	02
04	3.7 C	4.0 C	3.7 B	4.0 B	3.3	2.8	2.6	2.2	2.0	2.0	2.0	2.0	2.0	2.0	04
06	4.8 C	5.9 C	4.8 B	5.5	4.2	4.2	3.4	3.4	2.8	2.9	2.3	2.5	2.0	2.4	06
08	6.2	7.4	4.9	6.1	4.5	5.3	4.0	5.2	3.8	5.0	3.3	4.2	3.2	4.1	08
10	9.1	11.0	9.0	10.9	7.0	10.4	5.8	8.4	5.7	7.3	5.6	7.2	5.3	7.1	10
12	8.0	10.5	7.9	8.2	7.7	8.1	7.1	8.1	6.2	8.1	5.7	8.1	5.4	8.0	12
14	8.2	9.4	8.0	7.9	7.3	7.8	6.0	7.8	5.8	7.8	5.8	7.7	5.6	7.6	14
16	5.7	6.9	4.8	5.5	4.2	5.1	4.1	4.4	3.8	4.2	3.4	4.2	3.3	4.2	16
18	6.5	6.4	4.5	4.5	3.5	3.8	2.7	3.1	2.4	2.8	2.1	2.3	2.0	2.0	18
20	4.2 B	5.6	3.5	3.4	2.4	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	20
22	3.8 C	6.1	3.8	3.8	2.5	2.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	22
24	4.3 C	5.6 B	3.8	3.9	2.6	2.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	24

Figure 1-58. ISD book propagation chart example of LUF.

ADAK, ALASKA

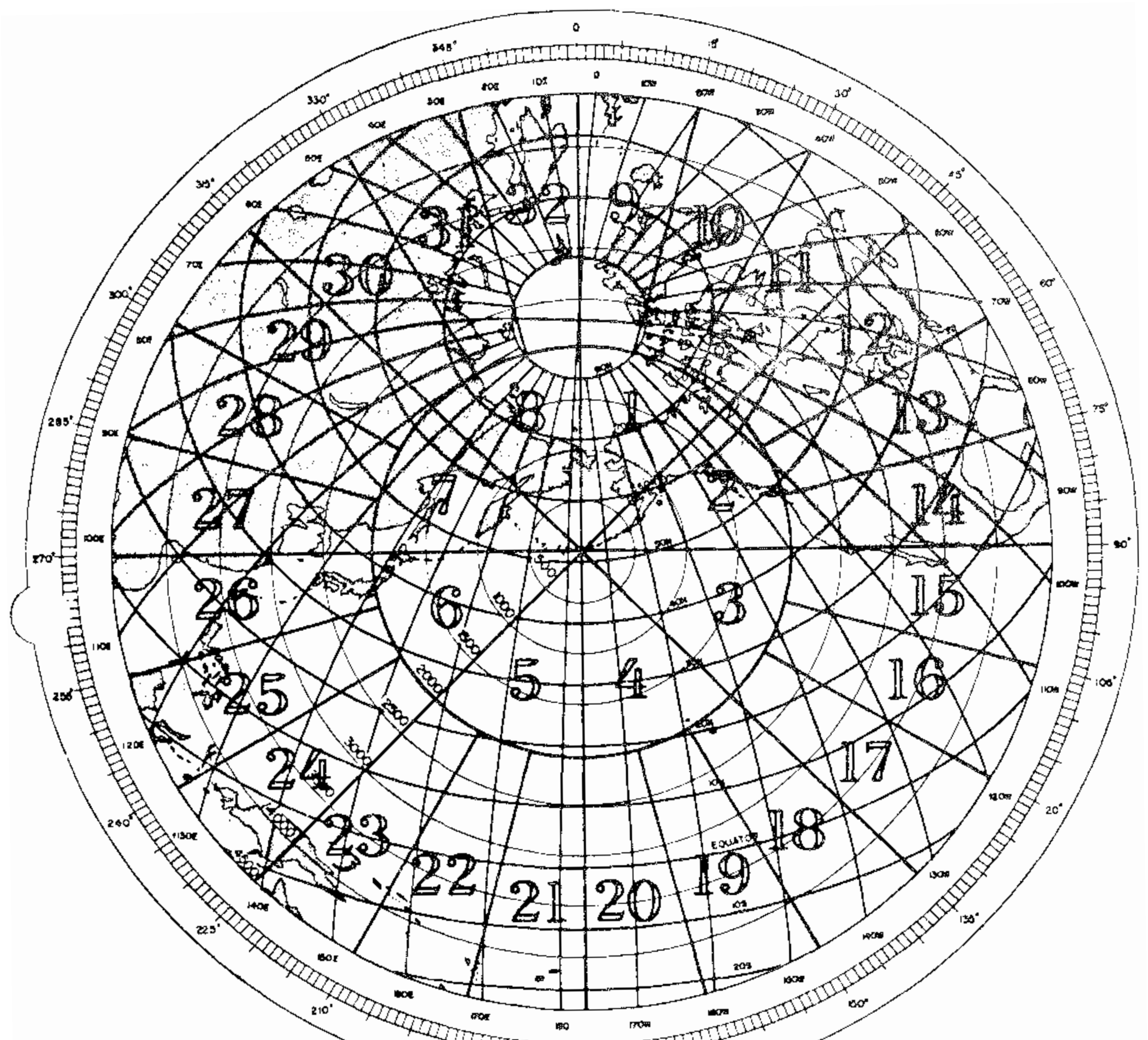


Figure 1-59. A/G book geographic sector example.

Figure 1-60 is an example of an A/G sky-wave propagation chart.

Propagation at or near vertical incidence presents a difficult antenna design problem due to the relative low frequency required for sky-wave communications at short distance and the desire to operate using antennas as small as possible. The analyses performed under this effort provided the necessary antenna design to provide the required system reliability. This work is being undertaken as part of the Near Vertical Incident Skywave (NVIS) Performance project that directly supports the U.S. Army Communications-Electronics Engineering Installation Agency.

Using an antenna description and gain profile from a report by Harold Tolles ("A Short Low Profile Antenna for 1.5 to 4.1 MHz Frequency Communications," Technical Report EMEO-PED-79-6, August 1979), an antenna gain file was created for input to the IONospheric Communications Analysis and Prediction (IONCAP) program. A model of the antenna was constructed and used to establish a reference point relative to the gain pattern described in the above report. Also, an antenna gain file for input to IONCAP describing a halfwave dipole at heights of 10 meters or one-quarter wavelength (whichever is smaller) was created. The IONCAP program was then run for typical Army operational circuits. An example is Central Europe, path lengths 40 to 400 km, all hours and months, and frequencies from 2 MHz to 6 MHz. An assessment of the values returned from IONCAP was made with emphasis on circuit reliability and signal-to-noise ratio.

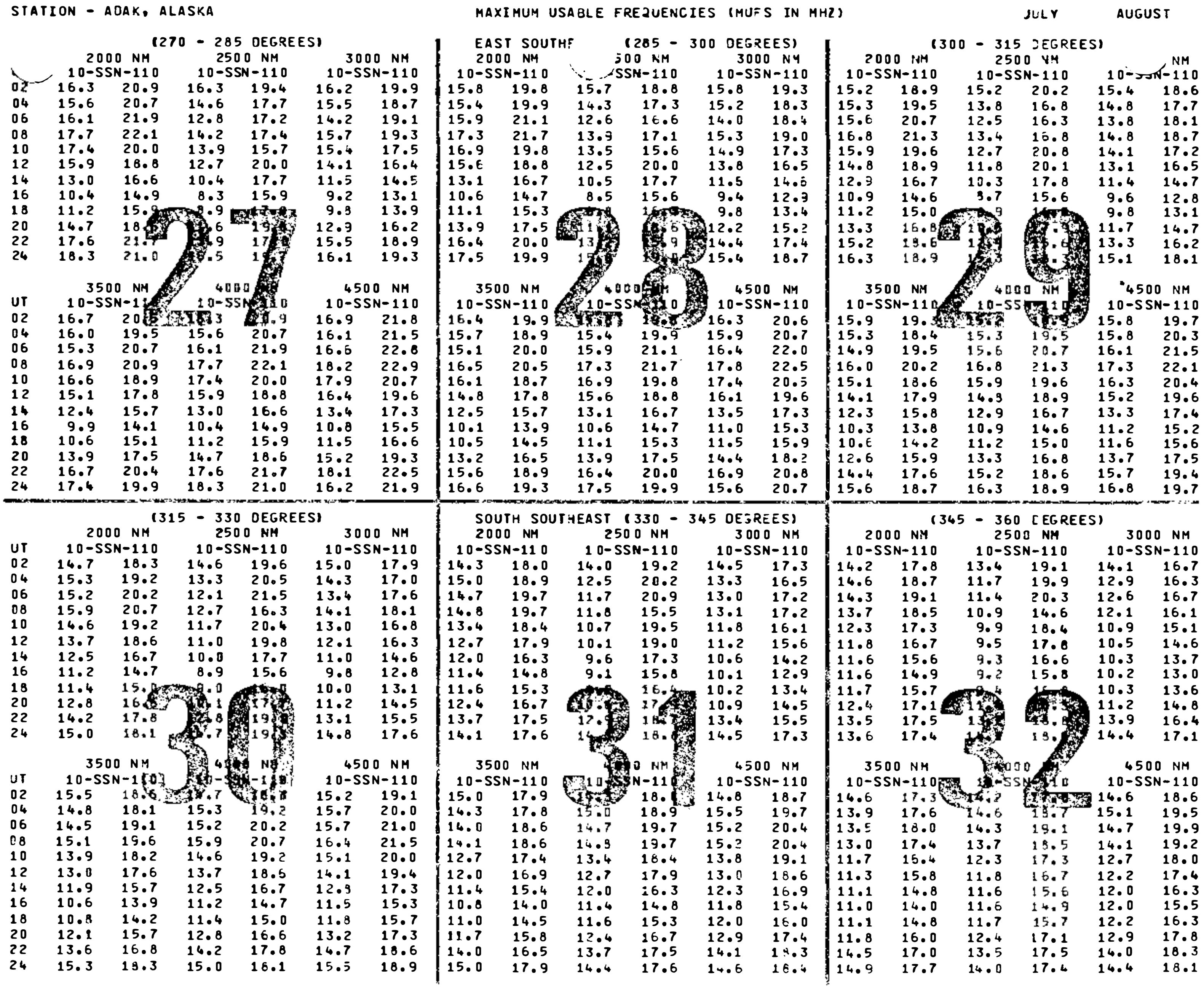
Another related project was directed toward the development and implementation of an interactive processor to generate input to the IONCAP program. The project supports operational requirements of the sponsor by providing methodology for individuals who may have a limited background in HF propagation to interface with the complex HF propagation program developed by ITS. Specifically, the user will respond to a sequence of detailed questions presented by the interactive processor. The interactive processor will have the capability of evaluating the user's responses by checking for possible inconsistencies and requesting the user to submit a new response to a question if an inconsistency is detected. The processor will also have the capability of providing assistance to the user should the user have difficulties responding to the questions presented. The interactive processor will convert the user responses into the appropriate IONCAP card image input.

The Institute has continued work on the development of a new MF sky-wave propagation model in FY 83 under the MF Propagation Studies project. The higher power AM stations south of the United States have caused interference in some U.S. AM broadcast service areas. Currently accepted sky-wave prediction models tend to underestimate field strengths in the Western Hemisphere. The Institute, in cooperation with the Federal Communications Commission, established MF monitoring sites at Cabo Rojo, PR, and Kingsville, TX, to try to observe signals from the Central and South American stations. This capability provided the potential for measuring signals with sky-wave reflection points less than 30° north geomagnetic latitude which in the long term could yield information so that the effects of frequency, geomagnetic latitude, ionospheric loss, and solar activity on the performance of long distance MF signals can be properly evaluated. This, in turn, would lead to a realistic MF sky-wave prediction model.

The Institute closed down the Cabo Rojo site after over a year of monitoring. A final report was written on the data collected at this site and is now in the review process. Monitoring continued at the Kingsville site using its highly directional Beverage antennas. Only the data storage tapes from the control computer are being periodically shipped to the Institute for analysis. By using an antenna model developed by the Lawrence Livermore Laboratories and a calibration of the Beverage antenna, observed AGC readings are transformed into field strength values. The monthly and seasonal medians of hourly medians are then analyzed for differences between predicted and observed values, relative seasonal variations, and relative changes of observed and predicted values. These results are now being compiled for a project milestone report. Figure 1-61 shows the receiver calibration curve used to convert AGC readings to input power to the receiver in dBm.

Solar protons emitted in association with flares are known to cause VLF phase anomalies in the earth's polar regions and subsequent radio navigation errors as large as 5 miles. The thrust of this study was to identify the effects of solar proton events on some transpolar Omega navigation signals for comparison with simultaneous particle flux measurements. The results show that in 1982 there were several periods when the phases of 10.2 kHz Omega signals received over transpolar paths were advanced anomalously. The phase anomalies were quantified by removing the normal or characteristic diurnal phase from the observed phase during suspected periods. The phase advances at peak were about 95 centicycles and lasted about 14 days. Figure 1-62 shows the phases at the 10.2 kHz Omega signals (normal or "quiet" days removed) received over a northern path (Hawaii to Norway), a mid-latitude path (North Dakota to Hawaii), and a southern path (Australia to Argentina). It is interesting to note that the phases were advanced for days on the polar paths but not on the mid-latitude path.

The prediction of radio communication performance is a matter of statistically comparing the computed signal-to-noise ratio (SNR) for a given grade of service. System performance is also highly dependent on the detailed statistical characteristics of both the signal and the noise (and interference) as well as the SNR. Proper design of communications systems also requires detailed knowledge of the interfering noise process. The ability of a design engineer to make a correct computation of SNR and its variation often determines the success of a given radio circuit. Generally, the computation of the signal level over a given path can be made accurately. This is not the case when it comes to estimating the noise level or other noise characteristics.



STATION - ADAK, ALASKA   MAXIMUM USABLE FREQUENCIES (MUFS IN MHZ)   JULY   AUGUST

27

(270 - 285 DEGREES)

	2000 NM		2500 NM		3000 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	16.3	20.9	16.3	19.4	16.2	19.9
04	15.6	20.7	14.6	17.7	15.5	18.7
06	16.1	21.9	12.8	17.2	14.2	19.1
08	17.7	22.1	14.2	17.4	15.7	19.3
10	17.4	20.0	13.9	15.7	15.4	17.5
12	15.9	18.8	12.7	20.0	14.1	16.4
14	13.0	16.6	10.4	17.7	11.5	14.5
16	10.4	14.9	8.3	15.9	9.2	13.1
18	11.2	15.9	8.9	[illegible]	9.8	13.9
20	14.7	[illegible]	[illegible]	[illegible]	12.9	16.2
22	17.6	21.7	[illegible]	[illegible]	15.5	18.9
24	18.3	21.0	[illegible]	[illegible]	16.1	19.3

	3500 NM		4000 NM		4500 NM	
UT	10-SSN-110		10-SSN-110		10-SSN-110	
02	16.7	[illegible]	[illegible]	[illegible]	16.9	21.8
04	16.0	19.5	15.6	20.7	16.1	21.5
06	15.3	20.7	16.1	21.9	16.6	22.8
08	16.9	20.9	17.7	22.1	18.2	22.9
10	16.6	18.9	17.4	20.0	17.9	20.7
12	15.1	17.8	15.9	18.8	16.4	19.6
14	12.4	15.7	13.0	16.6	13.4	17.3
16	9.9	14.1	10.4	14.9	10.8	15.5
18	10.6	15.1	11.2	15.9	11.5	16.6
20	13.9	17.5	14.7	18.6	15.2	19.3
22	16.7	20.4	17.6	21.7	18.1	22.5
24	17.4	19.9	18.3	21.0	16.2	21.9

28

EAST SOUTHF (285 - 300 DEGREES)

	2000 NM		2500 NM		3000 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	15.8	19.8	15.7	18.8	15.8	19.3
04	15.4	19.9	14.3	17.3	15.2	18.3
06	15.9	21.1	12.6	16.6	14.0	18.4
08	17.3	21.7	13.9	17.1	15.3	19.0
10	16.9	19.8	13.5	15.6	14.9	17.3
12	15.6	18.8	12.5	20.0	13.8	16.5
14	13.1	16.7	10.5	17.7	11.5	14.6
16	10.6	14.7	8.5	15.6	9.4	12.9
18	11.1	15.3	[illegible]	[illegible]	9.8	13.4
20	13.9	17.5	[illegible]	[illegible]	12.2	15.2
22	16.4	20.0	[illegible]	[illegible]	14.4	17.4
24	17.5	19.9	[illegible]	[illegible]	15.4	18.7

	3500 NM		4000 NM		4500 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	16.4	19.9	[illegible]	[illegible]	16.3	20.6
04	15.7	18.9	15.4	19.9	15.9	20.7
06	15.1	20.0	15.9	21.1	16.4	22.0
08	16.5	20.5	17.3	21.7	17.8	22.5
10	16.1	18.7	16.9	19.8	17.4	20.5
12	14.8	17.8	15.6	18.8	16.1	19.6
14	12.5	15.7	13.1	16.7	13.5	17.3
16	10.1	13.9	10.6	14.7	11.0	15.3
18	10.5	14.5	11.1	15.3	11.5	15.9
20	13.2	16.5	13.9	17.5	14.4	18.2
22	15.6	18.9	16.4	20.0	16.9	20.8
24	16.6	19.3	17.5	19.9	15.6	20.7

29

(300 - 315 DEGREES)

	2000 NM		2500 NM		3000 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	15.2	18.9	15.2	20.2	15.4	18.6
04	15.3	19.5	13.8	16.8	14.8	17.7
06	15.6	20.7	12.5	16.3	13.8	18.1
08	16.8	21.3	13.4	16.8	14.8	18.7
10	15.9	19.6	12.7	20.8	14.1	17.2
12	14.8	18.9	11.8	20.1	13.1	16.5
14	12.9	16.7	10.3	17.8	11.4	14.7
16	10.9	14.6	8.7	15.6	9.6	12.8
18	11.2	15.0	[illegible]	[illegible]	9.8	13.1
20	13.3	16.8	[illegible]	[illegible]	11.7	14.7
22	15.2	19.6	[illegible]	[illegible]	13.3	16.2
24	16.3	18.9	[illegible]	[illegible]	15.1	18.1

	3500 NM		4000 NM		4500 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	15.9	[illegible]	[illegible]	[illegible]	15.8	19.7
04	15.3	18.4	15.3	19.5	15.8	20.3
06	14.9	19.5	15.6	20.7	16.1	21.5
08	16.0	20.2	16.8	21.3	17.3	22.1
10	15.1	18.6	15.9	19.6	16.3	20.4
12	14.1	17.9	14.8	18.9	15.2	19.6
14	12.3	15.8	12.9	16.7	13.3	17.4
16	10.3	13.8	10.9	14.6	11.2	15.2
18	10.6	14.2	11.2	15.0	11.6	15.6
20	12.6	15.9	13.3	16.8	13.7	17.5
22	14.4	17.6	15.2	18.6	15.7	19.4
24	15.6	18.7	16.3	18.9	16.8	19.7

30

(315 - 330 DEGREES)

	2000 NM		2500 NM		3000 NM	
UT	10-SSN-110		10-SSN-110		10-SSN-110	
02	14.7	18.3	14.6	19.6	15.0	17.9
04	15.3	19.2	13.3	20.5	14.3	17.0
06	15.2	20.2	12.1	21.5	13.4	17.6
08	15.9	20.7	12.7	16.3	14.1	18.1
10	14.6	19.2	11.7	20.4	13.0	16.8
12	13.7	18.6	11.0	19.8	12.1	16.3
14	12.5	16.7	10.0	17.7	11.0	14.6
16	11.2	14.7	8.9	15.6	9.8	12.8
18	11.4	[illegible]	[illegible]	[illegible]	10.0	13.1
20	12.8	[illegible]	[illegible]	[illegible]	11.2	14.5
22	14.2	17.8	[illegible]	[illegible]	13.1	15.5
24	15.0	18.1	[illegible]	[illegible]	14.8	17.6

	3500 NM		4000 NM		4500 NM	
UT	10-SSN-110		10-SSN-110		10-SSN-110	
02	15.5	18.6	[illegible]	[illegible]	15.2	19.1
04	14.8	18.1	15.3	19.2	15.7	20.0
06	14.5	19.1	15.2	20.2	15.7	21.0
08	15.1	19.6	15.9	20.7	16.4	21.5
10	13.9	18.2	14.6	19.2	15.1	20.0
12	13.0	17.6	13.7	18.6	14.1	19.4
14	11.9	15.7	12.5	16.7	12.3	17.3
16	10.6	13.9	11.2	14.7	11.5	15.3
18	10.8	14.2	11.4	15.0	11.8	15.7
20	12.1	15.7	12.8	16.6	13.2	17.3
22	13.6	16.8	14.2	17.8	14.7	18.6
24	15.3	18.3	15.0	16.1	15.5	18.9

31

SOUTH SOUTHEAST (330 - 345 DEGREES)

	2000 NM		2500 NM		3000 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	14.3	18.0	14.0	19.2	14.5	17.3
04	15.0	18.9	12.5	20.2	13.3	16.5
06	14.7	19.7	11.7	20.9	13.0	17.2
08	14.8	19.7	11.8	15.5	13.1	17.2
10	13.4	18.4	10.7	19.5	11.8	16.1
12	12.7	17.9	10.1	19.0	11.2	15.6
14	12.0	16.3	9.6	17.3	10.6	14.2
16	11.4	14.8	9.1	15.8	10.1	12.9
18	11.6	15.3	[illegible]	[illegible]	10.2	13.4
20	12.4	16.7	[illegible]	[illegible]	10.9	14.5
22	13.7	17.5	[illegible]	[illegible]	13.4	15.5
24	14.1	17.6	[illegible]	[illegible]	14.5	17.3

	3500 NM		4000 NM		4500 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	15.0	17.9	[illegible]	[illegible]	14.8	18.7
04	14.3	17.8	15.0	18.9	15.5	19.7
06	14.0	18.6	14.7	19.7	15.2	20.4
08	14.1	18.6	14.8	19.7	15.2	20.4
10	12.7	17.4	13.4	18.4	13.8	19.1
12	12.0	16.9	12.7	17.9	13.0	18.6
14	11.4	15.4	12.0	16.3	12.3	16.9
16	10.8	14.0	11.4	14.8	11.8	15.4
18	11.0	14.5	11.6	15.3	12.0	16.0
20	11.7	15.8	12.4	16.7	12.9	17.4
22	14.0	16.5	13.7	17.5	14.1	18.3
24	15.0	17.9	14.4	17.6	14.6	18.4

32

(345 - 360 DEGREES)

	2000 NM		2500 NM		3000 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	14.2	17.8	13.4	19.1	14.1	16.7
04	14.6	18.7	11.7	19.9	12.9	16.3
06	14.3	19.1	11.4	20.3	12.6	16.7
08	13.7	18.5	10.9	14.6	12.1	16.1
10	12.3	17.3	9.9	18.4	10.9	15.1
12	11.8	16.7	9.5	17.8	10.5	14.6
14	11.6	15.6	9.3	16.6	10.3	13.7
16	11.6	14.9	9.2	15.8	10.2	13.0
18	11.7	15.7	9.4	[illegible]	10.3	13.6
20	12.4	17.1	[illegible]	[illegible]	11.2	14.8
22	13.5	17.5	[illegible]	[illegible]	13.9	16.4
24	13.6	17.4	[illegible]	[illegible]	14.4	17.1

	3500 NM		4000 NM		4500 NM	
	10-SSN-110		10-SSN-110		10-SSN-110	
02	14.6	17.3	14.2	[illegible]	14.6	18.6
04	13.9	17.6	14.6	19.7	15.1	19.5
06	13.5	18.0	14.3	19.1	14.7	19.9
08	13.0	17.4	13.7	18.5	14.1	19.2
10	11.7	16.4	12.3	17.3	12.7	18.0
12	11.3	15.8	11.8	16.7	12.2	17.4
14	11.1	14.8	11.6	15.6	12.0	16.3
16	11.0	14.0	11.6	14.9	12.0	15.5
18	11.1	14.8	11.7	15.7	12.2	16.3
20	11.8	16.0	12.4	17.1	12.9	17.8
22	14.5	17.0	13.5	17.5	14.0	18.3
24	14.9	17.7	14.0	17.4	14.4	18.1

Figure 1-60. A/G book propagation chart example of MUF.

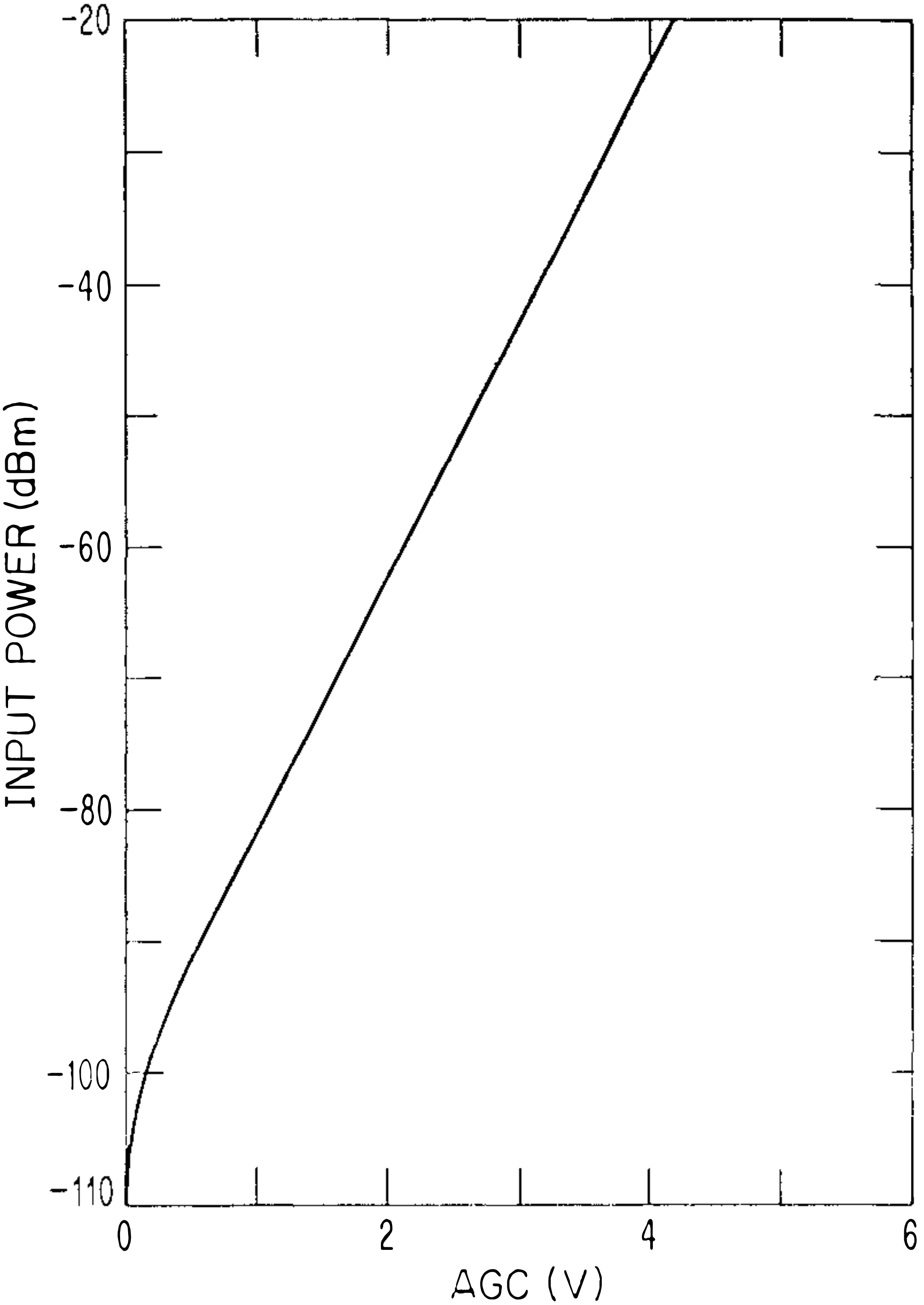


Figure 1-61. Receiver calibration curve.

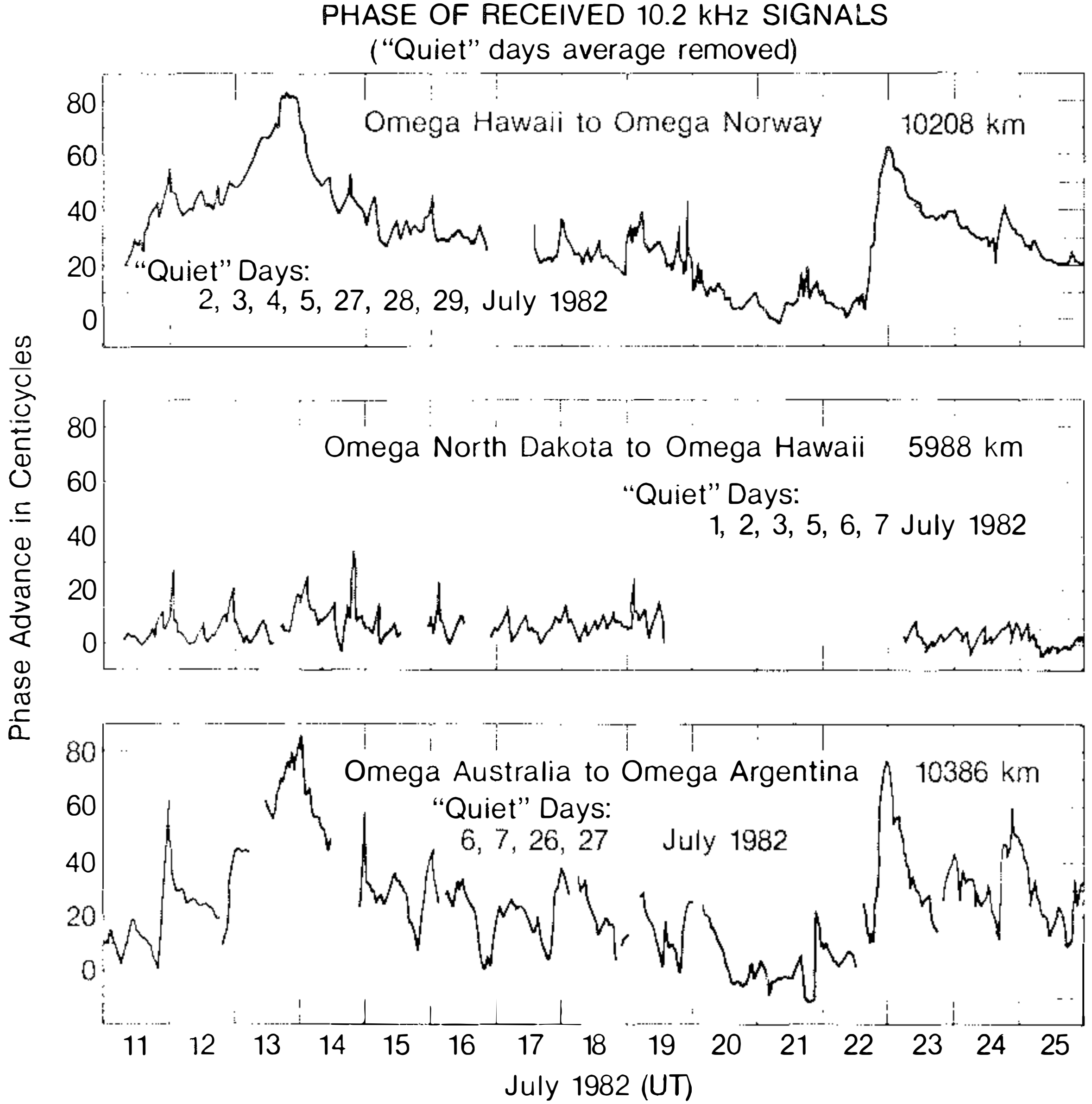


Figure 1-62. Phases of the 10.2 kHz omega signals received over a northern path, mid-latitude path, and a southern path.

Existing noise models consist primarily of the worldwide atmospheric noise maps contained in CCIR Report 322 and estimated man-made noise levels given in CCIR Report 258. In addition to these two basic models, there are numerous other special purpose models for estimating noise at aircraft altitudes (and beyond), from power lines, from automobiles, from electrified railroads, from nuclear generating plants, etc. The problems with all of the above models are that they are based on limited measurements, disregard significant sources of EMI, are limited in frequency range, are not available in the form of source model, and are not necessarily applicable to new modulation modes employed in newer radio systems. Also, there is a large data base of measurements that, heretofore, have not been incorporated into the existing models.

There is a need for an overall, comprehensive, usable noise model for application to telecommunication problems. The Institue is currently conducting a program to perform various preliminary tasks needed before an overall model can be developed and to obtain an improved atmospheric noise model.

The existing worldwide atmospheric noise model (CCIR Report 322) was developed from approximately 4 years of measurements from a worldwide network of 16 measurement stations. This network made measurements for 5 years (longer in a few cases) past the publication of CCIR Report 322 in 1963. Also, additional data are now available from other locations, primarily many years of data from 10 Soviet measurement stations. All this additional data has been analyzed and an updated worldwide atmospheric noise model is being prepared. The locations for the measurement data are:

Worldwide Network Locations (CCIR 322)

Balboa, Canal Zone	79.5W,	9.0N
Bill, Wyoming	105.2W,	43.2N
Boulder, Colorado	105.1W,	40.1N
Byrd, Antarctica	120.0W,	80.0S
Cook, Australia	130.4E,	30.6S
Enkoping, Sweden	17.3E,	59.5N
Front Royal, Virginia	78.2W,	38.8N
Ibadan, Nigeria	3.9E,	7.4N
Kekaha, Hawaii	159.7W,	22.0N
New Delhi, India	77.3E,	28.8N
Ohira, Japan	140.5E,	35.6N
Pretoria, S. Africa	28.3E,	25.8S
Rabat, Morocco	6.8W,	33.9N
San Jose, Brazil	45.8W,	23.3S
Singapore, Malaysia	103.8E,	1.3N
Thule, Greenland	68.7W,	76.6N

New Locations

Laem Chabang, Thailand	100.9E,	13.05N
Alma Ata, USSR	76.92E,	43.25N
Ashkhabad, USSR	58.3E,	37.92N
Irkutsk, USSR	104.5E,	52.0N
Khabarovsk, USSR	135.0E,	50.0N
Kiev, USSR	30.3E,	50.72N
Moscow, USSR	37.32E,	55.47N
Murmansk, USSR	35.0E,	69.0N
Simferopol, USSR	34.03E,	45.02N
Sverdlovsk, USSR	61.07E,	56.73N
Tbilisi, USSR	40.0E,	41.72N

The real-world noise environment is almost never Gaussian in character, yet receiving systems in general use are those that are optimum for white Gaussian noise (i.e., linear matched filter or correlation detectors).

It is well known that Gaussian noise is the worst kind of noise in terms of minimizing channel capacity or in its information destroying capability. This means that very large improvements in the performance of systems can be achieved if the actual statistical characteristics of the noise and interference are properly taken into account, and there have been various significant efforts in the last few years in this area.

When confronted with real-world noise, the earlier and usual approach was to precede the "Gaussian receiver" by various ad hoc nonlinearities (e.g., clipper, hole punchers, hard limiters, etc.) in order to make the noise look "more Gaussian" to the given receiver. Later, optimum systems were derived using models of the actual noise. These systems are adaptive in nature and usually very difficult to realize physically. If, however, the following two assumptions are made:

1. the desired signal becomes vanishingly small and
2. the time-bandwidth product is large, so that a large number, N, of independent samples from the interfering noise process can be used in the detection decision process,

then a "locally optimum" detector, generally termed a "locally optimum Bayes detector" or LOBD, can be obtained. Under some rather strict conditions, these LOBD detectors approach true optimality (asymptotically) as the above two assumptions are met, and usually take the form of the "normal" Gaussian receiver preceded by one or more particular nonlinearities.

In actual use, the desired signal may be "small," but not "vanishingly small" and the time bandwidth product may not be particularly large. Recent work, for one typical example of broadband impulsive noise, has removed the above two assumptions to investigate the "truth" of the standard LOBD and hard-limiter performance estimates. The first assumption (vanishingly small signal) is removed analytically and the second (large N so that Central Limit Theorem arguments can be used) is removed by Monte Carlo computer simulation.

Results are shown in Figures 1-63 and 1-64. In Figure 1-63, three curves are given for the binary CPSK system, the standard theoretical result ($S \rightarrow 0$) from the well-known LOBD theory using the above two assumptions, the result ($S \not\rightarrow 0$) where the first assumption was analytically removed, and the corresponding hard limiter result ($S \not\rightarrow 0$) where performance was also calculated without the $S \rightarrow 0$ assumption. Computer simulation results are also shown for the LOBD nonlinearity and the bandpass limiter, and we see that the calculated results are quite close to the simulated results in all cases. In Figure 1-63, N = 100, so we expect the Central Limit Theorem to apply.

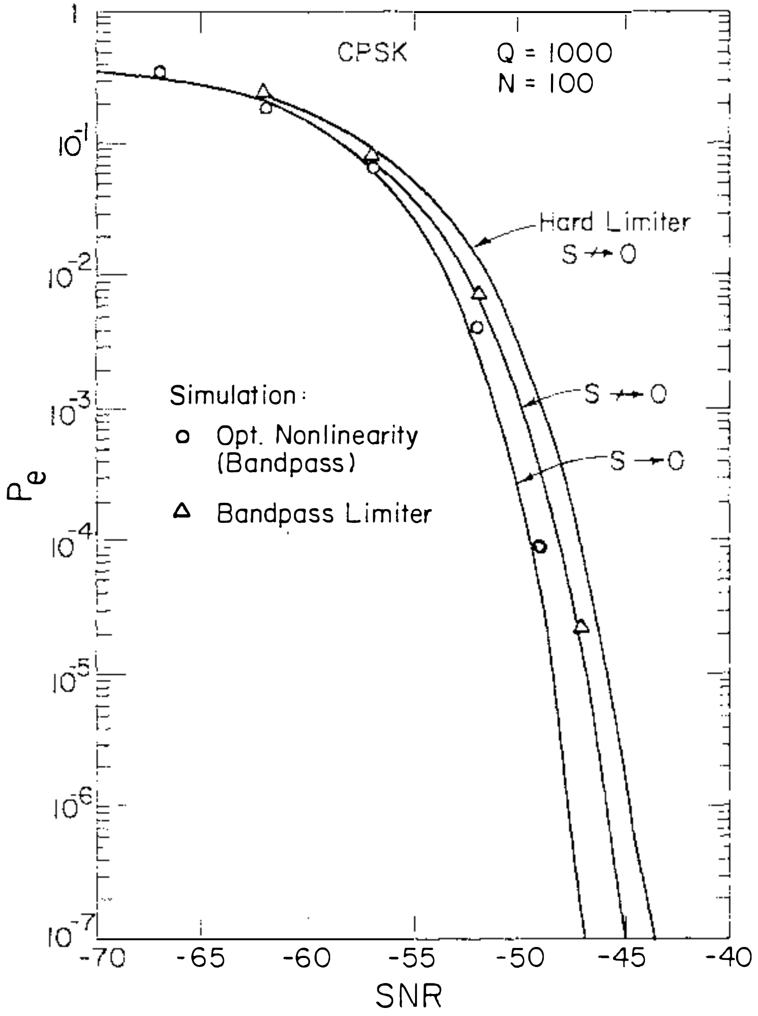


Figure 1-63. Calculated and simulation results for the hard-limiter and LOBD nonlinearities for N=100.

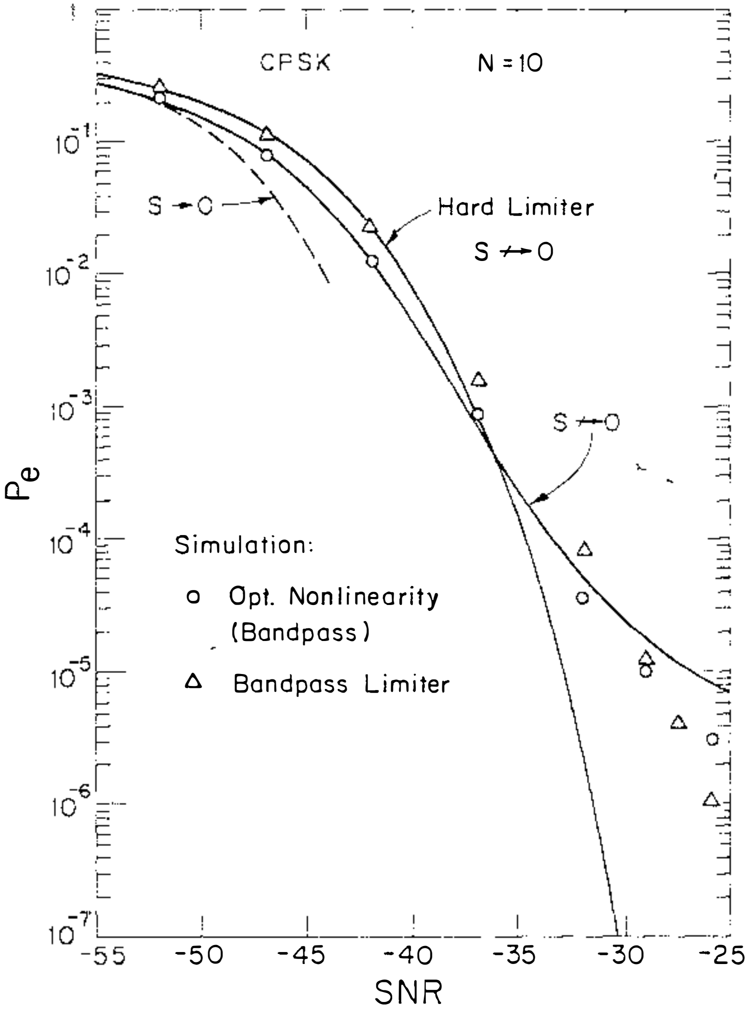


Figure 1-64. Calculated and simulation results for the hard-limiter and LOBD nonlinearities for N=10.

Note that for this example of impulsive noise we require using the LOBD designed to match the interference, a signal-to-noise ratio ($N = 100$) of about -47 dB to achieve a P_e of 10^{-6}. The corresponding linear receiver in Gaussian noise (optimum) would require a signal-to-noise ratio of -10 dB ($N = 100$) to achieve a P_e of 10^{-6}. That is, the LOBD in its interference has a 37 dB processing advantage (in the limit, large N) over the linear receiver in Gaussian noise (or over the linear receiver in this example of impulsive noise).

Figure 1-64 shows results for $N = 10$. First, we note that performance cannot be calculated from the normal LOBD results as noted by the dashed curve ($S \rightarrow 0$). The hard limiter calculation ($S \not\rightarrow 0$) matches the simulation results only for small signal levels and departs rapidly as the signal increases. The LOBD calculated results ($S \not\rightarrow 0$) follow the simulation results better. The differences are due to the Central Limit Theorem approximation used for calculated results not being valid for $N = 10$, especially in the tails. The most interesting result shown, however, is that the hard limiter outperforms the LOBD as the signal level increases (around SNR = - 28 dB and $P_e = 10^{-6}$ in this case).

Figure 1-65 shows simulation results for a different example of impulsive noise. This example, in terms of its first-order distribution, does not look "a whole lot different" from the example of Figures 1-63 and 1-64, being also highly non-Gaussian. Figure 1-65 shows the linear receiver, constant signal results along with those for the bandpass limiter and the LOBD nonlinearity. First note that, as usual, use of nonlinearities for $N = 1$ gives no improvement over the linear receiver, but, of course, does give improvement for $N = 10$ and 100. For $N = 100$, this improvement, however, is only 6 dB compared to 37 dB for the previous example. This shows that we cannot arbitrarily say, by inspection, that a noise process which is "tremendously" non-Gaussian can result in "tremendous" improvement over the corresponding Gaussian or linear receiver situation.

1.4.3 Applications of Propagation Predictions

Numerous studies have been undertaken by ITS to apply the knowledge gained from the experimental studies and the propagation prediction techniques developed over the years to specific telecommunication system performance issues.

The project Ground Wave Measurements in the HF Band is in support of a requirement by the Defense Nuclear Agency (DNA). This project incorporates the results of HF ground-wave prediction work undertaken by ITS to form an important part of current DNA effort to improve and upgrade communication systems for the military in the European theater. The final prediction model will be used to evaluate contractor system designs as well as operational system acceptance testing.

Ground-wave prediction methods based on a smooth-earth assumption are adequate for most needs at medium and low frequencies. However, at HF, terrain features and path electrical characteristic inhomogeneity are very important. A closed form analytical solution of HF ground-wave propagation over irregular and inhomogeneous terrain is impossible because the earth's surface cannot be described by a continuous function. The solution to this problem must rely on numerical techniques, and program WAGNER, based on an integral equation, represents one such solution. As long as the elevation change in the path is not too abrupt, nor the frequency too high, WAGNER can predict the transmission loss over irregular and inhomogeneous terrain. The primary purpose of this project is the validation of this technique for prediction of received HF ground wave along a path of irregular terrain with forests, buildings, and with or without snow cover.

Implementation of WAGNER requires a program input estimate describing the effective thickness and nature of the slab of intervening ground cover and, also, the ground conductivity and dielectric constants along the path from transmitter to receiver. In addition to providing some checks for the newest improvements to WAGNER, this project will attempt to set guidelines describing how these estimates can best be made. Reliable use of the model will require measurements of actual HF radiations for comparison to model predictions.

A van type truck with a receiver system has been instrumented to make mobile measurements. Data are collected, recorded, and evaluated as the vehicle is driven along and across pie-shaped radials emanating from a fixed transmitter. Measurements are made of received field strength, bit error rate, height-gain, and ground constants versus geographic location of the receiver van. Since data analysis for model comparison requires assurance of homogeneity of measured/predicted differences that are stratified for selected comparisons, a substantial amount of data must be taken. In the receiver van, the use of computer control of instrumentation, data acquisition, and recording systems facilitates the collection of large amounts of data. Additionally, a computer-controlled system is particularly desirable whenever test arrangements need to be reconfigured. These updates are likely to occur as the data are analyzed at significant intervals so that data acquisition improvements can be planned for the next measuring effort.

This versatility of receiver instrumentation allows measurements to be made as the van moves along and across the pie-shaped radials; consequently, the location of the van must be accurately known and recorded as data are collected at that location. Two devices for determining the van's location are being planned. One is a distance processor connected to the van's transmission to record distances the van travels and the other is an inertial navigation system for van positioning. The distance processor will be used as an aid to locate zero velocity update (ZUPT) locations for the navigation system.

The receiver antenna, located on the roof of the van, is a wideband monopole approximately 2 meters long. An integral active network

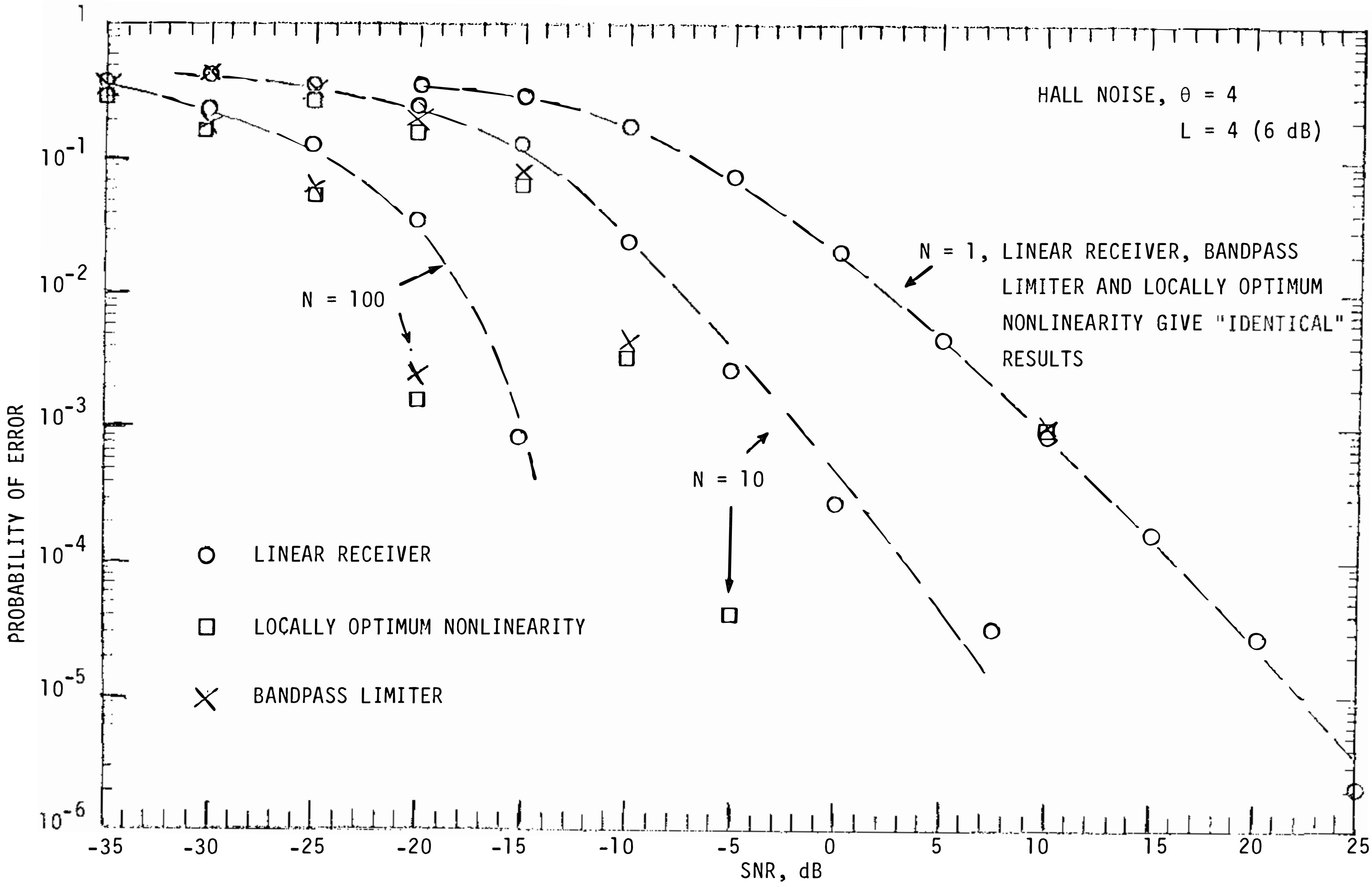


Figure 1-65. Simulation results for Hall noise, θ=4, for a linear receiver and for the LOBD and bandpass limiter nonlinearities.

located in the base insulator provides an input impedance greater than the reactive component of the antenna base impedance resulting in essentially a flat frequency response across the HF band. Consequently, the active network output signal voltage across a resistive termination is related to the antenna incident signal strength by a constant factor across the frequency band.

The transmitter van houses a 500-watt wideband rf amplifier and a computer to control the operating frequency, the transmitter output power, and the mode of modulation.

A trailer-mounted, diesel-driven alternator is towed by the transmitter van to provide prime power whenever shore-based power is unavailable. Line voltage regulators are used to help maintain a constant voltage source for the transmitter equipment.

A full-scale model of the transmitting antenna has been built for initial tests of the antenna radiation pattern. A $\lambda/4$ long vertical monopole was erected with the base on a wire mesh ground screen having an area of about 14,000 ft^2.

The VOA HF Propagation Studies project has provided support to the Voice of America (VOA) in the areas of HF propagation predictions and operational studies for a number of years. This support has continued through this year. The Institute has provided circuit performance predictions for over 180 VOA broadcast circuits. These predictions are used by the Voice of America in the scheduling of frequencies for broadcasts. In addition, the Institute still provides VOA with remote access to its computer programs that are used to determine HF propagation conditions.

Specific studies have been undertaken by the Institute in support of Voice of America preparation for the 1984 HF Broadcasting WARC.

As a result of actions taken at the General World Administrative Radio Conference of 1979, two World Administrative Radio Conferences (WARC) dealing with HF broadcasting will take place. The purpose of the HF Broadcasting WARC will be to plan and develop procedures to more effectively utilize the HF spectrum for broadcasting purposes. The conference will be held in two sessions, the first to begin in early 1984.

Telecommunications operations in the high frequency (HF) portion of the spectrum are directed toward international broadcasting by many administrations in the world. In the United States, in particular, international broadcasting by short wave (HF) is an integral part of the foreign policy. The outcomes of the HF Broadcasting WARC are of vital concern to the United States. In order to assess that U.S. positions at the conferences are based on sound technical decisions, the Institute has developed automated methods to assign HF frequencies for broadcasting purposes under the HF Broadcasting WARC project that supports NTIA, VOA, and the Board for International Broadcasting. The procedure that is being developed will allow studies of trade-offs between such parameters as power and protection ratios under different channel assignment scenarios to simulate broadcast operations using the best available information. Figure 1-66 shows the results of a test comprising reception point selection methods in terms of a channel usage factor and a cost factor.

A knowledge of service and interference ranges associated with existing and future air navigation aids is an important part of the FAA's spectrum planning effort. Coverage, interference, and propagation prediction capabilities developed by NTIA as part of the Air Navigation Aids project are utilized to provide much of this information.

In recent years much of this effort has been involved in developing and running programs containing the IF-77 propagation model to aid in updating various FAA handbooks. This year a coherent mathematical description of the present IF-77 model was developed and will be published as a single report, "The IF-77 Electromagnetic Wave Propagation Model," by G. D. Gierhart and M. E. Johnson, FAA Report No. DOT/FAA/ES-83/3, September 1983.

Also, an effort is being made to effectively run the model on a smaller computer, the HP 1000.

Two further tasks are currently under way:

1. Production of computer-generated propagation and interference predictions as requested by the FAA. These will include, among others, the Microwave Landing System (MLS), the Butler DME, the Wilcox DME, and the Area VOT.

2. Ongoing comparisons of predictions with experimental data and with other models.

The Technical Support/Propagation and Spectrum Engineering project was established as a consulting and advisory activity to the Federal Aviation Administration (FAA) with respect to frequency planning and management in the aeronautical frequency bands. Specific issues related to actions of the International Civil Aviation Organization (ICAO) were studied, and several informal letter reports were issued to the FAA.

The U.S. Coast Guard Consulting project provides "quick reaction" radio propagation predictions and short-term studies as required by the Coast Guard for the operation of their large network of HF and VHF communication systems. In addition, seasonal propagation charts were provided as requested by the Automated Mutual-Assistance Vessel Rescue (AMVER) program. These prediction charts are distributed to the many AMVER participants to aid them in choosing the best frequency and Coast Guard communication station with which to log their AMVER reports.

One of the special propagation studies done this year was to provide the Coast Guard with an estimate of the percentage of time that a communication path existed between each of 51 transmitter sites and four receiver locations on each of four frequencies.

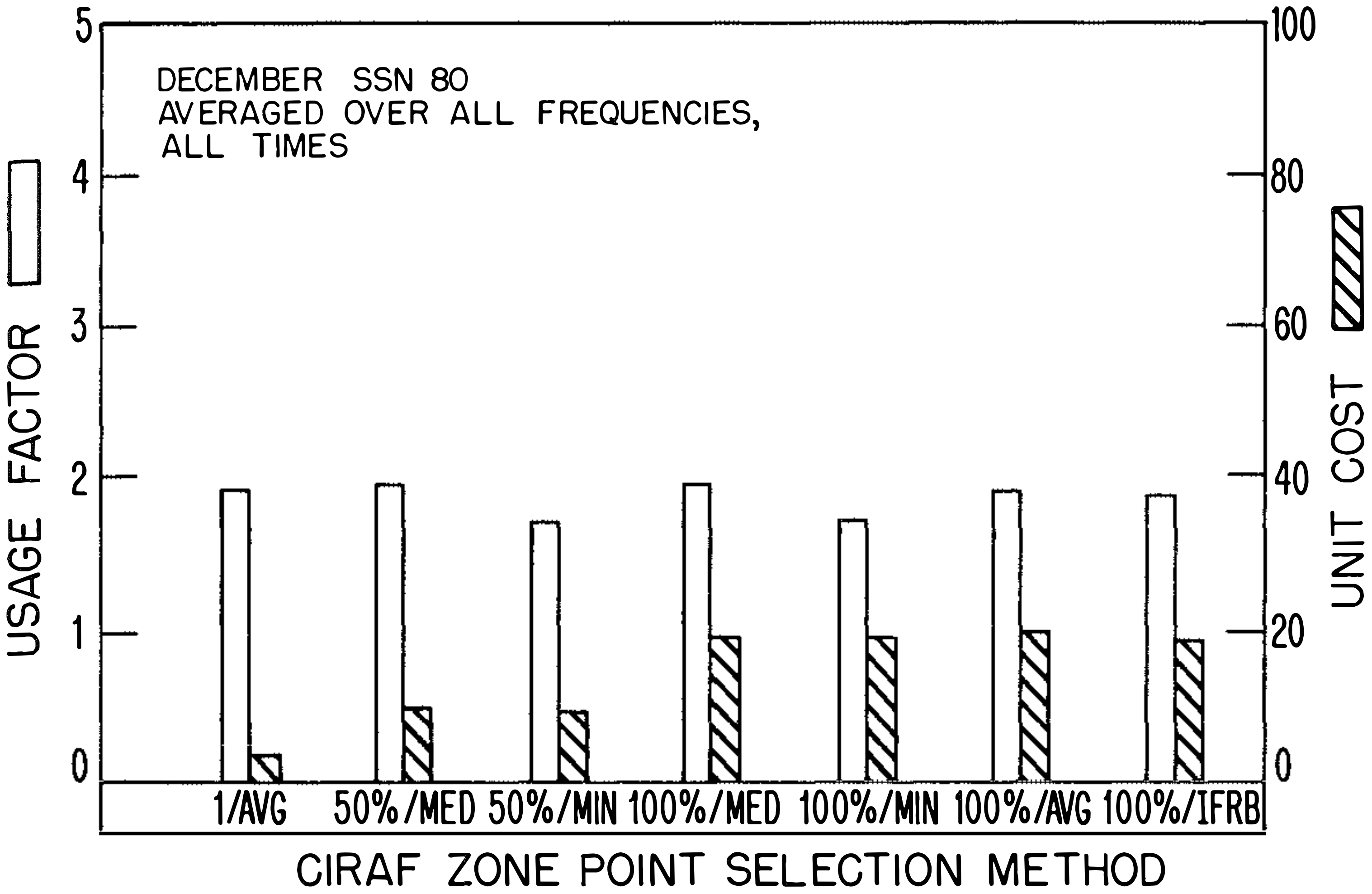


Figure 1-66. Sensitivity test of selection method in terms of usage factor and unit cost.

Wideband Consultation. The Army is well along in the development of a number of new tactical communications systems, some of which employ wideband (spread spectrum) modulations. These systems are unusual in that "system" emphasis is much stronger than with traditional radios. System performance, for example, is highly dependent on networking. System design was initially done using simplistic methods for evaluating the performance of the rf links and hardware. Software design proceeded based on those analysis results. Initial testing of the prototype hardware for both the PLRS (Position Locating and Reporting System) and JTIDS (Joint Tactical Information and Data System) and more rigorous system analyses have identified requirements for a substantially better understanding of transmission effects on wideband signals and for greater confidence in available propagation methodology for the narrow-band case.

The Institute has provided the Army with an experimental design that describes the functional requirements for wideband propagation measurement systems, and for the design of experiments to collect wideband data. These data will be used for the verification and/or development of propagation models of definable statistical confidence. The Institute has also provided expertise to the Army for guidance in Army contracts with industry, both in developing wideband measuring systems and deployment of these systems.

The Interdepartmental Radio Advisory Committee (IRAC) relies on its Technical Subcommittee (TSC) for recommendations and advice on technical matters. The project, TSC Support, supports the transfer of results of ITS research to relevant tasks of the TSC. This year, the goal has been to develop a practical, quantitative definition of the terms relating to "spectrum efficiency," and to apply the definition to selected bands above 940 MHz. The project leader is acting as Convenor of TSC Working Group 13, which is charged with developing the definitions.

Developing a quantitative definition of the (previously) qualitative term, "spectrum efficiency," has proven to be difficult and controversial. The Working Group has agreed on the following general form for the definition:

$$\frac{\text{(spectrum-space used by a reference system)}}{\text{(spectrum-space used by the system being evaluated)}}$$

"Spectrum-space used" is defined to be the product of the bandwidth, physical space, and time denied by the system to other users. The physical space is usually area for terrestrial systems, but may be volume (for example, for radar), or even degrees of arc for geostationary satellite systems. The "reference system" was originally intended to be an "ideal" system, but it usually is not practical to define an ideal system. Instead, the reference system is to be a good, but practical, state-of-the-art system.

An interim, or progress, report has been prepared for IRAC. If the concept is acceptable, a computer model for calculating the efficiency for fixed and mobile services in selected bands between 947 MHz and 40 GHz will be developed and tested in FY 84.

NSA HF/VHF Propagation Studies. For several years ITS has provided support to the National Security Agency (NSA) in technical areas pertaining to HF/VHF propagation and numerical simulation of long-distance HF propagation system performance. In addition to providing technical assistance, ITS has accepted specialized studies in support of NSA objectives and operational requirements. In particular, ITS has developed and/or implemented specific analytic techniques to assist NSA in the development of operational and analytical procedures.

This project was directed toward study and plans for the development and/or implementation of analytic techniques to determine the operating characteristics necessary to provide reliable communication between the locations when an incomplete specification of operating characteristics is provided. The project will also assess the ability of one or more monitoring stations to detect these communications and to rank the monitoring stations according to their respective abilities of detection. The primary project objectives were:

- to provide technical assistance to sponsor in HF/VHF propagation
- to undertake specific HF/VHF propagation studies to assist the National Security Agency in the development of analytical techniques for operational use.

CHAPTER 2. SYSTEMS AND NETWORKS

The Systems and Networks Division conducts research and analysis programs directed toward assessing and developing domestic and international standards, investigating economic network alternatives, and conducting research and analysis of advanced networks including satellite networks for future applications. The activities of this Division are supported in part by programs from other Government agencies. The objectives for this subelement of ITS activities are:

- To develop uniform, functional methods of specifying and measuring performance of telecommunication systems as seen by the end user.
- To promote the development and international adoption of technical standards in the telecommunications and information industries.
- To formulate and advocate regulatory, legislative, and institutional reforms to the FCC, Congress, and industry in order to promote competition and deregulation where feasible,and to ensure the universal availability of basic telecommunication services.
- To provide technical efforts to support administrative conferences such as the World and Regional conferences of the International Telecommunication Union (ITU), the International Radio Consultative Committee (CCIR), and the International Telegraph and Telephone Consultative Committee (CCITT).

The Systems and Networks Division comprises four groups: (1) Switched Networks Analysis, (2) Satellite Networks Analysis, (3) System Performance Standards and Definition, and (4) System Performance Engineering Analysis. The programs of each group are directly or indirectly related to one or more of the objectives listed above. These programs are described in the subsequent paragraphs.

SECTION 2.1 SWITCHED NETWORKS ANALYSIS

The Switched Networks Analysis Group of the Systems and Networks Division conducts a broad program of applied research, exploratory development studies, concept studies analysis, and experimentation directed toward support of ITS program elements, and programs of other Government agencies (e.g., the U.S. Army and the National Communications System). The Group's programs focus on advanced switched networks for telephone, data, message, facsimile, and television services. State-of-the-art programs are performed to guide the technical development and application of new circuit-switching and store-and-forward switching techniques as well as other innovative network concepts and architectures. The end objective of all programs is to obtain improved services for the user community through better resource utilization and performance at lower costs in competitive markets.

Information Technology Policy. The objectives of the Information Technology project are to identify issues in information policy that require national attention, to research these issues, and to assist in preparing necessary action by the Department of Commerce. This first year's work concentrated on identification of issues. This material is published in a report by R.K. Salaman and E.C. Hettinger entitled "Overview of Information Policy." In addition to this report, assistance was provided in addressing specific policy concerns raised by the Administration and the Congress. The latter included long-range goals in international telecommunications and information, the First Amendment issues concerning broadcasting, the Postal Service E-COM offering, local telephone rate increases, and participation in the Commerce Council on Industry and Trade, Working Group on Intellectual Property.

An indication of political concern in the information policy area can be gained by a review of Congressional activity. In the first 9 months of the first session of the 98th Congress, about 200 bills and resolutions were introduced that were relevant to the development and impact of information on the economy and society. By far the largest group (60%) dealt with high technology--particularly the preparation offered by the educational system, and the need to improve the United States position in international trade. About 35% of Congressional "information policy" activity concerned telecommunications and information policy directly, divided about evenly between these two areas. The telecommunication concentration was a continuation of broadcast and common carrier deregulation and the resulting concerns. Information policy issues primarily concerned intellectual property--particularly copyright issues. There was a marginal continuing concern in Congress about Government competition with the private sector information services.

An issue of particular importance is international trade. It is quite evident that in recent years the services sector trade has played an important role by providing a sufficient positive balance to counteract the growing negative balance of merchandise trade. It appears that over 4000 of the services are information intensive. More work is required to identify what policies can be established to stimulate the continued growth of the information services trade balance.

Another area of information policy attention has been focused on the protection of intellectual property rights. There has been continual concern for revision of the 1976 Copyright Act to accommodate the requirements of rapid microelectronic technology advances. Issues still unresolved include the home recording of off-the-air programs, piracy of copyrighted program material, and the protection of copyrighted computer firmware and software.

Work in the next several years will focus on copyright issues, particularly concerning computer use, and issues of international trade in information goods and services.

NTIA Common Carrier Technical Program. One objective of this program is to promote diversity of services and effective competition and to minimize regulation for domestic and international telecommunications industries. As part of this effort the Institute conducts technical studies and responds to notices of inquiry (NOI) from the Federal Communications Commission (FCC) where the Administration's viewpoint needs to be expressed. Such responses are ways used to develop and promote policies to minimize Federal interference with the free functioning of the domestic marketplace in the field of telecommunications equipment and services.

One example of such an NOI response is a study conducted in response to FCC Docket No. CC 81-216 on petitions seeking to amend Part 68 of the rules in order to permit registration and direct electrical correction of customer-provided equipment to the Dataphone Digital Service (DDS). (See Figure 2-1.) The DDS is a tariffed service offering of AT&T. The existing tariff required that customers using the DDS must connect to this service through a carrier-provided service terminating unit known as the channel service unit (CSU). The CSU connects to an office channel unit (OSU) and then through a series of multiplexers to the long haul transmission facilities as shown in Figure 2-1.

In a technical study conducted by the Switched Networks Group, ITS found no unique technical solution to define the demarcation point between the service provider and the customers' premises equipment.

Another FCC NOI response, currently under way, concerns the Integrated Services Digital Network (ISDN). In this NOI (General Docket 83-841), released August 10, 1983, the FCC solicited comments on 1) how they can best ensure that the ISDN(s) are structured to foster competition and serve the public interest, 2) how specifications of ISDN can best conform to the regulatory scheme (basic and enchanced dichotomy) adopted in the second computer inquiry, 3) how the Commission can best continue to promulgate pro-competitive policies as ISDN develops, and 4) how they can best represent the divergent interests of U.S. service providers, equipment manufacturers, users, and the public at international forums. The Institute, in close cooperation with its parent organization, the National Telecommunications and Information Administration in Washington, DC, is currently preparing a response to these questions. This response will indicate a number of issues and actions that are expected as a result of the evolution of ISDN.

In addition, ITS, under this program has formed and chairs a technical working group to study and resolve ISDN issues that arise in the U.S. joint ISDN working party. This group is composed of industry and Government representatives who work on specific problems for the joint working party. Examples include

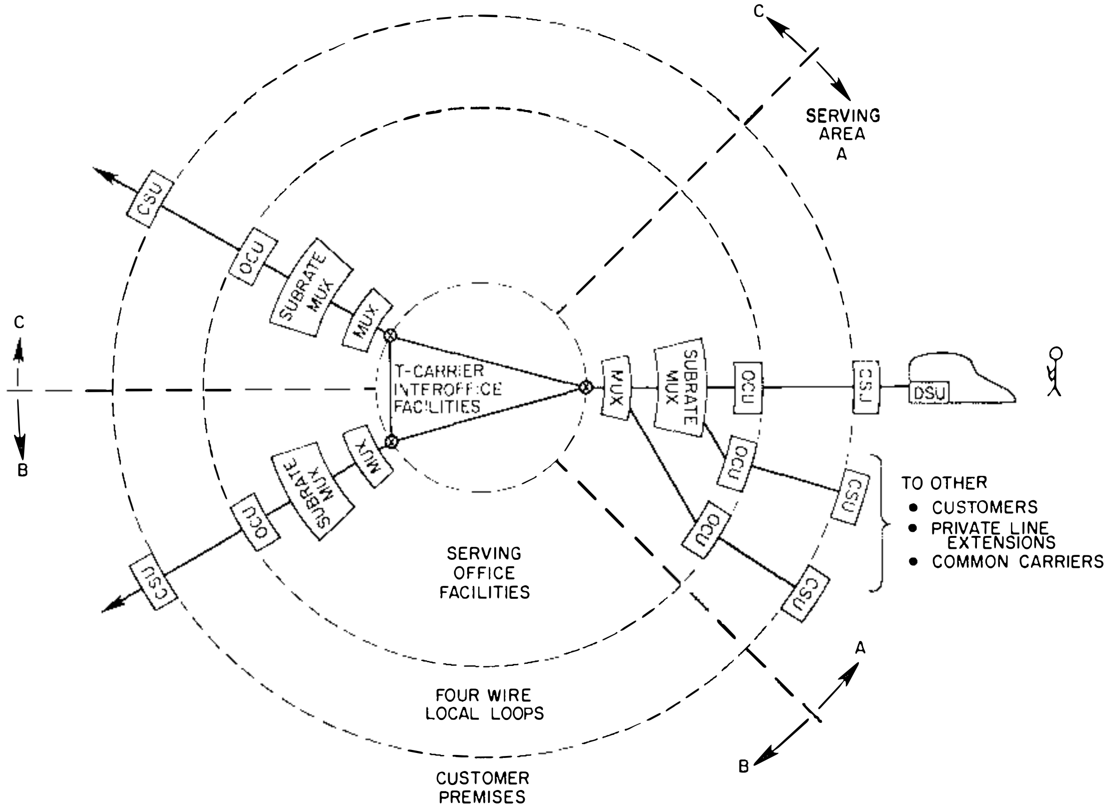


Figure 2-1. The digital data system concept.

numbering plan issues, data and voice dichotomies, and voice digitization processes. The ITS Switched Networks Group is currently working on an ISDN Primer for use by NTIA and other Government agencies as an aid to understanding why ISDN is needed, what it will look like, and the issues that must be resolved.

Militarily Critical Technologies List Review. The Export Administration Act (EAA) of 1979 directed that the U.S. Government develop a list of Militarily Critical Technologies (MCTL) for export control purposes. The primary responsibility for the MCTL development rests with the Department of Defense (DoD). The Department of Commerce (DoC) was given the responsiblity in consultation with DoD to review and revise the Commodity Control (CCL) "for the purposes of insuring that export controls under the National Security Control section cover and, to the maximum extent consistent with the purposes of the EAA, are limited to militarily critical goods and technologies."

The overall requirement for the MCTL is that it shall be sufficiently specific to guide the determinations of any official exercising export licensing responsibilities under the EAA. DoD has developed and promulgated an MCTL and the DoC has established an interagency MCTL Implementation Project for the purpose of full incorporation of the MCTL into the CCL.

The National Telecommunications and Information Administration was requested by the DoC International Trade Administration (ITA) to assist in the interagency MCTL Implementation Project relative to telecommunications equipment, goods, and arrays of know-how. This assistance was provided by the Institute because of the detailed knowledge required of the technology involved.

The objective of this project was to perform a comparison between the Commodity Control List, Supplement No. 1 to paragraph 399.1 of the Export Administration Regulations dated October 1, 1981, and the DoD Militarily Critical Technologies List (MCTL) (U), dated October 1, 1981. The comparison was directed to determine if the CCL entries included the MCTL items, but was limited to only those subjects concerned with telecommunications. The comparison was done on the basis that major subject areas were to be investigated first, followed by selected case studies.

A method for organizing and managing the comparison study was developed along with a matrix structure for summarizing the results of the comparison between the two lists. A case study example was also developed for a modern digital, modularly designed telephone circuit switch to show the type of synthesis process which is required prior to a sort and match analysis between lists.

A report presenting a first level review of the 1981 MCTL and the 1982 CCL in the area of telecommunications was completed in June 1983.

DSN Access Area Program. This is a continuation of a previous project being conducted for the U.S. Army's Communication Systems Agency (CSA). It involves a series of tasks for engineering services for the Defense Switched Network Access Area (DSNAA). Tasks include the development of experimental strategies and test objectives for a concept validation facility (CVF) to test DSNAA concepts using the Experimental Integrated Switched Network (EISN).

Initially, EISN nodes will be implemented at Fort Monmouth and at Fort Huachuca by the U.S. Army. The equipment and facilities required at each site will change depending on the experiment and as new objectives are added. Some of the major test areas to be implemented are tabulated below.

- Transmission facilities from various carriers using parameters determining analog and digital quality of service, i.e., tests of 64 kb/s end-to-end user facilities.
- Switching facilities with stored program control including the interface with older switches; also tests of dual homing features.
- Local network and terminal equipment involved in interactive and bulk data transmission and possibly the integration of terrestrial packet switching in the CVF test system.
- Administration, operation, and maintenance of trunk traffic, base access and maintenance of communication integrity through data security measures (e.g., use of end-to-end encoding techniques). A critical test in this area would be the use of common channel signaling (CCS) via a private line network. These CCS tests would be heavily influenced by the extent of routing and signaling tests within the EISN experiment series. However, areas of useful exploration would be the multiplexing of low speed (e.g., 12 b/s) telemetry data on the signaling channel in a base access area.

Some of the required test elements are shown in Figure 2-2. These include, but are not limited to, interactive data terminals, teleconferencing, bulk data (host computer), and local area networks that can be based for an office local network or a high performance computer local network. Integrating the high speed LAN into an intra-and inter-base communications system may also be considered as appropriate for a CVF.

As part of this effort, ITS has prepared three informal reports to the sponsor covering 1) test objectives, 2) CVF implementation and testing, and 3) network control. We are currently working on refinement of test objectives and the design of tests to be performed. Emphasis is on telecommunications within the access areas themselves rather than the long distance transmissions.

Another task is to determine the impact of technological advances, standards, Government regulations, and legislative actions on the future DSN and particularly on the access area

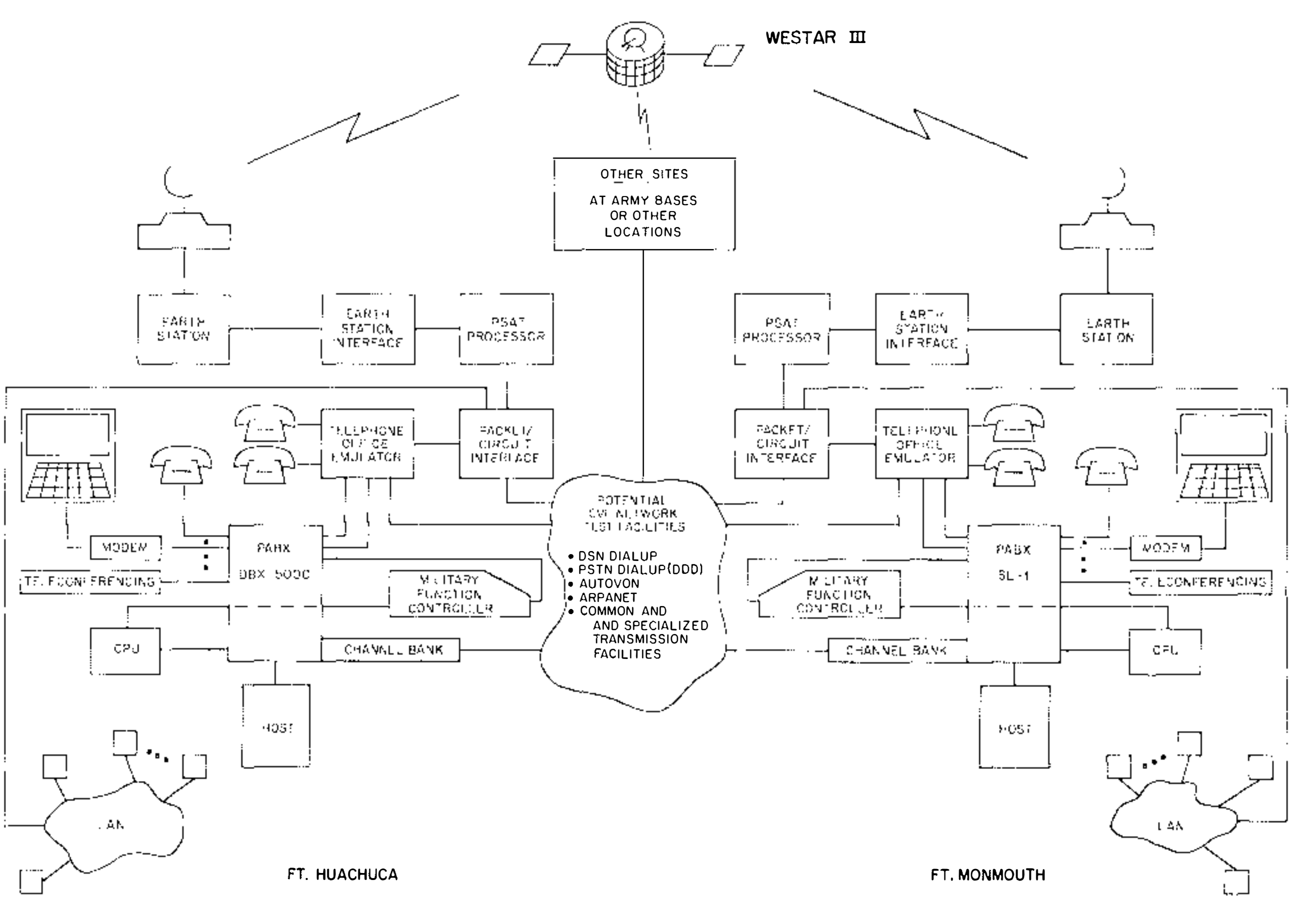


Figure 2-2. Concept validation facility for DSN using EISN-type nodes.

and local networks used by the military departments. Technical briefs are prepared and submitted as issues arise or as questions are resolved. Standards activities that could impact the Defense Switched Network are addressed. The task leader participates in the American National Standards Institute (ANSI) for this purpose.

Finally, ITS provides technical assistance to the CSA in developing R&D programs and in assisting the progress of programs conducted by industry. Institute personnel participate by developing statements of work, reviewing proposals, attending program status reviews, participating in technical working groups, critiquing reports, and conducting independent studies to support these efforts. Results are documented and submitted to CSA usually as technical briefs or informal reports that convey the ITS position, recommendation, or other technical information.

NCS Interoperability Study. The purpose of this study is to examine the impact of Integrated Digital Services Network (ISDN) standardization on the Federal emergency communications requirements identified in Presidential Directive NSC-53. This directive states, in part, that "it is essential to the security of the United States to have telecommunications facilities adequate to satisfy the needs of the nation during and after any national emergency. This is required in order to gather intelligence, conduct diplomacy, command and control military forces, provide continuity of essential functions of government, and to reconstitute the political, economic, and social structure of the Nation. Moreover, a survivable communications system is a necessary component of our deterrent posture for defense." This Presidential Directive establishes the role of the National Communication System (NCS) and the NCS responsibility to plan and prepare for mobilization of public and private telecommunication facilities to meet emergency needs.

Although the nature and level of communication support required varies widely with the nature of the emergency, two broad categories of missions may be defined, namely: time-critical missions where continuous communication capability is essential between specific user pairs and non-time-critical missions where some restoral delay is acceptable. This project focuses on the latter category. Missions in this second category include nonmilitary Government functions. These are best addressed through gradual enhancement and integration of

Federal and commercial common user networks. The existing Public Switched Telephone Network (PSTN) has many desirable characteristics for use under such conditions. It is ubiquitous, provides enormous redundancy in essential facilities, and offers full interoperability. However, it is designed primarily for analog communications and has a hierarchical control structure that does not effectively utilize surviving facilities. The ISDN concept promises benefits similar to those of the existing PSTN, but also promises to eliminate many of the PSTN disadvantages through digitization and service integration.

Two key ISDN issues have been identified as particularly significant to this study. These are signaling and digitization. Signaling is important because it is the key to service integration, damage assessment, and flexible control of restoral. Digitization is an important issue because it is currently not cost effective at long distances. The network must be all digital if restoral routing involving many tandem links is to be feasible.

The signaling system identified for the ISDN is CCITT Signaling System No. 7. The user part of this signaling system could provide enhanced error protection to address specialized threats such as HEMP (High Altitude Electromagnetic Pulse), and could also convey user priority information similar to that provided in AUTOVON. Such information could be signaled on subscriber loops via the User Data Fields of Open Systems Interconnect (OSI) protocol data units (e.g., Connection Request) if appropriate link access protocols are developed. A unified signaling system for ISDN should be developed that (1) controls all services, features, and functions and (2) is responsive to the NCS unique applications.

The ISDN concept is to provide end-to-end channels to the user interface that are compatible with the Pulse Code Modulation (PCM) voice digitization rate of 64 kb/s and multiples or submultiples thereof. Unfortunately this concept will not become a reality until digital long-haul transmission becomes cost effective. The existing PSTN employs analog FM/FDM long-haul transmission facilities for economic reasons. Although extensive portions of the network operate in a digital mode (e.g., voice encoded PCM), these "islands" of digital operation are generally limited to densely populated areas. The digital portion of the network covers a relatively small part of the geographic area of the U.S. A "hybrid" service offering is being planned by CCITT Study Group XVIII as an interim measure in recognition of this problem.

DTE/DCE Standards. CCITT international standards committees have continued to define customer/network interface requirements for the Integrated Services Digital Network (ISDN). It is nearly certain that the basic access will support two 64,000 bit/s channels plus signaling and overhead for a planned bit rate of 192 kbits/s. Primary access to the ISDN will extend this basic access to a 23-channel access plus signaling and overhead to achieve a user/network interface at 1.544 Mb/s. Other channels under consideration include multiples of 384 kbit/s digital bit streams. Third-generation projections (time frame = 1990 and beyond) would indicate that bit rates up to 10 megabits/s may be reasonable for large customer (e.g., Federal facility) interface access to an ISDN. An analysis of the digital performance of transmission media was carried out to assess the limitations of coaxial cable, twisted wire pair, and optical fiber waveguide in supporting user terminal-to-network interchange circuits for future ISDN applications.

A figure of merit was defined for metallic transmission media operating in a baseband digital mode. This figure of merit assumes that distortion of the transmitted digital pulse limits the ability of a digital system to correctly interpret a received binary signal in the absence of noise. Thus, a maximum bit rate is determined that can be transmitted over a given distance with a required error-free quality of service. This rise/decay time distortion of rectangular input pulses (baseband binary digital modulation) is clearly observable as horizontal jitter in the familiar eye pattern measurements often used on digital systems. This jitter is expressed as a percentage of the theoretical data unit interval, which is the reciprocal of the bit rate in seconds. Performance standards may be defined by this jitter figure or by the rise time (10 to 90%) of the leading edge of the pulse expressed as a decimal fraction of the theoretical data unit interval.

A first-order analysis of metallic transmission lines has been carried out (Hull, J.A., A.G. Hanson, and L.R. Bloom; NTIA Report 83-121) based on the recognition that at sufficiently high frequencies (frequencies corresponding to the Fourier components of a typical digital pulse ∿5 to 50 megahertz) the lumped-constant series resistance of metallic transmission lines is dominated by the skin-effect impedance. Both the impulse response and the response to a step function input signal may be derived. A normalized plot of the impulse response function is shown in Figure 2-3.

A figure of merit for metallic transmission media of the form $Fm = P\ell^2$ = constant may be defined where P is the maximum bit rate (reciprocal of minimum bit interval) of rectangular pulses (megapulses per second) and ℓ is the cable length (kilometers). Thus for an assumed system requirement of 10 megapulses over a distance of 1 km, the required Fm = 10. The shortest data unit interval for such metallic transmission media is determined by the intersymbol interference created when successive pulses overlap. If one assumes that an overlap corresponding to that which occurs where the data unit interval corresponds to the time required for the amplitude of the impulse response to decay to 0.1 of its peak value is acceptable, then a figure of merit can be derived for metallic transmission media such as coaxial cable, twisted wire pair, and twinaxial lines. This same data unit interval also corresponds to approximately twice the 50% response time to a step input signal. The analysis provides a figure of merit that can be calculated from the geometric and physical parameters of the cable. This analysis also allows the derivation of

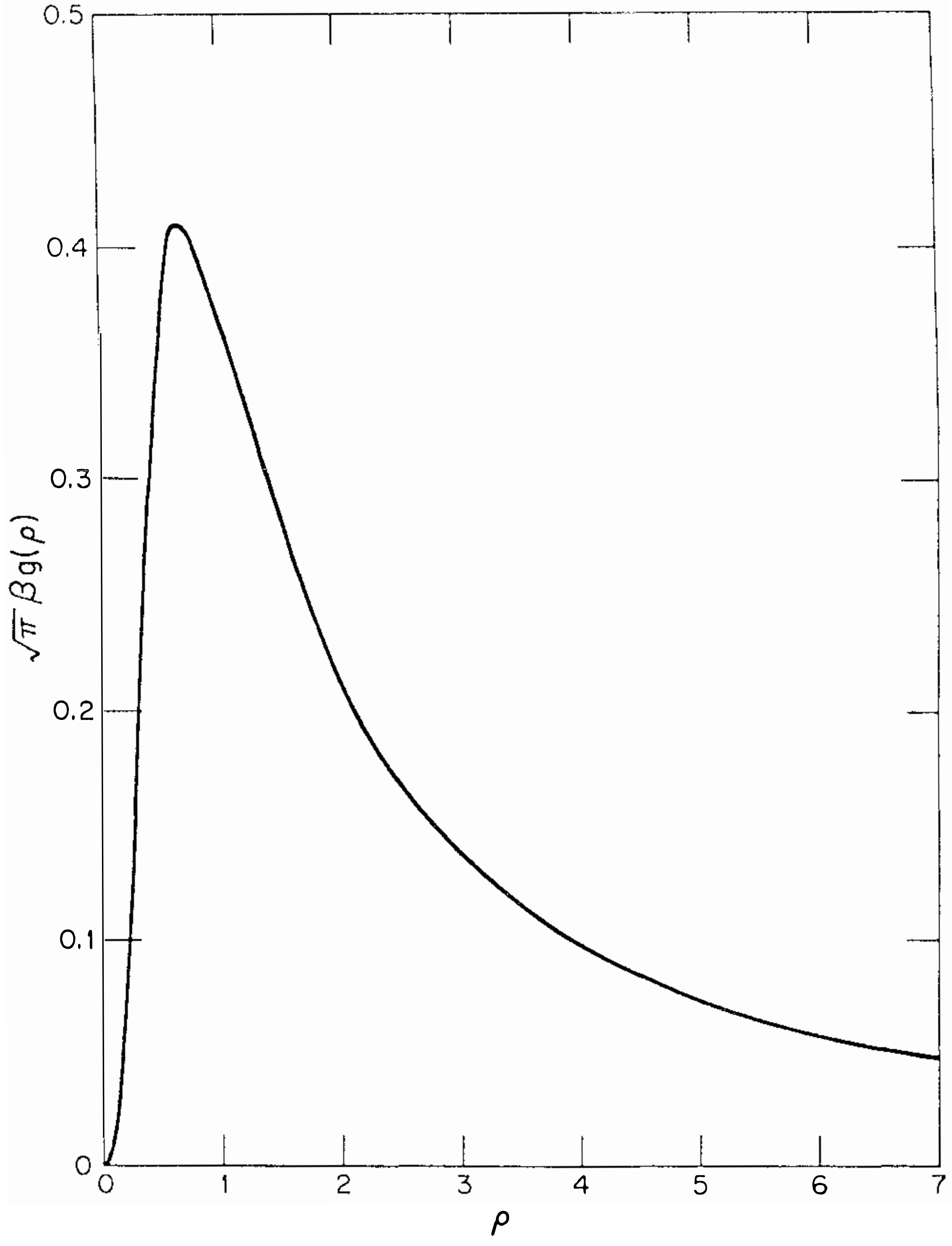


Figure 2-3. Normalized impulse response for coaxial cable.

the figure of merit based on an attenuation coefficient measurement made at a frequency where skin-effect impedance dominates the series resistive component of the lumped constants for the transmission line. The figure of merit allows the user to determine the digital performance of transmission media when only the attenuation coefficient is provided by the manufacturer. For more details, the reader is referred to the referenced report.

The open literature was reviewed to determine the digital performance of optical fiber waveguides and to develop engineering approximations that are useful in system design considerations. Relationships of generally published manufacturer's performance data (i.e., -3 dB bandwidth) and a maximum digital pulse repetition rate indicates that for multimode fibers, the maximum pulse rate is approximately 1.3 x the -3 dB bandwidth. For optical fiber waveguides a useful figure of merit is obtained by the expression $Fm = P\ell$ = constant. More detail is available in the report.

The results of these analyses have been presented to technical representatives of a leading cable manufacturing company, to a working committee of the American National Standards Institute (ANSI) responsible for high-speed transfer of data between elements of a large computer facility, and to an EIA committee responsible for revision of existing DTE/DCE standards. Also, the report has been distributed to the member agencies of the Federal Telecommunications Standards Committee in preparation for the development of a Federal standard on optical fiber interchange circuit.

DES Related Standards. The Institute is engaged in the development of interoperability related standards for the encryption of digitized voice, and for the use of encryption with CCITT Group 3 facsimile equipment. This work is being performed under the sponsorship of the National Communications System (NCS).

The Institute is providing technical support and expertise to NCS in the development of three proposed Federal standards. These are proposed Federal Standard (pFS) 1015 entitled "Telecommunications: Analog to Digital Conversion of Voice by 2400 Bit/Second Linear Predictive Coding," pFS-1029 entitled "Telecommunications: Interoperability and Security Requirements for Encryption of Narrowband Digitized Voice Using the Data Encryption Standard," and pFS-1028 entitled "Telecommunications: Interoperability and Security Requirements for Use of the Data Encryption Standard with CCITT Group 3 Facsimile Equipment."

The first two standards mentioned above relate, of course, to the encryption of voice traffic. Proposed FS-1015 specifies a standard method of digitizing the speech waveform using Linear Predictive Coding (LPC) techniques. This standard will ensure compatibility among Government-owned narrowband speech coders. Proposed FS-1029 specifies the method to be used to encrypt the output of such speech coders. The third standard listed (pFS-1028) specifies the method of encryption to be employed when using CCITT Group 3 compatible facsimile equipment.

The ITS technical role in the development of these standards primarily involves either writing the initial draft of the most significant portions of the standards or providing recommendations on the initial technical content of the standard. Another role involves analyzing industry and Government comments on the proposed standards, and recommending revisions to the standards based on these comments. The Institute has also assisted the Federal Telecommunications Standards Committee in assessing the technical and economic impact of each of these standards.

Interconnect Facility (ICF) Technical Design Study. This study analyzed the two-way communication link found between a U.S. Army Satellite Earth Terminal and a Defense Communications System (DCS) Technical Control Facility. This link, termed the interconnect facility, includes a particular transmission medium (e.g., twisted-wire pair, coaxial cable, or optical fiber) and communication interface equipment. The study established operational and practical engineering design guidelines to allow selection of the best ICF implementation approach from a variety of implementation options.

The ICF must be engineered and installed as one communication link in a worldwide network, the DCS. Consequently, it must comply with numerous Federal, military, and industry standards, specifications, and practices. A multitude of documents were reviewed and applicable technical parameters were collected to provide the requirements base for the ICF study.

Available military and commercial interface equipment was identified that would be required for the various implementation alternatives. Technical interface characteristics were determined for the equipment.

The primary thrust of the ICF study was aimed at providing the sponsor, the U.S. Army Communications-Electronics Engineering Installation Agency, with graphs depicting the relationship of communications data rate to path length (distance) for the transmission media of interest. For example, to what distance can 22 gage twisted-wire pair be used if data is transferred at 100 kb/s and error-free operation is desired? Since very little guidance was available from military documents, and cable manufacturers' data was scarce relative to data rate and path length, figures of merit were derived for basic cable categories--twisted-wire pair, coaxial, and optical fiber. Graphs were then constructed showing recommended operating ranges for particular cables. Available actual cable measurement data substantiated the accuracy of the constructed curves for chosen system environments (e.g., MIL-STD-188-114).

Other ICF environmental concerns were considered in providing guidelines for the Army ICF designer. These included High Altitude Electromagnetic Pulse (HEMP), security (TEMPEST), shielding and grounding, and temperature and moisture.

The end product of the ICF study was a handbook, sufficient in detail but not theoretically burdensome, which allowed the Army to select the ICF type appropriate for a chosen site. The curves developed by ITS may also be used in other data communication applications.

OTCIXS/TADIXS Study. This study deals with concept development for two U.S. Navy communications networks. The specific networks use tactical HF radios deployed as backup for satellite over-the-horizon targeting and related missions. One system is called Officer in Tactical Command Information Exchange Subsystem (OTCIXS) and the other, Tactical Digital Information Exchange Subsystem (TADIXS).

From a broad top-down view, the Navy communications system can be divided into three functional areas: (1) strategic, (2) long haul (to and from units at sea), and (3) tactical communications among operational units at sea. Figure 2-4 shows the configuration of these nearly global communications components. The HF subsystems are to supplement the tactical, large capacity, satellite resource with a survivable "thin line" connectivity.

The TADIXS is tasked to broadcast a class of messages from shore to ships, with a list of requirements that specify data rates, link operation, precedence, security, performance, etc. The OTCIXS is to provide tactical interconnection between platforms at sea, primarily all within the same battle group. Because of the geographies involved, TADIXS has to span thousands and OTCIXS hundreds of miles, respectively.

For both OTCIXS and TADIXS, the study suggests a further three-phase sequence of development. Phase I is to rely entirely on existing naval HF equipments. Phase II utilizes the best available military and civilian state-of-the-art HF assets. Phase III develops the most advanced HF technology, such as hardware and software derived in conjunction with the U.S. Navy HF Improvement Program (HFIP). The rationale and technical output of the project are published in a report to the sponsor, entitled "Multichannel Adaptive HF System Concepts to Back Up Over-The-Horizon Communications," December 20, 1982.

SECTION 2.2 SATELLITE NETWORK ANALYSIS

The development and growth of a vigorous commercial satellite industry is clearly evident. Today, there are well-established services for domestic, regional, and international, large volume, geographically centralized services in the Fixed-Satellite

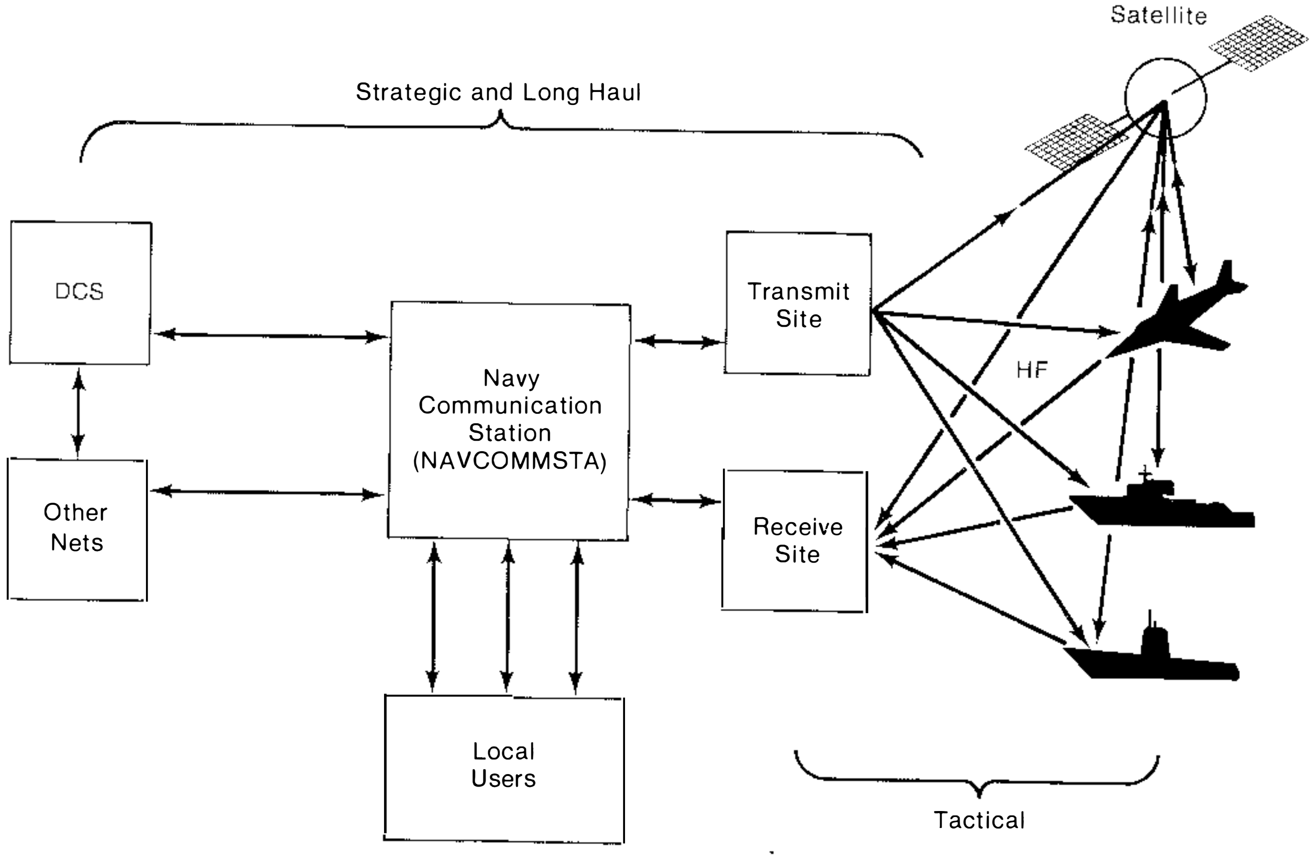


Figure 2-4. The Navy communications system.

Service (FSS). Within the next year, Broadcasting Satellite Service (BSS), often referred to as Direct Broadcast Statellite Service, will be introduced in the United States. The National Telecommunications and Information Administration (NTIA) has had primary responsibilities in assuring that adequate frequency spectrum and geosynchronous orbit resources are available to support the growth of the industry--and that responsibility continues.

A resolution passed at the 1979 World Administrative Radio Conference (WARC) calls for another WARC to be convened in two sessions--1985 and 1988. The first session will consider the need for planning (i.e., international agreement on assignment of frequencies and orbit locations) all space services. The second session will undertake planning as determined necessary during the first session. The Fixed Satellite Service is the principal focus of preparation for the 1985 Space WARC. Throughout this year, ITS has provided technical support to United States preparation for the conference through participation in the IRAC Ad Hoc 178 group.

The Broadcasting-Satellite Service (BSS) has developed more slowly than the FSS. During July 1983 the RARC for ITU Region 2 BSS met in Geneva to resolve the issues of spectrum sharing by the FSS and BSS between 12.1 GHz and 12.3 GHz and how frequency spectrum and geosynchronous orbit for BSS would be shared among ITU Region 2 administrations. Nearly three years ago, U.S. companies began submitting applications to the Federal Communications Commission (FCC) for licenses to construct and place in service broadcasting satellites for direct home reception. Nine of 14 original applications ultimately were accepted by the FCC and by November 4, 1982, a total of eight construction permits had been granted, conditional upon agreements reached at the 83 RARC-BS. There have been at least four additional applications filed with the FCC in a second-round opportunity for filing. It becomes clear that U.S. requirements for spectrum and orbit assignments, going into the conference, would be substantial. Strong technical background for the U.S. position at the conference, therefore, would be essential. The Institute has provided substantial technical support to U.S. preparation for the RARC-BS, including scenario analyses to demonstrate efficient use of frequency and orbit resources by the United States.

Earlier discussion mentioned a well-developed commercial satellite industry (in the FSS) for large volume, geographically centralized services (large trunk applications). However, utilization of satellite technology by dispersed, low-volume users (thin-route applications in rural areas) has not been nearly so successful. Such utilization does not offer the economic incentives of large trunk applications and will occur only when lower-cost ground terminals are available. This is true in spite of the fact that there is clear need, particularly in less-developed parts of the world, for basic communications capabilities, and satellite communications technology seems to offer the best solution to that need. A jointly supported effort with the Department of State (DoS), Agency for International Development (A.I.D.) was initiated in 1980 to define a low-cost earth terminal design and to build an initial terminal following that design. That terminal would be used in engineering and performance tests to establish the design integrity and thereby encourage industry development and production. The original earth station design and service requirements study followed a parametric approach by establishing a matrix of options for technical characteristics of components of the earth station, such as the antenna size, the low noise amplifier noise temperature, and the high power amplifier output capabilities. Technologies that could be used for telephony, such as single channel per carrier frequency modulation (SCPC-FM), digital voice encoding such as adaptive delta modulation with quadrature phase-shift-keying (QPSK), or voice synthesis such as linear predictive coding (LPC) with QPSK, also are used as parameters of the study. This study guided the development of technical specifications for the earth station. Major earth station components now are being purchased in accordance with those specifications.

The ITS Satellite Communications System work comprises three NTIA-sponsored projects plus two complementary projects sponsored by the Agency for International Development. There have been two additional projects in the Satellite Network Analysis Group sponsored by the National Security Agency. These projects have been directed to propagation of radio signals rather than satellite network analysis. These seven projects, established for management tractability are:

1. Technical Support to Planning, and Preparation for the 83 RARC-BS
2. Technical Support to Planning and Preparation for the 85/88 Space WARC
3. Development of the Geostationary Satellite Orbit Analysis Program (GSOAP)
4. Technical Support to the A.I.D. Rural Satellite Program
5. Technical Support to A.I.D. in Development of a Low Cost Television System for Educational Applications
6. Multiple Knife-Edge Diffraction Studies
7. Pulse Distortion Studies.

Technical Support to Planning and Preparation for the 83 RARC-BS. As noted earlier, the 1979 WARC of the International Telecommunication Union resolved that a Regional Administrative Radio Conference for planning of the Broadcasting-Satellite Service (RARC-BS) of the ITU Region 2 (North, Central, and South America and Greenland) would be convened in 1983 and that a detailed frequency allotment and orbital positions plan would be drawn up for the Region. The outcome of the RARC-BS has been recognized to have major impacts on efficient use of the frequency-orbit resources available for the Region 2 countries and on future development of the U.S. Direct Broadcast Satellite industry. In preparation efforts for the U.S. position for the RARC-BS, various problems are being studied by the U.S. National Committee for CCIR (International Radio Consultative Committee), IRAC Ad Hoc 177, and the FCC Advisory Committee on the

1983 RARC-BS established under the FCC Docket No. 80-398. In this fiscal year, the ITS contributions have been made through participation mainly in the Computer Users Group, a Working Group under Ad Hoc 177.

Support to the Computer Users Group for planning and preparation for the 83 RARC-BS consisted of service area polygon point data verification, rain zone index data verification, scenario development and analysis using the Spectrum Orbit Utilization Program (SOUP) interference analysis program, and development of a Scenario Performance Measuring Program using the output of the SOUP program.

The Institute verified all of the service area polygon point data that were being used by the Computer Users Group. Each of the service areas was plotted out on a map to check each of the polygon points for accuracy and to see if the service area polygon points could be improved.

The Institute also verified all the rain zone index data for each of the service area polygon points. A program was written to calculate the rain zone index for each polygon point and to compare it to the original rain zone index data. Because of the large number of differences between the calculated rain zone indexes and the original ones, another program was written to automatically calculate the correct rain zone index for each polygon point and insert it into the service area data file.

Scenario development and analysis to implement a plan of satellite orbital locations for Region 2 was accomplished using the SOUP computer program running on a mini-computer at the FCC in Washington, DC. The Institute was assigned analysis tasks to minimize the interference present in the Region 2 countries assuming three continental U.S. service areas with one satellite location each. This work involved not only adjusting satellite locations to minimize the interference present, but also changing antenna parameters, channel bandwidth, channel separation, protection ratio templates, and other technical parameters to observe their effect on the interference present in the region.

To better understand the difference in two or more different scenario analysis runs, a Scenario Performance Measuring Program, which uses the SOUP analysis output, was developed at ITS and made available to the Computer Users Group. The program partitioned the range of possible carrier-to-interference (C/I) ratios into 16 bins and placed the corresponding C/I ratio for each polygon point in one of the 16 bins. This procedure was also done for the median C/I ratio of each service area. By looking at the total bin counts for the polygon points and the service areas and comparing them to other scenario runs, the relative performance of two or more scenarios could be determined. This information was quite valuable when comparing two scenarios with relatively small changes.

An example of scenario analysis results is shown in Figures 2-5 through 2-8. The scenario includes only nine Northern Hemisphere countries of Region 2. There are 18 service areas and a total of 205 polygon points which define the service areas within these countries. Figure 2-5 shows a summary of the scenario and SOUP input data used for the analysis. The SOUP interference analysis summary report is five pages of computer output just for this simple scenario. Figure 2-6 shows the first of those five pages. Figures 2-7 and 2-8 show the Scenario Performance Measuring Program statistical summaries of results. Figure 2-7 shows that 83.4% of the polygon points have nonnegative C/I ratios. Figure 2-8 shows that the median C/I for 88.9% of the service areas is nonnegative.

Support to Planning and Preparation for the 85/88 Space WARC. In the introductory comments for the Satellite Network Analysis Group work, brief mention is made of a resolution passed at the 1979 WARC calling for a World Administrative Radio Conference to be convened in two sessions to consider the need for planning all space services to assure equitable use of the frequency and orbit location resources and to accomplish planning as determined necessary during the first conference session. The first session is scheduled for 1985, and the second session now is scheduled for 1988.

Prior to and during the 83 RARC-BS, it became clear, as a result of technical analyses, that rigid planning for the Broadcasting-Satellite Service would inhibit flexibility in implementing that service. Yet Broadcasting-Satellite Service, probably, is the most amenable service to such planning when one considers the other space services. The Fixed-Satellite Service certainly represents the majority of space systems that have been placed in service. And a view seems to be emerging in the United States that a position should be taken with regard to the Space WARC that planning only be considered for some frequency bands allocated to Fixed-Satellite Service.

In considering (and developing) a position that the United States should take regarding planning of space services, one question that is being asked has to do with mandatory use of reference antenna patterns in calculating interference. Related to this question is the fact that relatively little data has ever been submitted to the CCIR to describe the performance characteristics of earth station antennas used for FSS applications. This lack of data is particularly acute for relatively small antennas, i.e., when $D/\lambda < 100$, where D equals the diameter of the antenna and λ equals the wavelength of the radio energy being received or transmitted by the antenna.

In response to these needs for technical information, and as support to preparation for the 85/88 Space WARC, ITS has collected off-axis gain performance patterns of antennas produced by U.S. manufacturers. Over 80% of the antennas listed in applications for licensing by the FCC in the 4/6 GHz band for Common Carrier Services have been obtained and analyzed to determine recommendations that can be offered to Space Services planners including CCIR study/working groups for antenna sidelobe

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                              AGGREGATE DOWNPATH SUMMARY ITS8352
 ITS 3 CONUS AREA SCENARIO  -  JUNE 22, 1983
 U.S. & CANADA INTERFERENCE SCENARIO (3 SATELLITES EACH)
 UPDATED RAIN ZONE DATA * BLOCKING * DOWNLINK ONLY
 RARC = RR04 * SATELLITE TRANSMITTER POWER = -105.0 DBW/M2
 PROTECTION RATIO = PND2 * PRO = 28 DB
 CHANNELIZATION = CB06 (36 CHANNELS) * 24 MHZ/CHANNEL
 DOWNPATH ANTENNAS: ST = AP16 , ER = AF01 (0.9M) * CIRCULAR POLAR.

                   | SERVICE | ORBITAL |  ELEV ANGLE ! PROTECTN | # OF PTS |      MARGIN
ADMINISTRATION     |  AREA   |   LOC   |  MIN |  MAX | TIME (1) | POS/TOTAL|  MIN |  MAX | MEDIAN
___________________|_________|_________|______|______|__________|__________|______|______|______
Canada Pacific     | CANA1004|  160.0  |  6.5 | 25.1 |  01:56   |  12/15   | -1.3 |  1.4 |  0.8
Canada Prairies W. | CANA2005|  160.0  !  5.3 | 18.9 |  02:56   |  15/15   |  0.1 |  1.4 |  1.0
Canada Prairies E. | CANA3006|  115.0  | 10.2 | 32.2 |  23:56   |   8/10   | -1.8 |  1.6 |  0.7
Canada Ontario     | CANA4007|  115.0  |  7.6 | 31.7 |  00:56   |  16/18   | -0.2 |  1.5 |  0.8
Canada Quebec      | CANA5008|   85.0  | 10.5 | 37.2 |  23:56   |  10/18   | -1.8 |  1.2 |  0.1
Canada Atlantic    | CANA6009|   85.0  | 19.2 | 36.3 |  00:56   |  15/15   |  0.1 |  1.3 |  0.9
Mexico             | MEXICO12|  110.0  | 50.9 | 67.0 |  23:36   |   9/10   | -0.1 |  1.4 |  0.9
Mexico             | MEXICO22|  110.0  | 53.4 | 67.1 |  00:36   |  11/11   |  0.6 |  1.6 |  1.3
Belize (U.K.)      | HNBBE020|  140.0  | 28.1 | 29.7 |  02:36   |   0/ 6   | -3.9 | -1.5 | -2.0
Guatemala          | GTMIFF01|  140.0  | 28.8 | 33.6 |  02:36   |   0/ 5   | -0.8 | -0.2 | -0.6
Cuba               | CUB00012|   87.0  | 61.6 | 64.7 |  00:04   |  18/20   | -0.8 |  1.5 |  1.0
Bahama Islands     | BAH00R01|   87.0  | 56.2 | 61.4 |  00:04   |   8/ 8   |  0.3 |  1.2 |  0.7
Jamaica            | JMC00029|   87.0  | 65.5 | 66.4 |  00:04   |   8/ 8   |  1.2 |  1.5 |  1.5
Haiti              | HTIIFF01|   87.0  | 60.9 | 64.7 |  00:04   |   4/ 4   |  1.1 |  1.3 |  1.2
Alaska             | ALS00033|  175.0  |  8.0 | 26.7 |  00:56   |  11/11   |  0.6 |  1.7 |  1.1
United States Pac  | USAPSV03|  145.0  | 21.6 | 41.8 |  00:56   |   6/ 8   | -0.3 |  1.2 |  0.7
United States Cent | USACSV03|  130.0  | 21.9 | 46.7 |  01:56   |   8/11   | -1.4 |  0.8 |  0.3
 USA EASTERN (3 SE | USAESV03|  100.0  | 27.6 | 54.9 |  00:56   |  12/12   |  0.4 |  1.3 |  0.6

                                                          ___________
                                                 Total:     171/205
```

Figure 2-5. Summary of scenario and SOUP input data for nine Northern Hemisphere Region 2 countries.

```
                        AGGREGATE DOWNPATH SUMMARY FOR ITS8352                                  PAGE    1


BLOCK SERVICE   SAT      TEST POINT   **** CO-CHANNEL ****  UPPER-ADJ    LOWER ADJ    NEXT UPPER   NEXT LOWER        TOTAL
CODE    AREA   LONG       LAT-LONG    WST-INTFR C/I   MARGN  C/I  MARGN  C/I  MARGN  C/I  MARGN  C/I  MARGN          MARGN


GP01 CANA1004 -160.0   70.0 -141.0 ALS00033  39.0   11.0  19.6    7.3  19.6    7.3   0.0    7.1   0.0    7.1 ***      0.7
              -160.0   70.0 -120.0 ALS00033  39.1   11.1  19.9    7.6  19.9    7.6  -0.1    7.0  -0.1    7.0 ***      0.8
              -160.0   60.0 -120.0 ALS00033  40.9   12.9  19.1    6.8  19.1    6.8  -1.8    5.2  -1.8    5.2 ***     -0.3
              -160.0   53.7 -120.0 USAPSV03  40.4   12.4  20.0    7.7  20.0    7.7  -1.0    6.0  -1.0    6.0 ***      0.5
              -160.0   49.0 -114.1 USAPSV03  36.0    8.0  18.3    5.9  18.3    5.9  -2.3    4.8  -2.3    4.8 ***     -1.3
              -160.0   48.3 -123.9 USAPSV03  38.3   10.3  19.9    7.6  19.9    7.6   0.0    7.1   0.0    7.1 ***      0.8
              -160.0   49.4 -126.7 USAPSV03  40.2   12.2  20.1    7.7  20.1    7.7   0.0    7.1   0.0    7.1 ***      1.0
              -160.0   52.6 -132.2 ALS00033  41.9   13.9  20.0    7.7  20.0    7.7   0.0    7.1   0.0    7.1 ***      1.1
              -160.0   60.3 -141.0 ALS00033  38.7   10.7  19.9    7.5  19.9    7.5   0.0    7.1   0.0    7.1 ***      0.8
              -160.0   49.2 -123.0 USAPSV03  38.8   10.8  20.2    7.9  20.2    7.9   0.0    7.1   0.0    7.1 ***      0.9
              -160.0   50.7 -120.4 USAPSV03  39.1   11.1  20.0    7.7  20.0    7.7  -0.6    6.4  -0.6    6.4 ***      0.6
              -160.0   49.5 -117.3 USAPSV03  37.3    9.3  19.2    6.9  19.2    6.9  -1.4    5.7  -1.4    5.7 ***     -0.3
              -160.0   53.9 -122.7 USAPSV03  41.5   13.5  20.7    8.4  20.7    8.4  -0.2    6.9  -0.2    6.9 ***      1.3
              -160.0   58.8 -122.7 ALS00033  42.1   14.1  20.1    7.8  20.1    7.8  -0.7    6.3  -0.7    6.3 ***      0.8
              -160.0   61.0 -135.0 ALS00033  41.2   13.2  20.7    8.4  20.7    8.4   0.0    7.1   0.0    7.1 ***      1.4

GP01 CANA2005 -160.0   70.0 -120.0 ALS00033  40.1   12.1  20.3    8.0  20.3    8.0   0.0    7.1   0.0    7.1 ***      1.1
              -160.0   70.0 -115.0 ALS00033  39.6   11.6  20.2    7.8  20.2    7.8   0.0    7.1   0.0    7.1 ***      1.0
              -160.0   60.0 -101.8 CANA3006  40.7   12.7  20.2    7.9  20.2    7.9   0.0    7.1   0.0    7.1 ***      1.1
              -160.0   49.0 -101.3 USAPSV03  35.0    7.0  19.6    7.3  19.6    7.3   0.0    7.1   0.0    7.1 ***      0.1
              -160.0   49.0 -106.0 USAPSV03  35.8    7.8  20.0    7.7  20.0    7.7   0.0    7.1   0.0    7.1 ***      0.4
              -160.0   49.0 -114.1 USAPSV03  37.6    9.6  20.3    8.0  20.3    8.0   0.0    7.1   0.0    7.1 ***      0.8
              -160.0   53.7 -120.0 USAPSV03  40.8   12.8  20.8    8.5  20.8    8.5   0.0    7.1   0.0    7.1 ***      1.4
              -160.0   51.0 -114.0 USAPSV03  39.0   11.0  20.7    8.3  20.7    8.3   0.0    7.1   0.0    7.1 ***      1.2
              -160.0   50.0 -110.7 USAPSV03  38.0   10.0  20.4    8.1  20.4    8.1   0.0    7.1   0.0    7.1 ***      0.9
              -160.0   49.7 -112.8 USAPSV03  38.1   10.1  20.4    8.1  20.4    8.1   0.0    7.1   0.0    7.1 ***      1.0
              -160.0   53.5 -113.5 USAPSV03  40.1   12.1  20.9    8.6  20.9    8.6   0.0    7.1   0.0    7.1 ***      1.4
              -160.0   52.2 -106.7 USAPSV03  38.1   10.1  20.5    8.1  20.5    8.1   0.0    7.1   0.0    7.1 ***      1.0
              -160.0   62.0 -114.0 ALS00033  41.0   13.0  20.7    8.4  20.7    8.4   0.0    7.1   0.0    7.1 ***      1.4
              -160.0   50.5 -104.0 USAPSV03  36.2    8.2  20.1    7.7  20.1    7.7   0.0    7.1   0.0    7.1 ***      0.5
              -160.0   51.2 -102.5 USAPSV03  36.2    8.2  20.0    7.7  20.0    7.7   0.0    7.1   0.0    7.1 ***      0.5

GP02 CANA3006 -115.0   70.0 -115.0 CANA1004  40.7   12.7  19.5    7.2  19.5    7.2   0.0    7.1   0.0    7.1 ***      0.8
              -115.0   70.0  -95.0 CANA5008  47.4   19.4  19.3    7.0  19.3    7.0  -0.6    6.5  -0.6    6.5 ***      0.6
              -115.0   56.9  -89.0 CANA2005  39.0   11.0  17.7    5.3  17.7    5.3  -3.3    3.8  -3.3    3.8 ***     -1.8
              -115.0   52.8  -95.2 USACSV03  39.2   11.2  20.5    8.2  20.5    8.2   0.0    7.0   0.0    7.0 ***      1.1
              -115.0   49.0  -95.2 USACSV03  36.4    8.4  19.4    7.1  19.4    7.1  -0.8    6.2  -0.8    6.2 ***     -0.1
              -115.0   49.0 -101.3 USACSV03  35.4    7.4  19.5    7.2  19.5    7.2   0.0    7.1   0.0    7.1 ***      0.2
              -115.0   60.0 -101.8 CANA2005  44.6   16.6  21.0    8.6  21.0    8.6   0.0    7.1   0.0    7.1 ***      1.6
              -115.0   49.8  -99.9 USACSV03  36.7    8.7  20.0    7.7  20.0    7.7   0.0    7.1   0.0    7.1 ***      0.6
              -115.0   49.9  -97.2 USACSV03  37.3    9.3  20.2    7.8  20.2    7.8   0.0    7.1   0.0    7.1 ***      0.8
              -115.0   53.2  -99.3 USACSV03  40.2   12.2  20.8    8.5  20.8    8.5   0.0    7.1   0.0    7.1 ***      1.3

GP02 CANA4007 -115.0   70.0  -95.0 CANA5008  49.0   21.0  20.3    8.0  20.3    8.0   0.0    7.1   0.0    7.1 ***      1.4
              -115.0   70.0  -80.0 CANA5008  43.4   15.4  19.7    7.4  19.7    7.4   0.0    7.1   0.0    7.1 ***      1.0
              -115.0   47.3  -79.5 USAESV03  35.7    7.7  20.4    8.1  20.4    8.1   0.0    7.1   0.0    7.1 ***      0.6
              -115.0   45.6  -74.4 USAESV03  34.2    6.2  19.5    7.2  19.5    7.2   0.0    7.1   0.0    7.1 ***     -0.1
```

Figure 2-6. Example of SOUP interference analysis summary report for a scenario of 9 Northern Hemisphere, Region 2 countries with 18 service areas.

```
                              AGGREGATE DOWNPATH SUMMARY ITS8352

BIN NO.         BIN RANGE       BIN COUNT BIN PERCENTAGE CUML. BIN CNT. CUML. BIN PCT.
   1               M >=  10          0          0.00           0            0.00
   2         10 > M >=   6           0          0.00           0            0.00
   3          6 > M >=   5           0          0.00           0            0.00
   4          5 > M >=   4           0          0.00           0            0.00
   5          4 > M >=   3           0          0.00           0            0.00
   6          3 > M >=   2           0          0.00           0            0.00
   7          2 > M >=   1          83         40.49          83           40.49
   8          1 > M >=   0          88         42.93         171           83.41
   9          0 > M >=  -1          22         10.73         193           94.15
  10         -1 > M >=  -2           9          4.39         202           98.54
  11         -2 > M >=  -3           2          0.98         204           99.51
  12         -3 > M >=  -4           1          0.49         205          100.00
  13         -4 > M >=  -5           0          0.00         205          100.00
  14         -5 > M >=  -6           0          0.00         205          100.00
  15         -6 > M >= -10           0          0.00         205          100.00
  16        -10 > M                  0          0.00         205          100.00
```

Figure 2-7. Statistical summary of SOUP interference analysis results for a scenario with 205 points comprising 18 service areas in 9 Northern Hemisphere, Region 2 countries.

```
BIN NO.         BIN RANGE       BIN COUNT BIN PERCENTAGE CUML. BIN CNT. CUML. BIN PCT.
   1               M >=  10          0          0.00           0            0.00
   2         10 > M >=   6           0          0.00           0            0.00
   3          6 > M >=   5           0          0.00           0            0.00
   4          5 > M >=   4           0          0.00           0            0.00
   5          4 > M >=   3           0          0.00           0            0.00
   6          3 > M >=   2           0          0.00           0            0.00
   7          2 > M >=   1           6         33.33           6           33.33
   8          1 > M >=   0          10         55.56          16           88.89
   9          0 > M >=  -1           1          5.56          17           94.44
  10         -1 > M >=  -2           1          5.56          18          100.00
  11         -2 > M >=  -3           0          0.00          18          100.00
  12         -3 > M >=  -4           0          0.00          18          100.00
  13         -4 > M >=  -5           0          0.00          18          100.00
  14         -5 > M >=  -6           0          0.00          18          100.00
  15         -6 > M >= -10           0          0.00          18          100.00
  16        -10 > M                  0          0.00          18          100.00
```

Figure 2-8. Statistical summary results of service area median SOUP interference analysis results for a scenario with 18 service areas in 9 Northern Hemisphere, Region 2 countries.

reference patterns. The Institute is concerned with the effects on antenna performance of interference levels produced by adjacent satellites in light of the FCC's new Report and Order, Docket No. 81-704, which will eventually reduce satellite orbit separations from the present 4° to 2°.

Interference occurring at earth terminals results from terrestrial transmissions and also from transmissions from nearby satellites. In either case, significant interference contributions can be ascribed to co-frequency channels and to the 20 MHz offset-frequency channels in a frequency reuse system.

With regard to downlinks, primary interferers are:

- o the cross-polarization component of the channels shared in frequency with the first-adjacent satellites on either side of the primary satellites.
- o the co-polarized, 20 MHz frequency offset channels of the first-adjacent satellites on either side of the primary satellite
- o the co-polarized, co-frequency channels on the second adjacent satellites on either side of the primary satellite
- o the cross-polarization components of the two 20 MHz frequency offset channels of the second adjacent satellite on either side of the primary satellite.

This study considers the immediate sidelobe angle area (1° to 7°) and also considers greater angles to the extent that data are available from manufacturers.

Plots of antenna patterns from different manufacturers were obtained. These were digitized to obtain a data base of 168 patterns in the 4-6 GHz range and 69 patterns in the 6-7 GHz range. The data are being compared to the CCIR reference pattern (CCIR REC 465-1, 1982) given by

$$32 - 25 \log \phi \text{ (dB)} \qquad 1^\circ \le \phi \le 70$$

$$-10 \text{ dB} \qquad \phi^\circ > 70^\circ .$$

A typical pattern, referenced in the equation above, is shown in Figure 2-9. This shows the maximum values of the peaks relative to the reference in the interval for which the plotted value is midpoint. Values of gain that are less than zero indicate the pattern is below the reference, and values greater than zero indicate the pattern exceeds the reference pattern in that interval.

A statistical analysis of all patterns using other reference patterns is in progress. This will be used to determine a best reference for these patterns.

The data processing procedures are designed to simplify the addition of data as they become available.

Development of the Geostationary Satellite Orbit Program (SOUP). This development work, though conducted under a separate project title, is a part of the NTIA support to planning and preparing for the 85/88 Space WARC. To this end, a computer software system called Geostationary Satellite Orbit Analysis Program (GSOAP) is under development at ITS. It is a tool for analyzing space services scenarios (i.e., proposed orbit and spectrum use plans) by calculating the carrier-to-interference (C/I) ratios and the baseband signal quality measures such as the signal-to-noise (S/N) ratios or the bit error rates (BER's). The GSOAP model will be useful for various space services, but the primary emphasis is on the Fixed-Satellite Service (FSS).

The ITS effort in developing GSOAP has been sponsored by the NTIA Office of Spectrum Management (OSM). The OSM plans to use GSOAP in preparing for the forthcoming 1985 and 1988 Space WARC's (World Administrative Radio Conference for the planning of Space Services), both before and at the site of the Conferences. It is expected that GSOAP will interface with a scenario synthesis program that is planned to be developed later.

Items for which programming has been completed this year include:

- o coding of the worldwide map of the rain-climate zone index, based on the latest CCIR report as amended by the Conference Preparatory Meeting (CPM) for the 1983 RARC-BS
- o calculation of the rain attenuation and crosspolar discrimination based on the latest CCIR report
- o calculation of the polarization angle of a linearly polarized radio wave
- o calculation of various antenna gain patterns including the new CCIR patterns recommended by the CPM for the 1983 RARC-BS as well as a new shaped-beam pattern developed by ITS
- o calculation of the each-link and total C/I ratios
- o printing of the calculated each-link and total C/I ratio values.

In summary, most elements of modeling the antenna and propagation have been resolved.

Remaining modeling/programming efforts include:

- o calculation of the baseband signal quality
- o establishing the structure of, and the method for reading of, the input data files.

Efforts in completing this model will require a continuing close coordination with OSM.

The GSOAP is written in ANSI standard Fortran to facilitate its portability among various computers. Its portability from a large-scale computer at Boulder to a mini-computer at Annapolis has been tested several times and successfully confirmed.

A preliminary version of GSOAP, incorporating development to date, has been delivered to OSM. Efforts for developing GSOAP will continue into next year under funds directly appropriated to the ITS Satellite Communications System work.

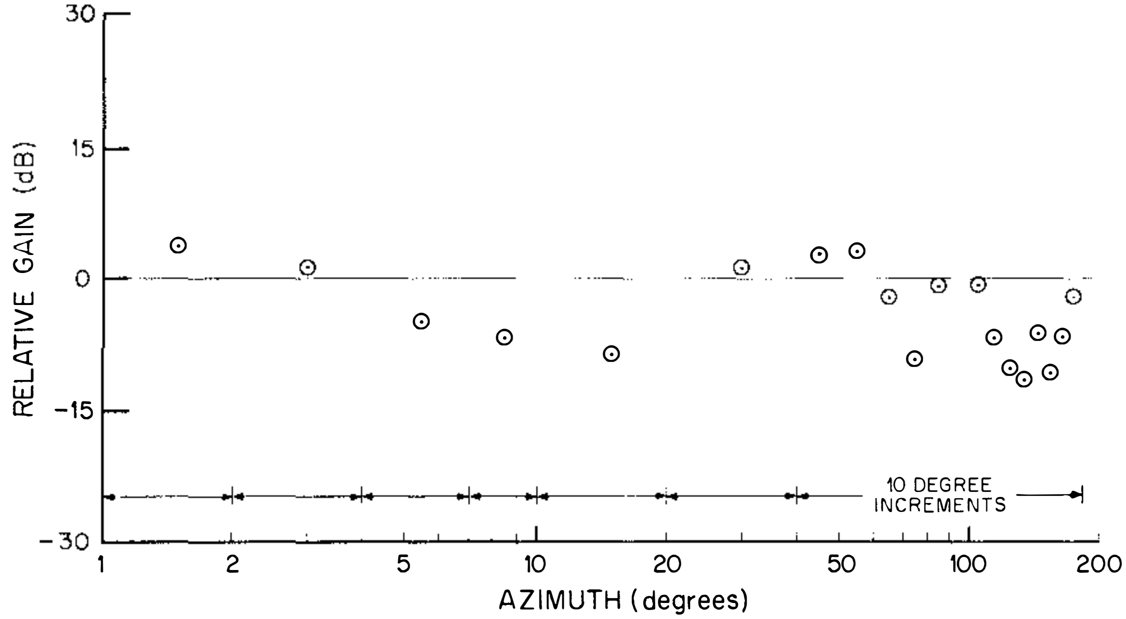


Figure 2-9. A typical antenna pattern referenced to the CCIR reference pattern. Values less than zero indicate the maximum values are less than the reference in the interval and values greater than zero indicate the maximum gain exceeds the reference. In this example, $D/\lambda = 92$.

Technical Support to the A.I.D. Rural Satellite Program. The Agency for International Development (A.I.D.) established the Rural Satellite Program as a cooperative effort between the United States and a number of developing nations to demonstrate the benefits of communication satellites and other communications technologies to the advancement of developing nations. The existence of ubiquitous communications systems in less developed rural areas of the world is expected to enhance food production and distribution, to improve health and family planning services, to improve productivity, and to facilitate access to education systems.

During this year we continued the analysis of thin-route earth station requirements, the results of which are summarized here. Satellite communications are likely to be used to provide thin-route telephone service in developing countries only if the cost of earth stations can be substantially reduced. A parametric analysis of earth-station design and service capabilities includes:

- six values of earth-station figure of merit, G/T, ranging from 17.5 to 30.0 dB/K
- five values of antenna diameter ranging from 3.0 to 10.0 m
- low-noise amplifier temperatures ranging from 55 to 200 K
- high-power amplifier output powers ranging from 1 to 400 W
- INTELSAT and Palapa (typical of many domestic satellites) satellite resources
- frequency modulation as well as digital encoding with phase shift keying for voice service.

Link budgets are developed from which the numbers of carriers that can be supported by 1/4 transponder are calculated. Assuming single channel per carrier as well as multiple channels per carrier service, the numbers of duplex telephone circuits per 1/4 transponder are calculated. Traffic analyses are performed to demonstrate the relationships between numbers of telephone subscribers per earth station, numbers of circuits provided at each earth station, and quality of service. Sampled cost information is presented and used to estimate earth station costs.

The initial results of this work were reported in NTIA Report 82-99 by R. D. Jennings. More recent work was reported in a paper entitled "Parametric Approach to Thin-Route Earth-Station Requirements" by R. D. Jennings and P. M. McManamon, presented by Jennings at the Fifth Annual Pacific Telecommunications Conference.

In October 1982 it was announced that the INTELSAT Board of Governors had agreed to an offering by INTELSAT of a tariff service for applications with bandwidth dedicated in the space segment for low density, thin-route traffic.

Small earth stations are to be involved for remote rural service to be used for domestic applications and for international applications such as the Pacific basin and the cluster of countries around and including Senegal. A shared access model, to be determined by INTELSAT, will be used. Traffic levels from an individual earth station could be as low as one voice channel at any one time.

The tariff would be designed to be offered on an individual voice circuit basis rather than being based on the percentage of total transponder capacity being allocated.

INTELSAT has established an ad hoc Working Group, together with a Technical Working Sub-Group and a Policy Working Sub-Group to develop details of thin-route service network design and modulation design. Staff from ITS have participated as members of the Technical Working Sub-Group.

In this fourth year of technical support by the Institute to the Rural Satellite Program, the process of contracting for five major components of a prototype small earth station for thin-route applications was completed, and planning for assembling and testing was begun.

A brief summary of the specifications of the major components ordered this year appears below, together with their respective suppliers. The hardware procurements have followed normal Government practices for competitive procurement. No recommendation or endorsement of these products and/or suppliers is intended or implied.

- Antenna: 5-m diameter with feed for circular polarization; voltage axial ratio 1.4 maximum.
  Supplied by Scientific Atlanta Model 8008. G_R = 44.4 dB at 3.95 GHz (Spec 43.5 dB minimum); G_T = 47.2 dB at 6.175 GHz (Spec 46.7 dB minimum)
- Low Noise Amplifier (LNA): 85 K noise temperature, 50 dB gain minimum. Supplied by Dexcel Model DXA 3115-03. (Assume: $T_S = T_{LNA} + 35\text{ K} = 85 + 35 = 120\text{K}$

  $$G_R/T_S = \frac{44.4}{10 \log 120} \cong 23.6 \text{ dB/K})$$
- High Power Amplifier (HPA): TWTA with P_{out} = 25 W (44 dBm) typical; 15.85 W (42 dBm) minimum; Gain = 45 dB. (Spec 15-40 W, 45 dB gain min.) Supplied by Varian Model VZC-6961D4.
  (Possible SCPC uplink EIRP = 47.2 + 14 = 61.2 dBW max.; 47.2 + 12 = 59.2 dBW typical.)
- Frequency Converters: Dual conversion, VHF crystal oscillator frequency control, stability = 10^{-6}. Specified for 6.150 GHz transmit (upconverter) and 3.925 GHz receive (downconverter). INTELSAT transponder 6. Supplied by COMTECH Data Corporation, Model 250AU/D.
- MODEMS/CODECS: QPSK rf MODEMS. SCPC-CVSD voice CODECS operating at 32 kbps. Forward Error Correction (FEC) CODECS at rate 1/2; convolutional encoder, sequential decoder. Required C/N_o = 49.6 dB-Hz for global beam edge; no other operating margin. Supplied by COMTECH Data Corporation, Model M200-X31 MODEM and Model M600 Alternate Date Voice CODEC.

Arrival of the last of these components at ITS Boulder is expected by the end of 1983.

We have identified four potential sites for locating earth stations during performance verification and demonstration tests.

Location	Existing Facility
Boulder, CO (USA)	ITS Laboratories
Etam, WV (USA)	Standard A Earth Station
Andover, ME (USA)	Standard A Earth Station
Gandoul, Senegal (Africa)	Standard A Earth Station

In Table 2-1 INTELSAT satellites serving the named locations are tabulated with the applicable look angles of the earth station antennas, the coordinates of the earth stations, and the coordinates of the satellites. The Senegal station has been included because of the interest of that location to our sponsor, A.I.D.

We have completed a draft of a Planning Flow Chart for assembling and testing the earth terminal, and are working on the numerous associated technical details, as well as questions of coordination.

Technical Support to A.I.D. in Development of a Low-Cost Television System for Educational Applications. In a second area of technical support to the Agency for International Development, ITS has awarded a contract to Battelle Memorial Institute Pacific Northwest Laboratories for conducting feasibility and planning studies for low-cost television systems adapted to less-developed countries. The Battelle study is a 9-month study slated for completion during 1984.

The objective of this 9-month study is to examine the cost/benefit situation with a range of technical approaches that might be applied to reduce the cost of television receivers and transmitters. Goals include the following:

- a value engineering study on conventional television receivers identifying ways to minimize manufacturing costs
- consideration of the added benefit that might come from significant departures from current design philosophies, based on combining some early approaches to television design with more recent advances in solid state circuitry and in signal processing
- physical modeling of a receiver incorporating characteristics identified as most useful.

The end result is expected to be a set of recommendations for a new and simplified approach to television systems that are responsive to the needs of rural villages and urban poor. Target criteria include:

- a cost reduction for receivers on the order of 90%
- a reduction in power requirements to the range of 5-15 watts
- a design adapted to local assembly and indigenous manufacture, in the developing countries, of major elements (such as picture tubes).

Multiple Knife-Edge Diffraction Studies. The reception of signals from a satellite at low angles of incidence may be affected by terrain obstacles near the receiving station. Even for a nominal radio line-of-sight, the tops of obstacles near the direct ray can produce

Table 2-1. INTELSAT Satellites and Earth Station Locations That Could be Used for Performance Verification and Demonstration Tests

Satellite Name and Longitude	Earth Station Antenna Look Angles	Earth Station Name and Coordinates			
		1.	2.	3.	4.
		Boulder (105.3° W,40.0° N)	Etam, WV (79.7° W,39.3° N)	Andover, ME (70.8° W,44.6° N)	Gandoul (17.0° W,14.7° N)
IV,F7 (307.0° E)	El. Ang.	19.75°	36.78°	35.62°	45.40°
	Az. Ang.	116.42	141.55	155.43	-109.25
IV,F1 (307.2° E)	El. Ang.	19.61°	36.67°	35.55°	45.60°
	Az. Ang.	116.25	141.31	155.17	-109.38
IV,F5 (322.0° E)	El. Ang.	8.59°	27.59°	29.17°	60.25°
	Az. Ang.	105.05	125.41	137.45	-123.47
IV-A,F4 (325.5° E)	El. Ang.	5.94°	25.18°	27.29°	63.41°
	Az. Ang.	102.62	122.17	133.71	-128.83
V,F2 (325.7° E)	El. Ang.	5.79°	25.03°	27.18°	63.59°
	Az. Ang.	102.48	121.99	133.50	-129.17

interference effects on the propagation loss. Furthermore, variations of atmospheric refraction in the lower part of the atmosphere can alter the path of the ray and cause masking by the obstacles in an otherwise direct ray path.

Also of interest in satellite communication systems are problems of interference by an unwanted signal from another satellite or from nearby transmitting earth stations. These unwanted signals often may be from trans-horizon sources, and their strength depends primarily on antenna beam limitations and ground wave propagation effects.

At the frequencies commonly used in satellite communications, the terrain features of a propagation path can often be characterized as a sequence of knife-edges because of the short wavelengths involved and because variations of electromagnetic ground constants are insignificant at these frequencies. Thus, the propagation loss over a particular path can be estimated by evaluating the diffraction loss due to multiple knife-edge diffraction.

Work has continued on the multiple knife-edge (MKE) diffraction model that was recently developed at the Institute. A new derivation of the MKE attenuation function using Fresnel-Kirchhoff theory resulted in the clarification of certain questions concerning the phase of the complex attenuation. Also the analytical basis for an improved computational procedure based on the partitioning of multiple integrals was developed. This new procedure enables the detailed evaluation of attenuation variation in the interference region for any combination of knife-edge heights. Comparisons have been made of the MKE attenuation function with expressions derived from the Geometrical Theory of Diffraction and the approximate solutions of Epstein-Peterson and Deygout. Results of the above studies are contained in NTIA Report 83-124.

Two types of computer programs to evaluate the MKE diffraction loss are available from the Institute. In the first type, the input data, consisting of a maximum of 10 knife-edge heights together with their separation distances, are read in by the user. In the second type, the input is a propagation path terrain profile provided by the user from which the program selects the ten (or less) most significant terrain points to represent the knife-edges. In both types the output consists of the attenuation (relative to free-space) due to MKE diffraction.

An interesting point about refractivity variations is that changes in refractivity can cause much more attenuation variability at microwave frequencies than at lower frequencies. Thus, at low angles of incidence from a broadcasting satellite, diffracting knife-edges together with refractivity fluctuations can have a significant effect on signal variability. The MKE propagation model provides a useful tool to assist in predicting this variability.

Pulse Distortion Studies. A small study, not related to satellite communications, but utilizing theoretical skills of a staff member in the Satellite Network Analysis Group, has been conducted to assess the degree to which pulses generated by the operation of electron-beam experiments are distorted by their reflection from the ionosphere.

There currently is a substantial amount of work directed toward assessing the feasibility of using charged-particle beam devices as weapons in military operations. A comprehensive program aimed at conducting electron-beam propagation experiments is under way at Laurence Livermore National Laboratory. In addition to the construction of a facility to generate and test electron-beam effects, theoretical studies are being undertaken in order to model the fields produced by the electron beam as a function of distance from the source.

Preliminary experiments indicate that the operation of electron-beam sources is accompanied by the generation of large amounts of radio energy in the HF portion of the electromagnetic spectrum. This radio energy has been observed to propagate to distances greatly removed from the source. It is natural to question whether or not such received signals can be utilized to determine selected characteristics of the charged-particle beam source. In order to answer this question, it is first necessary to ascertain the degree to which the pulse-shape of the HF radio wave is distorted as it propagates from the source to a given reception point. The distortion of the pulse will be due primarily to effects induced upon it by the ionosphere. Hence, it is necessary to determine the degree to which ionospheric variations will distort the HF pulses associated with the operation of charged-particle beams. It is this objective that is the subject of the Pulse Distortion Studies.

The initial phase of the study has consisted of determining an appropriate ionospheric model and developing the appropriate propagation equations. Differential equations for propagation at oblique incidence in a dispersive medium and assuming a vertical magnetic field have been formulated. The field components are approximated by expressions that reduce to the correct functions as the propagation angle of incidence decreases. Reflection coefficients have been derived for two ionospheric models: (1) the linear profile, and (2) the sech^2 profile. The latter profile provides a more realistic electron density variation and further studies will be based on this model.

The second phase of the work will be to numerically evaluate the impulse response function through the application of a Fast Fourier Transform. With the introduction of a given source pulse spectrum, reflected pulse shapes then can be generated for different values of the penetration frequency, scale height, collision frequency, magnetic parameter, and angle of incidence.

SECTION 2.3 SYSTEM PERFORMANCE STANDARDS AND DEFINITION

The principal focus of the System Performance Standards and Definition Group is the development and application of national and international telecommunication standards. Two projects are described. The first addresses a need within the U.S. for uniform means of expressing the performance of data communication services as seen by end users. The second supports U.S. participation in the development of international standards, particularly those dealing with public data networks and the Integrated Services Digital Network (ISDN). A common objective of the two projects is to facilitate private sector development and Federal procurement of digital telecommunication services.

Data Communications. The Institute's Data Communications project has two overall goals. The first is to promote competition and technology innovation in the telecommunication equipment and service industries. The second is to facilitate efficient matching of provider offerings with user needs in the increasingly diverse and competitive U.S. telecommunications environment. Both goals are being pursued through the development, promulgation, and application of user-oriented, network-independent data communication performance parameters and measurement methods. Key end products are Federal and American National standards, which provide a "common language" for performance description; prototype test equipment implementing the standards; and technical reports describing actual measurements of representative public and private data communication networks.

Two related data communication performance standards have been developed. The first defines the user-oriented performance parameters. That standard was approved as Interim Federal Standard 1033 in 1979, and was subsequently adapted for proposal as an American National Standard by a task group of the American National Standards Institute (ANSI Task Group X3S35). The second standard defines uniform methods of measuring the ANSI parameters. That standard was published as Proposed Federal Standard 1043 in 1981, and is now being prepared for formal proposal as an American National Standard by the same ANSI group.

A major Data Communications project milestone was achieved in FY 83: final ANSI approval and publication of American National Standard X3.102, "Data Communication Systems and Services--User Oriented Performance Parameters." That standard is unique in providing a set of performance measures that may be used to describe the quality of any data communication service, irrespective of network technology, architecture, topology, or user access protocol. The X3.102 parameters will give users a way of specifying communication requirements without presupposing any particular service; and will enable providers to describe service performance in terms that are understandable and relevant to users, but not specialized to any particular application. It is anticipated that ANSI X3.102 will ultimately replace Interim 1033 as a mandatory Federal Standard.

Table 2-2 summarizes the 21 user-oriented performance parameters defined in American National Standard X3.102. The parameters express performance relative to three primary communication functions: access, user information transfer, and disengagement. These functions correspond to connection establishment, data transfer, and disconnection in connection-oriented services, but are also applicable to connectionless services (e.g., electronic mail). They subdivide an overall data communication session in accordance with the user's perception of service and provide a specific focus for performance description.

In defining the standard parameters, each function was considered with respect to three possible results, or outcomes, an individual performance trial might encounter: successful performance, incorrect performance, and nonperformance. These possible outcomes correspond closely with the three major performance concerns (or "performance criteria") most frequently expressed by data communications users: speed, accuracy, and reliability.

One or more "primary" parameters were defined to express performance relative to each function/criterion pair. As an example, four primary parameters were defined for the access function: one speed parameter (Access Time), one accuracy parameter (Incorrect Access Probability), and two reliability parameters (Access Denial Probability and Access Outage Probability). Failures attributable to user nonperformance (e.g., called user does not answer) were excluded in defining each primary parameter.

The X3.102 parameters also include four "ancillary" parameters. Each ancillary parameter relates to a primary "speed" parameter, and expresses the average proportion of the performance time associated with that parameter that is attributable to user delays. As an example, the primary parameter Access Time normally includes delays attributable to the users (e.g., dialing time, answer time) as well as delays attributable to the system (e.g., switching time). The ancillary parameter User Fraction of Access Time expresses the average proportion of total Access Time that is attributable to the user delays. The ancillary parameters provide a method of "factoring out" user influence on the primary speed parameters to produce "user independent" values characterizing the unilateral performance of the system and also provide a basis for determining the entity (user or system) "responsible" for nonperformance failures (e.g., access timeouts).

The Institute's FY 83 Data Communications project had two major goals:

1. To facilitate completion and initial use of the ANSI measurement standard by developing and documenting key performance measurement software systems and techniques.
2. To conduct pilot measurements of three U.S. public data networks (PDN's) using ITS-developed, microprocessor-based test sets conforming to the ANSI standards.

Figure 2-10 illustrates the overall structure of the proposed ANSI measurement standard, designated X3S35/135. The standard is divided into four major parts. Sections 2 and 3 specify functional requirements for the two major measurement subsystems needed to obtain values for the standard X3.102 parameters:

Table 2-2. Summary of ANSI X3.102 Performance Parameters

FUNCTION	**PERFORMANCE CRITERION**			**PERFORMANCE TIME ALLOCATION**
	SPEED	**ACCURACY**	**RELIABILITY**	
ACCESS	ACCESS TIME	INCORRECT ACCESS PROBABILITY	ACCESS DENIAL PROBABILITY ACCESS OUTAGE PROBABILITY	USER FRACTION OF ACCESS TIME
USER INFORMATION TRANSFER	BLOCK TRANSFER TIME	BIT ERROR PROBABILITY BIT MISDELIVERY PROBABILITY EXTRA BIT PROBABILITY	BIT LOSS PROBABILITY	USER FRACTION OF BLOCK TRANSFER TIME
		BLOCK ERROR PROBABILITY BLOCK MISDELIVERY PROBABILITY EXTRA BLOCK PROBABILITY	BLOCK LOSS PROBABILITY	
	USER INFORMATION BIT TRANSFER RATE	TRANSFER DENIAL PROBABILITY		USER FRACTION OF INPUT/OUTPUT TIME
DISENGAGEMENT	DISENGAGEMENT TIME	DISENGAGEMENT DENIAL PROBABILITY		USER FRACTION OF DISENGAGEMENT TIME

Legend:

☐ Primary Parameters

☐ Ancillary Parameters

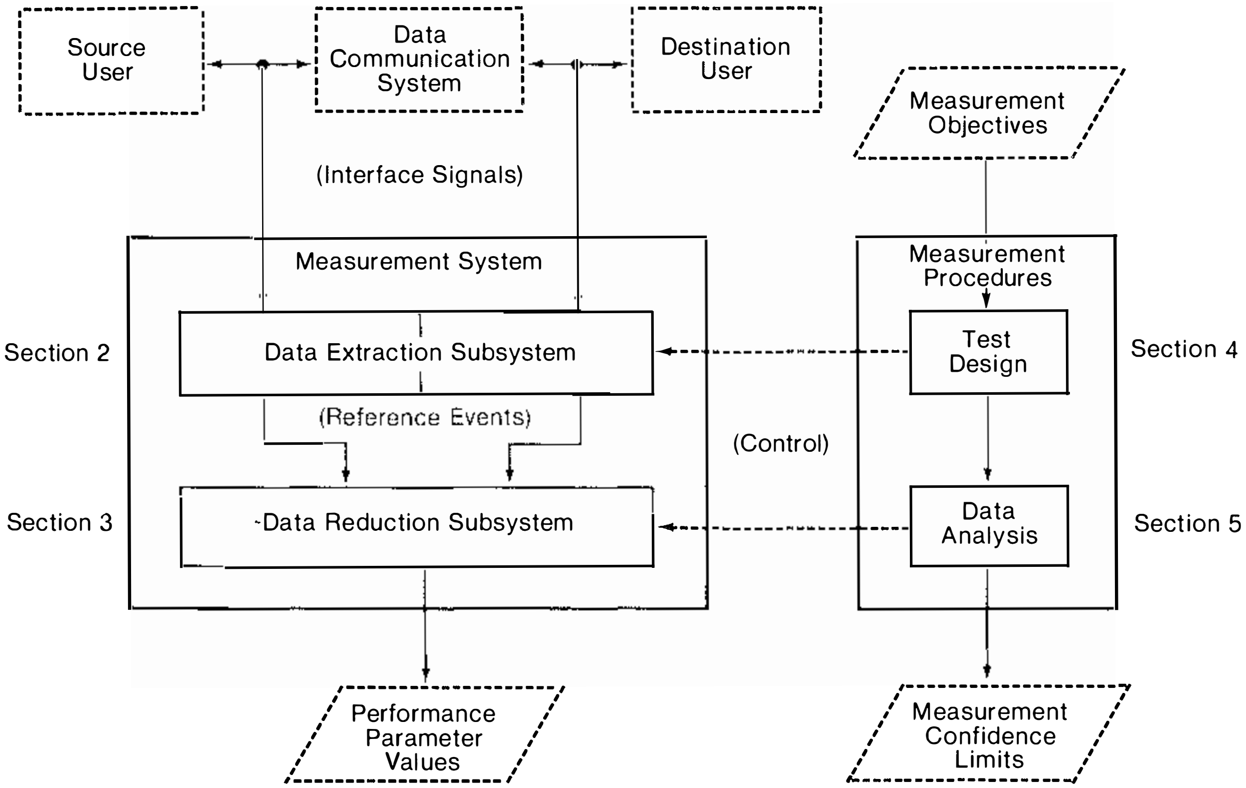


Figure 2-10. Overview of the standard.

Data Extraction and Data Reduction. The Data Extraction subsystem observes signals transferred across the user/system interfaces in real time, determines the performance significance and time of occurrence of each interface signal, and records this information in the form of a chronological sequence of reference events. The Data Reduction subsystem merges, correlates, and processes the reference event records to produce a set of measured X3.102 performance parameter values. These measurement subsystems are defined in functional terms (rather than in terms of a specific implementation) to afford users maximum flexibility in applying the standard.

Sections 4 and 5 provide general requirements and procedures for test design and post-test data analysis, respectively. The test design procedures guide the data extraction process and provide criteria for selecting measurement sample size. The data analysis procedures guide the data reduction process and identify data reduction variables which should be specified with the measurement results.

To facilitate use of the measurement standard, ITS has implemented procedures for accomplishing the data reduction, test design, and data analysis functions in two machine-independent FORTRAN computer programs. Figure 2-11 illustrates the first of these, the ITS Data Reduction Program. This program implements the Data Reduction functional specification presented in Section 3 of the measurement standard. It comprises three subprograms: PROLOG, ANALYZ, and EPILOG.

Program PROLOG, the first main program to be executed in a data reduction run, is responsible for preliminary checking and processing of input data. It reads operator-defined reduction specifications and extracted performance data and subjects these to a series of validity checks. If no errors are detected, it combines event data from the source and destination overhead information files to create a unified event history and writes this to the consolidated overhead information file. PROLOG concludes by writing consolidated data reduction specifications to a comprehensive specifications file.

Program ANALYZ, the second main program to be executed in a data reduction run, is responsible for the actual performance data analysis and parameter calculations. After reading the specifications file generated by PROLOG, program ANALYZ executes performance data analysis and parameter calculations for the X3.102 access user information transfer, and disengagement functions, specified by the test operator. Performance data analysis for a function consists of (1) examining performance data in the relevant overhead and user information files to identify performance trials and determine their outcomes, and (2) recording these outcomes in the associated performance outcome file and updating the affected assessment statistics. When the performance data analysis for a function is complete, ANALYZ calculates corresponding measured values of the standard X3.102 performance parameters. When all enabled performance assessment options have been completed, ANALYZ concludes by writing the assessment statistics and calculated performance parameter values to the statistics file and parameters file, respectively.

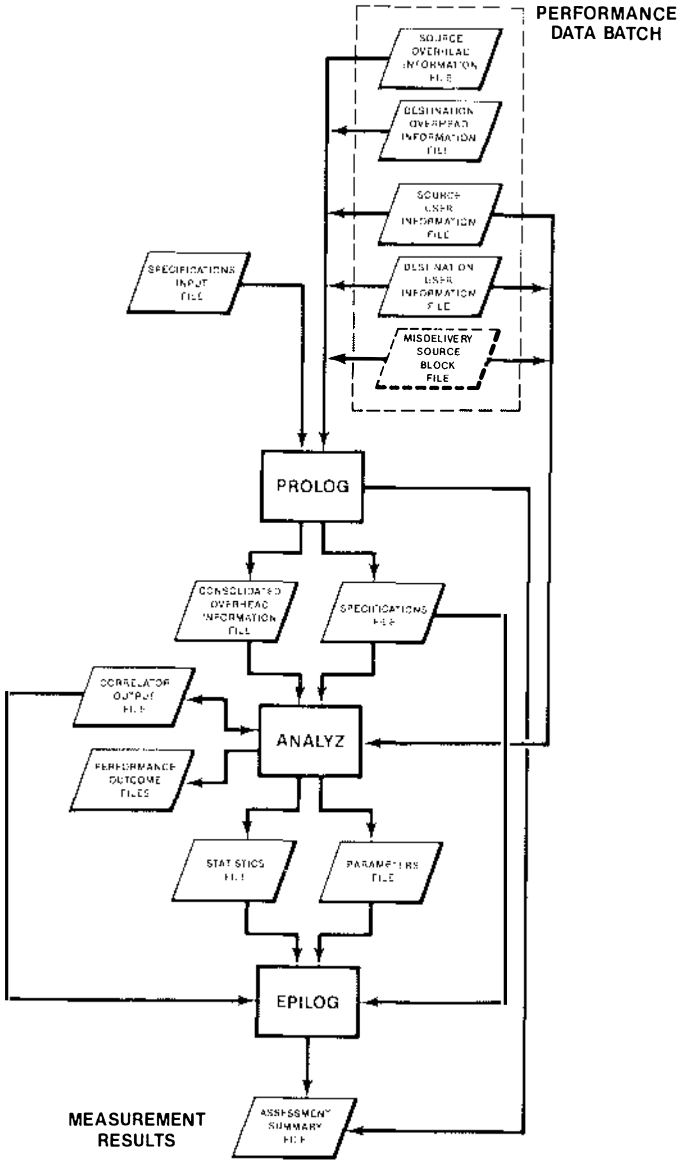


Figure 2-11. ITS data reduction program structure.

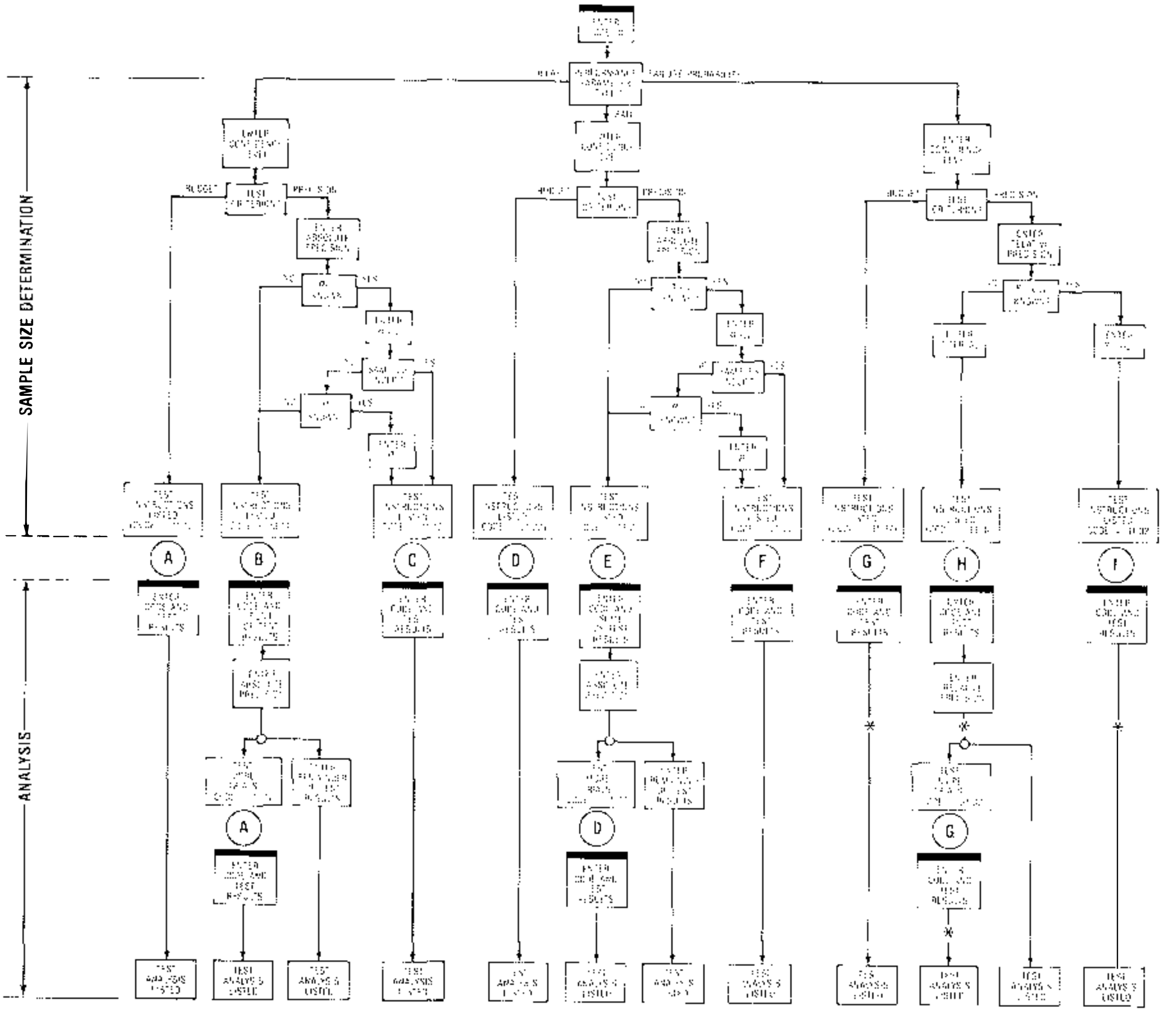
EPILOG, the last main program to be executed in a reduction run, reads reduction specifications, assessment statistics, and measured performance parameter values from the corresponding files and writes this information to a consolidated assessment summary file. Assessment results are then printed out to the operator. They may also be consolidated with previously or subsequently processed data to improve measurement confidence levels.

The ITS Data Reduction program has proven to be extremely valuable in experimental data communication performance measurements conducted at ITS. In measurements of the ARPANET, that program transformed what would have been a massive data reduction effort into a few minutes of computer time. The program is coded in ANSI (1977) Standard FORTRAN to enhance its transportability. It is available from ITS at duplication cost.

Figure 2-12 illustrates the second computer program ITS has developed to facilitate use of the measurement standard, the ITS Statistical Design and Analysis program. This program automates critical portions of the X3S35/135 test design and data analysis procedures--specifically, the rather complex mathematical processes of (1) determining the measurement sample size needed to obtain parameter estimates having a desired statistical precision, and (2) analyzing collected test data to determine the precision actually achieved in a measurement. The program is interactive and is normally accessed from a data terminal. As indicated in the figure, the program is divided into two major subprograms (top and bottom). These automate the sample size determination and data analysis processes, respectively.

The sample size determination subprogram leads the operator through a series of decisions that result in a selection of measurement sample size for a particular performance parameter. The program begins by asking the operator to identify the general type of parameter for which a measurement sample size is to be determined. The operator may specify either of three general parameter types: time delays, time rates, and failure probabilities. Once a particular parameter type has been specified, the program asks the operator to select a confidence level for which the parameter value is to be estimated. Two confidence levels may be selected: 90% and 95%.

The third decision in each case is the choice of a test limiting criterion. Two choices may be made, depending on the operator's test objectives and constraints. In most cases, the operator wishes to estimate a parameter's value with a specified precision. The precision is specified in absolute terms in the case of the time parameters--e.g., average delay +50 ms or average rate +50 bps. The precision is specified in relative terms in the case of the failure probabilities. As an



* IF THERE ARE FEWER THAN TWO FAILURES ENTER P ... (IF KNOWN)

Figure 2-12. Statistical test design and data analysis.

example, the operator might specify that confidence limits for a failure probability should be within $\pm 50\%$ of the measured value, e.g., confidence limits of $\pm(0.5)10^{-6}$ for an observed failure probability of 10^{-6}.

In the case of the time parameters, the program next asks the operator whether the variability (maximum standard deviation, σ max) of the measured value can be estimated from prior information. If so, the program proceeds to similar inquiries regarding the dependence of successive observations--e.g., whether Block Transfer times for successively transmitted blocks are more likely to be similar than those for randomly selected blocks. In each case, if no prior information is available, the operator is given parameters defining a preliminary test that will obtain the necessary information.

The program then uses the collected information to calculate the number of trials (e.g., observations of Block Transfer Time) needed to estimate the parameter value of interest with the operator-specified precision. The program outputs this information to the operator, together with a listing of ancillary information (e.g., return entry code, number of delays, total delay on each trial) that will be needed by the data analysis program to process the collected data.

In the case of the failure probability parameters, the program asks the operator whether the degree of dependence (conditional probability of failure given a failure in the preceding trial, p_{11}) is known from prior information. If so, the program uses this information to calculate the number of failures (e.g., bit errors) that must be observed in order to estimate the failure probability with the desired relative precision. This is the information the operator needs to delinate the test. If not, the degree of dependence is estimated by a worst case (95-percentile) value, and the program gives the operator parameters defining a preliminary test. Ancillary information needed to organize the test and the subsequent data reduction is provided in either case.

Each individual entry to the Statistical Design and Analysis program determines a sample size for a single parameter measurement. In a typical test, all parameters associated with a particular function (e.g., access) are normally measured together, using a common measurement sample. The size of that sample is determined by the particular parameter whose measurement precision is most important or most difficult to achieve. Sample sizes for the various parameters measured in such a test may be determined by successive entries to the sample size determination subprogram.

The second major statistical design and analysis subprogram, the data analysis subprogram, is entered with collected data after a measurement has been completed. Its function is to determine the precision actually achieved in a measurement. Such achieved precisions often differ from the precision objectives selected during test design, since actual measurement conditions are rarely identical to pretest assumptions.

The data analysis subprogram prompts the operator (or reads files) to determine the observed measurement results, then calculates the appropriate statistics from these results. In the case of the time parameters, the outputs are sample means and confidence intervals. In the case of the failure probabilities, the outputs are the ratio estimates themselves and their associated confidence limits.

The Statistical Design and Analysis program also enables users to determine whether data measured in different tests are statistically homogeneous (e.g., describe the same statistical population, performance conditions, etc.). Such data can be combined to provide better overall confidence in an evaluation of communication performance.

The Statistical Design and Analysis program will substantially improve the efficiency and economy of performance measurements by providing a simple method of determining quantitative relationships between test duration and test precision. Preliminary applications of this program indicate that a desired precision can often be achieved with far less measurement time (and cost) than test engineers intuitively expect. Project cost savings from such information can be substantial. Although developed specifically for the X3.102 parameters, the program can be used to determine measurement sample sizes and achieved precisions for any delay, rate, or probability parameter--the statistical problem is the same. The program is written in machine-independent (ANSI 1977 standard) FORTRAN and is available from ITS at duplication cost.

The FY 83 Data Communications project also provided an opportunity for some new research on an important and little-studied problem in data communication performance measurement--that of matching transmitted and received data, and detecting bit errors, deletions, and additions, when the time delay between data transmission and reception is variable. Such matching is essential to comprehensive performance measurement, since the various transmission failure probabilities cannot otherwise be measured. The Institute examined this problem briefly in FY 79 and developed a simple linear comparison procedure that proved to be effective in matching random binary data strings. This algorithm was implemented (as the BITCOR subroutine) in the ITS Data Reduction Program, and was used successfully in ITS measurements of the ARPANET.

The FY 83 study was undertaken with two objectives: (1) to improve the performance of the BITCOR subroutine in processing random data through the use of more sophisticated data manipulation and comparison algorithms, and (2) to develop new comparison algorithms applicable to the matching of data with known properties or structures--e.g., blocks with known headers or "canned" test data.

A particularly interesting matching algorithm was developed for the case where the transmitted data can be completely determined by the experimenter ("canned"). This algorithm is based on the generation and detection of a binary sequence called the Thue-Morse sequence. This sequence is generated by a binary counter that updates for each bit of transmitted data. If the counter at time T has the representation

$$T = \sum_{i=0}^{m} a_i 2^i$$

where $a_i = 0$ or 1, then the bit transmitted at that time is

$$b = \sum_{i=0}^{m} a_i \pmod 2 \quad .$$

"Mod 2" means that the bit is 1 if $\sum_{i=0}^{n} a_i$ is odd, or 0 if $\sum_{i=0}^{n} a_i$ is even.

The Thue-Morse sequence has the property that each string of the first 2^k bits is complemented in the string of 2^k bits starting at bit (2^k+1). This properly makes the data "self numbering," which should substantially improve the speed and reliability of matching. The Institute has developed a matching algorithm using the Thue-Morse sequence, published as NTIA Report 83-133 by W.J. Hartman. Its implementation and testing are planned.

The second major goal of NTIA's FY 83 Data Communications project was to conduct a series of experimental performance measurements of public data networks (PDN's). These measurements had two specific objectives. The primary objective was to demonstrate actual use of the proposed ANSI measurement standard in assessing the end-to-end performance of some typical PDN services. A secondary objective was to obtain some preliminary data on the performance of the various network alternatives. It is anticipated that the results of these pilot measurements will encourage and facilitate more comprehensive future measurements, both by data communication service providers and by users.

Figure 2-13 illustrates the overall plan of the PDN measurements. Two microcomputer-based test sets were developed: one emulating a network-accessible host computer and one emulating a remote data terminal (and its operator). The host emulator was located at ITS in Boulder and was connected to the local offices of each of three public data networks via 9.6 kbps leased telephone lines. The terminal emulator was placed in several remote test cities, where it obtained access to the PDN's via the local exchange telephone network. The terminal emulator was also able to communicate with the host emulator via the direct distance dial (DDD) telephone network, bypassing the PDN's. The switched local telephone links operated at 1200 bps.

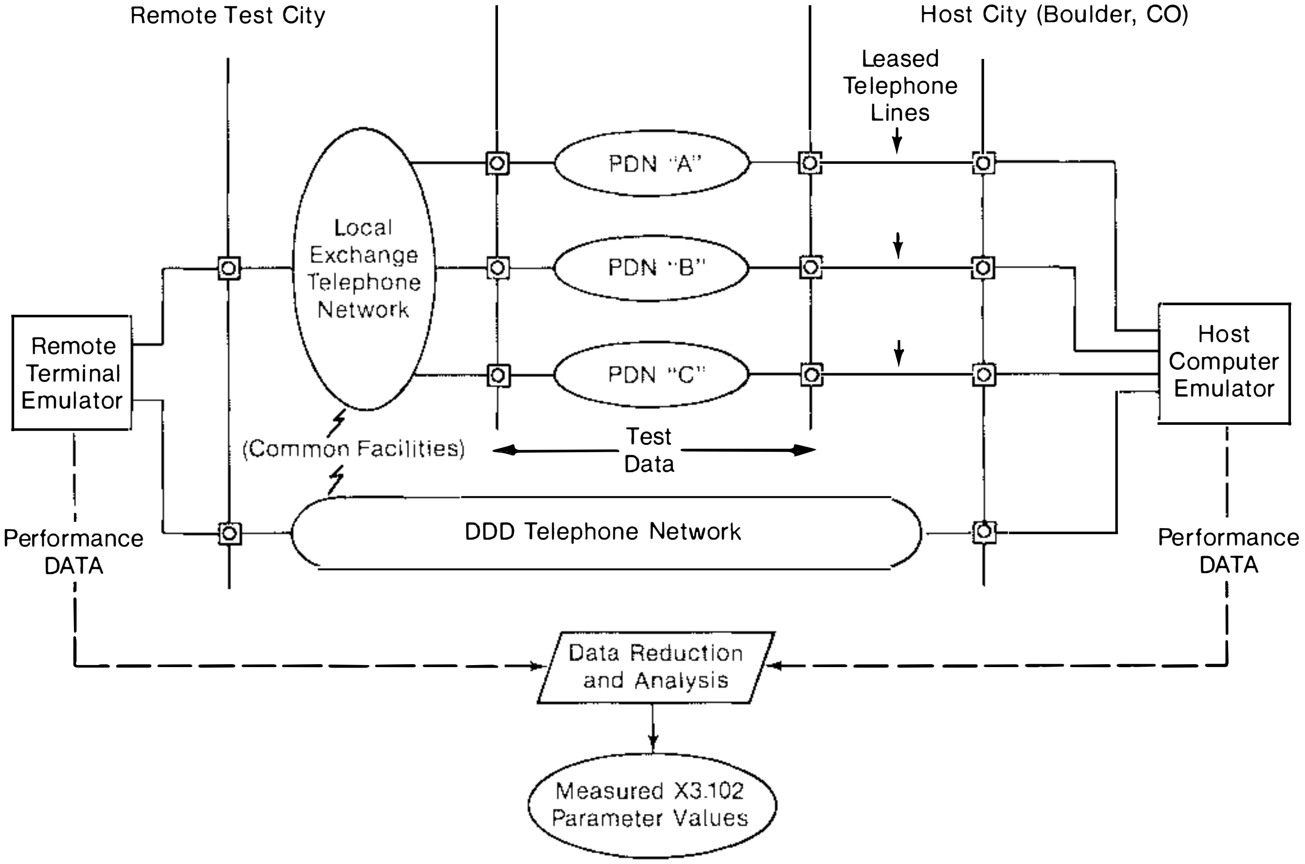


Figure 2-13. Overall plan of ITS Public Data Network measurements.

During actual testing, the remote terminal emulator established connection with the host over each of the four available paths in succession, logged into a special measurement application program in that computer, transmitted a file of "canned" test data, logged out, and disconnected. Both the remote terminal emulator and the host were programmed to record and time-stamp all interface events observed during a data communication session in accordance with the proposed ANSI measurement standard. The data extracted during each test were then transferred (via separate error-controlled lines) to a data reduction and analysis computer located in Boulder for conversion into X3.102 performance parameter values.

The interfaces actually instrumented during the test were within the host and terminal emulator microcomputers, between the (UNIX) operating systems and local application (measurement) programs. This selection of "probe points" makes it possible to reflect the delay and error recovery effects of "front end" software in the measured parameter values.

Figures 2-14 through 2-16 show some typical numerical results of the ITS PDN measurements. Figure 2-14 shows overall and component values for the X3.102 performance parameter Access Time--the total time between an end user's request for communication service and the start of actual user information transfer. In this application, the overall Access Time is divided into three components: local telephone connection time, PDN log-in and connection establishment time, and host computer log-in time. Inclusions of the latter time in overall Access Time is justified by the fact that the calling user (terminal operator) has no interest in communicating with the host computer's operating system per se; his goal is to access a particular user application program within that computer. Thus, the host computer's operating system is a part of the end-to-end data communication system from the end user point of view. Text editors, compilers, and data base handlers are examples of user application programs that are accessed via public data networks.

As Figure 2-14 indicates, the average Access Time observed in this particular measurement was about 45 s. On the average, the local telephone connection time was about 17 s, or 38% of the total; the PDN log-in and connection time was about 4 s, or 9% of the total; and the host computer log-in time was about 24 s, or 53% of the total.

These results suggest that a large proportion of the access delay currently experienced by public data network users is a result of factors outside the PDN boundaries (and outside the control of the PDN service provider). Even if host computer log-in time is excluded, the access delays outside the PDN are still more than four times greater than those within it. An obvious implication is that efforts to reduce the PDN connection time (e.g., transit delay for X.25 call request and call accepted packets) will do little to improve the customer's overall perception of service quality. The Access Time experienced by PDN users can, of course, be reduced substantially through the use of leased (rather than switched) terminal access arrangements.

Figure 2-15 shows typical virtual circuit connection times for two of the three PDN's tested. The measured time begins on completion of input of the host address to the PDN, and ends on the terminal's subsequent receipt of a host computer LOGIN prompt. For each network, the average virtual circuit connection time is about 2.7 s. Comparison of Figure 2-15a with Figure 2-14d suggests that under the conditions of this experiment, about two-thirds of the total PDN delay in establishing access is virtual circuit connection time. The other one-third is PDN log-in time. The latter function was automated in this experiment and would take longer if performed manually by a terminal operator.

Figure 2-16 compares overall Access Times for operator-to-program connections established via a PDN with corresponding times for connections established via the DDD telephone network. The PDN Access Times are about 8 s longer in this particular measurement. This is a result of two factors:

1. The PDN log-in time, which has no counterpart in the DDD network.
2. A longer host computer log-in time in the case of the PDN connections.

The latter factor is the more significant one. It is a direct result of longer transit delays and lower throughput in the PDN. More complete results of the ITS public data network measurements are being published in an NTIA Report.

International Standards. The Institute's International Standards project has two overall goals. The first is to enhance opportunities for U.S. firms to participate in international telecommunication markets by promoting the development and international acceptance of broadly-based, functionally oriented, nonrestrictive international telecommunication standards. The second is to ensure that the interests of competing U.S. firms are fairly represented, and properly coordinated, in U.S. contributions to international standards organizations in which NTIA has leadership responsibilities. These include the International Telegraph and Telephone Consultative Committee (CCITT) and International Radio Consultative Committee (CCIR).

The project involves three major functions. The first is to lead and coordinate U.S. participation in key standardization efforts of the CCITT and CCIR. This work is conducted under the auspices of the U.S. Department of State. Institute personnel currently chair two of the five U.S. CCITT Study Groups: Study Group D and the Joint Working Party on the Integrated Services Digital Network (ISDN). Study Group D prepares U.S. inputs to international meetings of CCITT Study Groups VII (Public Data Networks) and XVII (Data Transmission over Public Telephone Networks). The ISDN Working Party prepares U.S. inputs to international meetings of CCITT Study Group XVIII, which has overall responsibility for ISDN standardization within the CCITT. In

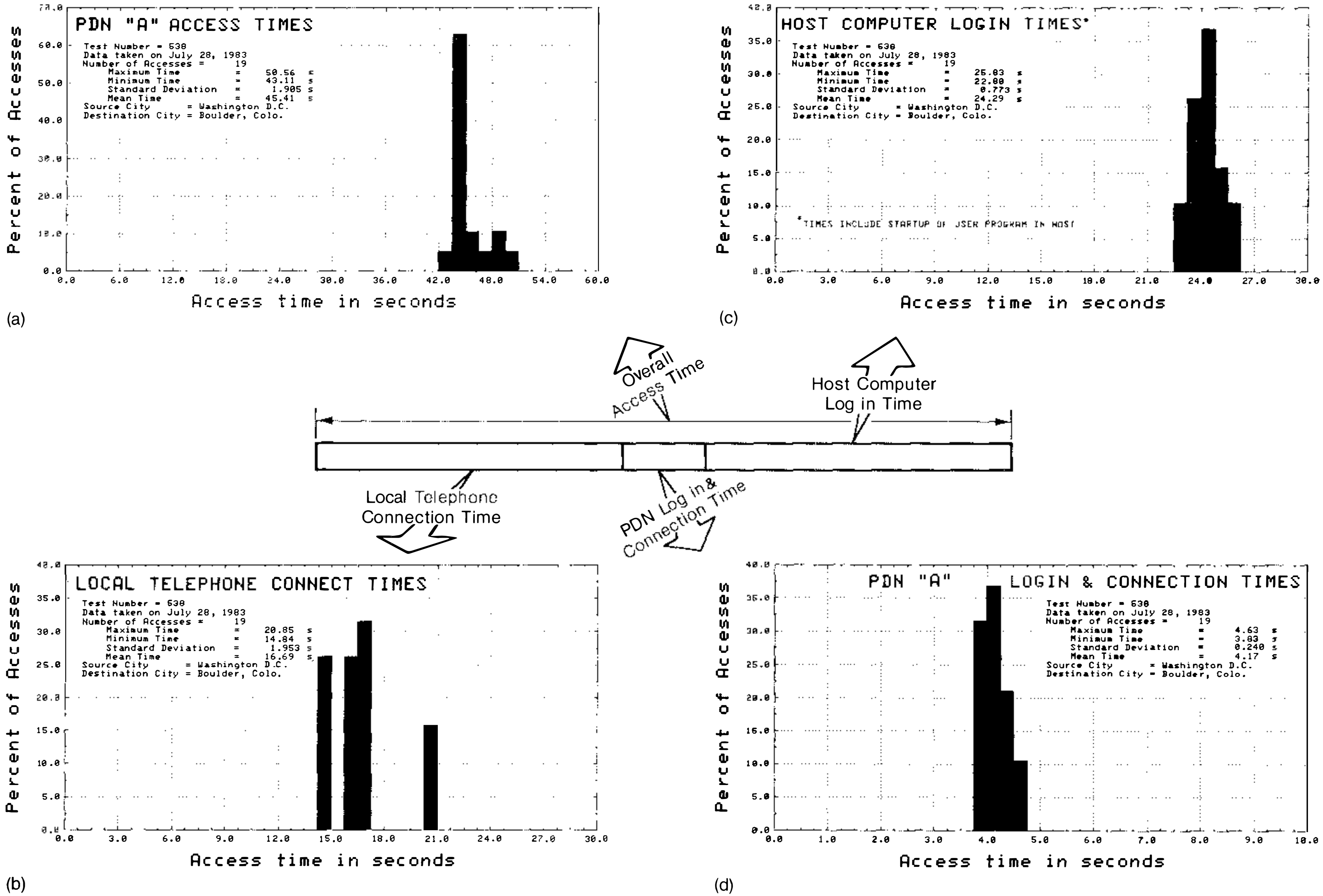


Figure 2-14. Overall and component values of access time.

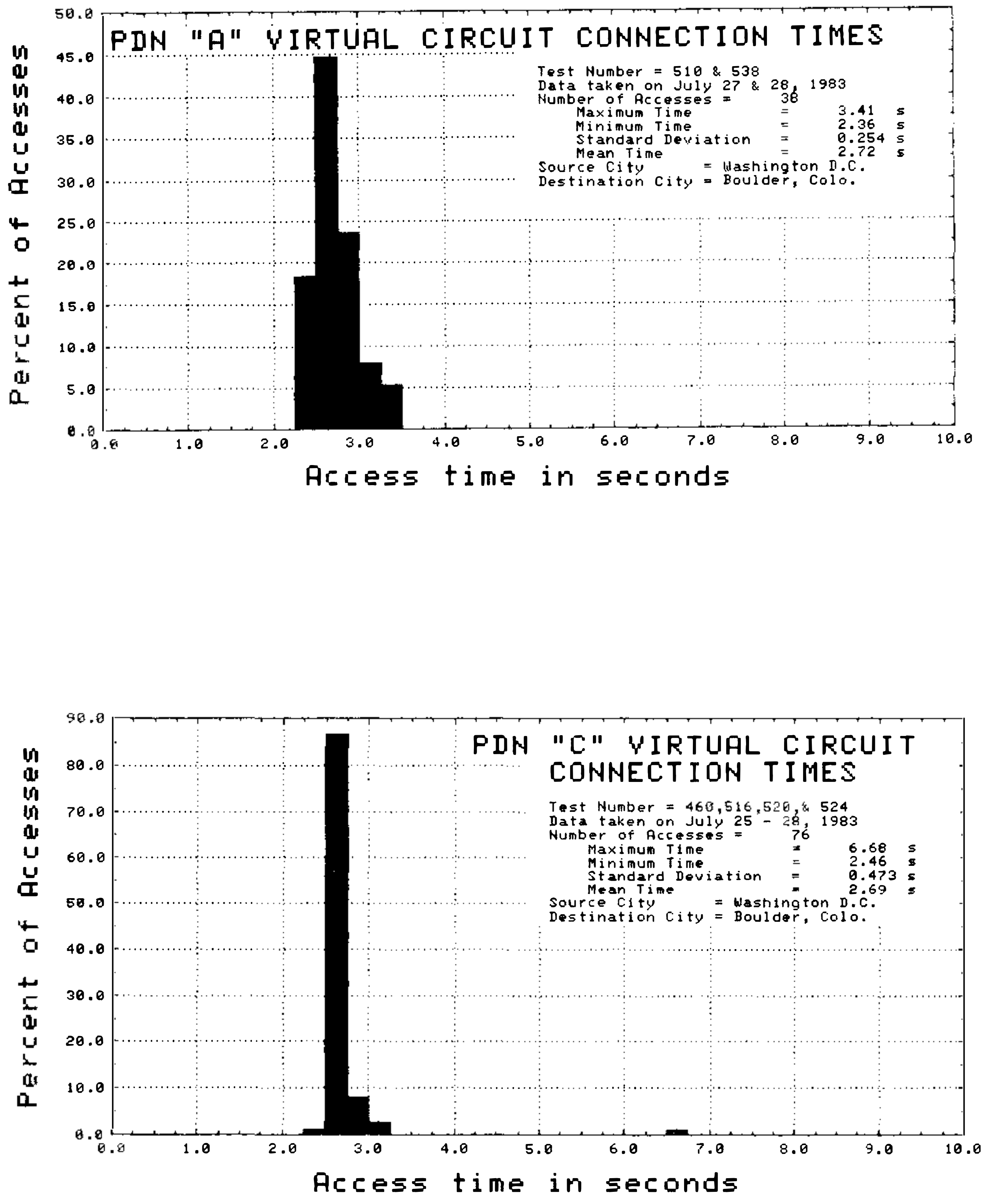


Figure 2-15. Virtual circuit connection times for two PDNs.

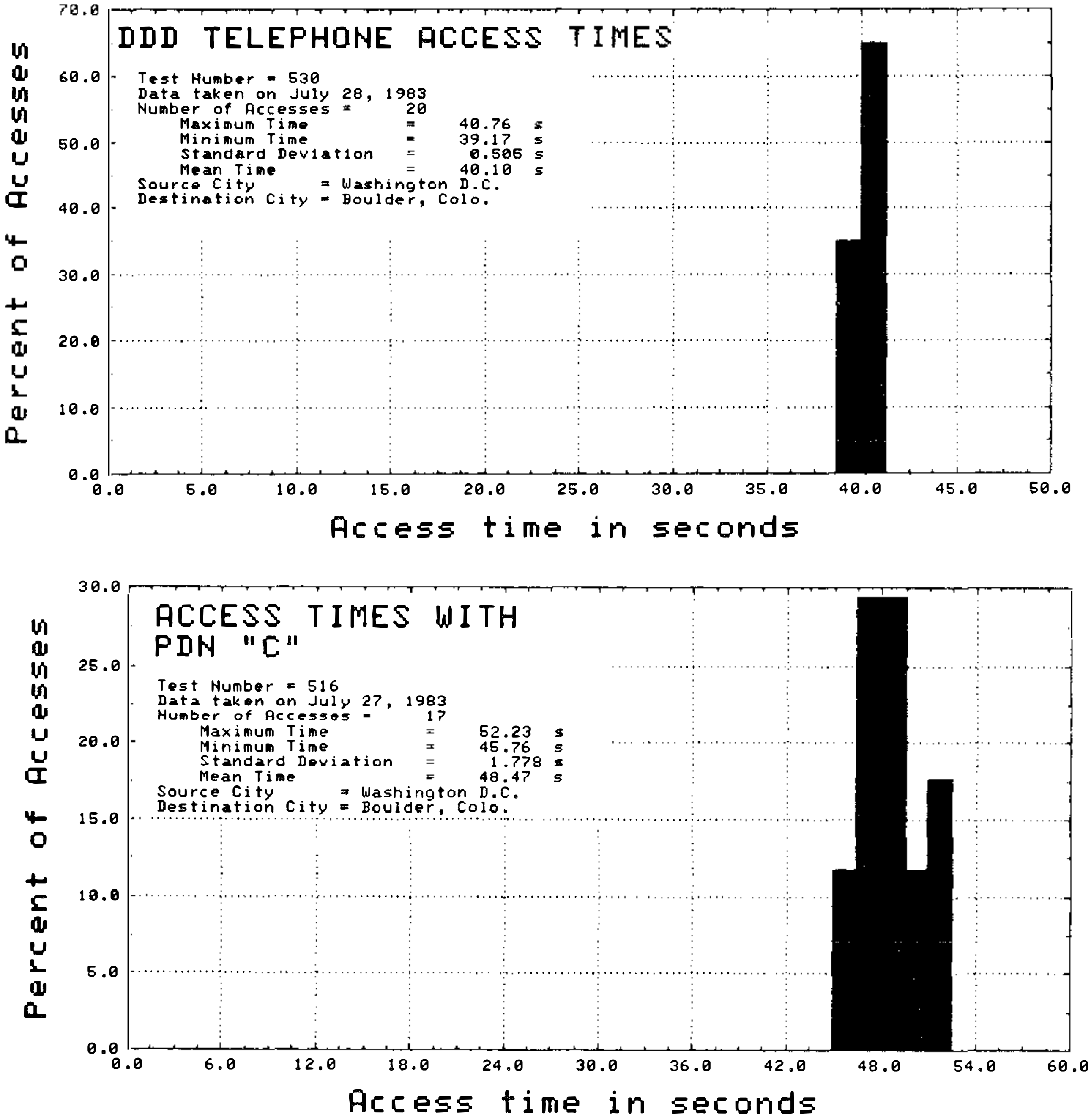


Figure 2-16. Comparison of PDN and DDD access times for operator-to-program connections.

addition, ITS provides international chairmanship of CCIR Interim Working Party (IWP) 8/11 (Direct Printing Equipment in the Maritime Mobile Service).

The responsibilities of a U.S. CCITT Study Group Chairman include the review, coordination, and approval of proposed U.S. contributions to CCITT; coordination of U.S. concensus positions on international standards issues; and leadership of the U.S. delegations to international CCITT meetings. CCIR IWP chairmen are responsible for the direction and coordination of international efforts leading to CCIR Recommendations, which govern spectrum use and the design of radiating communications equipment.

Activities in Study Group D during FY 83 included work on CCITT Recommendations in the following areas: 2400, 4800, and 9600 bps full duplex modems, the ISDN universal physical interface, the Open Systems Interconnection (OSI) reference model, message handling, subaddressing in the world numbering plan, connection of private networks to public data networks, and connection of public data networks with the Maritime Mobile Satellite Service.

Work in the ISDN Working Party included the development of Study Group XVIII inputs which helped shape 11 Draft CCITT Recommendations on ISDN. Major topics addressed in these Recommendations are ISDN services, the ISDN architectural functional model, the ISDN protocol reference model, addressing and numbering principles, network connection types, and user/network interfaces for basic and primary rate access to ISDN services. The Institute also organized (and now chairs) an ISDN Technical Working Group that researches technical issues and prepares draft contributions or ISDN as requested by the full Working Party.

A second major function of NTIA's International Standards project is to inform interested nonparticipants of significant developments in the various international standards committees for which NTIA has leadership responsibility. Over a period of time, this function broadens and strengthens U.S. input to the CCI's (and other international standards organizations) by adding new contributors and expanding the "knowledge base" from which U.S. contributions may be drawn. This function is accomplished by several means, including NTIA and open literature publications, tutorial workshops, and presentations at professional society and industry conferences. Specific FY 83 results included an NTIA Report describing the charter, structure, and activities of key U.S. Government and industry telecommunication standards organizations (in preparation) several open literature publications and conference presentations on ISDN and related CCITT activities; and the testing and documentation of a computerized data base containing key information from each of the over 900 white papers submitted to the 15 CCITT Study Groups during the current study period (NTIA Technical Memorandum 83-98).

The third major function of NTIA's international Standards project is to develop U.S. contributions to international standards organizations. Such contributions are undertaken on a selective basis, in situations where NTIA/ITS has special expertise or resources not readily available to other U.S. participants. A total of 10 such contributions were prepared in FY 83, each dealing with a particular aspect of Quality of Service (QOS) specification or measurement.

Four contributions were submitted to CCITT Study Groups VII and XVIII on the subject of error performance specification. The first addressed the issue of selecting a unit of observation (e.g., bit, block, or time interval) to be used in defining an error ratio parameter. This contribution showed that no single error ratio parameter can adequately specify data transmission accuracy when error clustering exists, and suggested that two parameters (Bit Error Probability and a time-based error ratio parameter such as Error-Free Seconds or Error-Free Deciseconds) be used in such specifications. The second contribution addressed the problem of interpolating between error ratio specifications for particular block lengths, and showed that the entire curve of Block Error Probability versus block length can be determine from any two specified points (e.g., Bit Error Probability and Error-Second Probability) if either a Markov chain or Neyman Type A error dependence model is assumed. (See Figure 2-17. The parameter λ is an error clustering index.) The third contribution examined the accuracy of an NTIA-developed Markov error model in representing the error behavior of real networks, and showed that the model can be accurately fitted to extensive measurement data collected in tests of the Bell System switched telecommunications network (Figure 2-18). The fourth contribution applied the Markov model in interpolating between two particular error probability values specified in an existing CCITT Recommendation (Recommendation G.821). The problem of error ratio specification has considerable economic significance to service providers, since the values specified in CCITT Recommendations influence future transmission

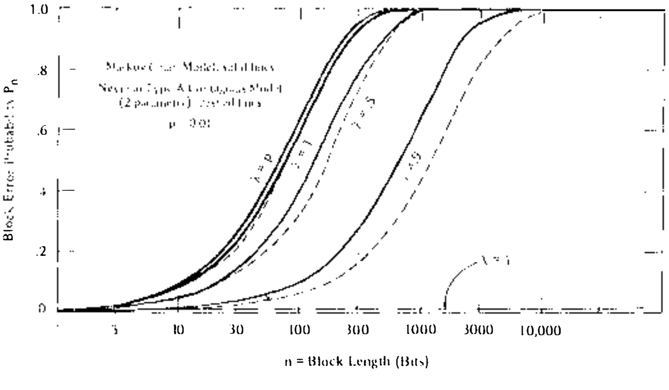


Figure 2-17. Effect of dependence (error clustering).

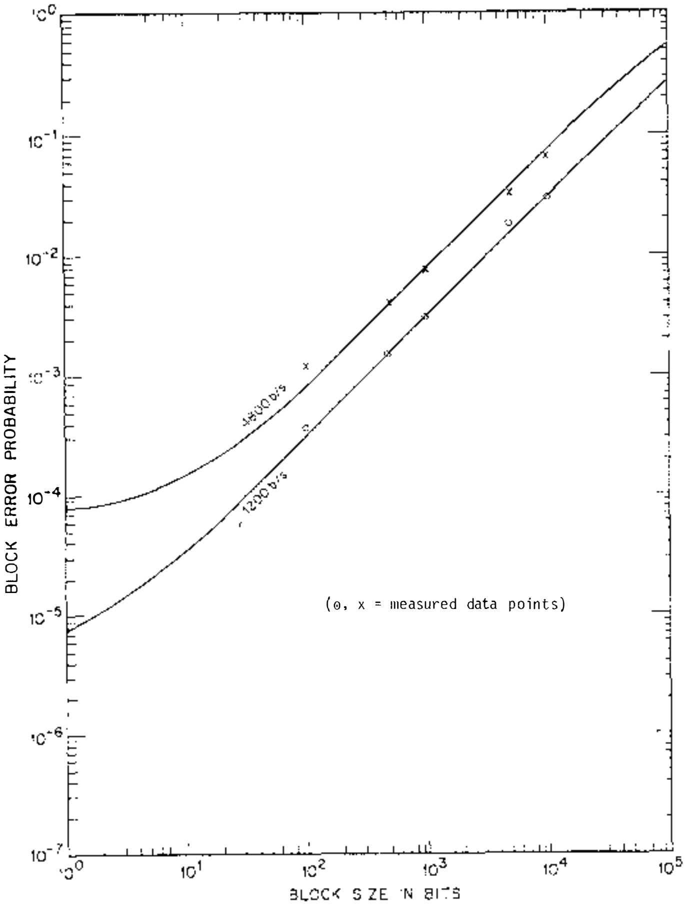


Figure 2-18. Markov model fitted to Bell System 1969-70 connection survey data (80 percentile error rates). Curves are fitted using block sizes 1 and 1000 only.

system designs (e.g., ISDN's) in many countries. Accurate specifications also enable users to more efficiently utilize costly international data communication services.

Two contributions were submitted to standards subcommittees of the International Organization for Standardization (ISO), both dealing with the definition of QOS parameters within the Open Systems Interconnection (OSI) Reference Model. One contribution, submitted to ISO's Technical Committee 97/Subcommittee 16/Working Group 6, proposed a comprehensive set of QOS parameters for the OSI Session Layer Service. The proposed parameters have been incorporated in the ISO draft Session Service standard, DP 8326.

The second contribution, submitted to ISO's TC 97/SC 6/WG 2, proposed refinements in the specification of throughput in the OSI Network Service (NS) Definition, DP 8348. The proposed changes will facilitate communication of NS-user throughput requirements within PDN's (e.g., international packet switching networks). The OSI standards are intended to enable the interconnection of dissimilar computer systems on a world-wide basis.

Four contributions were submitted to CCITT Study Group VII in order to complete and coordinate an NTIA-developed draft recommendation defining user-oriented, network-independent Quality of Service parameters for public data networks. The QOS parameters defined in this draft recommendation (designated X.140) are intended to be used in relating the performance capabilities of particular network services with user requirements (see Figure 2-19). The network specific performance parameters defined in other X-series CCITT Recommendations are focused on specific service interface protocols (e.g., X.21, X.25) and specific network configurations, e.g., X.92 hypothetical reference connections (HRX's). They are essential for network design and operation and component performance specification, but are not necessarily understandable or relevant to users. Similarly, performance requirements of users are often focused on particular applications (e.g., electronic funds transfer, text editing) and may not be directly useful to network providers. The general parameters provide a "common language" for relating the two. They enable users to specify communication requirements without presupposing any particular service, network, or protocol, and enable providers to describe service performance in terms that are relevant to users, but not specialized to any particular application.

The parameters specified in Draft Recommendation X.140 are compatible with those specified in American National Standard X3.102, which NTIA helped to develop under the Data Communications project. Working Party 4 of CCITT Study Group approved this draft recommendation at its final meeting in August 1983. Its approval at the 1984 CCITT Plenary Assembly would be a significant step forward in NTIA's efforts to enhance U.S. telecommunications trade opportunities through standards.

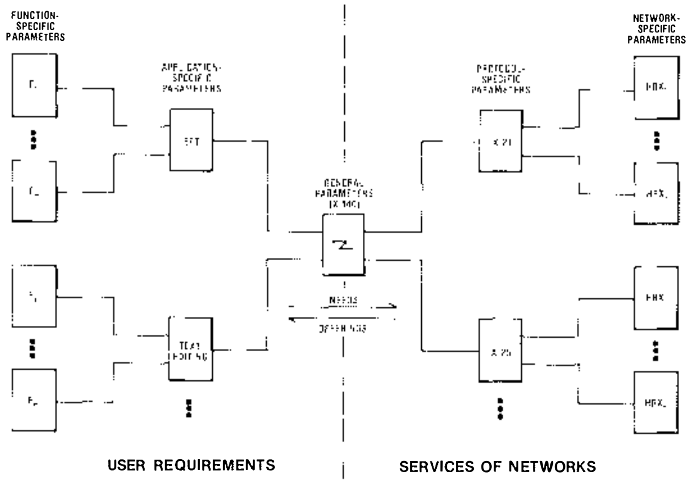


Figure 2-19. "Common language" function of the general QOS parameters.

SECTION 2.4 SYSTEM PERFORMANCE ENGINEERING ANALYSIS

The System Performance Engineering Analysis Group conducts a broad program of applied research, exploratory development studies, concept studies, analysis, and experimentation directed toward support of ITS program elements, NTIA offices concerned with policy, applications, and Federal systems and other Federal agencies. The Group performs experimental research in the area of radio-wave propagation in line-of-sight and tropospheric channels. The experiments include the testing of digital radio performance over these channels. The Group is also responsible for the development of line-of-sight, tropospheric, and HF channel simulators, as appropriate, for the laboratory evaluation of such radios. The Group uses the knowledge gained from the experimental measurement programs as a basis for developing computer models of line-of-sight and tropospheric channels. These computer programs are engineering tools useful for design of line-of-sight and tropospheric-scatter communication links.

In addition to the above program activities, the Group also performs systems analysis of telecommunications systems for other government agencies. The objectives of these programs are to obtain improved services, better resource utilization, and performance at lower costs in competitive markets.

Automated Performance Predictions for Mixed Mode Links. In the operation of near-line-of-sight and beyond-the-horizon microwave links, performance may be determined by more than one mode of radio wave propagation. This may come about as the result of a complete change from one mode to another or from two or more modes existing simultaneously. For example, a normally line-of-sight link could become a diffraction or scatter link or vice-versa, as a result of changes in refractivity gradient and effective earth radius. The objective of this project is to use the distribution of the apparent earth's radii for a given area as the data base for the algorithms used to calculate link performance. The algorithms and data base are used to prepare computer programs and document them.

To obtain a better estimate of the long-term variability transmission loss over mixed mode paths, there has long been a desire to use distributions of refractivity gradients. As pointed out by a number of workers, the distributions are difficult to use for this purpose since the refractivity gradient for a point location often does not represent the conditions for a significant distance along the path. The information needed is the probability that a particular positive refractivity gradient is exceeded over a large part of the transmission path. A model for estimating such distributions is provided by S.A. Schiavone (1981, Prediction of positive refractivity gradients for line-of-sight microwave radio paths, BSTJ, Vol. 60, No. 6, pp. 803-822). This model is designed for use in the United States, but many of the parameters used may be found on world maps. The scheme used on this project for obtaining an estimate of refractivity gradient time distribution for a path in any part of the world is a modification of Schiavone's method.

Link analyses based on path refractivity distributions are particularly useful for estimating the performance of marginal line-of-sight paths especially since the method has been tested. Long-term variability of paths with larger losses (beyond-the-horizon paths) can be calculated using path refractivity distributions but these estimates have not been tested extensively.

When the average refractivity changes from its median value for a significant part of a link, the terrain profile also changes (change in effective earth's radius) as well as the antenna pointing angle. Often, only one end of a beyond-the-horizon path may be affected, especially if the path is very long. By taking these changes into account, the long-term variability distribution of transmission loss may be calculated.

This project is sponsored by the U.S. Army Communications Electronics Engineering Installation Agency and is about 95% complete.

Automated Passive Repeater Link Engineering. The need exists for an automated prediction technique to estimate the performance of passive repeater links. The need can be filled efficiently using a desk-top computer with suitable interactive programs that provide the design engineer with a fast turnaround prediction presented in a report-ready format. The purpose of this set of programs would be to calculate the optimum orientation values for passive repeaters from the earth geometry parameter values of the terminal and repeater sites and to calculate the performance of the link based on the passive repeater size, antenna gains, other equipment parameters, as well as atmospheric and terrain parameters.

Three passive repeater types must be considered:

- separate interconnected parabolic antennas using no active elements
- one-plane reflector
- two-plane reflectors.

In mountainous terrain, access to active repeater stations is often a problem as is the power source especially during winter months. A solution to this problem is often the use of a passive repeater that requires no power and little maintenance. With the passive repeater on the hilltop, the active repeater may be placed near an existing road near reliable power at a low elevation. Although a passive repeater link generally exhibits more path loss than the direct line-of-sight link (were such a link available), the variability over the link is often less since beam angles of penetration through atmospheric layers are sharper. Other advantages often obtained using passive repeater systems are a significant decrease in susceptibility to interference and the capability of supporting wide bandwidths compared to diffraction, scatter, and even line-of-sight paths. The reasons for these advantages are the very narrow beam angles, the resistance to multipath due to high penetration angles, and the flexibility of placing terminal sites in low terrain using short towers, thus sheltering the relatively wide-beam terminal antennas from interfering sources.

Frequency diversity may be used on passive repeater paths. But space diversity can only be used on the long leg of a passive repeater path unless two sets of repeaters are used. If a double passive is placed approximately midpath on a long path, space diversity may be used at both ends of the path.

Design and calculation of a microwave path using a passive repeater is more complex than that of a path without one. However, procedures are specific and they lend themselves readily to interactive automation on a desktop computer.

The following steps are required to develop a prediction technique that is practical, computerized, and interactive:

1. Select an algorithm to calculate reflector and antenna orientation values from the earth geometry coordinates of the reflectors and antennas as well as median atmospheric parameters.
2. Design an algorithm to calculate and display the terrain profile and ray path geometry. The formats should provide a labeled plan view of the path, terrain profiles of each leg of the path, and a tabulation of geometric parameters.
3. Obtain an algorithm to calculate the median basic transmission loss across the link and provide a tabulation of assumptions and parameter values. This algorithm must include near-field effects and double passive repeater close-coupling loss calculations.
4. Design an algorithm that calculates the basic transmission loss variability and display this information in graphical and tabular form.
5. Design an algorithm that calculates the distribution of carrier-to-noise ratio for the link and display this output in graphical and tabular form.
6. Provide an algorithm that calculates the single receiver transfer characteristics for the path and provides a graphical output whenever such an output is applicable.
7. Design an algorithm that summarizes and calculates link performance along with parameter values used in making the performance prediction.
8. Prepare suitable programs coded to provide the calculations and outputs required by the various algorithms.
9. Provide suitable documentation with the programs including a program maintenance manual and a users manual.

The algorithms must be capable of analyzing performance of a passive repeater link made up of 4 legs (3 passive repeaters) where each repeater may be of any one of the three passive repeater types.

Because passive repeater links are usually made up of line-of-sight legs with adequate terrain clearance, line-of-sight analysis is used to calculate median-signal level and path-loss variability. The algorithms for line-of-sight link analysis must therefore be examined and the best available algorithms chosen for the passive repeater link analysis. The analysis structure should be designed such that an ordinary line-of-sight link is a special case of passive repeater analysis and thus greatly expands the utility of the program set. Some of the line-of-sight algorithms that must be included are:

- atmospheric attenuation
- atmospheric multipath
- rain attenuation.

This project is sponsored by USA CEEIA and is approximately 5% complete.

Digital Radio Performance Tests. In the Annual Technical Progress Report for 1982, performance tests of the Digital Radio and Multiplexer Acquisition (DRAMA) system were reported. The DRAMA radio is a military digital microwave system, designed for use on the Digital European Backbone (DEB) network in Europe. The Institute tested this radio for its susceptibility to multipath propagation problems, and participated in propagation experiments in the European theatre to determine if the multipath environment found on the coast of southern California would exist on the European links. The earlier tests confirmed that the DRAMA radio, in its original configuration, would not meet the desired transmission reliability in the presence of multipath, and that detrimental multipath can be expected a significant portion of the time on some European paths.

As a result of these tests, the U.S. Army Communications Electronics Engineering and Installation Agency (CEEIA) has initiated a series of performance tests designed to evaluate several proposed techniques to improve the DRAMA performance in a multipath environment. These include new algorithms for switched-diversity selection and newly designed adaptive equalization circuits. In addition, the tests will include the use of predetection combining at the IF level in the diversity receivers.

The tests are being conducted over a microwave link at the Pacific Missile Test Center (PMTC), Point Mugu, California, through cooperation of the U.S. Navy. The test link is one that is frequently subject to atmospheric multipath, created by strong ducting gradients in the refractive profile [Hubbard, R.W. (1979), Investigation of Digital Microwave Communications in a Strong Meteorological Ducting Environment, NTIA Report 79-24, August]. The performance of two digital microwave systems, operating at 44.7 and 12.9 Mb/s, were compared over brief intervals of time in a recent NTIA Report [Hubbard, R.W. (1983), Digital Microwave Transmission Tests at the Pacific Missile Test Center, Pt. Mugu, California, NTIA Report 83-126, June]. The performance data were augmented with propagation data and meteorological data. The multipath was measured and described through the use of the ITS PN Channel Probe [Linfield, R.F., R.W. Hubbard, and L.E. Pratt (1976), Transmission Channel Characterization by Impulse Response Measurements, OT Report 79-76, August]. This instrument and the test radios were all multiplexed over the same space-diversity path, so that a direct correlation between the multipath structure and the performance data was possible. The same configuration is being used for the current DRAMA radio tests. A standard "base-line" radio is operated as a reference for the performance data, and a second radio is used as the test radio in which the variations of the switching algorithms and equalization circuits are implemented. The tests are just beginning at the writing of this report, and are expected to continue through the first three quarters of CY 84.

A related project to that described above is also being conducted over the PMTC test link. The program is sponsored by the U.S. Army, Communications Systems Agency (CSA). It is centered on a new proposed method of angle-diversity reception for microwave radio transmission. The technique is a proprietary method developed by Signatron Inc., Lexington, MA. Under contract to CSA, Signatron has furnished an angle-diversity antenna to ITS for use in the tests. The antenna is mounted to the receiver location tower at PMTC alongside a matching antenna (provided by ITS) with a standard vertically-polarized feed. The Institute has designed and constructed a stable recording receiver to measure the received signal level (RSL) on three channels. Two channels are being recorded from the angle-diversity antenna, and the third (reference) channel from the ITS antenna. The RSL data will be compared statistically for the multipath fading parameters. The test system has been installed with duplexers in the receiver rf lines so that the PN Channel Probe (noted above in the DRAMA test program) can be used periodically to monitor the multipath structure in the angle and reference paths. If the tests indicate that the angle-diversity technique can improve the transmission performance of a digital radio, it is anticipated that this program will be expanded to include a direct measure of the DRAMA performance using the angle diversity receiving antenna. The initial tests are being conducted using one of the PMTC transmission (analog radio) frequencies at 7470 MHz.

The basic data acquisition system being used in these tests is described in the report referenced above (Hubbard, 1983).

Ditital Radio Performance Data. Following some digital propagation measurements performed by ITS in 1979 [Hubbard, R.W. (1979), Investigation of Digital Microwave Communications in a Strong Meteorological Ducting Environment, NTIA Report 79-24, August], the Range Communications Department of the Pacific Missile Test Center (PMTC), Point Mugu, CA, procured a commercial digital microwave (7350 MHz) radio. The system was multiplexed over an existing link in the PMTC network and placed under test for an extended period. The Institute was tasked by PMTC to develop the test procedures and instrumentation required to evaluate the performance of the radio under severe multipath conditions. The radio, supplied by a commercial vendor, was designated as the MDR-8. It was configured for space-diversity reception, using a vertical antenna spacing of approximately 29 m (95 ft), and each diversity receiver used a form of adaptive slope and notch equalization in the IF to compensate for multipath (frequency selective) fading. The objective of these tests was to determine if the radio would meet a high level of performance availability without the use of frequency diversity (as was originally recommended by ITS). The tests were conducted during 1980-1981. The radio transmission rate was 44.7 Mb/s (T3), and a pseudo-random bit stream at this rate was used to measure the error rate and burst-error statistics over the test link.

Cursory results of the tests showed that in a severe multipath channel (which is dominant during summer and early fall months) the radio would fall short of desired performance specifications. Thus, the PMTC devoted resources toward a configuration using both space and frequency diversity and improvements in the adaptive equalization circuitry. As a consequence, the detailed error-performance data were not completely analyzed by PMTC. The Institute retained the original data tapes collected during this program and analyzed only a limited amount of the data.

The U.S. Army (CEEIA) uses the MDR-8 digital radios in a number of operating links, and therefore became interested in the analyses of the error performance statistics. The Army has tasked ITS to analyze these data for the complete PMTC experiment.

A list of the signals recorded for the digital radio performance tests is shown in Table 2-3. In the following paragraphs we will describe the formatting of these data and outline the analysis procedures to be used.

Any long periods of error-free performance for the digital radio were registered on the terminal/printer of the data acquisition system. An example of these entries is shown in Figure 2-20. A "Code 3" on the record corresponds to an error-free period, counted as the number of error-free sync periods as defined later in Table 2-4. Error-free sync periods could be counted as high as 10^5 before a counter overflow. Thus, each Code 3 message on the terminal represents 73 s of error-free data. Figure 2-20 shows a continuum of these entries, interspersed with periods of error data. The periods of error are indicated on the figure with the drafted arrows, along with the duration of the recorded data on magnetic tape. Figure 2-20 also shows a typical message that was printed on the terminal for

Table 2-3. LSI-11 Minicomputer System (CPU) Data

DATA SOURCE	SIGNAL DESCRIPTION	DATA RECORD
	ANALOG	
44.7 MB/S DIGITAL RADIO (MDR-8)	1. RSL CHAN A (LOWER ANTENNA)	DIGITAL MAG TAPE
	2. RSL CHAN B (UPPER ANTENNA)	
	3. AE SLOPE CHAN A	
	4. AE SLOPE CHAN B	
	5. AE NOTCH CHAN A	
	6. AE NOTCH CHAN B	
	7. RAIL CLOCK REFERENCE	
	8. RAIL CLOCK DELAY	
	9. BIT ALIGNMENT	
	DIGITAL STATUS	
	1. REC IN SERVICE	DIGITAL MAG TAPE
	2. AGC/AE OFF NORMAL A	
	3. AGC/AE OFF NORMAL B	
	4. LOSS OF FRAME A	
	5. LOSS OF FRAME B	
	6. $BER > 10^{-7}$ A	
	7. $BER > 10^{-7}$ B	
	8. $BER > 10^{-2}$ A	
	9. $BER > 10^{-2}$ B	
	10. CONTROL SWITCH OFF NORMAL	
	DIGITAL ERROR DATA	
MK-4 BURST ERROR ANALYZER	1. BURST ERROR STATISTICS	DIGITAL MAG TAPE
	2. ERROR FREE SYNC PERIODS	TERMINAL PRINTER
PN CHANNEL PROBE	1. RSL CHAN A *	DIGITAL MAG TAPE
	2. RSL CHAN B *	
	3. TILT/NOTCH SIGNAL *	
PMTC ANGLE DIVERSITY	1. RSL CHAN 1 *	DIGITAL MAG TAPE
	2. RSL CHAN 2 *	

*PARALLEL DATA ON ANALOG MAGNETIC TAPE.

information to the system operator. In this instance, an end-of-tape message is seen, and the record shows that a new tape was mounted and the data system restarted with a data loss of approximately 3 minutes. Each entry is identified with the date (month/day) followed by the time of the entry (Zulu).

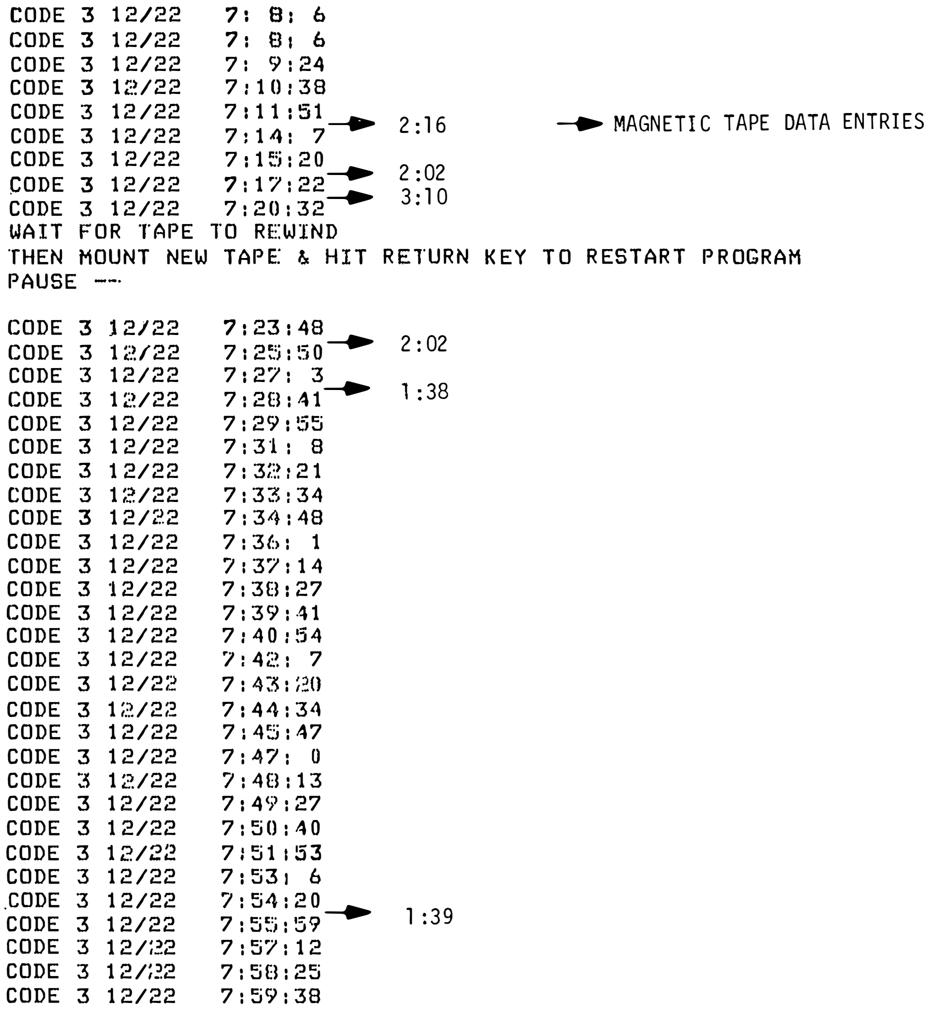
During error data, two distinct protocols were used to direct the computer system to transfer all buffered data to the magnetic tape. These were:

- any time that error data were received in the storage buffer; and
- any change in the receiver status/alarm signals at the 0.1 s intervals.

Thus, at any time either of the above conditions was met, the entire data file in the storage buffers was written to the magnetic tape. The buffers contained 5 s of data, and these were recorded as a single record. A data record is composed of four distinct blocks, organized as follows:

- data and time (Z), which serves to identify each record. Number of data entries in Block No. 4
- A/D data (16 × 50 grid)
- digital receiver status (100 ms intervals)
- digital burst-error data (100 ms timing marks).

A typical example of one 5 s data record, as read from the magnetic tape, is shown in Figure 2-21. The data blocks listed above are numbered accordingly in this figure. The A/D records in Block No. 2 are for the 16 channels from left to right, and the entries printed in decimal values. Block No. 3 contains the receiver status/alarm data, entered in an octal code for the 16 bits of information. The data in Block No. 4 are the burst-error data as recorded from a Tau Tron MK-4 instrument. The entry "40" represents the 100 ms timing marks within the block, during which no error or alarm data were rereceived. Starting after the 38th time mark (3.8 s after the record time in Block No. 1) the data indicate that either a burst of error or a receiver status signal was received. The data entries are treated in groups of three octal numbers, which show the digital status of all three I/O boards in this block. An interpretation of some of these octal entries, including details of the error performance data, are given in Table 2-5.



```
CODE 3 12/22   7: 8: 6
CODE 3 12/22   7: 8: 6
CODE 3 12/22   7: 9:24
CODE 3 12/22   7:10:38
CODE 3 12/22   7:11:51
CODE 3 12/22   7:14: 7 ──► 2:16        ──► MAGNETIC TAPE DATA ENTRIES
CODE 3 12/22   7:15:20
CODE 3 12/22   7:17:22 ──► 2:02
CODE 3 12/22   7:20:32 ──► 3:10
WAIT FOR TAPE TO REWIND
THEN MOUNT NEW TAPE & HIT RETURN KEY TO RESTART PROGRAM
PAUSE --

CODE 3 12/22   7:23:48
CODE 3 12/22   7:25:50 ──► 2:02
CODE 3 12/22   7:27: 3
CODE 3 12/22   7:28:41 ──► 1:38
CODE 3 12/22   7:29:55
CODE 3 12/22   7:31: 8
CODE 3 12/22   7:32:21
CODE 3 12/22   7:33:34
CODE 3 12/22   7:34:48
CODE 3 12/22   7:36: 1
CODE 3 12/22   7:37:14
CODE 3 12/22   7:38:27
CODE 3 12/22   7:39:41
CODE 3 12/22   7:40:54
CODE 3 12/22   7:42: 7
CODE 3 12/22   7:43:20
CODE 3 12/22   7:44:34
CODE 3 12/22   7:45:47
CODE 3 12/22   7:47: 0
CODE 3 12/22   7:48:13
CODE 3 12/22   7:49:27
CODE 3 12/22   7:50:40
CODE 3 12/22   7:51:53
CODE 3 12/22   7:53: 6
CODE 3 12/22   7:54:20
CODE 3 12/22   7:55:59 ──► 1:39
CODE 3 12/22   7:57:12
CODE 3 12/22   7:58:25
CODE 3 12/22   7:59:38
```

Figure 2-20. An example of the terminal/printer record from the digital data acquisition system. Periods between entries greater than 73 s (indicated by the arrows) show the times when error data were recorded on the magnetic tape.

A complete analysis of the recorded data has not been made at this writing. Some analyses are in process under the Army project, and a detailed report is anticipated early in CY 84. The material provided here is merely to indicate the manner in which the data were formatted and the methods for compiling the results. It can be seen, for example, that a complete distribution of error-free time can be readily compiled by totalizing the time for Code 3 entries. In like manner, the following are examples of the statistical data that will be developed in future analyses from the error data:

- o distribution of the lengths of error-free sync periods (from Code 0 and Code 1 data)
- o distribution of error-free gaps (Code 1 Code 2 data)
- o distribution of error bursts
- o distribution of the error-free periods between bursts (>gap length)
- o distribution of error-burst lengths
- o distribution of the number of errors within a burst
- o distribution of the ratio of burst length to error count within a burst
- o distribution of sync-loss counts and duration.

The above list is not exhaustive, but it includes the major distributions that can be readily obtained with the proper search program of the data tapes. Since these data are essentially synchronous with the propagation-oriented data, the potential for meaningful studies of the correspondence between these data is quite high. As one example, consider the correlation between spectral distortions measured by the "tilt" and "notch" signals in

Table 2-4. Microwave Radio Performance Data

PN TEST CODE = $(2^{15}-1)$ = 32,767 BITS/SEQUENCE

TRANSMISSION RATE = 44.736 MB/S

BIT PERIOD (T) = 1/44.736 = .022353--MICROSECONDS

PN SYNC PERIOD = 32,767 x T = 732.45--MICROSECONDS

10^5 SYNC PERIODS = 73.245--SECONDS

ERROR GAP LENGTH = 256 BITS

TAU TRON MK-4 BURST ERROR ANALYZER DATA:

CODE 0 --	FIRST BURST AFTER A NUMBER OF ERROR-FREE SYNC PERIODS COUNTS NUMBER OF ERROR-FREE SYNC PERIODS
CODE 1 --	FIRST ERROR-BURST DISTRIBUTION COUNTS NO. OF BITS FROM LAST SYNC TO FIRST ERROR COUNTS NO. OF BITS IN ERROR COUNTS THE LENGTH OF THE BURST IN NO. OF BITS
CODE 2 --	SECOND (OR SUBSEQUENT) BURST DISTRIBUTION WITHIN A SYNC PERIOD SUBSEQUENT BURST DECLARED IF GAP LENGTH IS EXCEEDED DISTRIBUTION DATA SAME AS CODE 1
CODE 3 --	SYNC COUNTER HAS REACHED 10^5 ERROR-FREE SYNC PERIODS CODE 3 MESSAGE AND DATE/TIME LINE ARE PRINTED ON THE DATA SYSTEM TERMINAL
CODE 4,5, 6, 7 --	SAME AS CODES 0,1,2,3 RESPECTIVELY, INDICATING THAT THE MK-4 FIFO BUFFER IS FULL

the A/D data bank and the detailed error analysis listed above. The results will illustrate what the most important performance parameters are and should lead to conclusions toward methods of improving the performance. This aspect, coupled with an evaluation of the meteorological description of the transmission channel, offers an approach to the analysis that encompasses all of the system and propagation variables.

The status/alarm data from the experiment expand the concepts noted above. For example, distributions of the diversity switching and duration of time that a given receiver is selected are also available from the data. Referring to Table 2-3, other significant parameters for analyses are:

- rail clock statistics
- bit alignment characteristics
- BER alarm distribution for independent diversity receivers
- loss of frame data for each diversity receiver.

The above discussion is presented here only to convey the methods used in both collecting these data and analyzing their results and meaning. The Institute is currently developing the computer routines and programs that will automatically retrieve, decode, and display these results in accordance with the analysis summaries given above. When this project is completed, a technical report in the NTIA series will be published.

Digital Troposcatter Communications. The Institute has supported the U.S. Air Force for several years in the test program for the AN/TRC-170 Digital Troposcatter Radio Systems. The Air Force maintains a test-bed and Tactical Communications Test Office (AFTCTO) at Fort Huachuca, AZ, for this program.

In previous years, ITS developed a pseudo-random noise (PN) probe for application to troposcatter circuits. The probe uses a digital bit stream, clocked at rates up to 20 MHz, and develops an impulse response of a transmission channel from which the delay-spread characteristics over a tropo channel may be measured. The instrument operates at 70 MHz and interfaces with the tropo radio at that IF level. The instrument was used initially to measure the delay-spread parameter for several candidate test links for the AN/TRC-170 system. In these measurements, an AN/TRC-97 system was used as the host radio. The objective was to determine that the delay-spread over the selected links did not exceed the design criteria for the AN/TRC-170 systems. The results of the measurements were presented

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①      12     22      7     24     37     98

     -1107  -1082   -746   -828  -2048  -2048    209    122   -320    -36    -15   -463   -882  -1263  -1593  -1758
     -1105  -1096   -741   -828  -2048  -2048    198    123   -311    -33    -13   -462   -882  -1261  -1589  -1760
     -1109  -1107   -744   -831  -2048  -2048    191    128   -313    -34    -13   -461   -883  -1257  -1589  -1759
     -1109  -1115   -750   -837  -2048  -2048    173    126   -315    -34    -15   -465   -879  -1260  -1595  -1765
     -1109  -1122   -742   -834  -2048  -2048    154    103   -327    -35    -15   -460   -885  -1260  -1599  -1769
     -1113  -1130   -725   -830  -2048  -2048    133     79   -341    -36    -15   -462   -879  -1261  -1604  -1773
     -1107  -1136   -708   -825  -2048  -2048    112     52   -358    -37    -13   -466   -881  -1261  -1609  -1778
     -1104  -1137   -701   -830  -2048  -2048     93     23   -379    -38    -15   -462   -879  -1261  -1610  -1775
     -1111  -1137   -707   -836  -2048  -2048     76      2   -402    -37    -15   -458   -877  -1260  -1609  -1779
     -1120  -1136   -708   -828  -2048  -2048     66    -11   -417    -39    -13   -460   -875  -1257  -1604  -1773
     -1132  -1132   -708   -822  -2048  -2048     62    -22   -429    -40    -15   -462   -877  -1255  -1599  -1777
     -1149  -1127   -716   -819  -2048  -2048     67    -28   -440    -41    -15   -461   -877  -1253  -1596  -1777
     -1149  -1116   -711   -809  -2048  -2048     79    -29   -442    -41    -14   -461   -875  -1250  -1588  -1773
     -1134  -1100   -697   -806  -2048  -2048     89    -21   -436    -40    -16   -460   -876  -1248  -1582  -1771
     -1100  -1089   -661   -805  -2048  -2048     91     -9   -423    -40    -16   -463   -875  -1249  -1578  -1768
     -1055  -1086   -610   -809  -2048  -2048     91      2   -411    -38    -14   -458   -876  -1248  -1580  -1761
     -1033  -1077   -525   -812  -2048  -2048     99     11   -405    -39    -15   -460   -877  -1247  -1573  -1745
     -1018  -1072   -541   -814  -2048  -2048    103     19   -401    -36    -16   -360   -730  -1154  -1526  -1703
      -982  -1068   -732   -815  -2048  -2048    104     17   -398    -37    -15   -476   -893  -1228  -1550  -1711
      -964  -1068   -831   -814  -2048  -2048    110     18   -397    -38    -14   -478   -906  -1256  -1565  -1709
      -937  -1068   -866   -814  -2048  -2048    109     25   -390    -39    -15   -469   -895  -1259  -1575  -1701
      -886  -1063   -884   -822  -2048  -2048    109     39   -377    -38    -15   -468   -889  -1257  -1575  -1695
      -849  -1068   -984   -827  -2048  -2048    107     46   -370    -41    -14   -465   -888  -1258  -1578  -1679
      -785  -1075  -1128   -830  -2048  -2048    109     45   -369    -37    -16   -462   -885  -1257  -1580  -1664
      -778  -1082  -1231   -831  -2048  -2048    113     41   -375    -37    -14   -464   -881  -1258  -1580  -1640
      -851  -1080  -1206   -826  -2048  -2048    120     41   -385    -37    -16   -457   -877  -1253  -1578  -1635
      -908  -1077  -1125   -806  -2048  -2048    127     33   -397    -37    -15   -459   -876  -1253  -1579  -1654
②    -992  -1071   -961   -787  -2048  -2048    133     38   -401    -48    -13   -455   -873  -1247  -1583  -1675
     -1054  -1063   -883   -773  -2048  -2048    125     43   -397    -40    -14   -455   -876  -1249  -1580  -1702
     -1082  -1060   -869   -763  -2048  -2048    118     38   -396    -38    -14   -456   -875  -1249  -1584  -1732
     -1087  -1057   -868   -759  -2048  -2048    123     35   -395    -39    -17   -457   -874  -1250  -1583  -1745
     -1090  -1041   -859   -765  -2048  -2048    127     39   -386    -38    -17   -459   -875  -1247  -1583  -1748
     -1066  -1035   -869   -769  -2048  -2048    137     43   -378    -38    -14   -462   -879  -1247  -1579  -1749
     -1043  -1027   -890   -769  -2048  -2048    134     53   -369    -37    -17   -458   -877  -1248  -1577  -1743
     -1046  -1025   -890   -767  -2048  -2048    135     51   -373    -37    -14   -459   -877  -1248  -1577  -1734
     -1031  -1006   -895   -763  -2048  -2048    145     52   -369    -37    -18   -466   -877  -1254  -1573  -1731
     -1003   -990   -909   -757  -2048  -2048    154     55   -361    -36    -14   -459   -866  -1234  -1567  -1721
      -975   -979   -926   -744  -2048  -2048    143     63   -357    -37    -16   -455   -861  -1219  -1557  -1706
      -944   -957   -911   -765  -2048  -2048    132     56   -349    -35    -14   -460   -834  -1175  -1537  -1684
      -922   -944   -845   -804  -2048  -2043    135     52   -353    -37    -14   -437   -744  -1059  -1460  -1635
      -928   -943   -797   -867  -1855  -1776    143     52   -359    -35    -15   -304   -511   -893  -1329  -1559
     -1222   -950   -745   -907   -280  -1566    150     59   -398    -39    -14    -69   -158   -637  -1119  -1446
     -1303   -964   -758   -909   -109  -1586    158     58   -398    -37    -14   -189   -330   -707  -1121  -1500
     -1303   -990   -798   -875   -128  -1660    165     59   -385    -37    -15   -284   -491   -812  -1170  -1556
     -1263  -1024   -773   -836   -275  -1785    179     71   -371    -36    -15   -358   -643   -940  -1239  -1601
     -1259  -1040   -768   -809   -282  -1893    197     80   -362    -37    -14   -384   -728  -1036  -1311  -1643
     -1266  -1054   -793   -793   -274  -2014    201     79   -360    -36    -16   -401   -786  -1121  -1385  -1685
     -1255  -1069   -796   -791   -314  -2048    229     87   -352    -35    -17   -425   -840  -1195  -1453  -1726
     -1249  -1079   -762   -790   -341  -2048    243     97   -347    -35    -13   -434   -868  -1255  -1514  -1761
     -1216  -1082   -752   -793   -405  -2048    252     99   -336    -34    -16   -449   -884  -1278  -1550  -1788

    177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706 177706
③  152706 152706 152706 157706 157706 157706 152706 152706 152706 152706 152706 157706 157706 157706 157706 157706
    157706 157706 157706 177706 177706 177706 157706 156702 152706 152706 152706 152706 156706 157706 157706 157706
    157706 157706

        40     40     40     40     40     40     40     40     40     40     40     40     40     40     40     40
        40     40     40     40     40     40     40     40     40     40     40     40     40     40     40     40
        40     40     40     40     40     40 177302 177020 177777 177306   6027  21421 177302 171043 177777 157706
④    6047  32030     40 157702 171022 177777 157706   6051  21421 157702 171002 177777 157706   6030  31030 157706
      6021  32030 157712   6040  33022 156702 171221 177777     40 156706   6042  30024 156702 171046 177777 156706
      6060  23424 156702 171101 177777 152706   6051  23424     40     40     40     40     40     40     40     40
        40     40

○  DATA BLOCK NO.
```

Figure 2-21. An example of one 5 s data record read from the digital magnetic tape. The four independent data blocks are numbered in the figure; their content is described in the text.

Table 2-5. Contents of the Octal Data from Figure 2-2

DIGITAL DATA DECODE: 12/22/80 7:24:37 Z

INDEX NO.	OCTAL CODE	STATUS
1-16	177706	CODE 1, REC B, NORMAL OPERATION
17-19	152706	CODE 1, REC B, NORMAL OPERATION REC A BER $>10^{-7}$ and 10^{-2} REC A LOSS OF FRAME
20-22	157706	CODE 1, REC B, NORMAL OPERATION REC A BER $>10^{-7}$
23-27	152706	AS ABOVE
28-35	157706	AS ABOVE
36-38	177706	AS ABOVE
39	157706	AS ABOVE
40	156702	CODE 0, REC B, NORMAL OPERATION REC A BER $>10^{-7}$ and 10^{-2}
41-33	152706	AS ABOVE
45	156706	CODE 1, REC B REC A BER $>10^{-7}$ and 10^{-2}
46-50	157706	CODE 1, REC B REC A BER $>10^{-7}$

BURST ERROR DATA DECODE FOLLOWING INDEX NO. 38

38+	177302	CODE 0, REC A, NORMAL STATUS
	177020	BURST BEGAN AFTER 10 x 10^3 ERROR FREE SYNC PERIODS (NO MEANING)
	177306	CODE 1, REC A, NORMAL STATUS
	006027	BURST BEGAN 17 x 10^3 BITS AFTER LAST SYNC PULSE
	021421	BURST STATISTIC: 11 ERRORS IN LENGTH 23 BITS
	177302	CODE 0, REC A, NORMAL STATUS
	171043	BURST BEGAN AFTER 23 x 10^0 ERROR FREE SYNC PERIODS
	177777	(NO MEANING)
	157706	CODE 1, REC B, REC A BER $>10^{-7}$
	006047	BURST BEGAN 27 x 10^3 BITS AFTER LAST SYNC PULSE
	032030	BURST STATISTIC: 18 ERRORS IN LENGTH 34 BITS

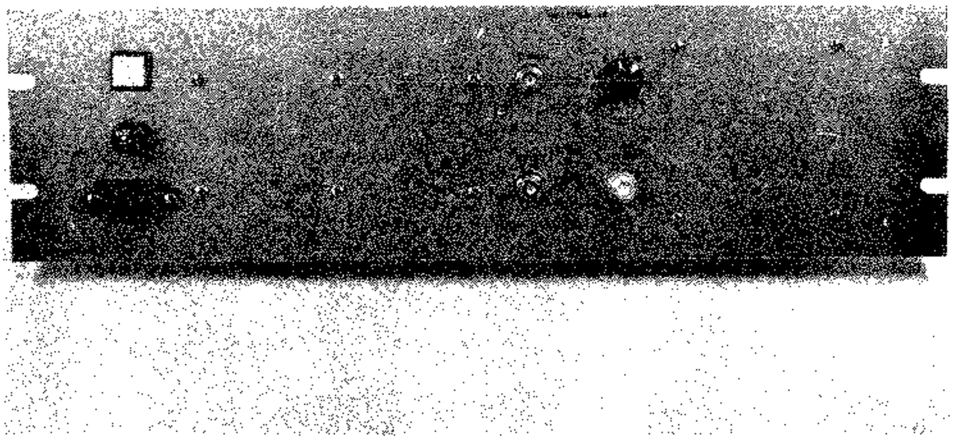
in NTIA Technical Memorandum 83-84 [Hubbard, R.W. (1983), Delay-Spread Measurements over Troposcatter Links, March]. Subsequent to these measurements, the AFTCTO has continued to use the ITS probe instrument to obtain additional data from other test links in Arizona and Florida.

The most recent activity in this program has been the design and construction of a new PN probe system for the AFTCTO. The instrument was designed to be used as a permanent and integral part of the test instrumentation assembled for the AN/TRC-170 test program. The new instrument has many advanced features and operational improvements that were not in the original ITS instrument. A complete list of the characteristics and specifications are given in Table 2-6. Figure 2-22 shows the transmitter panel, and Figure 2-23 shows the modular construction of the receiver and the full front panel. The system was completed and delivered to the AFTCTO in March 1983.

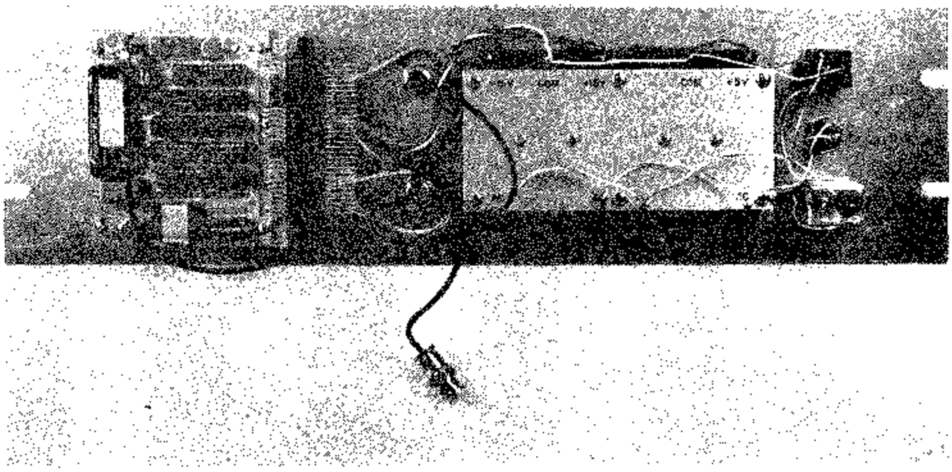
Transmission Monitor and Control (TRAMCON) Related Programs. The initial effort in creating the TRAMCON system involved the development of a set of software to use existing ADP assets to monitor the first stage of the Digital European Backbone or DEB-I. Three minicomputer systems were used to monitor 13 microwave sites in this first digital upgrade of the European communication system. This interim system provided the field operator with a method to observe and manage a series of communications facilities from a central location. This in turn affords the opportunity to establish a centralized maintenance dispatch function and further to reduce the need for site manning. The refinements in the monitor and display system have evolved during an evaluation period when this system was in actual operation. Beneficial feedback from the users of the system have significantly improved the utility of this system.

Table 2-6. Troposcatter Probe Characteristics

General	
Construction: Dual Channel for Diversity Applications	
Single 19" Rack-Mount Panel Transmitter	
Modular Unit Receiver	
Signals Processed: PRBS Correlation Detection (4 Channels/Each Receiver)	
Received Signal Level(RSL)	
Transmitter	
PRBS Generator/Selectable Clock Rates	5 MHz 10 MHz 20 MHz External
Operating Frequency	70 MHz
Output Signal Level	0 dBm
Receiver	
PRBS Clock Rate	Same as Tx
Operating Frequency	70 MHz
Correlation Channels (Each Receiver)	
Co-phase	4
Quad-phase	4
Power Impulse (Sum of Squares Output)	1
Time Displacement Between Correlators	1 Bit Each
Correlation Synchronization (Manual Clock Control)	0.1 Bit
Calibration: Integral Source with Precision Attenuator	79 dB Range
RSL: Recorder Output (Each Receiver)	70 dB Dynamic Range
Sensitivity (Minimum Impulse Response)	-100 dBm

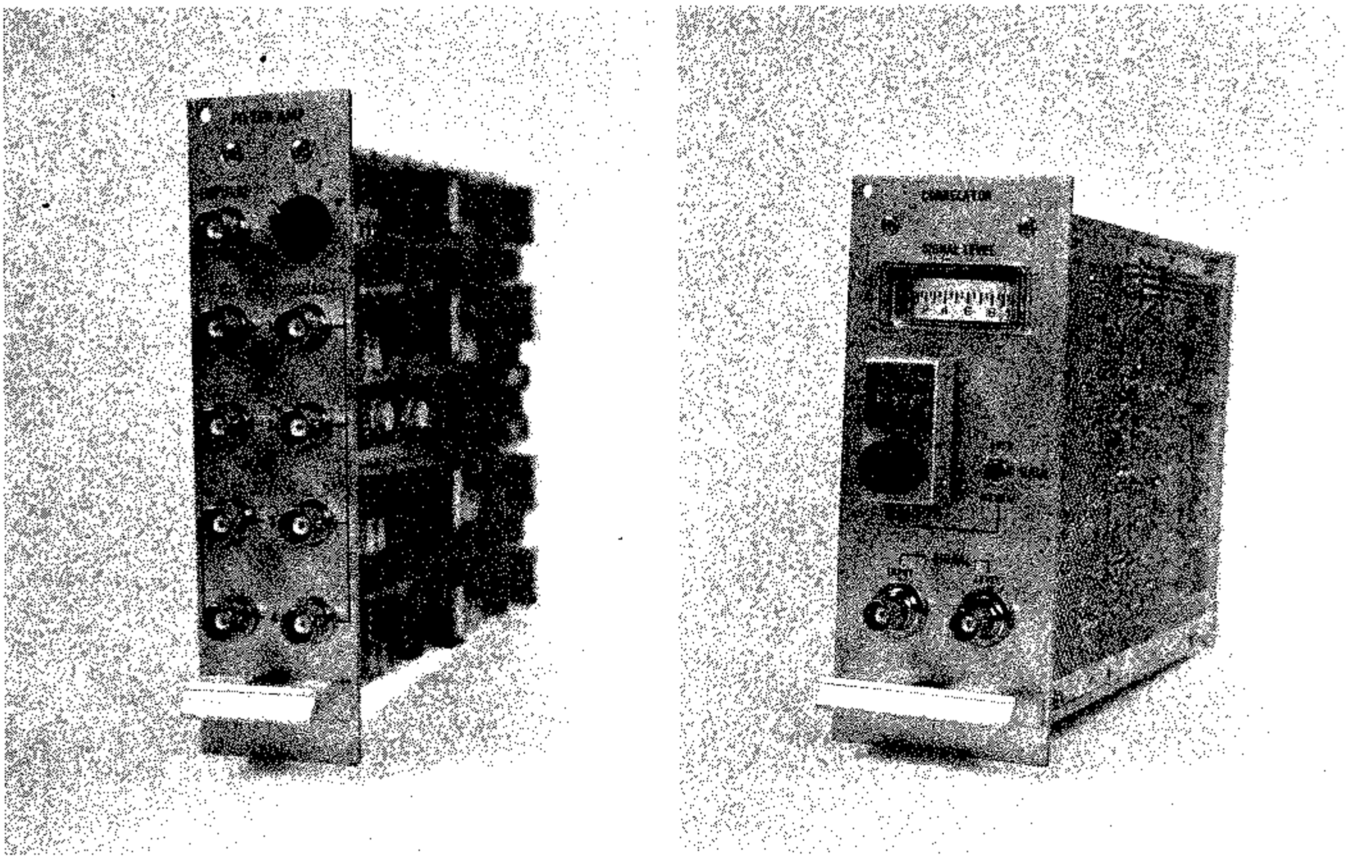


(a) panel view

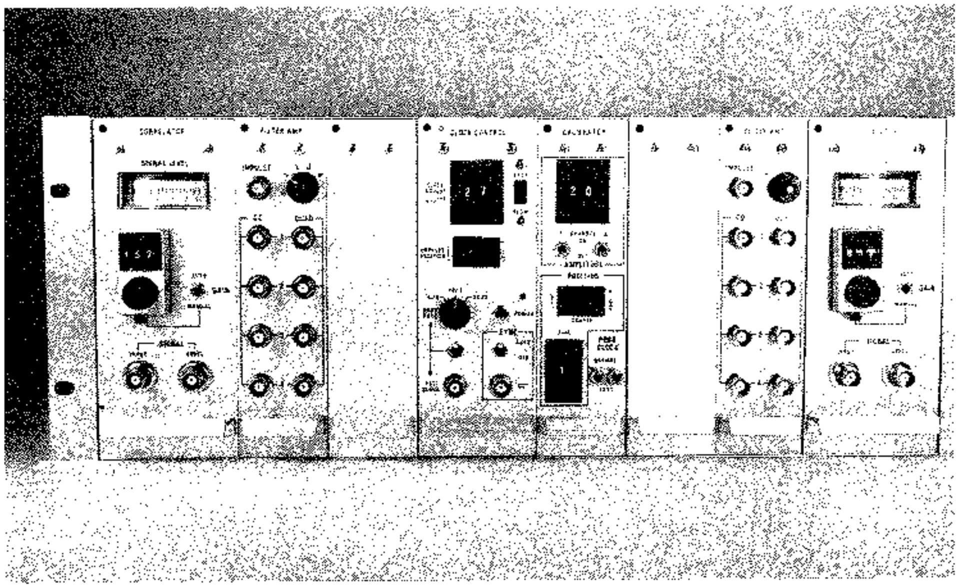


(b) rear view (protective cover removed)

Figure 2-22. Transmitter chassis of the troposcatter PN probe.



(a) modular units used in the receiver



(b) front panel view of the complete dual receiver

Figure 2-23. Receiver unit of the troposcatter PN probe.

Deployment of this system demonstrated the many benefits to enhance system operation and system availability. In mid 1981, the TRAMCON system was established as an integral part of the digital European upgrade by amending the DEB Management Engineering Plan to include the TRAMCON function. A series of development and deployment steps were established by the management and technical committees for TRAMCON. These steps include stages of development and refinement of software capabilites for the master terminal, the addition of an intelligent remote unit, and the establishment of an intra-TRAMCON master network.

The TRAMCON system was established to monitor, collect, and display data that reflects the operational status of a digital communication system. These data are typically those status and alarm indicators that are normally designed into the hardware that make up the transmission system and the analog and pulse parameters that give a measure of the transmission quality. These alarms and parameters indicate which receiver and transmitter is on line, a loss of data stream activity, which multiplex is carrying the mission traffic, what the received signal level is, and the number of reframe attempts by the multiplex, as examples.

The general functional relationship of the master terminal is given in Figure 2-24. The present master consists of a minicomputer system with the peripherals shown. The responsibility of the master is to collect status and parameter information from all remotes within its control, to assemble these responses into usable displays for the system manager using English text, and to maintain a near-term history of system status and performance. The general functional capability of the remote unit is shown in Figure 2-25. The general objective of the remote unit is to sense electrical parameter changes that indicate the operating parameters of a digital microwave system at a location, formulate those changes into a response, and transmit this change information to the master upon request. The master-remote relationship is shown in Figure 2-26. A segment may consist of more than one master--one with polling, switch, and monitor responsibility, the others with monitor responsibility. A segment may consist of up to 24 remote terminals.

During FY 1983, a version of the TRAMCON master that allowed field configuration of site and DEB segment specific information was developed and installed at Donnersberg and Reese-Augsburg, Federal Republic of Germany,

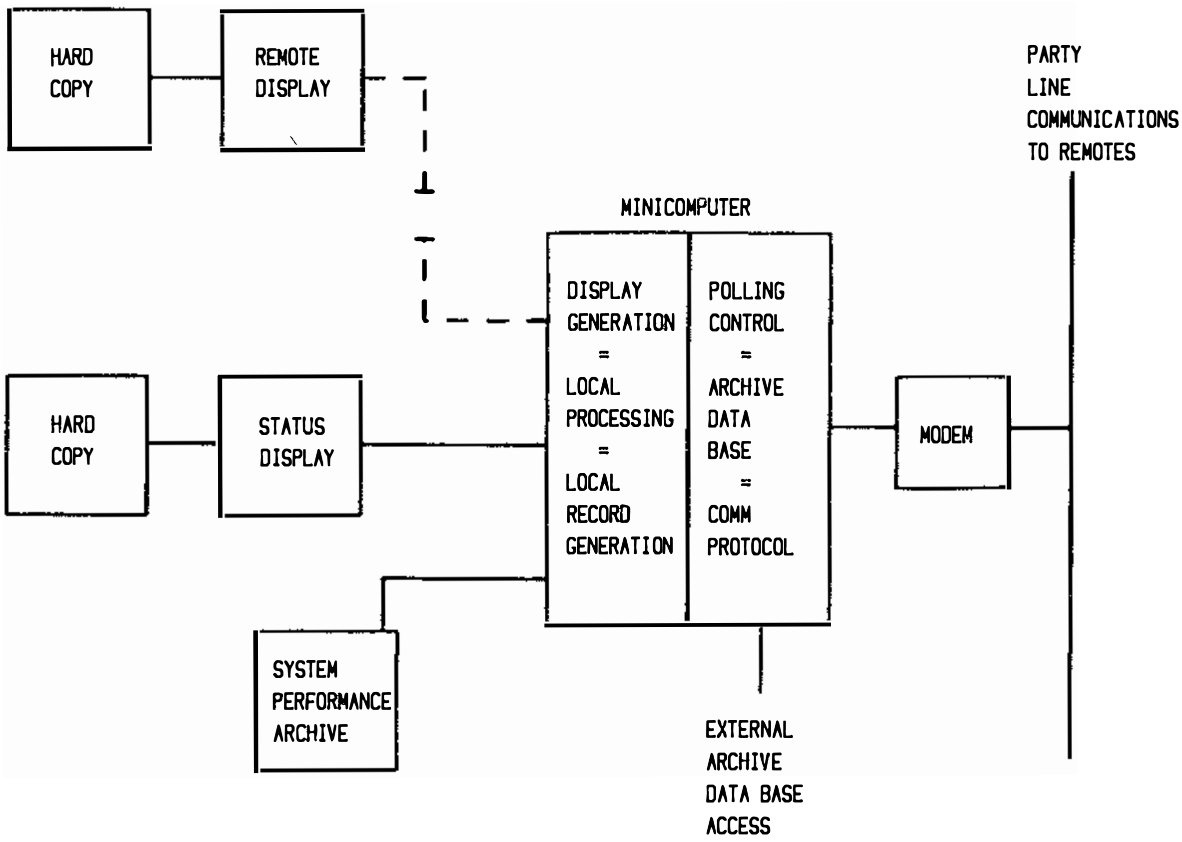


Figure 2-24. The general functional relationship of the master terminal.

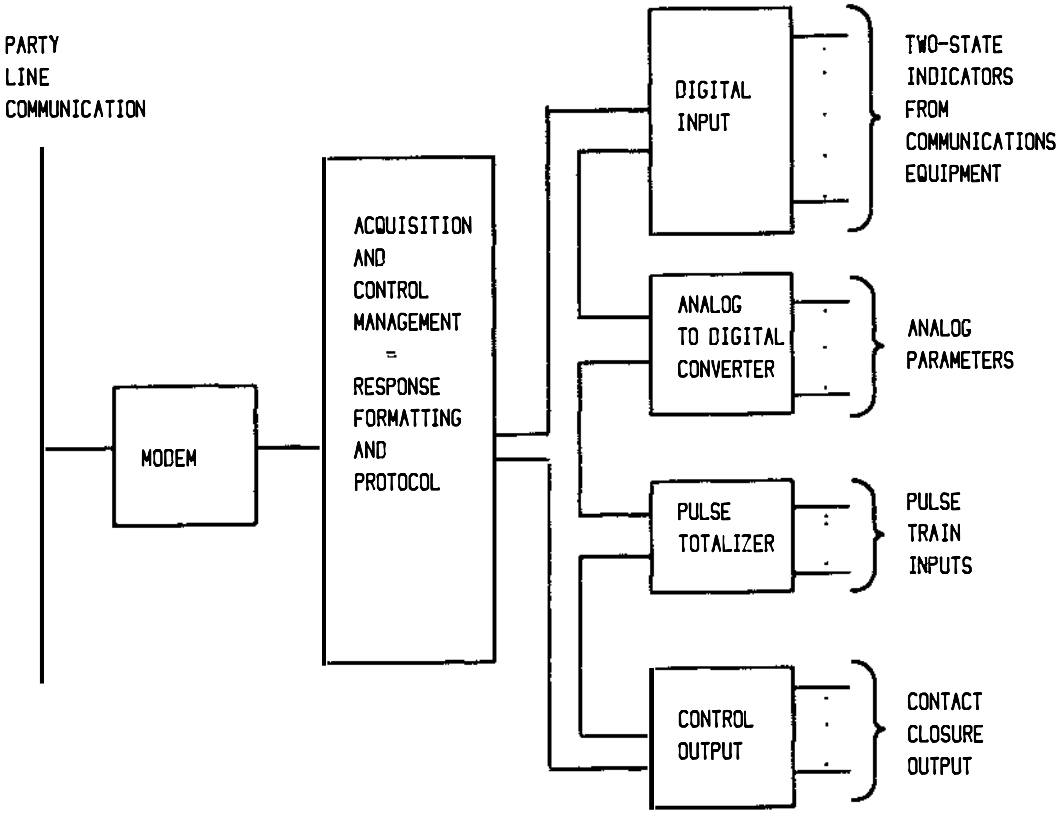


Figure 2-25. The general functional capability of the remote unit.

communication facilities in support of the DEB-IIA segment. This involved the procurement and integration of a new-generation computer system and peripherals, the development of software that would not only be compatible with the new processing system but would also support the functions established in the original system, and software that added significant, new capabilities. Initial familiarization and training on the operation of the early version of this system was provided to Air Force and Army personnel who have been assigned various test and evaluation efforts.

Requirements Analysis for the European Defense Communications System. The Institute conducted a study of survivability, interoperability, reconstitution, and network performance issues in the European Defense Communications System (DCS). The objective of this study, which was sponsored by the U.S. Army Communications Systems Agency, was to identify new hardware and software R&D initiatives that would lead to the enhanced performance of the European DCS. An improved European DCS is required for the following reasons:

- the need to make critical telecommunication services survivable in a hostile environment (nuclear or conventional war, sabotage, or electronic warfare)
- the need for increased interoperability of the DCS with other networks
- the need for better communications grade of service for administrative, logistics, and command and control traffic
- the need to provide enhanced telecommunication services to meet new class-of-service requirements such as increased use of facsimile, increased data transmission, and possibly video teleconferencing
- the need for new or enhanced features, some of which are unique to military telecommunication systems.

Figure 2-27 depicts several approaches for addressing the survivability issue. One starts with a robust network design, adds site hardening as appropriate, provides for post-attack service restoration through the use of reconstitution packages, and develops an ability to interoperate with other networks for the purpose of alternate routing. Each of these approaches is a necessary ingredient for achieving the goal of communication services survivability for the critical user.

Interoperability between the DCS and other networks has the additional purpose of extending network geographic coverage. Tactical assets could be employed to extend DCS services into areas not normally covered by the DCS. Conversely, DCS assets could be utilized to interconnect two geographically separated tactical operational areas if the DCS and tactical assets are interoperable.

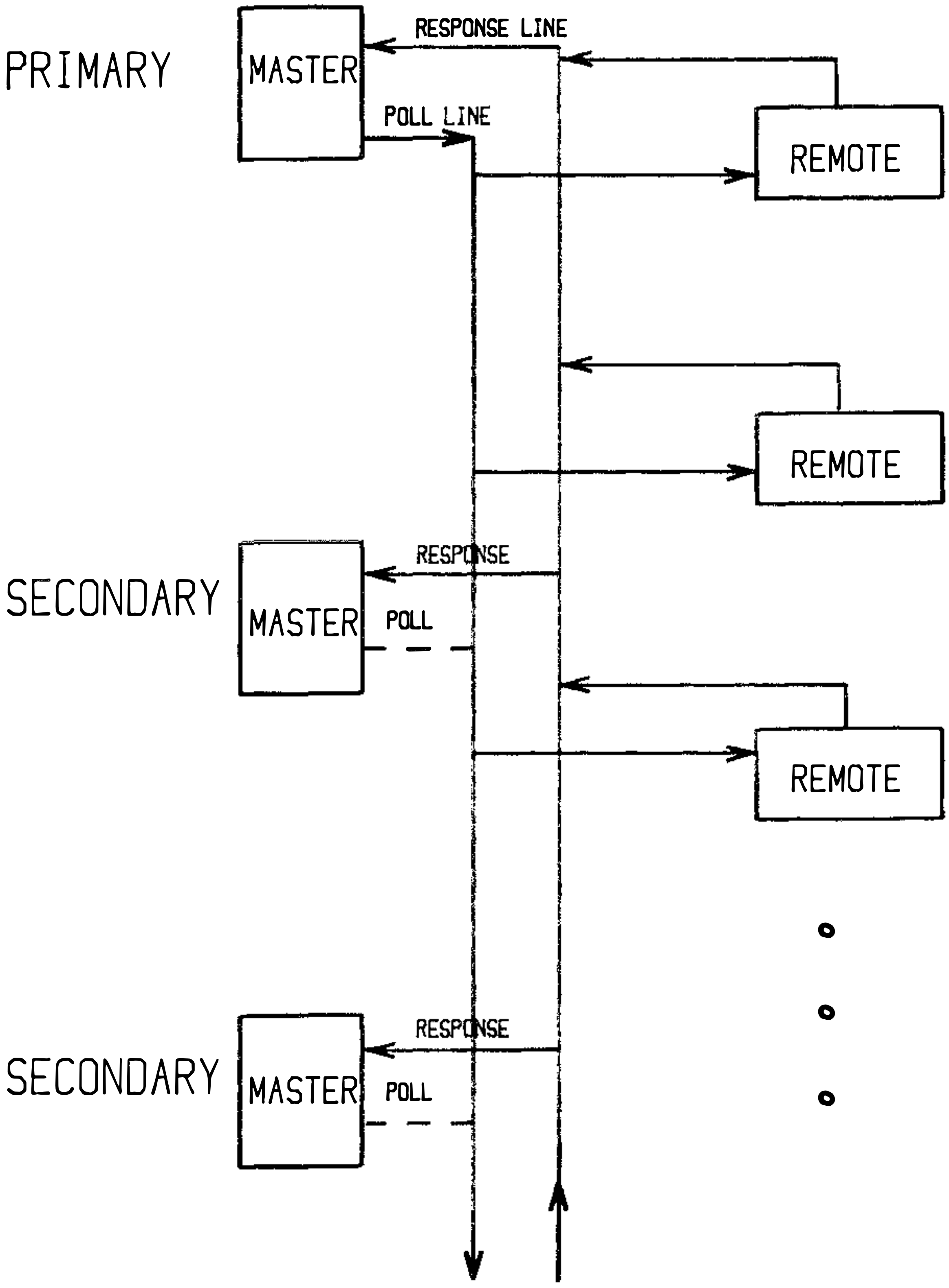


Figure 2-26. The master-remote relationship.

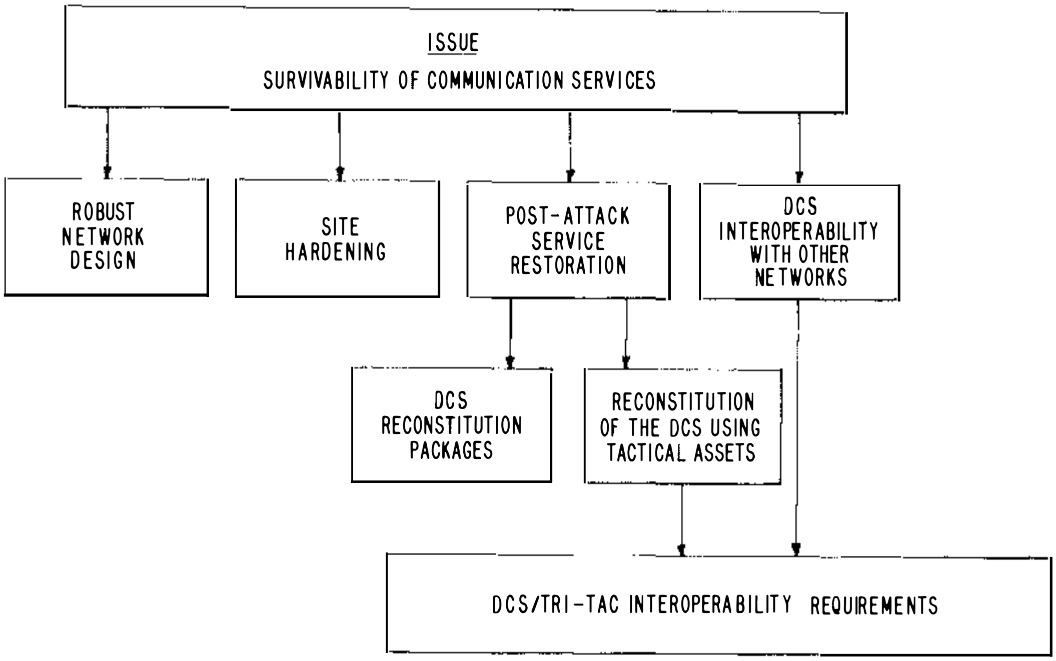


Figure 2-27. DCS/TRI-TAC interoperability as it relates to communications services survivability.

The study conducted for CSA resulted in recommendations for a number of new R&D programs for new hardware development, additional propagation measurement programs, or for additional studies that should be performed.

Recommendations for the interoperability issue include both hardware development and additional study research. These recommendations correspond to two types of interoperability, namely the pipeline level of interoperability and the end-to-end interoperability. Pipeline level interoperability consists of interoperability of transmission systems while end-to-end interoperability consists of interoperability of all aspects of a telecommunications system including network management and control facilities, signaling facilities, numbering plans, etc. For the digital pipeline interoperability, the development of a new multiplexer is recommended. This multiplexer would be compatible with a variety of tactical and strategic transmission rates. For end-to-end interoperability, additional study of network interoperability requirements is recommended. This study should include investigation of signaling system and system control (SYSCON) interoperability.

Another issue that was investigated during this study was the performance of line-of-sight (LOS) digital radios in the European DCS. It was concluded that the performance of new radios being procured for use in the DCS could best be evaluated through the use of a line-of-sight channel simulator. Theoretical prediction of digital radio performance is intractable for channels other than the additive white gaussian noise (AWGN) channel. Field testing of LOS digital radios can be time-consuming and expensive. Because of the expense, testing is often limited, which may reduce costs, but which provides an incomplete picture of radio performance. The development of hardware capable of simulating the LOS channel-fading environment is therefore recommended. This would provide the capability for exhaustive testing of digital radio performance in the laboratory.

The radio test configuration is depicted in Figure 2-28. The simulation is performed under the control of a microcomputer that steps the channel simulator through a variety of channel fading conditions. Both fade depths and the relative propagation delay of the refracted signal compared to the direct signal are under the control of the microcomputer. It is expected that this channel simulator will be developed during Fiscal Year 1984.

U.S. Forest Service Telephone System Requirements Analysis. The Institute has performed a number of studies for the U.S. Forest Service. The earlier studies were in support of Forest Service Regions 2 and 4. The studies provided assistance to these Regional Offices in the assessment of regional near-term telecommunications systems requirements and in the development of a planning process that would address long-range telecommunications requirements. This effort has been expanded by the Forest Service Washington Office as will be discussed in the following paragraphs.

The objective of the current project is to provide assistance to Forest Service Regional, Supervisor, and District Offices, stations, and laboratories in assessing telecommunication needs, identifying problem areas, developing cost-effective solutions,

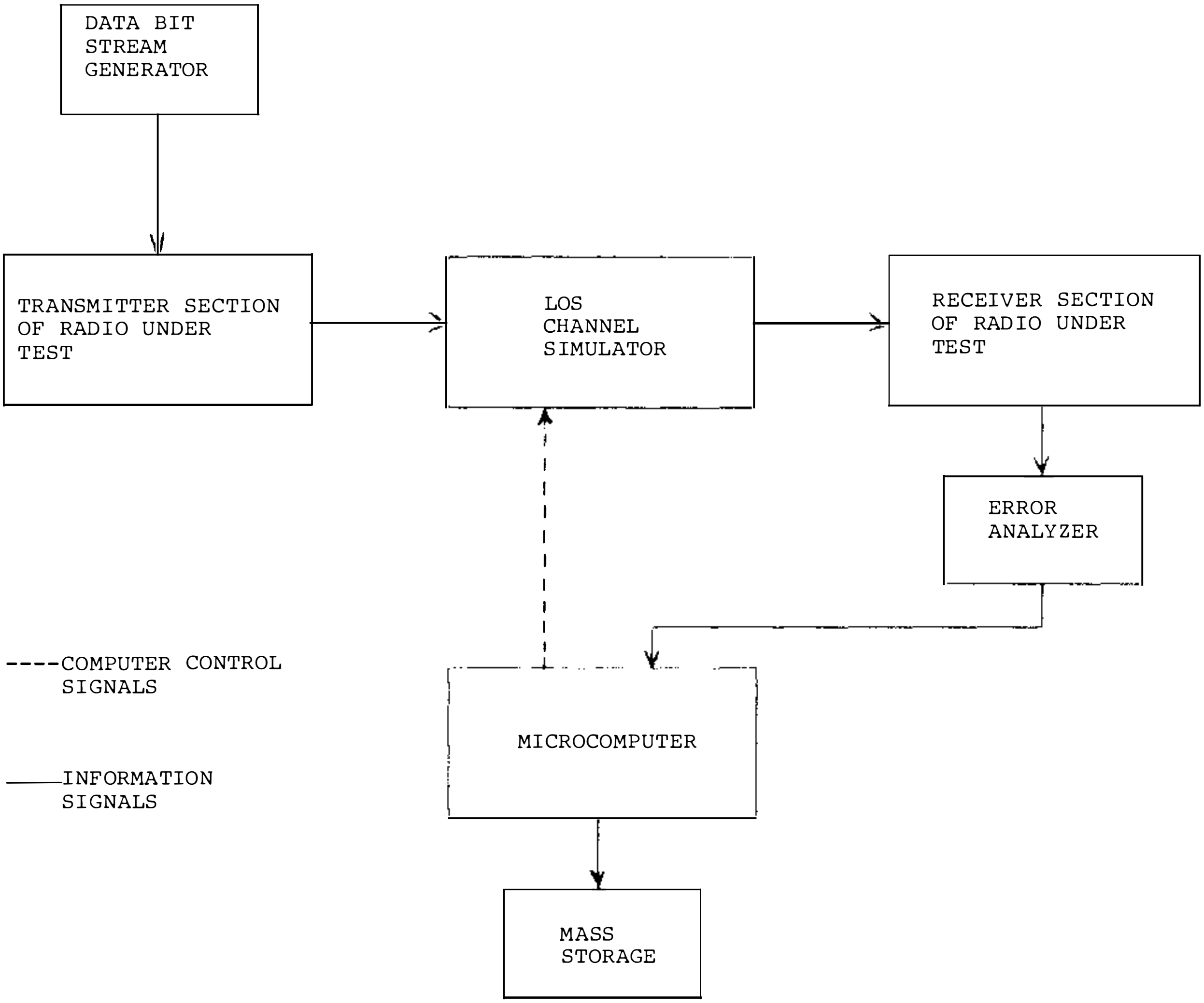


Figure 2-28. Simulator test configuration.

and obtaining General Services Administration (GSA) approval, as necessary, for any new equipment and services required. This study effort takes the telecommunication problem areas identified in earlier studies and develops suggested guidelines for use by Forest Service personnel in addressing these issues. It is envisioned that the reports produced during the course of this study will provide a foundation for a telecommunications handbook to be used by personnel at all levels of the Forest Service who are responsible for voice telecommunications.

The current study being conducted for the Forest Service Washington Office consists of four tasks. The tasks are to:

1. analyze the process for requesting GSA approval for the acquisition of telecommunication equipment or services
2. provide guidance for conducting voice telecommunication needs assessments
3. provide an overview of the types of telecommunication equipment and services available and a short survey of sources of supply
4. develop procedures for performing voice telecommunication traffic analyses.

The problems addressed in this study are not unique to the Forest Service. Most, if not all, Government agencies are facing similar telecommunications problems in this era of deregulation, divestiture, and rapidly changing telecommunications technology. In the past, the telephone system manager had little choice but to go to the local telephone company representative for all of his telephone needs including the end instrument, the Private Branch Exchange (PBX), and both local and long-distance service. Deregulation and divestiture now provide an atmosphere that is conducive to increased competition. This makes it imperative that the telephone system manager shop around for the best buy in both telephone equipment and services. Starting with the Carterphone decision in the late 60's and continuing through deregulation actions by the FCC and the AT&T divestiture ordered by the Federal courts, there have been a long series of events that have spawned new long-distance services and encouraged the development of the telephone interconnect industry.

One problem faced not only by the Forest Service, but other Government agencies and industry as well is that more expertise is now required for the cost-effective management of telephone systems. With the increased availability and sophistication of both equipment and services, trained personnel are needed to identify requirements, develop telephone system specifications, evaluate proposed equipment and services, and install and effectively manage new telephone systems. The objective of the current study is to provide basic reference information that will be available to Forest Service personnel at all levels. The reports are oriented toward personnel who have not necessarily had broad experience and training in telephone systems. This is a necessary first-step in the development of a handbook approach for telephone systems acquisition and management that is designed to have practical utility throughout the Forest Service.

ANNEX I
ITS PROJECTS FOR FISCAL YEAR 1983
ORGANIZED BY DEPARTMENT AND AGENCY

Project	Title	Leader
AGRICULTURE, DEPARTMENT OF		
	U.S. Forest Service	
9104542	Forest Service Communication Requirements Analysis	Hoffmeyer
COMMERCE, DEPARTMENT OF		
	National Oceanic & Atmospheric Administration	
9104510	NOAA Weather Radio Update	Adams
9104532	National Weather Service Field Strength Calibrations	Smilley
9104539	OMEGA Solar Proton Event Data	Steele
	National Telecommunications and Information Administration (NTIA)	
9071102	Minority Technical Planning Services	O'Day
9101121	Spectrum Advocacy	O'Day
9101123	Spectrum Trade-Off Research	Berry
9102100	Common Carrier Technical	Linfield
9102101	Information Technology Policy	Salaman
9102102	Network Terminations/DDS	Linfield
9104120	Data Communications	Seitz
9104123	International Standards	Seitz
9104124	Military Critical Technology List Review	McManamon
9104140	83 RARC Preparation Support	Jennings
9104142	85/87 Space WARC Support	Jennings
9107100	Technical Subcommittee Support	Berry
9107120	Spectrum Engineering Development	Berry
9107122	RSMS Operations	Matheson
9107123	RSMS Development	Matheson
9107124	Spectrum Resource Assessments	Grant
9107125	RSMS Upgrade	Matheson
9107126	HF Broadcasting-WARC	Washburn
9107127	Geostationary Satellite Orbit Analysis Program	Jennings
9108101	MF Propagation Models & Data Acquisition	Washburn
9108102	VHF/UHF Propagation Studies	Haakinson
9108108	Millimeter-Wave Modeling & Experimental Data Acquisition	Rush
DEFENSE, DEPARTMENT OF (DoD)		
9101518	DoD Consulting	Spaulding
9104372	Ionospheric Mapping	Rush
9104462	Ground-Air Propagation	Stewart
9104486	HF/VHF Propagation Studies	Teters
9104504	Pulse Distortion Studies	Vogler
9104508	TAEMS Consulting	Marler
9104519	Boundary Studies	Thompson
	Air Force Systems Command (ESD)	
9104465	Troposcatter Bench Mark Tests	Pratt
9104468	Advanced DEB IV EFAS	Skerjanec
9104481	Digital Diversity Combiner	Skerjanec
9104492	System Monitoring Automated Remote Terminals	Farrow
9104499	Heath Tropospheric Tests	McLean
9104538	TRAMCON Manual & Training	Skerjanec
9104540	Tropospheric Bench Mark Tests	Hubbard
	Air Force Miscellaneous	
9104431	AN/MSR-(T4) Receiver System	Barghausen
9104524	Mobile Test & Exercise System--Radar Upgrade	Layton
9104525	RSMS Measurements/Holloman AFB	Matheson

Project	Title	Leader
	Army Communication Command (USA/CC)	
9104432	HF Antenna Simulation	Rush
9104474	Automated Predictions for Mixed Mode Links	Hause
9104495	Near Vertical Incident Skywave Antenna Analysis	Stewart
9104496	Army HF Propagation Study	Teters
9104503	Rain Rate Model	Dutton
9104518	DRAMA Radio Tests	Hubbard
9104520	Interconnect Facilities Technical Design Study	Pietrasiewicz
9104523	Army Millimeter-Wave Plan	Liebe
9104533	Army HF Propagation Study	Teters
9104534	Meteor-Scatter Propagation Studies	Smith
9104535	MDR-8 Performance Analysis	Hubbard
9104541	Automated Passive Repeater Link Engineering	Hause
9104544	Air-to-Ground & Intermediate and Short Distances - Books	Teters
	Army Communications-Electronics Command (CENCOMS)	
9104423	Millimeter Wave Vegetation	Violette
9104467	Network Communication Model	Adams
9104514	Wideband Consultation	Adams
	Army Communications Systems Agency (CSA	
9104475	European DCS Requirements Analysis	Hoffmeyer
9104478	Extended Range Communications Study	Adams
9104497	Defense Switched Network Access.Area Program	Linfield
9104511	DoD Noise Model	Spaulding
9104530	Angle Diversity Measurements	Hubbard
	Army Research Office (ARO)	
9104405	Millimeter Wave Attenuation	Liebe
	Defense Communications Agency (DCA)	
9104498	DTE/DCE Standards	Hull
9104517	National Communications System Interoperability Study	Hull
9104536	Data Encryption Standard--Related Standards	Pomper
	Defense Nuclear Agency (DNA)	
9104526	HF Ground Wave Measurements, Part II	Adams
	Navy Miscellaneous	
9104509	Naval Security Group Detection	Spaulding
9104512	OTCIXS/TADIXS Study	Nesenbergs
9104529	EP-3 Sensor Update	Thompson
INTERNATIONAL COMMUNICATION AGENCY (ICA)		
9104473	HF Propagation Studies/Voice of America	Washburn
STATE, DEPARTMENT OF		
9104411	AID Assistance	Jennings
TRANSPORTATION, DEPARTMENT OF (DoT)		
	Federal Aviation Administration (FAA)	
9104515	Air Navigation Aids	Johnson
	U.S. Coast Guard (USCG)	
9101532	Consulting USCG	Adams
OTHER		
9102586	IONCAP Requests	Teters

ANNEX II
PROJECT INDEX

ANNEX III
ITS PUBLICATIONS - FISCAL YEAR 1983

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AVAILABILITY OF PUBLICATIONS

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ANNEX IV

GENERAL AND HISTORICAL INFORMATION OF ITS

The Institute for Telecommunication Sciences (ITS), largest component of the National Telecommunications and Information Administration, is located at the Boulder Laboratories of the Department of Commerce and has (as of Sept. 30, 1983) a full-time permanent staff of 85 and other staff of 19. In FY 1982, its support consisted of $3.7 million of direct funding from Commerce and $4.9 million in work sponsored by other Federal agencies.

The Boulder Laboratories include research and engineering components of the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the National Telecommunications and Information Administration. Common administrative services are the rule in the Boulder Laboratories. The Radio Building, which houses ITS, is on the U.S. Department of Commerce campus at 325 Broadway.

The following brief history shows the Institute's beginnings. The Radio Section of the National Bureau of Standards was founded prior to World War I and played a major role in the evolution of our understanding of radio propagation. Dr. J. H. Dellinger, its director for most of the period up until World War II, was strongly convinced of the importance of research and gave it practical application as first chairman of the Study Group on Ionosphere Propagation in the CCIR.

During World War II, the Interservice Radio Propagation Laboratory (IRPL) was organized at the National Bureau of Standards, under the direction of Dr. Dellinger. His group provided a common focus for military needs in propagation during the war. In 1946, the Central Radio Propagation Laboratory (CRPL) was established, and in its early years had direct ties with the Defense Department; for example, senior officials of DoD would appear before Congress to defend the CRPL budget. In 1949, Congressional concern for the vulnerability of Government laboratories located in Washington, DC, and the crowding of the NBS Connecticut Avenue campus made it advisable for the radio research work to be taken elsewhere.

Three sites, one in California, one in Colorado, and one in Illinois, were considered, and Boulder, Colorado, was selected. The first group from CRPL, which at that time included radio standards work, moved to Colorado in 1951, and the move was completed in 1954, during which year President Eisenhower dedicated the NBS Radio Building. The Radio Standards program left CRPL at the time of the move to Boulder, and has pursued a parallel existence at Boulder in NBS since that time.

In 1954, CRPL consisted of two research divisions: Radio Propagation Physics and Radio Propagation Engineering. The Radio Systems Division was formed in 1959. In 1960, the Upper Atmosphere and Space Physics Division and the Ionosphere Research and Propagation Division were formed from the Radio Propagation Physics Division. In 1962, CRPL received a full-time director, Dr. C. Gordon Little. In 1965, Dr. H. Herbert Holloman, first Assistant Secretary for Science and Technology in Commerce, implemented a decision to unify geophysics in Commerce with the creation of the Environmental Science Services Administration (ESSA), made up of the Weather Bureau, the Coast and Geodetic Survey, and the Central Radio Propagation Laboratory. At that time, the CRPL was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the Institute for Telecommunication Sciences came into being. It contained the telecommunications-oriented activities of ITSA. Dr. E. K. Smith served as an interim director for one year and was followed by R. C. Kirby who was director for the ensuing three years.

Meanwhile, in Washington, major attention was being given to the organization of telecommunications in the Federal establishment, and the Department of Commerce established an Office of Telecommunications in 1967. Reorganization Plan No. 1 of 1970 and Executive Order 11556 established the Office of Telecommunications Policy (OTP) in the Executive Office of the President, and assigned additional responsibilities to the Secretary of Commerce in support of OTP. To meet these responsibilities, the Office of Telecommunications (OT) was given expanded responsibilities on September 20, 1970, and ITS, along with its programs, property, personnel, and fiscal resources, was transferred to OT.

In 1971, Douglass D. Crombie became director of ITS. ITS has shifted from its strong emphasis on radio wave propagation and antennas since 1970 in the direction of applications in spectrum management and in telecommunication systems.

In March 1978, President Carter signed Executive Order 12046 which established the National Telecommunications and Information Administration and merged some of the functions of the Office of Telecommunications Policy with those of the Office of Telecommunications in the new agency. ITS was assigned the responsibility of managing the telecommunications technology research programs of NTIA and providing research support to other elements of NTIA as well as other agencies on a reimbursable basis. Among other assigned tasks, the Institute was to remain "...the central Federal Government laboratories for research on transmission of radio waves."

In January 1981, Dr. William F. Utlaut assumed responsibility for the direction of the Institute. A major reevaluation of programmatic and organization structure was carried out under his direction to redefine and aline the efforts of ITS to meet changing requirements and responsibilities.

The Institute and its predecessor organizations have always played a strong role in pertinent scientific (URSI), professional (IEEE), national (IRAC), and international (CCIR, CCITT) telecommunications activities. The director of CCIR from 1966 to 1974 was Jack W. Herbstreit, a former deputy director of CRPL and ITSA, and the current CCIR Director is Richard C. Kirby, formerly director of ITS. At the present time, the U.S. preparatory work for 2 of the 11 Study Groups of CCIR is chaired by members of ITS (U.S. Study Groups 1 and 6), and staff members of ITS lead U.S. delegations to 3 CCITT Study Groups (VII, XVII, and XVIII) and actively participate in the International Organization for Standardization (ISO). The Institute also actively supports the Interdepartment Radio Advisory Committee (IRAC).

The work ITS does for other agencies in the Government derives its legal authorities from 15 U.S.C. 272(3) "Advisory Services to Government Agencies on Scientific and Technical Problems" and 15 U.S.C. 272(f) "Invention and Development of Devices to Serve Special Needs of Government." As a matter of Federal policy, NTIA does not accept work more appropriately done by other nongovernment or government organizations. It is also a matter of policy that all sponsored work reinforce NTIA's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

Within these policy guides, ITS aspires to being <u>the</u> Federal laboratory for research in telecommunications. It is clear that the Government has a responsibility to pursue long-range studies in telecommunications that are not economically profitable for industry. It is also clear that the Government must have its own, independent laboratories to assess the significance of research conducted elsewhere. Toward these ends, ITS strives to maintain a knowledgeable staff that is working on the frontiers of technology and is in touch with the telecommunications problems of the Federal Government. The Department of Defense has long been the primary source of advanced technology. At the present time, the largest part of the other agency sponsorship of ITS comes from needs of the Department of Defense. The Institute maintains, however, a significant portion of its other agency work in support of civilian Federal agencies, where there is also clear need for Government expertise in high technology areas.

ANNEX V
ORGANIZATIONAL DIRECTORY

INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
325 Broadway, Boulder, Colorado 80303
(303) 497 + Extension (FTS 320 + Extension)

Name	Mail Code	Ext.	Room
DIRECTOR'S OFFICE			
UTLAUT, William F. - Director	ITS.D	3500	3020
GEISSINGER, Marcia L. - Secretary	ITS.D	5216	3020
O'DAY, Val M. - Executive Officer	ITS.D1	3484	3023
WALTERS, William D. - Budget & Support Services	ITS.D2	5414	3019
CAHOON, Lenora J. - Technical Publications	ITS.D3	3572	3020
SALAMAN, Roger K. - Special Technology Liaison	ITS.D6	5397	3015
SPECTRUM DIVISION			
RUSH, Charles M. - Deputy Director	ITS.S	3821	3423
EM Transmission Measurement BARGHAUSEN, Alfred F. - Chief	ITS.S1	3384	3443
Spectrum Use Measurement MATHESON, Robert J. - Chief	ITS.S2	3293	3420A
Propagation Model Development and Application SPAULDING, A. Donald - Chief	ITS.S3	5201	3415
Spectrum Management Analysis and Concept Development ADAMS, Jean E. - Chief	ITS.S4	5301	3461
SYSTEMS AND NETWORKS DIVISION			
O'DAY, Val M. - Acting Deputy Director	ITS.N	3484	3023
Switched Networks Analysis PIETRASIEWICZ, Val J. - Chief	ITS.N1	3723	2238B
Satellite Network Analysis JENNINGS, Raymond D. - Chief	ITS.N2	3233	2235
System Performance Standards and Definition SEITZ, Neal B. - Chief	ITS.N3	3106	2221
System Performance Engineering Analysis HOFFMEYER, James A. - Chief	ITS.N4	3140	2234C

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