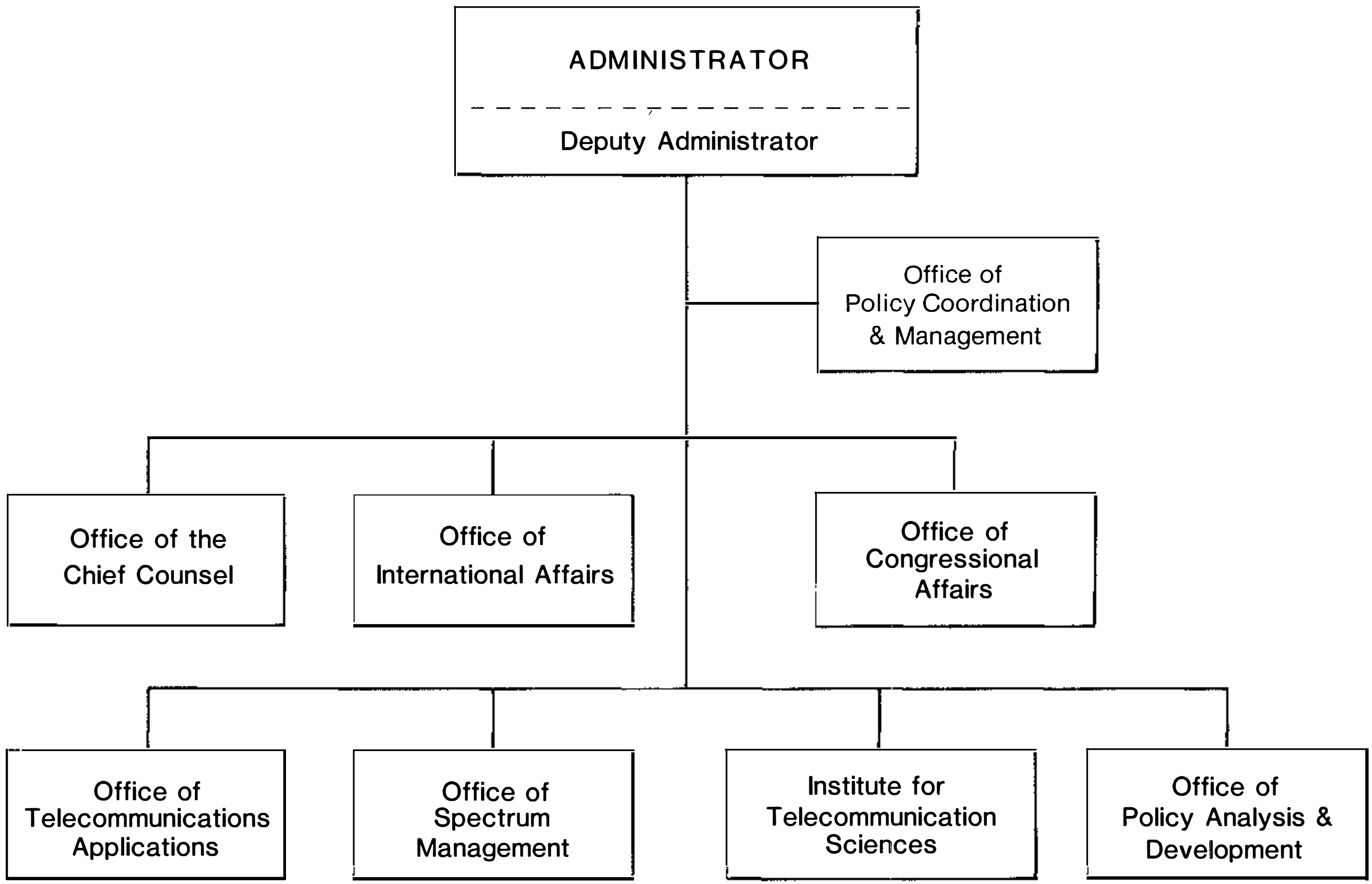
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

ANNUAL TECHNICAL PROGRESS REPORT 1982

For the period from Oct. 1, 1981, through Sept. 30, 1982

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

Bernard J. Wunder, Jr., Assistant Secretary
for Communications and Information

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INTRODUCTION

This annual report reviews the activities and accomplishments of the Institute for Telecommunication Sciences for the fiscal year ending September 30, 1982. It is intended to serve as a reporting mechanism to the 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 may be 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 which can lead to more efficient use of the spectrum resource; this is primarily related to the interactions between radio systems and the electromagnetic environment.

Since radio waves are strongly influenced by the environment in which they propagate, the transmission models, depending upon radio frequency, account for the effects of terrain electrical properties, shape, and surface cover; the non-ionized lower atmospheric gases, meterology, and spatial structure; and the highly variable time and spatial properties of the ionized region of the upper atmosphere. These models then provide statistical estimates of signal attenuation, dispersion, multipath, and other factors which determine the rate of information transmission and quality of performance systems provide. With additional information obtained from measurement and evaluation of the spectrum-consuming properties of antennas, receivers, and transmitters and from measurement of spectrum occupancy, development of spectrum planning techniques and ways of more intensively sharing the spectrum have resulted from work in this program. These efforts 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 done.

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 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 which 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 which 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 trade-offs 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 <u>Tradeoffs for Efficient Use of the Spectrum project</u>. There are two useful forms of output: a user-oriented, interactive computer program for making spectrum-conserving frequency assignments and general principles of efficient frequency assignment that can guide the development of frequency-distance separation rules for a service.

Before a practical frequency-assignment program could be developed, the idealized model of a radio service used in the initial research had to be enhanced to better represent actual conditions, and procedures for handling the more complicated model had to be developed. Six enhancements were developed and installed this year.

1. The maximum number of transmitters that can be handled during a run was increased. Software changes doubled the maximum number from 200 to 400. Additional memory was purchased for the mini-computer that will double the latter figure.

2. The program was modified so that existing or priority assignments can be maintained while optimizing the spectrum use of other applicants.

3. The research program finds the minimum bandwidth required to license all applicants, assuming that enough spectrum was available. Actually, all service bands are limited to the allocated bandwidth. The ability to recognize and operate within such a limitation was installed in the program.

4. A graph-theoretic technique called "bichromatic interchange" was installed. (The name comes from graph-coloring mathematics, which is the basis of the frequency-assignment program.) When a new applicant requires assignment of a previously-unused channel, this technique examines the possibility of interchanging channel assignments among those stations blocking the new applicant so that all can provide service in the presently-occupied bandwidth. This technique has the greatest promise for optimizing sequential frequency assignments when the applications arrive one, or a few, at a time and assignments must be made without knowing where future applicants will be.

5. There are two or more kinds of service authorized in many bands. The equipment and procedures in the services may differ significantly. The ability to handle up to five different (or different classes) of service with intra- and interservice frequency-distance separation rules was developed.

6. The most significant development was the ability to make assignments guided by a "constraint matrix," rather than by frequency-distance separation rules. The element c(i,j) of the constraint

matrix contains any assignment constraints between station i and station j that must be observed when assigning frequencies. The constraints may result from calculations of signal-to-interference ratio, from assigned priorities, or from other causes. All that is necessary is that they be stated. The constraint matrix provides the efficient frequency assignment algorithm with an interface to a broad range of problems that are not amenable to frequency-distance separation rules, for example, HF broadcasting frequency assignments.

Last year a general curve for the spectrum cost of first-adjacent-channel distance separation rules was developed and is now included in the Documents of the CCIR (Report 729). This year the spectrum cost of a second-adjacent-channel separation distance was studied. Figure 1-1 shows the results. All distances in the study are normalized to the co-channel separation distance so that the curves can be applied to any service. The horizontal axis in Figure 1-1 is the required distance separation for second-adjacent-channel stations divided by the co-channel separation distance. The vertical axis is the percentage increase in total bandwidth required to satisfy all applicants as a result of the second-adjacent-channel distance separation rule. The different curves are for different first-adjacent-channel distance separations.

For first-adjacent-channel distances that are small relative to the cochannel separation distance, a second-adjacent-channel rule requires very little additional spectrum until the second-adjacent-channel distance is greater than one-third of the cochannel separation distance. The knee in the curve depends on the first-adjacent-channel separation distance. Beyond the knee, the spectrum cost of a second-adjacent-channel rule rises sharply as the separation distance increases.

The behavior is different if the first-adjacent-channel distance separation is large. In this case, the spectrum cost of a second-adjacent-channel rule increases almost linearly with the required separation distance.

The difference in behavior caused by the difference in the first-adjacent-channel separation distance is counter to the intuition of many experienced engineers. This discovery of counter-intuitive principles shows the value of the study.

We also studied the question of whether it is more efficient to frequency-segregate services or to mix them. In a mixed band, a transmitter can be assigned any frequency in the band that does not violate the frequency-distance separation rules. It is assumed that there are intra- and inter-service frequency distance separation rules. It was proven (Berry and Cronin, Proc. 1982 IEEE EMC Symposium) that a mixed service never takes more total bandwidth than contiguous segregated services if the same frequency distance separation rules are applied to the two arrangements. Furthermore, if there are only cochannel distance separations required, the mixed service never requires more bandwidth than the segregated services, even if the bands are not contiguous. If there are other than cochannel distance separation rules, and the bands are located further apart than the largest frequency separation with a required distance separation, and if possible interference to other services is ignored, the frequency segregated services may take less bandwidth. However, it is likely that the same characteristics that required non-cochannel separation distances in the mixed service will require inter-service separation distances with the (unconsidered) services in adjacent bands that will eliminate the advantage.

The analytical results showed only that mixing services does not require additional bandwidth. Computer simulation studies indicate that in some cases it requires less. For the computer simulation, we assumed that stations were located randomly in a square. Cochannel stations in service A had to be separated by at least dA km; cochannel stations in service B had to be separated by at least dB km. Two stations, one from each service, could share a channel only if they were separated by (dA+dB)/2 km. The channel width was the same for both services. Figure 1-2 shows the average number of channels required to assign 200 stations randomly located in a square with side 2A, as a function of the ratio dB/dA. Each set of stations was assigned twice--once in a mixed service, and once in a frequency segregated service. The mixed service took less total bandwidth in every case.

This is not true for all possible mixtures of services. If services are both resistent to interference from similar transmitters, but susceptible to interference from some kind of transmitters (satellite earth stations and radar, for example) there is apparently no advantage to mixing. For a case where the inter-service cochannel frequency separation is 10 times the intra-service cochannel separation, the total required bandwidth was the same for mixed and segregated services.

Related to the above effort, a number of special analysis capabilities were developed and applied to assist the NTIA Public Telecommunications Facilities Program (PTFP). Results of this work produced maps showing regions of radio and television coverage in the United States as in Figure 1-3. Estimates of population covered were also prepared for each map. The methodology used to prepare these maps is described in a paper entitled "Television Coverage in the Coterminous United States: Methodology and Results," to be published in a special issue of the IEEE proceedings.

A further illustration of the spectrum engineering techniques work undertaken by ITS is the Expanded FM Capacity project. The current FM broadcast rules do not allow second- and third-adjacent-channel transmitters to be any closer to existing transmitters than the distance to the existing transmitter's protected contour (i.e., 15 miles for Class A, 40 miles for Class B, and 65 miles for Class C transmitters). However, if the FCC maintains its requirement to provide an audio

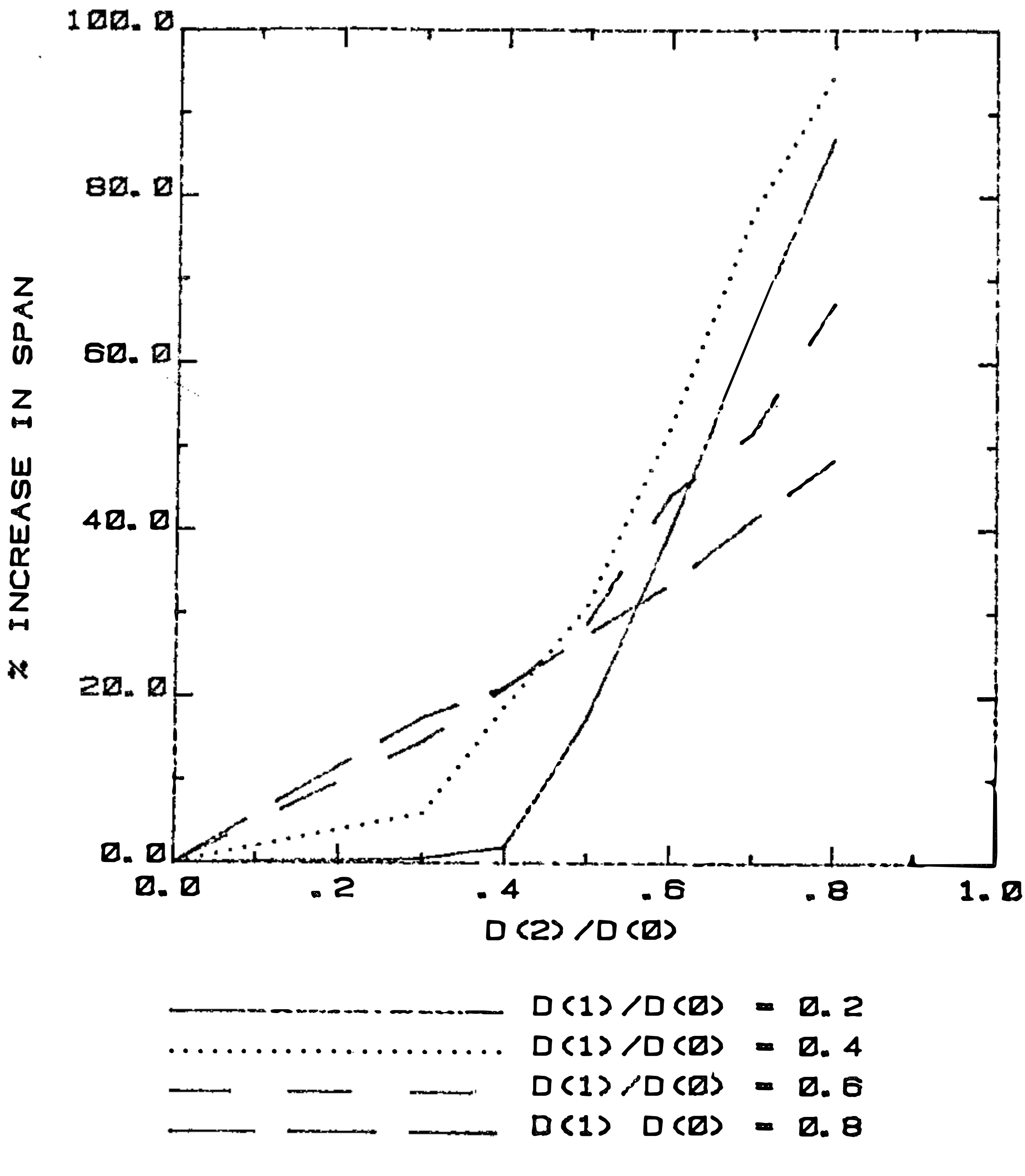


Figure 1-1. Percentage increase in total bandwidth required to provide all applicants with channels for the case described in the test, as a function of the second-adjacent channel separation distance. D(0) is the required separation distance for cochannel stations; D(1) is the required separation distance for stations on adjacent channels; and D(2) is the required separation distance for stations two channels apart.

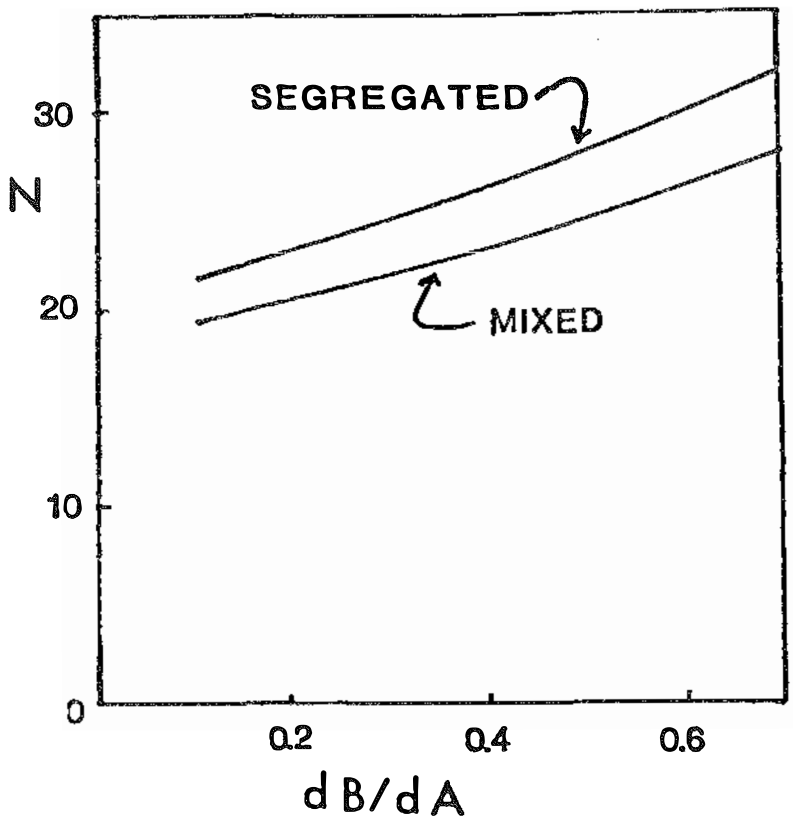


Figure 1-2. Number of channels required to satisfy 200 stations randomly located in a square in a frequency-segregated service and in a mixed mode.

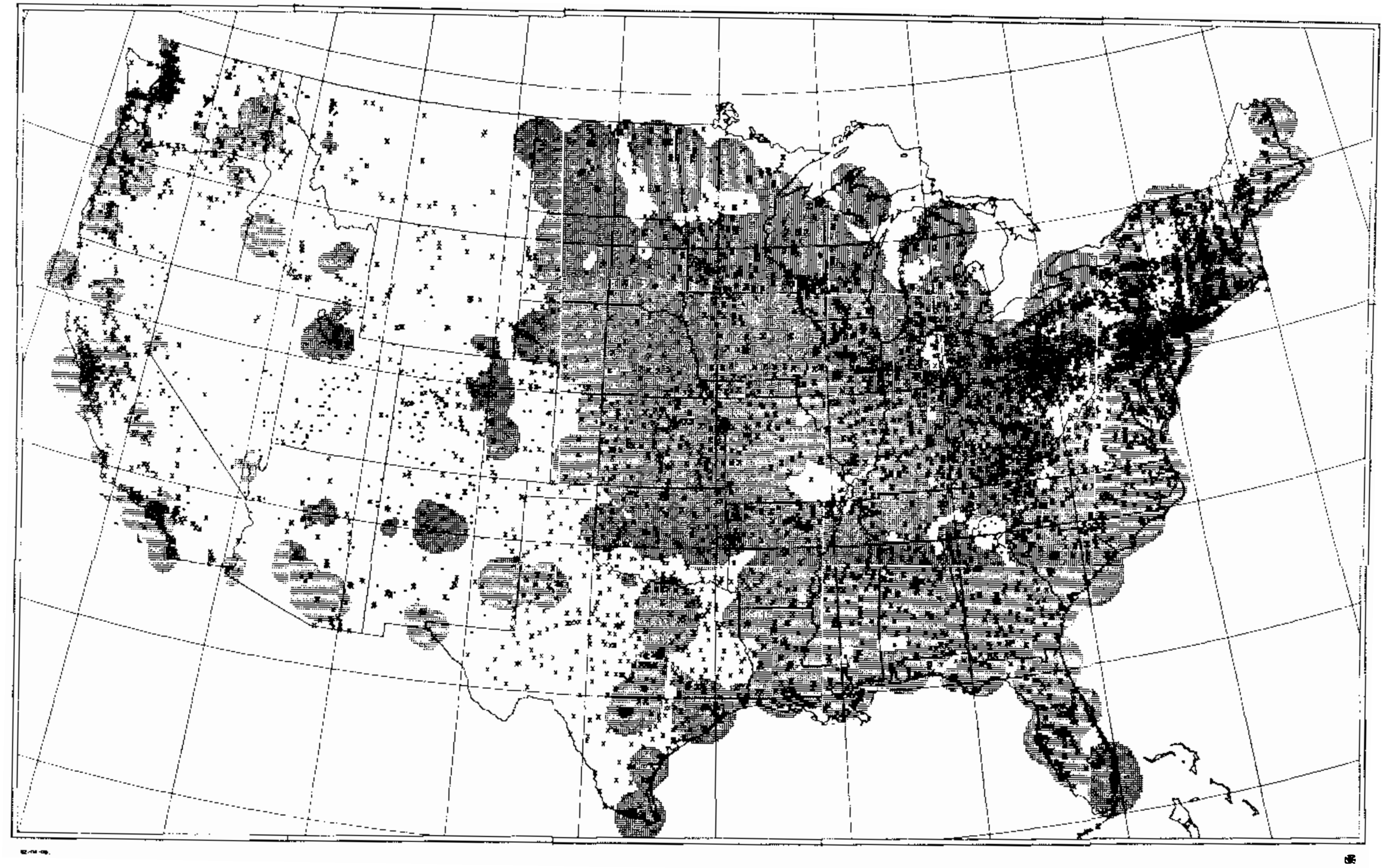


Figure 1-3. Public television and radio coverage in the United States.

signal-to-interference ratio of 30 dB and its policy to develop rules based on good quality receivers, there may be reasons to reduce the second- and third-adjacent-channel minimum mileage separation requirements, based on the performance of today's median FM broadcast receiver. The Expanded FM Spectrum Capacity project provided for the review of existing measurements of FM receiver properties and the laboratory measurement of additional receivers to establish the basis for these conclusions. In FY82, work on this project consisted of additional analyses of data obtained from measurements of the performance of a number of FM receivers in the presence of interference from other FM signals. Also, data were obtained from other laboratories and included in the analyses. The data and analyses were presented in a report that is being prepared for publication. The Spectrum Engineering Development Support project provides analysis support to the Spectrum Engineering and Analysis Division (SEAD) of NTIA.

In many congested spectrum-use environments, there is significant variability in almost every factor influencing communications success. Transmitters may be mobile or their locations may be unknown, either because data are not available or because the systems have not yet been deployed. Antenna heights may depend on availability of favorable locations or on desired coverage of individual systems. Transmitter powers may vary by specification or because of aging and different maintenance procedures. Transmission loss varies with details of the transmission path and often with time because of weather or other geophysical events. Message traffic or channel usage may vary with the requirements of the users. Therefore, any realistic estimate of communications success must be probabilistic. It should be based on consideration of the statistical distribution of all significant factors.

The work this year has been focused on improved knowledge of the practicality of optimum frequency assignment methods. Several of the capability enhancements described in the progress report for the Tradeoffs for Efficient Use of the Spectrum project were developed at the suggestion of SEAD engineers. To test the methods, SEAD retrieved current assignments in the 410-420 MHz band from the Government Master File. The assignments were for two busy areas: Houston, TX, and the Tennessee Valley, and two rural areas--Grand Canyon, AZ, and Yellowstone, WY. The band is shared by wideband fixed service, narrowband fixed service, and land mobile radio. SEAD also devised plausible frequency-distance separation rules to prevent intra- and inter-service interference. The frequency assignment program was used to assign frequencies to see how much bandwidth was necessary to provide the service.

The band chosen turned out to be sparsely-populated, so that the present level of service could be provided in less than one-fifth of the allocated bandwidth. However, assignments are now spread throughout the entire band because users choose their frequency rather than having it chosen by the assigning authority.

It also turned out that the transmitters in the test areas were mostly within one cochannel separation distance of each other. Thus, there is little opportunity for frequency sharing--nearly every transmitter in the area required its own channel. As a result, the frequency-assignment program did only a little better than any person with a list of locations and a list of available channels could do. The optimum frequency assignment program is useful when there are many more users than channels and they are distributed over an area with a radius at least twice the cochannel separation distance.

The reliability of direct radio links (probability of successful communications on the link) can be computed using models developed by ITS and others. Advanced technology (for example, packet radio) allows efficient networking of land mobile radio (LMR) systems that previously operated primarily on direct links. Communication system planners now want to know the probability of communications between two specified stations when any or all of the other stations in a net can be used as relay. In the Limited Network Communications Probability project, methods for computing that reliability for large networks are being developed.

Mathematicians know how to compute the probability. The problem is that a large network requires so many calculations that a parametric design study is impractical even on large computers if the calculation is done exactly. For example, the number of possible paths is approximately $e(N-2)!$, where $e = 2.72\ldots$, and N is the number of stations in a net. For a relatively small net containing 10 stations, there are more than 100,000 paths to examine, and a 50-station net would have more than 1064 possible paths. The goal of this project is to discover approximate statistical methods for extimating the probability of communications in large networks when any or all of the other stations in the network can be used as relays.

A state-of-the-art computer algorithm for small networks has been acquired and installed on our computer. It is used to test the accuracy of approximate statistical methods. We assume that a statistical method that is accurate for small-to-medium sized nets will be even better for large nets, because the accuracy of statistical methods usually increases with the sample size.

A modular, interactive computer program has been developed to do the calculations. The reliability of individual direct links is computed using the area-prediction model described by Hufford, Longley, and Kissick (NTIA Report 82-100). Figures 1-4 and 1-5 show some of the program's output for a small network. The radio frequency of the stations is 225 MHz; they are deployed in hilly terrain. Figure 1-4 shows the locations of the stations, and the reliability of the direct links. The coding of the lines was chosen to represent the condition of the links: the lower the

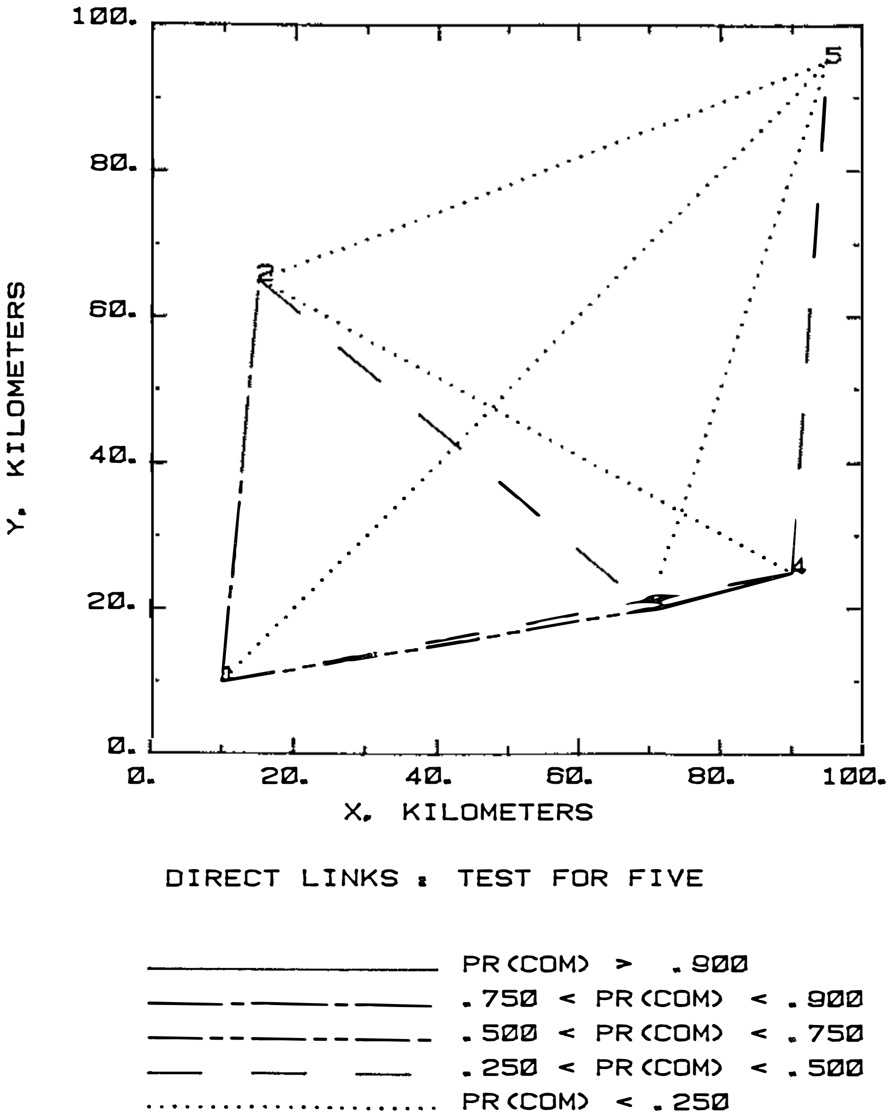


Figure 1-4. Direct link reliabilities for an example five-station network. PR(COM) is the reliability.

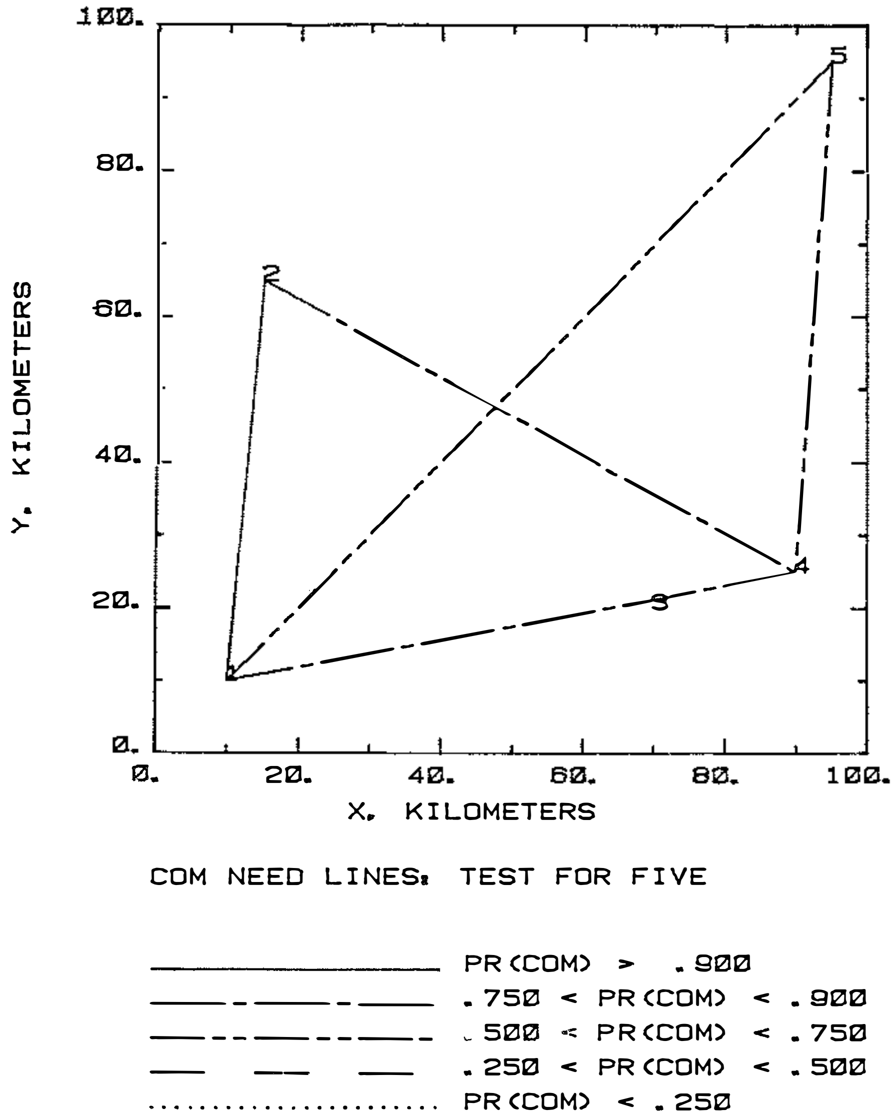


Figure 1-5. Probabilities of communicating between two stations, using all other stations as relays. Same conditions as in Figure 1-4.

probability of communications, the more broken is the line. The calculations were made assuming that the direct link probabilities are independent of each other. Table 1-1 shows the link reliabilities to 3 significant digits. The reliabilities for most of the direct links are small; the example was chosen for illustration.

Figure 1-5 shows the probability of communicating between two specific stations when all others are available as relays. The probabilities are of course higher than in Figure 1-4. For example, the reliability of the direct link from station 1 to station 5 is 0.154 (see Table 1-1), but when relays are used the probability of communication is 0.566--over three times as great. The increased probability of communications results from having the paths 1-2-5, 1-3-5, and 1-3-4-5 as alternate routes.

Several methods for computing approximate reliabilities in large networks have been tested. The best of these combines exact and statistical methods. The reliability resulting from the direct link, the two-link paths, and possibly the three-link and four-link paths is calculated directly. It is assumed that these paths as a group are independent of higher-order paths, and that the higher order paths are highly dependent on each other because they share many of the same links. Neither assumption is exactly correct, but they are approximately correct, and they are wrong in opposite directions. Thus, the approximate answer based on them is accurate enough for many practical applications.

Table 1-1. Direct Link Reliabilities and Full-Network Reliabilities for an Example Five-Station Network

From Station	To Station	Direct Link Reliability	Full-network Reliability
1	2	0.846	0.905
1	3	0.622	*
1	4	0.379	0.843
1	5	0.154	0.566
2	3	0.295	*
2	4	0.175	0.799
2	5	0.245	*
3	4	0.925	*
3	5	0.186	*
4	5	0.263	0.566

*Not computed.

A link performance analysis tool has been developed as a result of the Ground Network 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 operation of the net is 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 such considerations as large capital investments in equipment or specific frequency management concepts being employed under specific operational scenarios. In response to direction from NTIA/FSSM, 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 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 U.S., 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 items:

(1) Review the characteristics of existing and proposed Government and non-Government Systems within the 1605-2000 kHz band, including those which could be expected to move out of the band in response to the results of the WARC-79 and other national agreements.

(2) Review previous compatibility analysis of systems within this band.

(3) 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.

(4) Review existing technical standards and channeling plans and determine the impact of state-of-the-art technology on band usage.

(5) Identify and outline specific problem areas requiring additional analysis, if any.

(6) 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 early FY83.

In the Spectrum Resource Assessment of the 5650-5925 MHz Frequency Band the 5650-5925 MHz band is being 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 $\pm$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 World Administrative Radio Conference (WARC), the portion of this band from 5850 to 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 to 5925 MHz band on a primary basis in the U.S. Ad Hoc 172 has also proposed U.S. Footnote YY11 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 the INTELSAT type coming into the band in the mid 1980's.

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.

There is some difficulty in assessing the main beam-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 being taken up 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.

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 which 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 dBW/m^2/80 MHz beam edge

-82.6 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

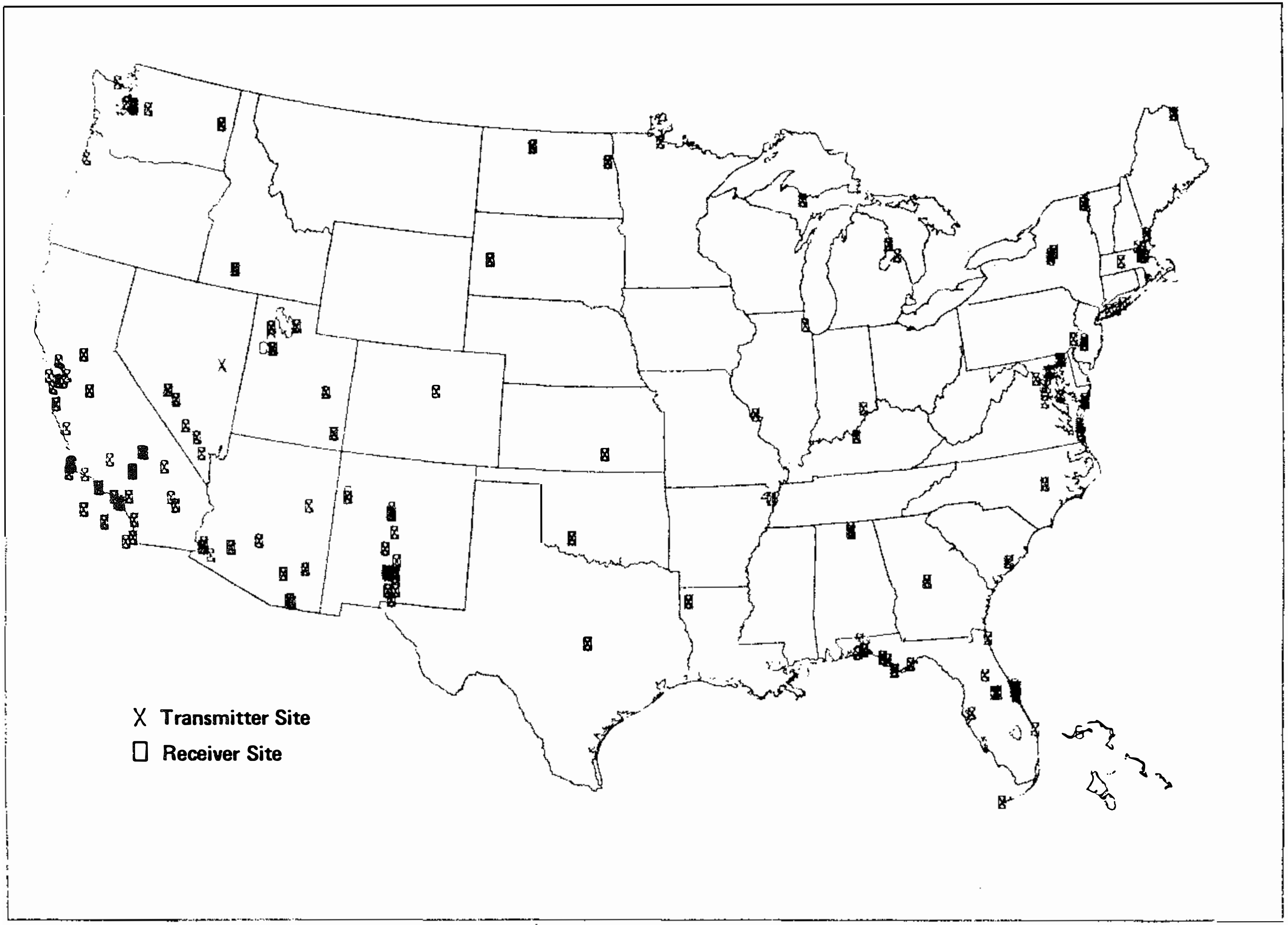


Figure 1-6. Geographic distribution of Government frequency assignments in the 5650-5925 MHz band.

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

$$C/I = P_T - P_I + G_T - G_I - (L_T - L_I) - M - \emptyset \qquad (1)$$

where: $P_I = P_i + G_i$ = Radar radiated power, dBW

$P_T = P_T + G_T$ = Earth station radiated power, dBW

G_T=Satellite antenna gain in the direction of the earth station, dBi

G_I=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)

$$\emptyset = \emptyset(B_I, B_T, D) \quad \begin{cases} 0 & \text{for } B_T \frac{\sqrt{D}}{B_T} > 1 \\ 20 \log \frac{B_I}{B_T \sqrt{D}} & \text{for } B_T \frac{\sqrt{D}}{B_I} < 1 \end{cases}$$

B_T=Satellite receiver 3 dB bandwidth, Hz

B_I=Radar 3 dB emission bandwidth, Hz

D =Radar compression ratio.

Maximum interference to satellite receiver occurs when:

$$L_T - L_I = 1.0 \text{ dB}$$

and

$$G_T - G_I = -3.0 \text{ dB}. \qquad (2)$$

Substituting equations (2) above into (1) gives

$$C/I = P_T - P_I + (-3) - (1) - (1.2) + 0$$
$$= P_T - P_I - 5.2 \qquad (3)$$

(Note, $\emptyset = 0$ for this case).

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

Type	Instrumentation
Frequency	$\geq$ 5650-5900 MHz
Power	1 MW peak
Antenna Gain	47 dBi
Beam Shape	Pencil

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

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

The desired C/I ratio to be used here for the satellite receiver is C/I = 25 dB.

For the case of the AN/FPS-16 then the C/I criteria is exceeded by 47.2 dB for main-beam-to-mainbeam coupling.

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 which would involve 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. 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 approximatly 4.88 m diameter (AN/FDS16) was calculated and the results are listed in Table 1-4.

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 side lobe
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 to 1.07	31.5	1st side lobe
5	14.8	
10	7.3	
20	-0.2	
40	-7.6	
48 $\leq\phi\leq$ 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

$G_i(\overline{\theta})$ = 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 25 dB by 32.8 dB.

For the minimal angle, θ, that the radar must be pointed away from the geostationary orbit position for C/I = 25 dB

$$P_T - P_i - G_i(\theta) - 5.2 + \theta = 25 \qquad (5)$$

$$G_i(\theta) = -0.2$$

$$32 - 25 \log \theta = -0.2$$

$$\theta = 19.4°.$$

For the AN/SPS 10 radars the minimal angle, θ, that the radar must be pointed away from the geostationary orbit position for the C/I = 25 dB criteria is

$$G_i(\theta) = 90 - 54.5 - 5.2 - 25$$

$$= 5.3$$

$$32 - 25 \log\theta = 5.3$$

$$\theta = 11.7°.$$

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 to be published early in FY83. Also given in the report are the frequency dependent rejection characteristics of the satellite which 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 system 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 59.8 dBW radiated power to provide a C/I = 25 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 is met. A combination of reduced power and off-tuning could also be used.

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 cannot often be made simply, because of requirements for 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 housed in the van shown in Figure 1-7. In FY82, Measurement Van Operations using the RSMS continued measurements of Federal Government radio frequency usage in its tenth year of operation. As in FY81, RSMS measurements contained a mix of directly funded measurements and sponsor-supported measurements. The directly funded measurements continued to support Spectrum Resource Assessment (SRA) being done mostly in the Annapolis offices of NTIA. These intensive studies of individual frequency bands used measurements of current spectrum usage as one of the key pieces of data for predicting future usage in those bands. Five major sets of measurments were performed by the RSMS in FY82, as well as some smaller measurements of individual signals. These are listed here and will be described in more detail later:

(1) EWCAS (Electronic warfare, close air support)

(2) Seattle area measurements

(3) Noise from video games

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

(4) JPL measurements at Goldstone

(5) Site survey for Systems Planning Corporation.

Measurement activities were somewhat curtailed this year to allow more time to be spent in designing a replacement measurement system for the RSMS. In FY82, the new system was designed and $335,000 was allocated to purchase components for the new system. Most of the required components were purchased in FY82. In FY83, the entire RSMS effort will be directed at construction and integration of the new measurement system, although some measurements may be conducted on an emergency basis. The new system is expected to be operational in FY84.

The RSMS is a computer-controlled measurement system contained in a motorhome-type vehicle (Figure 1-8). This system allows spectrum measurements to be made over the 100 kHz - 18 GHz range in a highly automated manner, which permits the efficient collection of statistically significant amounts of spectrum usage data. In land mobile radio (LMR) bands, for example, channel usage is measured and analyzed at the rate of 125 channels/s--more than 10,000,000 individual channel usage measurements every day. Other families of calibration, measurement, and analysis programs are available to measure radar band usage and to measure general usage in wide frequency bands with mixed types of signals. Most of these programs are designed to operate with or without operator intervention.

Measurements were made of a military exercise this year. A large part of the Government portion of the spectrum is allocated for military systems, so the efficient utilization of these bands is of concern to frequency managers (just as the efficient utilization of the nonmilitary Government bands is of concern). Since many of these bands are not heavily used during peacetime, measurements during a military exercise are one method of obtaining some estimates of usage during heavier military activity. These measurements also provide some insight to operational frequency requirements on a military test range.

The RSMS made measurements of spectrum usage at EWCAS (Electronic Warfare/Close Air Support) near Nellis AFB this year. Measurements were made in selected frequency bands between 30 MHz and 18 GHz. About 5 weeks of measurements were made from a remote hilltop site on the Nellis test range. The SRA report is being written by NTIA personnel in Annapolis.

The second major NTIA measurement activity by the RSMS in FY82 included a series of measurements in the Seattle area. Two special areas of activity were planned for the Seattle measurements, besides a standard series of spectrum usage measurements in selected radar and LMR bands. Spectrum usage in the 9300-9500 MHz band is of special concern because of the large number of maritime and airborne radars, as well as increasing use of active repeater beacons. In addition, in the Seattle area a series of VTS (Vessel Traffic System) radars use this band to provide very high resolution images of ships in the whole Puget Sound area. These images are relayed to a central location and are displayed for controllers who can give navigation instructions to ships. A set of measurements of peak amplitude and pulse counts for three thresholds was made to provide data for an SRA being done in this band. These measurements were made from a mountaintop about 35 mi NW of Seattle over a 3-day period. The figures shown here summarize 53 sets of measurements of this band. All measurements made in this band were made with a 4-s "dwell" time. Since radars in this band typically rotate every 4 s, data were accumulated for 4 s at each measured frequency. This ensures the measured peak amplitude of the radar will include the signal when the radar is pointed at the RSMS; it also tends to make the pulse counts representative of a complete radar rotation period. Figure 1-9 shows the statistics of peak received amplitude for 53 measurement periods. At each frequency, the upper line shows the highest signal received during the entire 53 scans. The middle (dashed) line shows the average of the peak measured signals, and the bottom line shows the minimum of the peak amplitudes received in the 53 measurements. Possibly the most striking feature of this graph is the difference in characteristics between the fixed radars (e.g., 9310 MHz) and the more random population of mobile radars (e.g., 9340-9460 MHz). Figure 1-10 shows the number of radar pulses in a 4 s period that exceeded -80 dBm, the lowest amplitude threshold, as a function of frequency. Again, the three lines represent the highest count of 53 4-s samples, the average count for all 53 samples, and the value of the lowest count received during 4 s. Figure 1-11 and Figure 1-12 are similar, but show the results of counts for thresholds of -70 dBm and -61 dBm, respectively.

A set of measurements of band occupancy in the 7.8-8.4 GHz microwave band is also underway in the Seattle area. This study has been given priority at this time because of the need to relocate existing microwave links to the lower part of the band. (The WARC changed the frequency allocation on the upper half of the band.) This study will include measurements of microwave emission spectra for various channel loading conditions, propagation between microwave sites, and the spectrum usage of the microwave band as seen through operational microwave antennas. By connecting to existing microwave antennas, the RSMS will see exactly what the microwave receiver sees, including suppression of off-axis signals. A measurement at this point will automatically include exact factors for the emission spectra of interfering signals, propagation, and antenna gains. On the other hand, measurements are generally expensive and may not take time-variable factors into account. The major question this study will answer is whether a measurement-aided frequency assignment plan for this band can more efficiently squeeze channels in than a computer/data base assignment plan (which must generally use fairly conservative models to handle the worst-case situations).

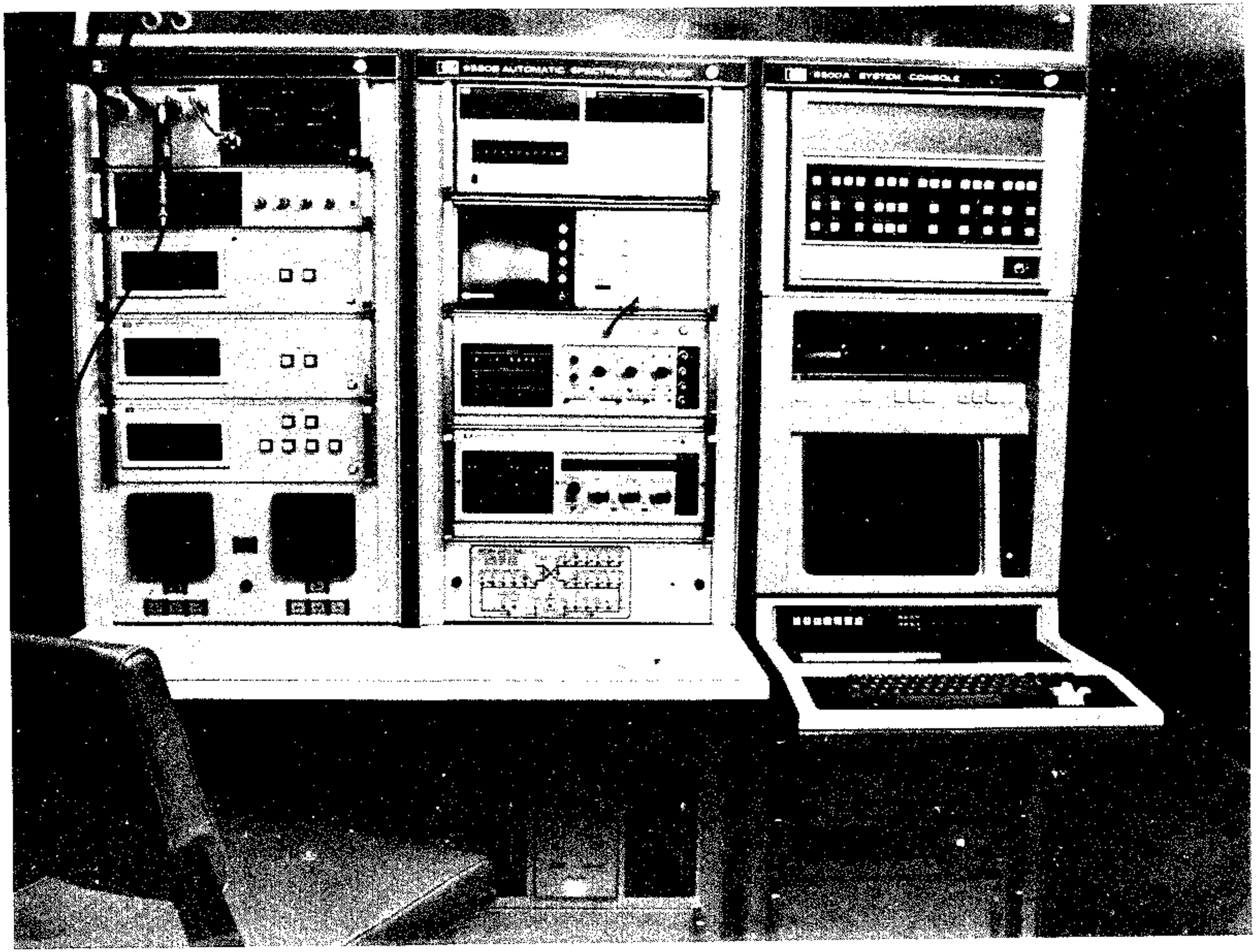


Figure 1-8. Measurement system used by RSMS.

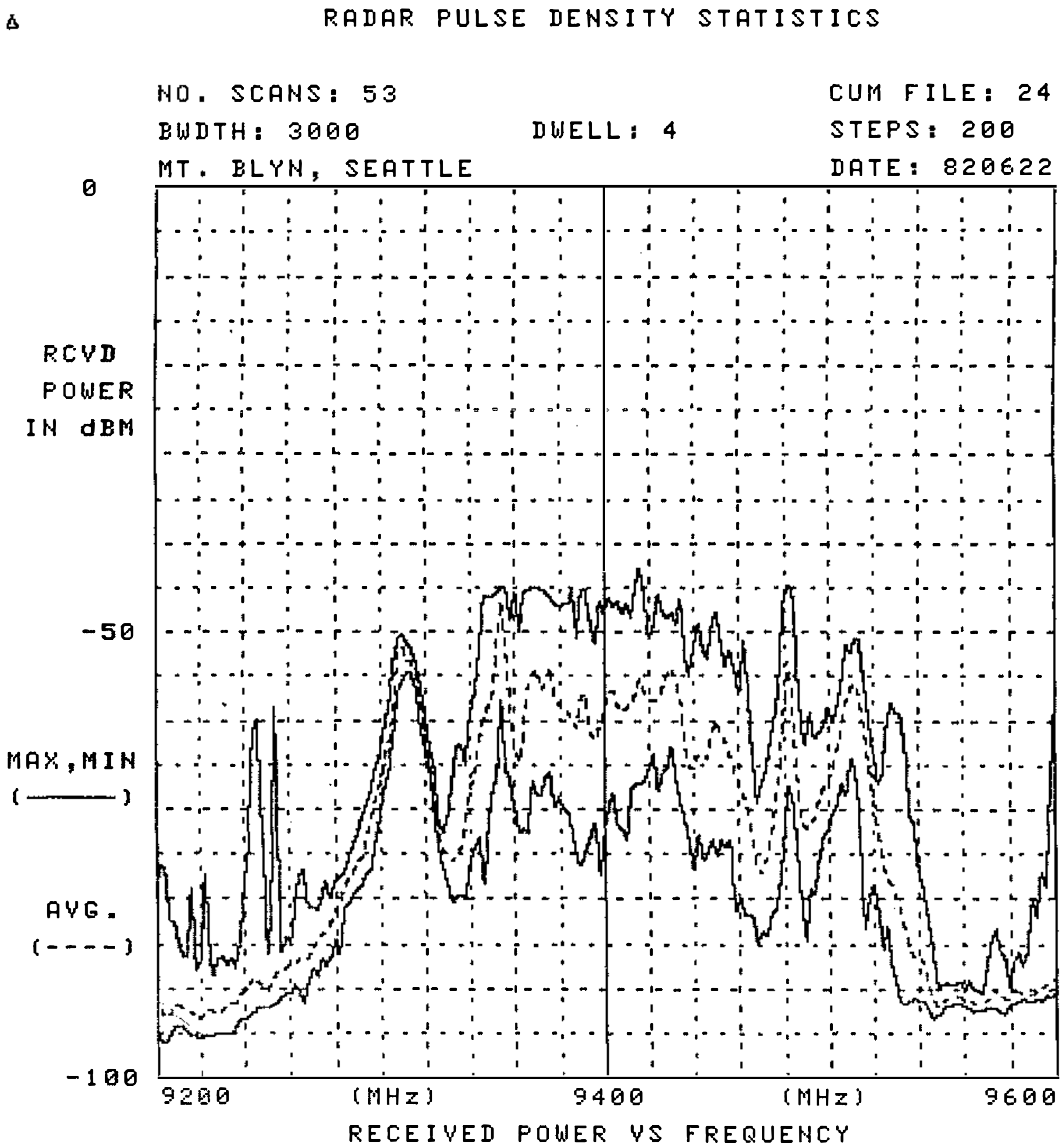


Figure 1-9. Radar amplitude statistics.

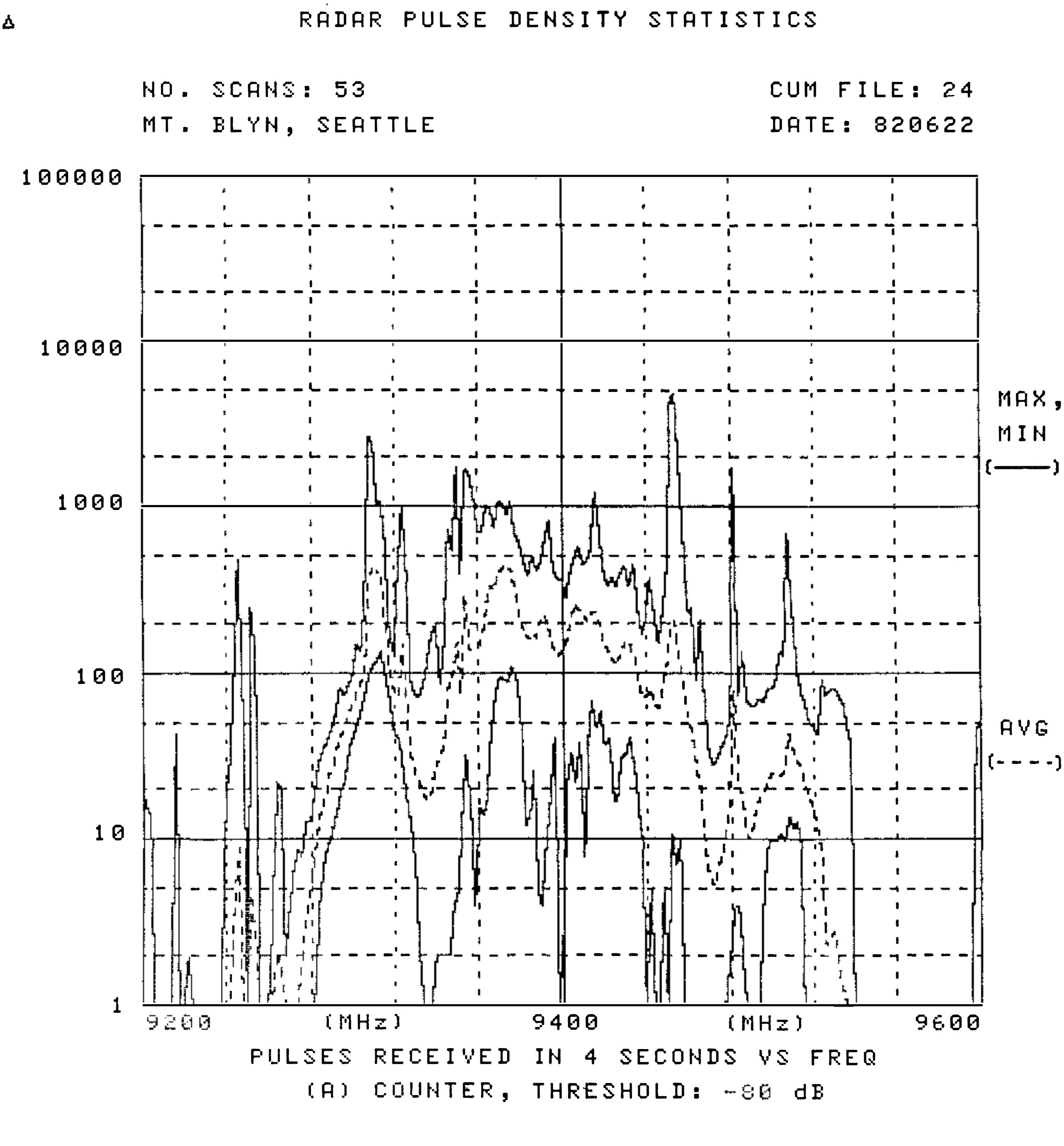


Figure 1-10. Statistics for pulse > -80 dBm received in 4-second periods.

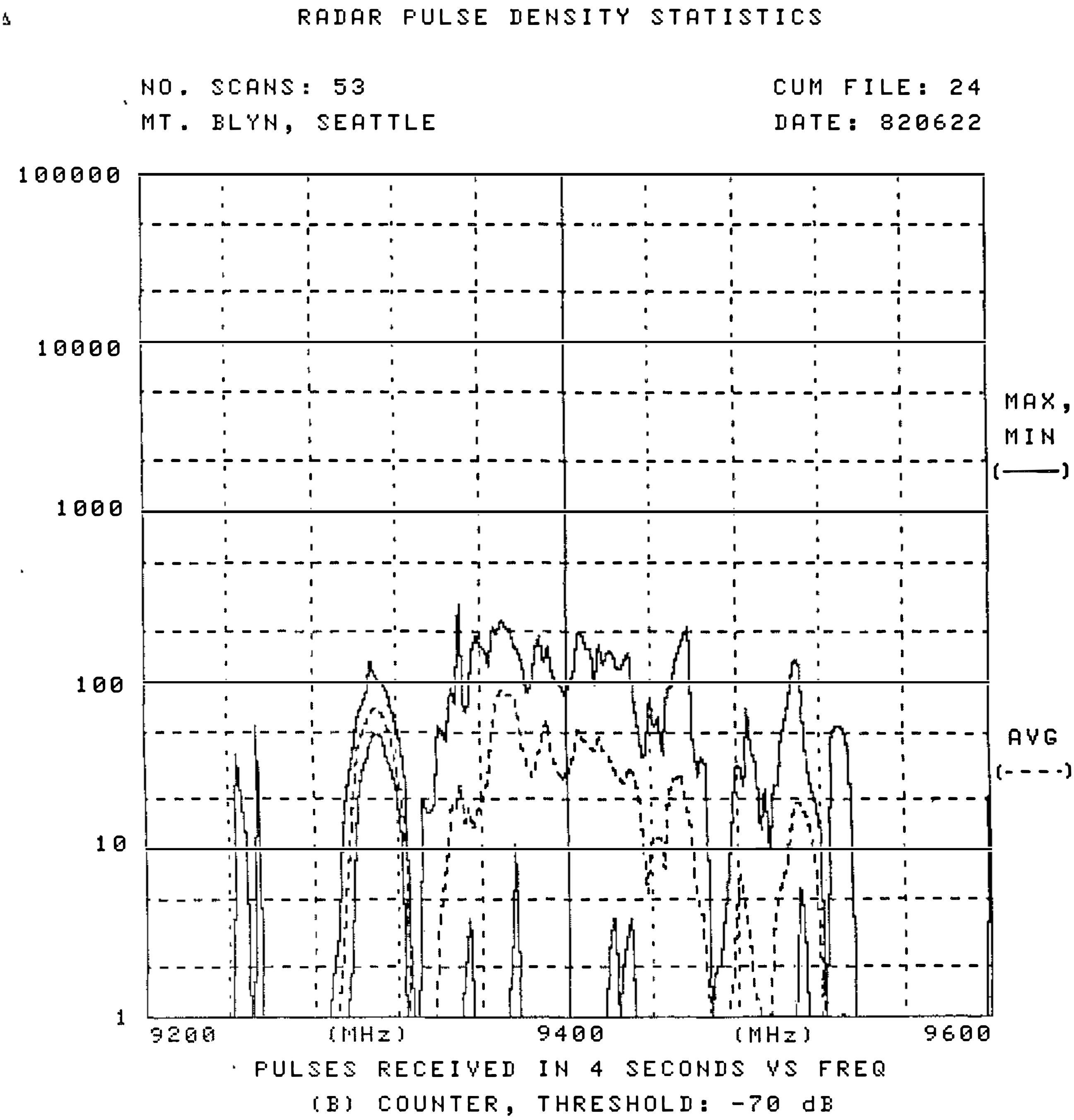


Figure 1-11. Statistics for pulse > -70 dBm received in 4-second periods.

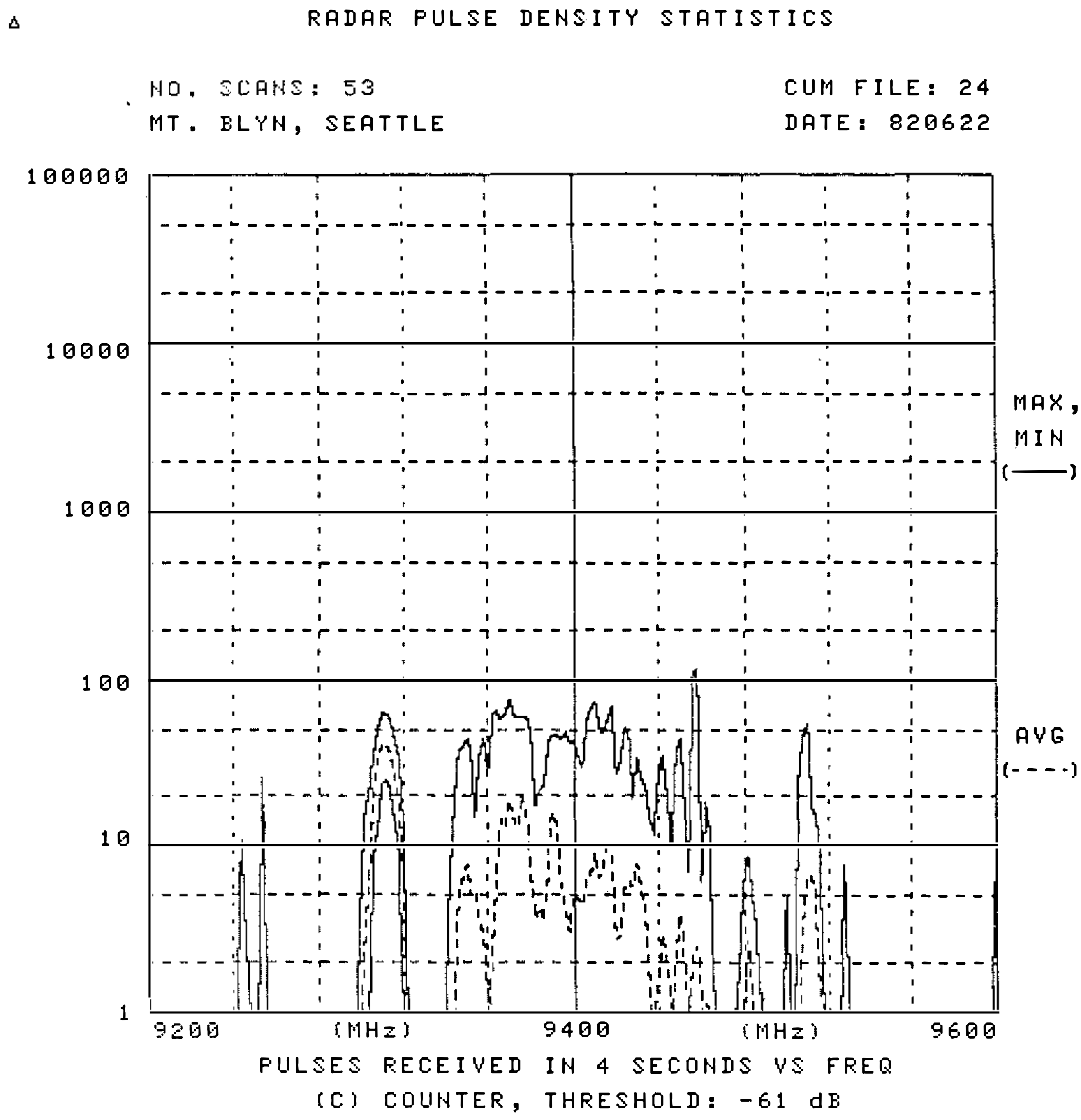


Figure 1-12. Statistics for pulse > -61 dBm received in 4-second periods.

The RSMS made a series of measurements of the electronic noise generated by video games. These measurements were done in response to concerns about the limits recently established by the FCC on "Part 15" devices. Measurements were made at several video game arcades in Colorado and California. Although the significance of the data is still being evaluated, numerous signals were observed that are near the current FCC limits.

RSMS Measurements at Goldstone were made for Jet Propulsion Laboratory to provide data on several problems relating to the deep-space receiving site Barstow, CA. This site contains several large dish antennas used to communicate with deep-space craft (i.e., outside of Earth orbit). Besides the extremely sensitive receivers used at these sites, several of the sites employ high-power transmitters used to transmit commands to spacecraft and for radar studies of planets. The largest of these transmitters, for example, transmits a CW radar signal with 400 kW power. Currently, the several sites are well isolated from each other by several miles and intervening mountains. There are a number of logistics reasons to consolidate these sites into a single site, but it is not known how much interference between sites would result from this move. In addition, Goldstone's neighbors have recently become much more active electronically, and there is some concern about how much the quiet environment has degraded.

Therefore, we were asked by JPL to make some spectrum occupancy measurements over the 1-12 GHz range. These measurements would 1) show whether the transmitters produced spurious sidebands which could cause interference to the very sensitive receivers, and 2) show what signals were present in the general environment.

The most significant challenge these measurements presented was to measure with sufficient sensitivity. Although the desired -140 dBm sensitivity could be obtained with the use of a 1 kHz measurement bandpass, the RSMS would be forced to tune so slowly that 4-5 days (24 hr/da) would be required for a single measurement over the 1-12 GHz range. This would not have permitted all of the desired measurements to be made in the available amount of time.

Fortunately, JPL was able to provide the use of their "RFI Van", a 65,000 channel FFT spectrum analyzer. It was determined that the RSMS could be modified to provide a 20 MHz wide signal to the JPL RFI Van, which would provide a continuous simultaneous measurement equivalent to 65,000 channels, each channel with 300 Hz bandwidth. This allowed the RSMS to rapidly measure the spectrum in 20 MHz steps, while still achieving the desired sensitivity. Figure 1-13 shows a block diagram of the combined measurement system.

Because of different signal-processing techniques (the RSMS could measure pulsed radar signals better) and the need to see real-time indications of data, it was decided that the RSMS would make measurements simultaneously to the JPL RSMS Van. However, since the RFI Van could provide the required sensitivity, the RSMS would use larger measurement bandwidths (10 kHz or 100 kHz). Although system maintenance problems prevented all of the work at Goldstone from being performed exactly as planned, many days and nights of environmental data were measured and emission spectrum measurements were made on all of the transmitters.

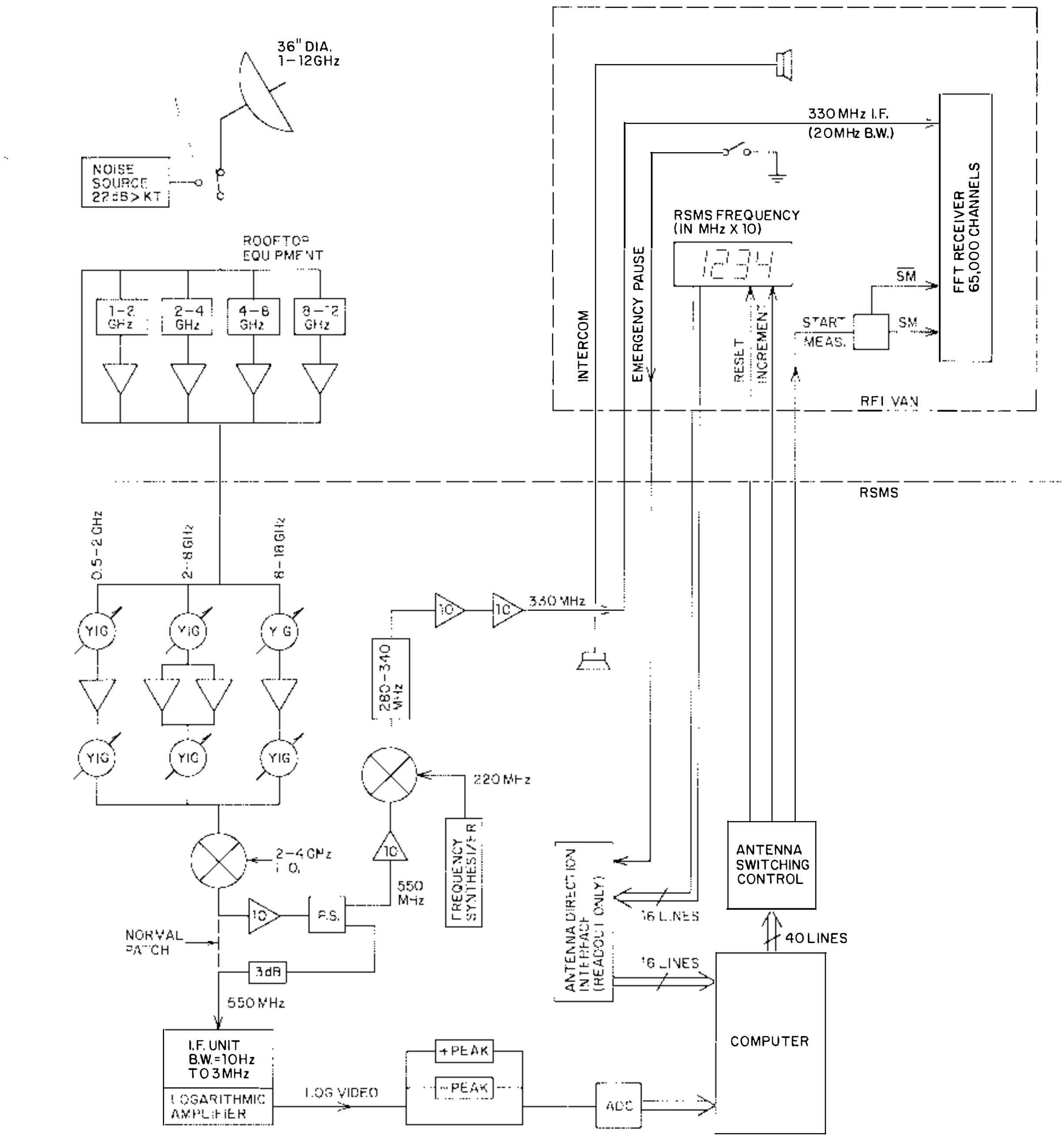
Figure 1-14 shows the RSMS during a typical transmitter spectrum measurement. The dish antenna on the roof of the RSMS is receiving signals scattered from the subreflector of the 210 ft dish antenna. The dish is aimed straight up and radiating 400 kW continuously. The RFI Van is located between the RSMS and the large dish antenna.

The RSMS Measurements for System Planning Corporation (SPC) involved a survey of environmental signals present at a site over the 0.15-18 GHz range. 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 configuation shown in Figure 1-15. 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 below 1 GHz); and 5) calibrate and start again. This program was designed to operate without requiring intervention from an operator, and 9 days of data were gathered on an 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 1-16 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 detectors. If neither the peak or 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 analysis. In general, data were recorded on magnetic tape, but hardcopy output like Figure 1-16 was also produced as required.

Two different versions of the measurement programs were used--a low resolution (lo-res) and a high resolution (h-res) version. The hi-



BLOCK DIAGRAM OF RSMS / RFI VAN

Figure 1-13. Block diagram of RSMS/RFI van measurement system.

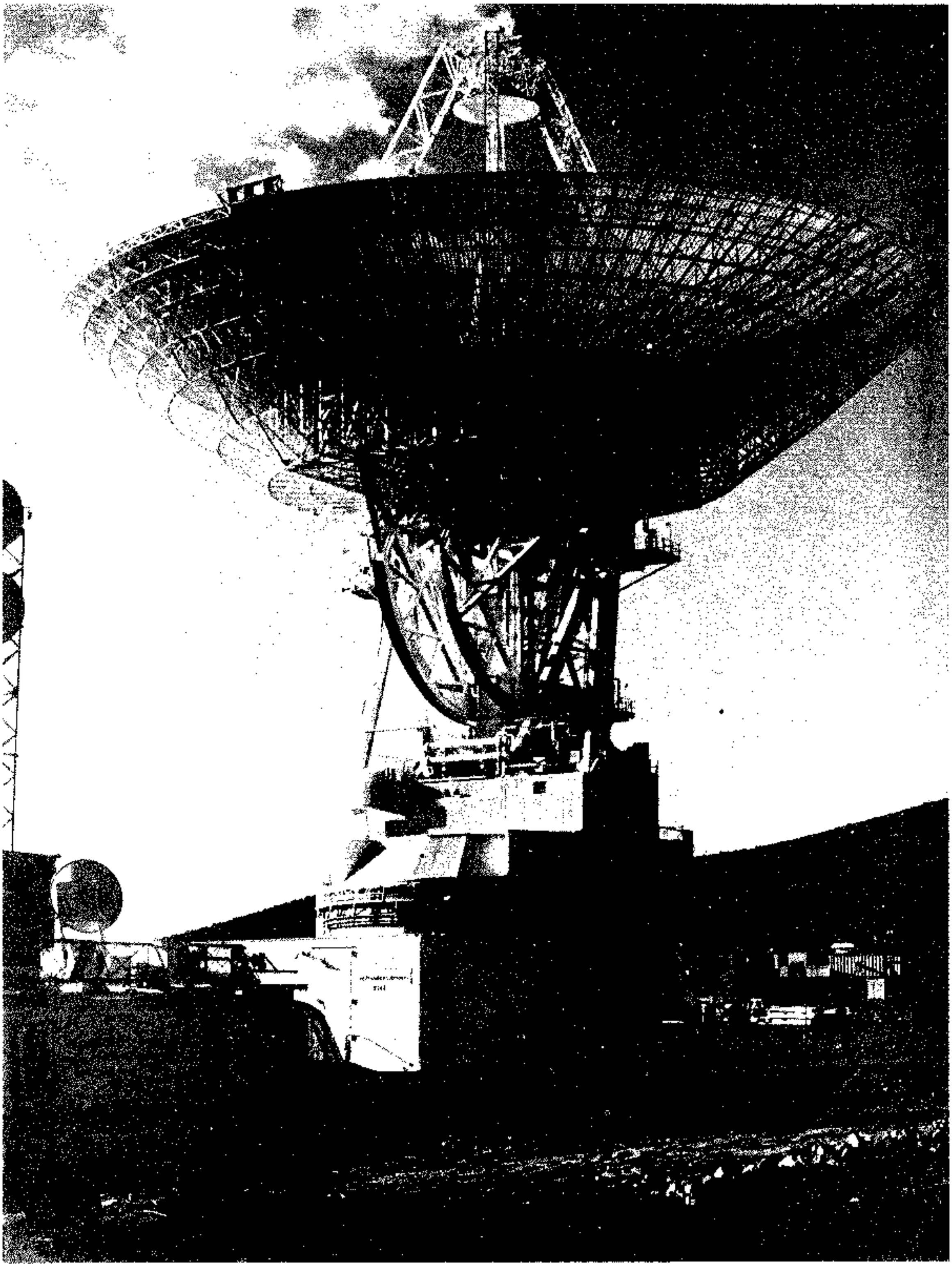


Figure 1-14. RSMS measuring spectrum from planetary radar at Goldstone.

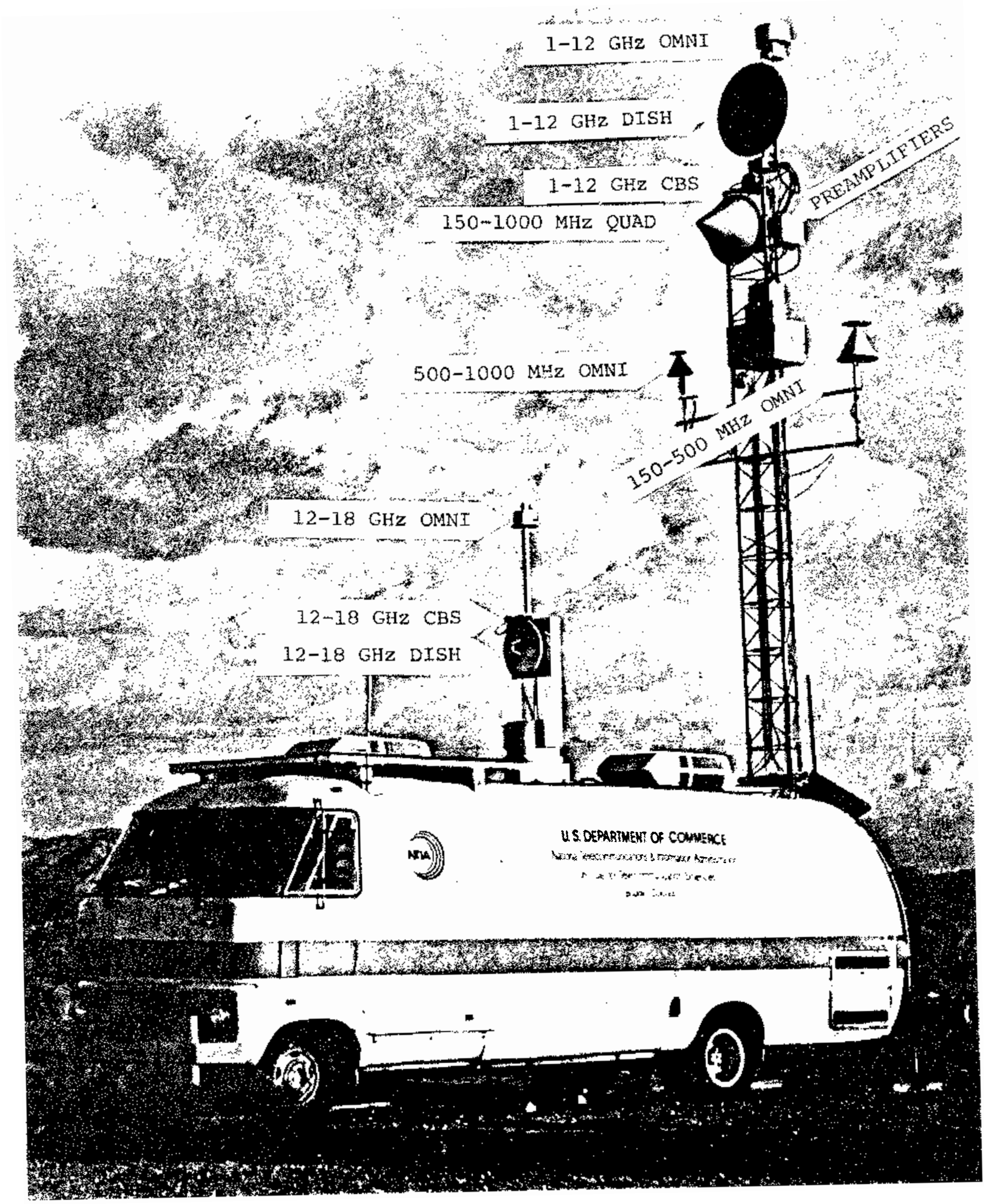
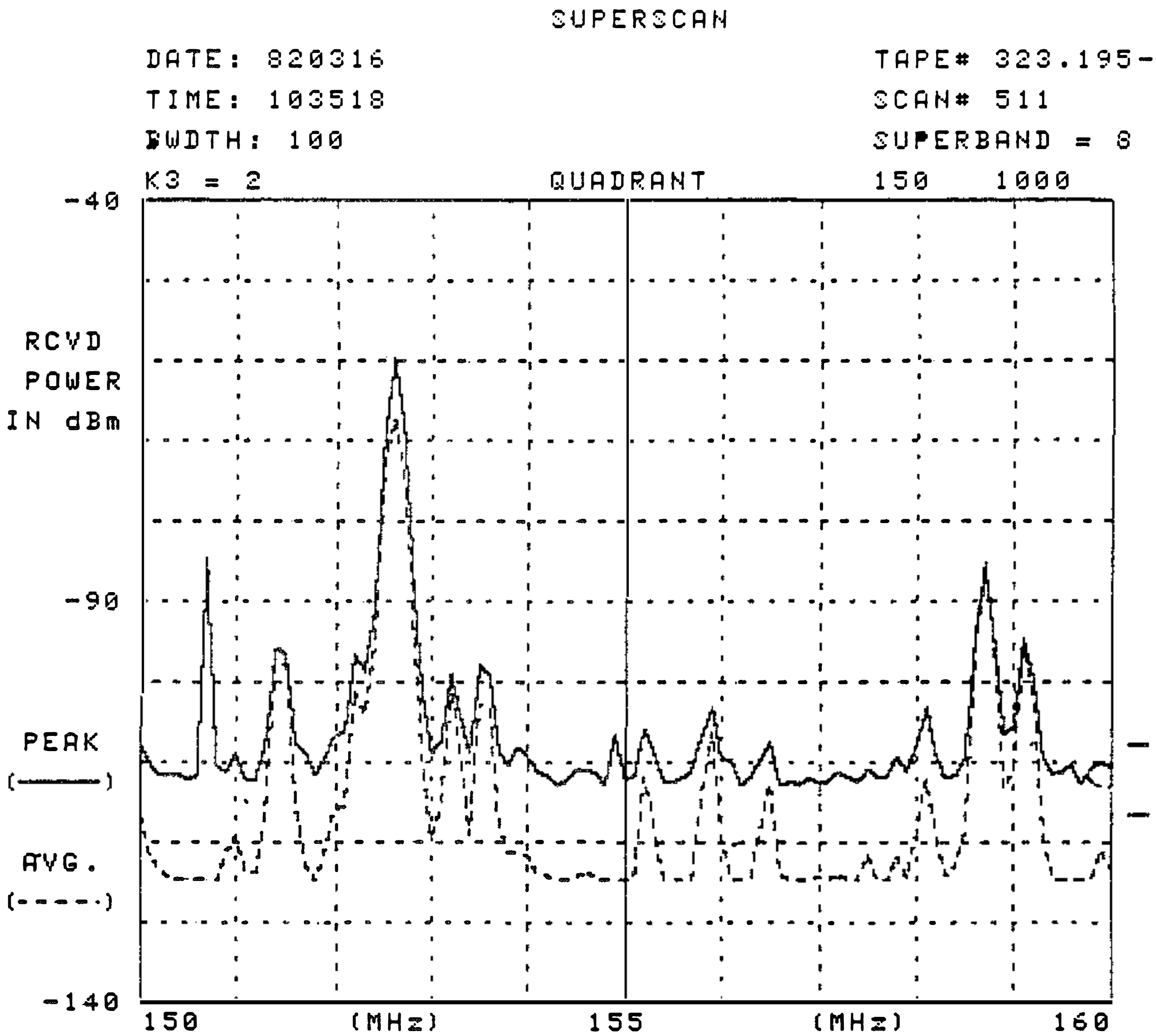


Figure 1-15. RSMS configured for 15-18 GHz measurements.



TAPE: 323.195 RCRD: 1 DATE: 820316 TIME: 103518
SCAN: 511 DIR(P): 2.25178E+28 DIR(A): 5.18815E+18
ANTS(AV): 0 0 0 0
ANTS(PK): 0 0 0 0
Athresh: -116.628 Pthresh: -107.628
PSCAN(AV): FREQ= 152.6 dBm= -67
PSCAN(PK): FREQ= 152.6 dBm= -59.5

Figure 1-16. Sample of lo-res data.

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	100 kHz	1000 kHz
Bandwidth, f > 1 GHz	1000 kHz	100 kHz
No. of scans, 15-18 GHz	255	2550
Meas time, 0.15-18 GHz	17 min	3 hr

The measurement process provided thousands of graphs which needed to be combined to give a more concise look at frequency usage. Part of the data analysis that was performed took lo-res like Figure 1-16 and compressed it 100:1 in frequency. This allowed the entire 150 MHz - 18 GHz range to be covered in three graphs, Figures 1-17, 1-18, and 1-19. The "frequency-compression" process saved only the highest amplitude peak measurement and the highest amplitude average measurement from each of the original graphs. These two points were graphed as the representative amplitudes for the entire original graph. One hundred of these sets of points were used to make a new graph, which covered 100 times the frequency range of the original graphs. One of the more obvious features these graphs show is the relative much higher usage of spectrum for frequencies below 1 GHz. The responses marked with an "X" in Figure 1-19 are responses caused by internal responses in the measurement system and do not represent real signals.

Measurements of radar pulse densities in the 2700-3100 MHz band were undertaken at two sites in the Los Angeles area in FY81 as part of the Radar Studies in Los Angeles project. A report on these measurements was completed in FY82 and published by FAA as DOT/FAA/RD-82/17, "S-Band Radar Pulse Densities in the Los Angeles Area."

In the course of the last several years of measurements with the RSMS, it has become increasingly apparent that the original RSMS measurement equipment would benefit from a redesign based on modern components and practices. The main problems were related to reliability and maintainability. Not only have we experienced more failures recently, but repair of those failures has been aggravated by nonavailability of parts and service. A number of field measurements were badly affected by poor operation of the system. Accordingly, a decision was made this year to begin work on an improved measurement system, expanding the Measurement Van Development work. With limited resources available for this RSMS Upgrade it was decided to reuse the original vehicle, antenna tower, equipment racks, etc. These components have given good service in the past, and only limited benefits would result from replacement of these items.

The major changes will be in the computer system and in the rf and IF hardware. Substantial technical advances have been made in the past few years, which should be expected to give generally better performance. In addition, our experience with the original system has identified several specific areas where improvements would make measurements more reliable, or more accurate, or more simple. Table 1-6 shows some of the areas where specific improvements have been designed.

Table 1-6. Upgraded Solution

RSMS Problem	
Many problems with computer failure	100% redundancy in computer system
Many problems with freq synthesizer	Spare frequency synethsizer
Limited dynamic range	Fundamental mixing to 18 GHz
Intermod and other spurs	Hardware overload detectors
Poor noise figure	Tower-top preamplifiers
Limited program and data storage	512K-bytes plus Winchester disc
Slow measurement speed	LMR speed doubled to 250 Chan/s
	QuickSearch speed increased 20x

A block diagram of the planned radar receiving system is shown in Figure 1-20. Signals enter the system through a 0-70 dB step attenuator. The signal is routed through the appropriate preamp/converter unit, where typical signal processing involves YIG-tuned preselection, low noise preamplification, YIG-tuned post selection, and mixing to a 271.4 MHz IF. The bandwidth of the IF hardware is in excess of 100 MHz after mixing and is signal bandwidth constrained only by the bandwidth of the YIG filters preceding the mixer. The local oscillator for the mixer is furnished by a commercial 2-18 GHz frequency synthesizer which is connected to the mixer used for the selected frequency range. Except for the frequency synthesizer, all of the rf components in the front end will incorporate many pieces from the original system.

The 271.4 MHz IF signal from the preamp/converter units enters the IF processing unit which allows three simultaneous independent modes of signal processing. Wideband log video is produced by a logarithmic amplifier connected to the 271.4 MHz IF. Since the IF bandwidth is wider than the rf bandwidth, the log amplifier will respond to all signals passing through the rf components. Thus, the log amplifier can be used as an rf overload detector. The wideband log video signal can be sampled by the computer, and additional rf attenuation can be added if signals near the saturation level are measured by the computer. The wideband log video also contains the best (i.e., least distorted by insufficient risetime) presentation of radar pulse shape. A

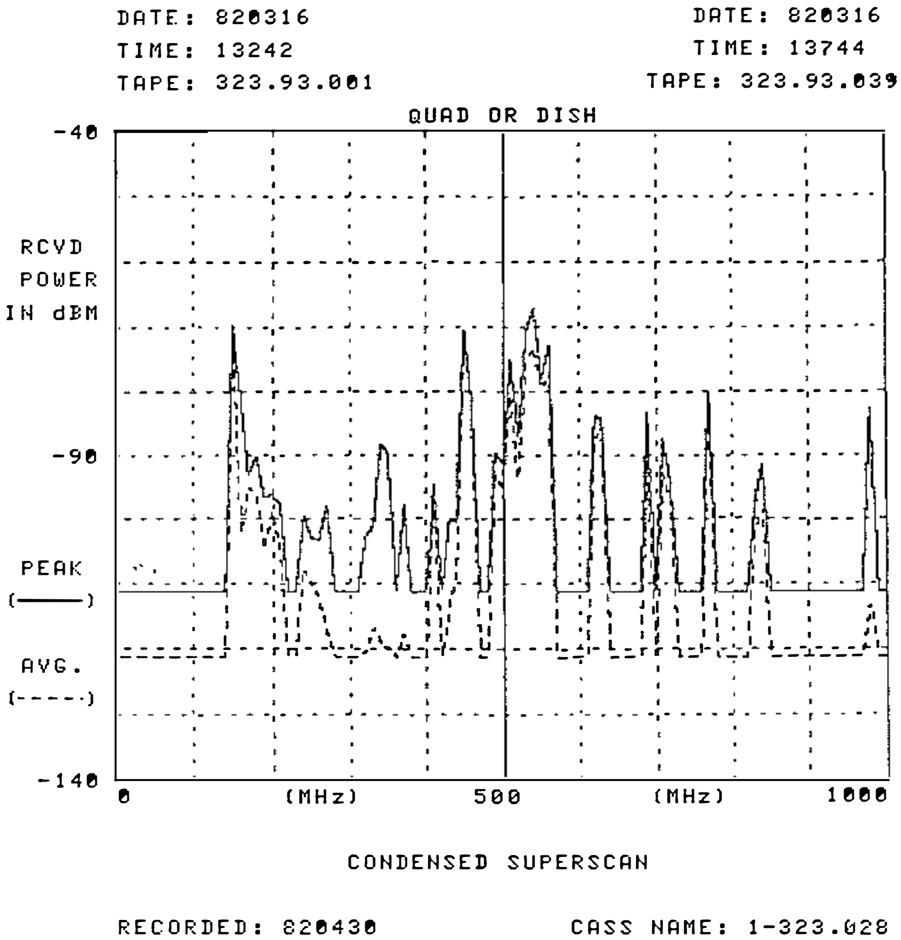


Figure 1-17. 0-1000 MHz frequency usage.

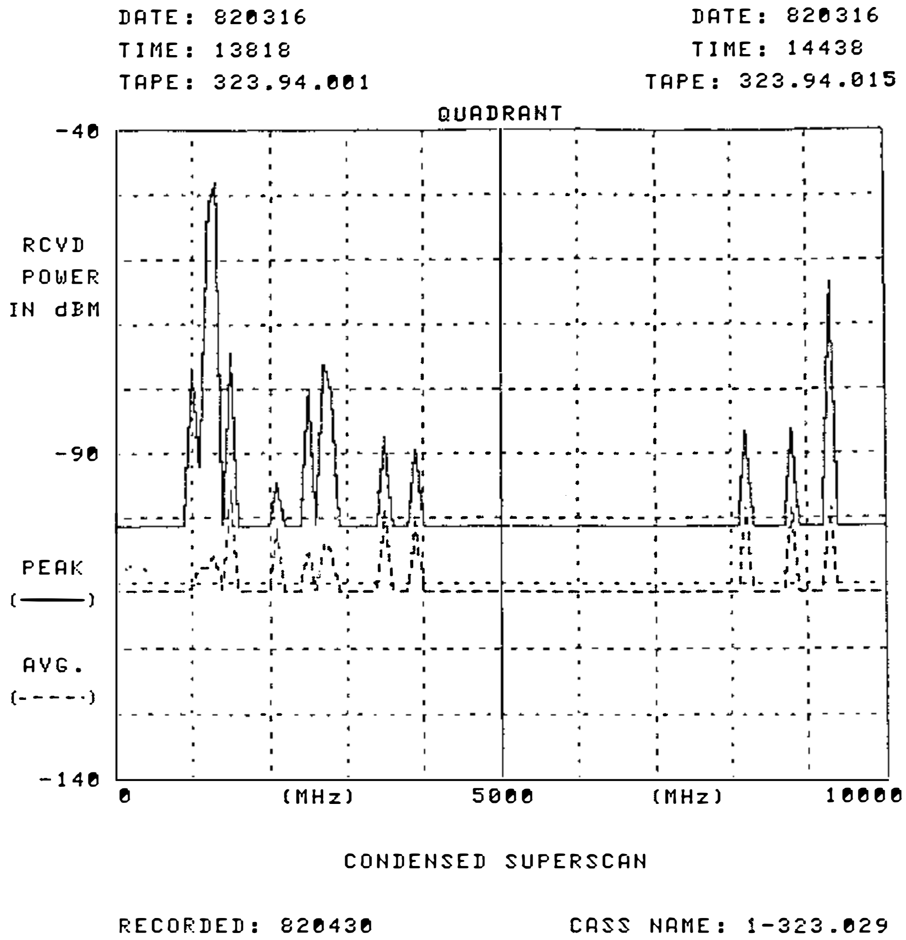


Figure 1-18. 0-106 Hz frequency usage.

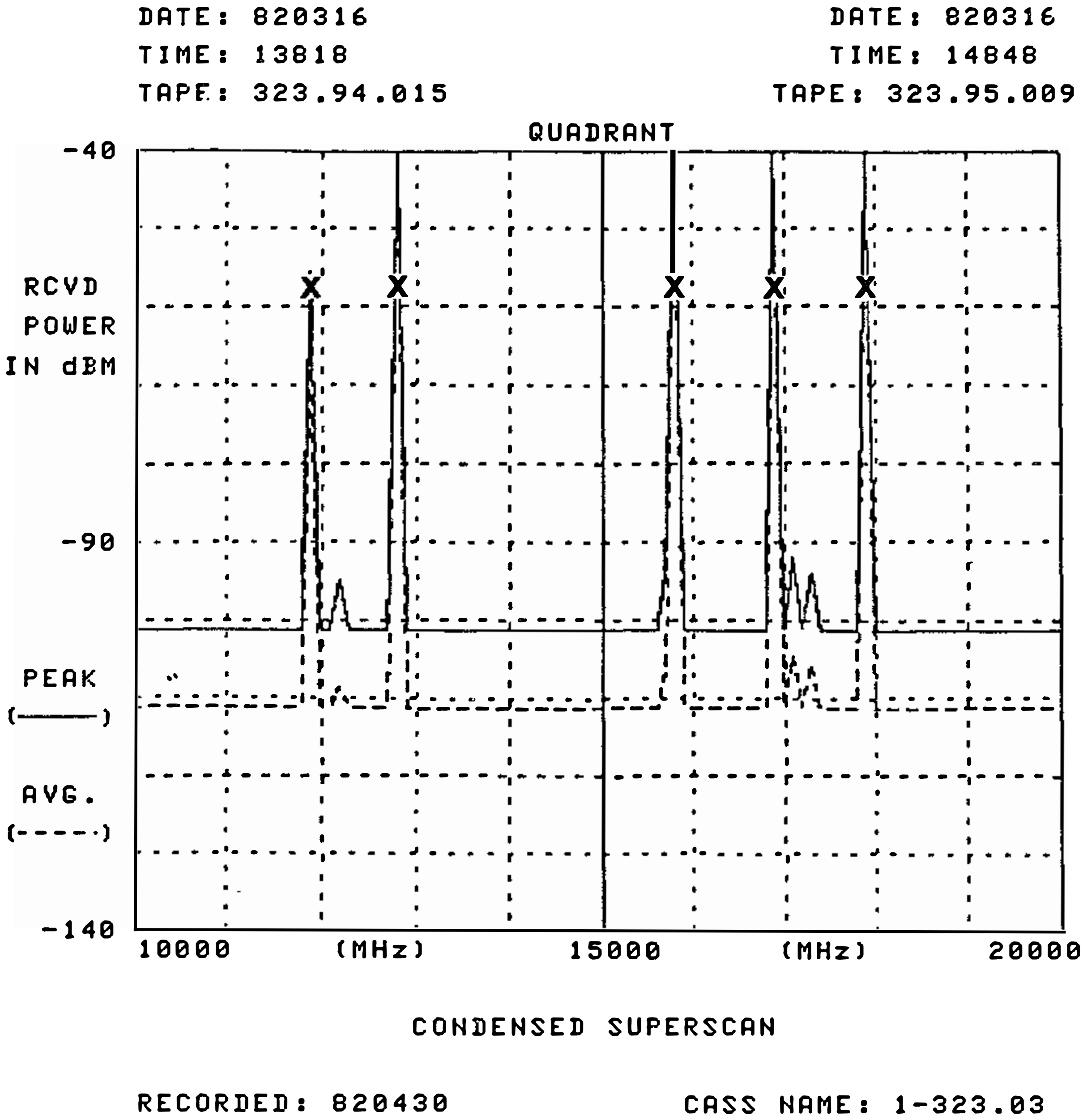


Figure 1-19. 10-186 Hz frequency usage.

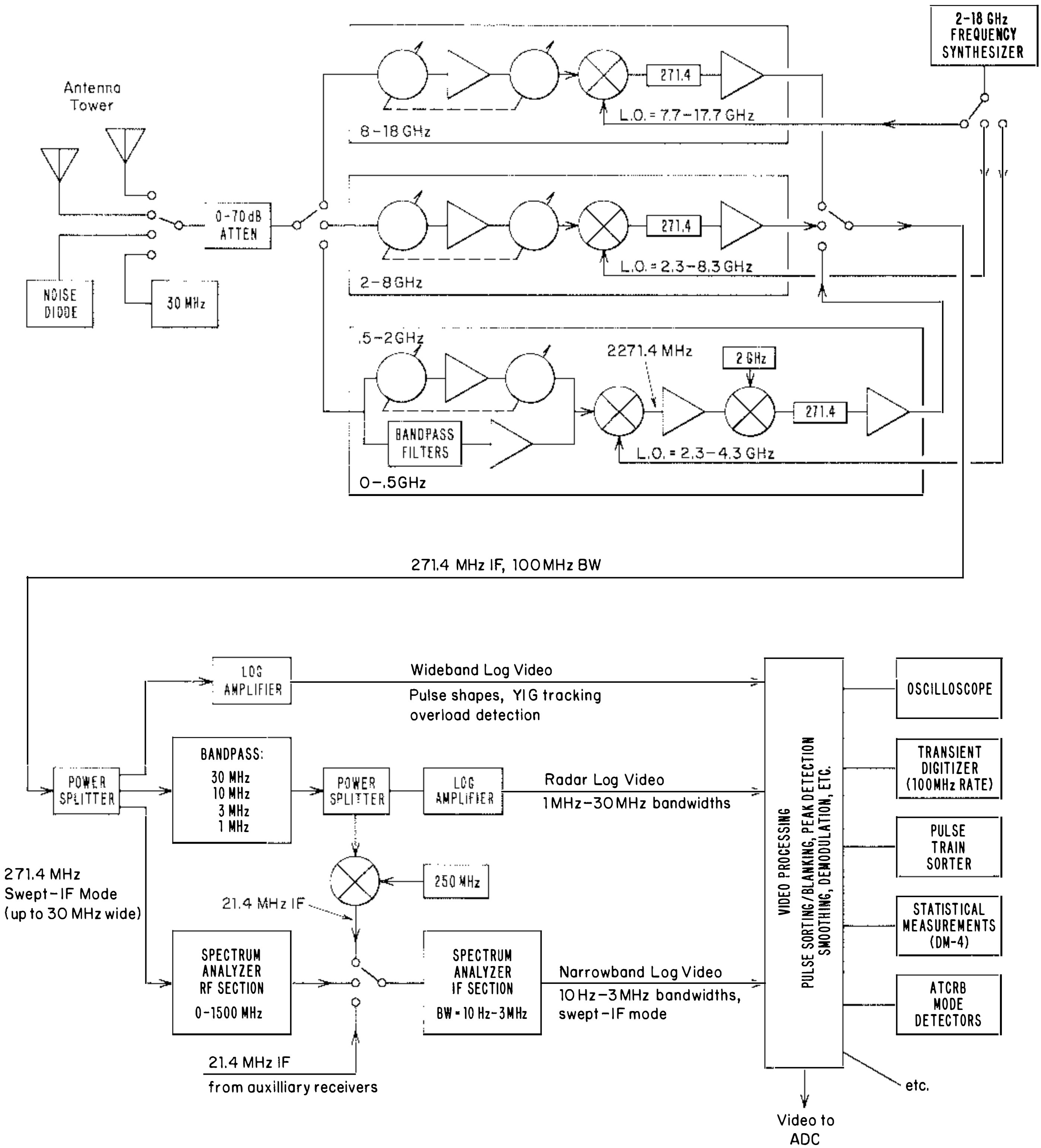


Figure 1-20. Radar receiving system planned for RSMS.

transient digitizer connected to this point will provide total measurement system video bandwidths greater than 35 MHz. Finally, the wideband log video can be used to examine the shape of the YIG preselector bandpasses. In combination with a comb generator, this capability can be used to test the actual frequency of peak YIG response. Simple correction algorithms can be used to force the YIG to the desired frequency, thus ensuring accurate tracking of the YIG at all times.

Another log amplifier with 80 dB dynamic range is used with a set of switched IF bandpass filters to produce the radar log video signal. The radar log video will generally be used for the majority of radar spectrum usage measurements. Measurement bandwidths less than 1 MHz are produced using the measurement bandwidths in a spectrum analyzer IF section operating with a 21.4 MHz IF. A portion of the 271.4 MHz IF is mixed down to 21.4 MHz to provide the required signal. The spectrum analyzer IF section allows the selection of bandwidth between 10 Hz and 3 MHz, providing 10, 30, 100, 300, etc., steps over the bandwidth range.

The rf section of the spectrum analyzer is used as a sweeping receiver in a "swept-IF" mode. In this mode, the spectrum analyzer rf section sweeps across a portion of the IF bandwidth, measuring that portion of the IF bandpass with greatly increased resolution and sensitivity. Although a similar function could be realized by sweeping the frequency of the preamp/converter while using the spectrum analyzer IF section with a narrow bandwidth, the swept-IF mode has some considerable advantages. The main advantage is substantially increased measurement speed. The 2-18 GHz frequency synthesizer requires about 20 ms to change frequency, even for small steps; 1000 steps would require 20 s. The rf section of the spectrum analyzer can tune across 1000 steps in less than 1 s. Thus, the swept-IF mode greatly increases measurement speed. To measure a wide frequency range with great sensitivity, for example, one might step the 2-18 GHz frequency synthesizer in 10 MHz steps. At each step, the spectrum analyzer would sweep across a 10 MHz range, using 1000 steps of 10 kHz each. This is a particularly efficient measurement technique, since all of the built-in spectrum analyzer routines are available to efficiently search for peak signal levels, etc.

Further processing of the various log video signals will permit measurements to be made of detailed radar pulse shapes, to do sorting of radar pulse trains, to view signals on an oscilloscope, and to gather wide bandwidth statistics on signal amplitudes (processed at 31 levels simultaneously).

A greatly improved computer system will control the measurements and analyze the data from them. Two identical computer systems will be located in the RSMS, with a third system in the Boulder Labs. The system in the Boulder Labs will have additional disc memory capabilities and be optimized toward analyzing the large amounts of data from the RSMS. Each of the two computers in the RSMS will be able to operate all systems in the RSMS on a time-shared basis. Normally, however, each computer will be programmed to operate the radar receiver or the LMR receiver, giving the maximum measurement speed. The failure of one computer would normally result in sharing of the remaining computer between functions or dropping the lower priority functions. The computer systems will be operated in an RTE mode, which will allow scheduling of multiple activities. A communications capability will allow system status to be interrogated over telephone lines and to allow events to be scheduled via telephone. All measurement hardware will be controlled via multiple IEEE-488 bus connections. Computer peripherals include a graphics terminal and thermal printer, a high-speed electrostatic graphics printer, a 4.6 megabyte Winchester disc, and a dual cartridge tape drive with 20 megabytes of capacity each. Plug-in cards in the computer will provide 12-bit ADC capabilities (50,000 readings/s) and quad 12-bit ADC capabilities (50,000 outputs/s).

The design effort for this work has been mostly finished, with procurement of parts well under way. The upgraded RSMS will be constructed and integrated in FY83, with the first measurements using the new system planned in FY84.

Another measurement system developed by ITS is the AN/MSR-() Multiple Receiver System. The AN/MSR-() is a mobile fully automatic multiple receiver system that is to be employed by the Air Force for autonomous and/or integrated operation with groundbased 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-() 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-() 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 insure that hardware/software design approaches and operational strategies by the AN/MSR-() 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 1982 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 which will be encountered in a real world EW environment. The simulator has an automatic time programmer which calls up different threats and ECM responses as often as once per second or any other longer period up to 8 minutes. The threat/ECM parameters of pulse width, pulse repetition interval, modulations, depth of modulation, etc., and their time/frequence 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 insure 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-() item(s) under test.

Other technical support efforts by ITS for the AN/MSR-() procurement have included (1) the derivation of data bases for radar threat emitters based on current intelligence sources 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 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/MST-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-() for comparison with operational measurements of actual performance during the conduct of in-situ 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 Institute also makes other types of measurements that are directed toward specific spectrum applications. The objective of the Earth Terminal Antenna Measurements project is the measurement of the magnitude of side-lobes produced by a specific 40 foot diameter antenna. This antenna was installed at the Table Mountain test site near Boulder, CO, where an aircraft was used to provide the necessary elevation angles for pattern measurements above the horizontal plane. The hemispherical power-gain radiation pattern was measured at siting angles of 45° and 90° above the horizon.

The test site was illuminated by an antenna mounted on a small aircraft with a separation distance between the aircraft and the test antenna of $0.8D^2/\lambda$ to $2D^2/\lambda$.

A relative-gain method of measurement was used with a single receiver switched rapidly between a reference gain antenna and the test antenna. The reference gain antenna was mounted onto an optical tracking system used to monitor aircraft position and output an elevation and azimuth reading relative to the test site.

The gain of the test antenna relative to the gain of the reference antenna is equal to the difference in received signal levels plus a constant factor composed of the differences in cable losses. The power-gain of the reference antenna is known; therefore, these relative gain data are corrected to absolute gain data by the addition of the reference gain value.

Data obtained from the measurements were plotted to provide statistical power-gain patterns that were compared to the CCIR recommended power-gain envelopes for appropriately sized antennas.

The Institute assists the Federal Aviation Administration by making several types of spectrum-related measurements. The Federal Aviation Administration operates several "flight inspection aircraft" that can be equipped for a variety of missions. Among these is the airborne measurement of radio signals. The purpose of the current FAA Aircraft Calibration project is to determine the calibration constant for a particular antenna mounted on a particular airplane at the radio frequency of 100 kHz.

The aircraft calibration is a part of a larger study being conducted by the FAA--an evaluation of the effects of power line carrier (PLC) systems on airborne Loran-C receivers. The Loran-C navigation system is being considered as a supplement to and possibly a replacement for the VOR navigation system. Loran-C signals are centered on 100 kHz with 99% of the energy confined between 90 and 110 kHz.

The PLC systems which are operated by the electric power utilities for teleprotection, telecontrol, and other telecommunications operate in the frequency range from 10 to 535 kHz. The PLC signals are not intended to radiate; they are propagated along the power lines like guided waves. In practice, because real power lines contain various departures from ideal geometry, some of the guided signal can be launched as some other mode of propagation. There is some controversy as to how, or even if, this happens. At any rate, some level of radio-frequency signals exist in the airspace above power lines with PLC.

Since the FAA aircraft is being used in several experiments designed to measure the effects of PLC signals on a variety of Loran-C receivers, it is necessary to know the calibration constant (or antenna factor) of the aircraft antenna. This is so that the received signal level (in volts) at the aircraft antenna terminals can be related to the field strength (in volts/meter) external to the aircraft. Knowing the actual field strength of the Loran and/or PLC signals makes it possible to compare the planned measurements with those made by others.

The measurement aircraft with its receiving antenna must be calibrated as a unit, because at Loran-C frequencies (90-110 kHz) even the aircraft is quite small relative to a wavelength (about 3 km). In order to perform the calibration, the plane must be immersed in a known field; therefore, the field must originate from a calibrated source.

Since this aircraft calibration must be done at 100 kHz, it is not possible to use a test source because it could interfere with Loran-C navigation equipment in use. A Loran-C transmitter is the most likely and practical source. The effective radiated power (ERP) or the field strength at some distance must be accurately determined, and the pulsed nature of the signal format must be assessed. Another requirement of the calibration measurements is that they must be made over a smooth, homogeneous surface so that reliable predictions of field strength can be made. The use of an actual Loran-C transmitter located very near the sea would satisfy this requirement.

The U.S. Coast Guard, who is responsible for the operation of the Loran-C navigation system in the United States, operates the Loran Receiver Test Complex (LRTC) in Wildwood, NJ. The most important part of the LRTC is a calibrated Loran-C transmitting station which can be put on the air whenever it is needed. It is the fifth secondary in the Northeast U.S. chain when it is on. This means that it transmits a group of eight pulses in the standard Loran-C format, with a group repetition interval (GRI) of 99,600 μs.

The radiated power of the LRTC transmitter can be calculated from the antenna base current and the radiation resistance, both of which can be measured. The Coast Guard uses a loop to sense the current in the antenna's ground return; this is the antenna base current. The method used to determine the radiation resistance involves a standard procedure of measuring field strength.

During the previous fiscal year, the test plan and data recording instrumentation were finished. Early this fiscal year the test flights were made and the calibration constant was calculated. Its value is such that if one adds 127 dB to the received signal level (at the antenna terminals) in dBm, the result is the electric field strength in dBu.

Another spectrum measurement program that supports FAA objectives is the Instrument Landing System Interference Performance project. National and international guidelines are required to protect aircraft navigational aids from harmful interference. In order to establish reasonable guidelines, laboratory measurements are needed to determine how contemporary navigation receivers perform in the presence of various types and levels of interference. The Federal Aviation Administration (FAA) contracted with the Institute to perform a limited set of measurements on Instrument Landing System (ILS) Interference Performance. The FAA requires the interference performance measurements to support their participation in the International Civil Aviation Organization's study group on Harmful Interference to Radio.

ITS measured the performance of four ILS localizer receivers with cochannel interference. Four modulation modes for the interference signal included continuous wave (CW), phase-shift-keying (PSK), frequency-shift-keying (FSK), and frequency modulation (FM).

The ILS localizer is a ground-based radio system designed to give lateral guidance to aircraft with respect to a runway center line. The localizer carrier is modulated at 90 and 150 Hz in a spatial pattern that makes the 90-Hz modulation exceed the 150-Hz modulation when the aircraft is to the left of the course, with a difference in depth of modulation (ddm) between the 90-Hz and 150-Hz signals that is proportional to the angular displacement from the course center line. The localizer display shows a "fly right" indication to the pilot when the 90-Hz signal dominates. To the right of the course center line, the 150-Hz signal is greater than the 90-Hz signal; thus the localizer display shows a "fly left" indication.

Four localizer receivers were obtained through the FAA from manufacturers or Government agencies. The four receivers included two models used primarily by general aviation aircraft and two used by commercial aircraft. The four receivers were tested to determine receiver sensitivity and selectivity.

Figure 1-21 shows the equipment configuration for making the signal-to-interference ratio measurements. The audio analyzer was used to measure four of the localizer receiver outputs; i.e., localizer audio, course deviation voltage, flag voltage, and AGC voltage. These parameters were chosen as being potentially sensitive to interference. The audio analyzer has an audio generator whose output modulated the ILS signal generator. The audio analyzer monitored the receiver's audio output to

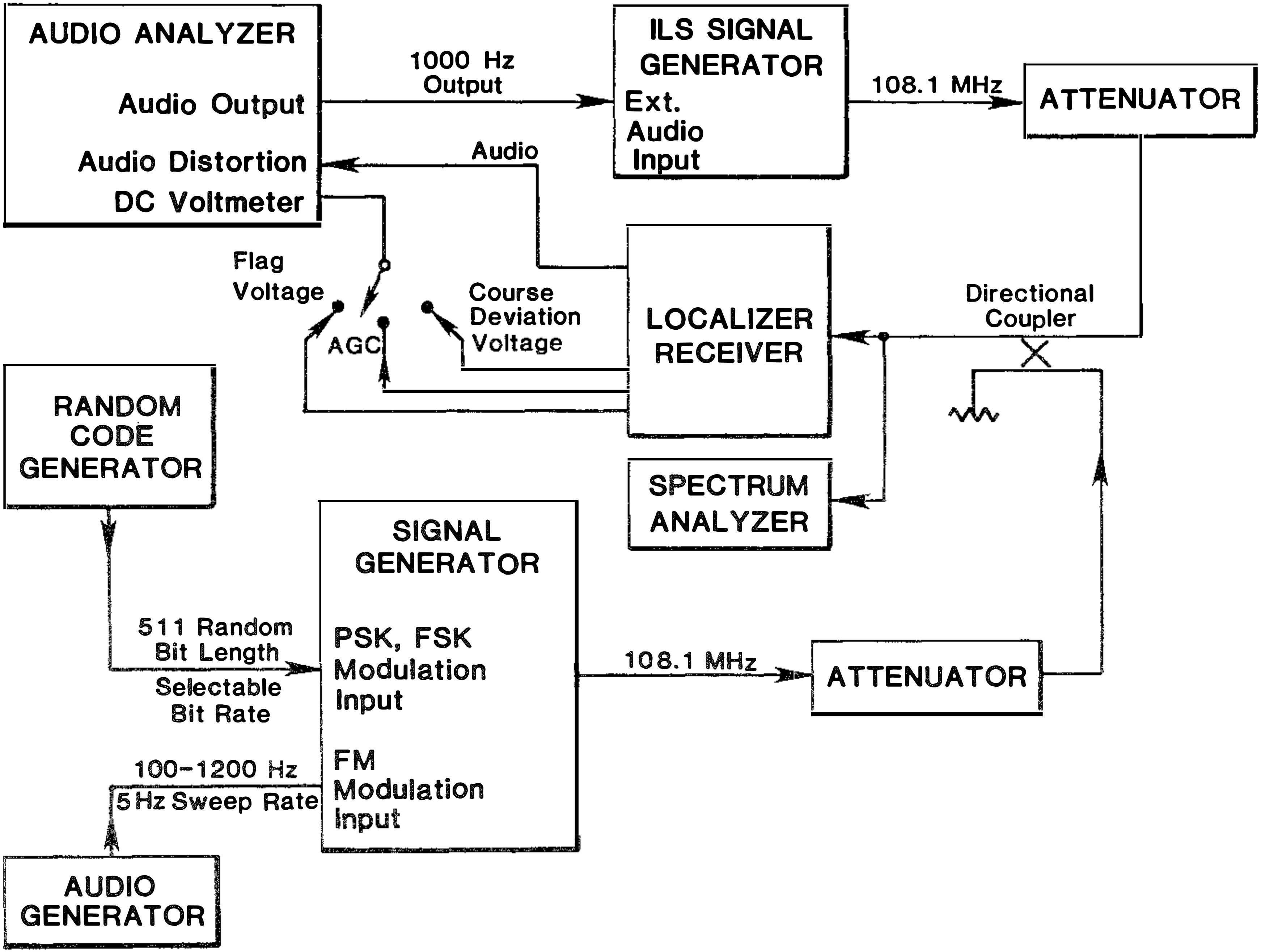


Figure 1-21. Signal-to-interference ratio measurement block diagram.

determine percent audio distortion. The ILS signal generator was set to simulate a signal that would produce the standard deflection of 0.093 dBm or 90 microamperes of course current in the receiver.

Table 1-7 gives the measured ILS receiver parameters and the parameter error conditions at which the input signal-to-interference power ratio was measured.

Table 1-7. Localizer Receiver Parameter Error Bounds

Parameter	Error Condition
Course deviation	Error bounds exceeded when course deviation is more than 15 μA from the standard deflection of 90 μA.
Flag indicator	Error bounds exceeded when 1) flag first appears peeping flag) and 2) when full flag is present.
Audio distortion	Error bounds exceeded when audio distortion percentage is increased by additional 1) one percent and 2) ten percent.
AGC voltage	Error bounds exceeded when AGC voltage changes by 1) 0.1 dB and 2) 1.0 dB.

The set of measurements suggest the following conclusions:

1) A 15 μA course error limit requires a greater signal-to-interference ratio than does a full warning flag, a 10-percent change in audio distortion or 1.0 dB change in AGC voltage.

2) The required signal-to-interference ratio to maintain less than 15 μA course error is nearly constant for each receiver as the desired input signal level is changed from receiver sensitivity to -27 dBm (1000 μV across 50 ohms).

3) The localizer receivers were most sensitive to CW interference, closely followed by PSK, FSK, and FM modulation interference.

4) The localizer receivers require about 20-dB signal-to-interference ratios to maintain less than 15 μA course deviation errors, when the interference does not cause 90 or 150-Hz heterodynes.

5) At precise frequency offsets of 90 and 150 Hz ± 2 Hz, a typical receiver required 32 dB signal-to-interference ratio to maintain less than 15 μA course error and 42 dB to maintain less than 5 μA course error. However, precise frequency offsets of 90 and 150 Hz between interference sources and ILS localizer transmitters have a very low probability in environments outside of the laboratory.

The Institute also develops specialized instrumentation to and in specific spectrum-related studies. The objective of the AFGL Refractometer project is to develop a Microwave Refractometer for the Air Force Geophysics Laboratory in support of their mm-wave studies. Their immediate need is for the Absolute Refractive Index and the frequency of the air turbulence. The refractometer is being designed for aircraft and fixed use. The Unit will have the capability of monitoring up to four temperature compensated cavities. The cavities can be automatically sequenced or they can be monitored individually in the manual mode. The refractive index and turbulence output is in two forms:

1. Digital for use with a computer to collect, store, and display the information.
2. Analog for use with a strip chart recorder.

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 which affect radio signals and are studied in this program are:

1. Attenuation by atmospheric gases, rain, snow, hail, clouds, or ionization.

2. Scattering by irregularities in the refractive index of the lower atmosphere or ionosphere.

3. Refraction, ducting, and multipath resulting from atmospheric or ionospheric layers.

4. Dispersion resulting from frequency dependent properties of the atmosphere, ionosphere, and earth.

5. Scintillation of amplitude, phase, polarization, and angle of arrival resulting from turbulence and irregular structure in the atmosphere and ionosphere.

6. 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 payed 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 an 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 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 a 5 MHz bandwidth with less than 10 minutes of outage per year from weather related sources. Rain attenuation has been 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 or 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 which cover a wider area typically have much lower rain rates and the total attenuation measured during these storms are 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 this data and theoretical predictions.

No time delay spread distortion produced by forward scattering from rain drops 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 which 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 1 to 2 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 mechanism, such as refractive defocusing, ground multipath, beam decoupling, and scintillation occurred at various times but the only effect on a narrow band 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 two 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 U.S. 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 requires further investigation. To provide a tool for this investigation, a millimeter wave diagnostic probe which can fully describe the propagation characteristics of a wide-band channel has been developed by ITS. 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 side band 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 which permit a 1/2 nanosecond time resolution in identifying time delay dispersion. A third mode provided by the probe is a spectrum of 2.5×10^4 coherent frequency lines for a 1 GHz bandwidth amplitude dispersion monitor. The output of the diagnostic probe describes the transfer function of the channel which 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 9.6, 11.4, 28.8, 57.6, and 94 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.

In order to calibrate the wide band probe, a test range was established using a 250 meter path folded with trihedral corner reflectors. A primary 39 cm reflector was fixed in distance and a secondary 22 cm reflection was placed on an adjustable beam using a worm gear positioner. With this configuration a range of $\pm$ 6 ns of signal arrival time relative to the fixed reflector was available. The amplitude ratios are adjusted by the separation perpendicular to the path so that the second reflector is positioned on the skirts of the transmitter and receiver antenna beam. In this manner, multipath distortion and fades are simulated to compile data sets for correlating bit-error-rate performance with measured channel impulse response and amplitude distortion. Figure 1-22 shows a sample plot of relative signal amplitude and BER versus displacement of the secondary reflector in nanoseconds of delay time. The displacement between amplitude peaks is equivalent to one cycle of the rf wavelength or 1 cm. The data rate is 500 mb/s (2 ns per bit duration); therefore, in the first nanosecond of delay most of the errors are due to signal-to-noise ratio change resulting from the signal fades. After 1 nanosecond, intersymbol interference becomes apparent by the irregular fringe of the BER plot. By 2 nanoseconds of delay the errors are due entirely to intersymbol interference because the modulation is a psuedo random phase-shift-keyed binary code and out of phase components do not occur after one bit duration. A family of plots, as in Figure 1-22, allows a prediction of BER given any multipath signal amplitude and delay. Figure 1-23 shows the probe impulse response and amplitude dispersion with a single reflector only (no multipath) and with a seconded reflector set for a 1/2 nanosecond multipath delay. The resulting BER is listed in the amplitude display. Noise was added to the link to increase the BER above 10^{-8}, the lower limit of BER detectability of the computer logging and data processing system. A 1/2 ns delay produces fades spaced 2000 MHz apart in the frequency spectrum. The impulse response of Figure 1-24 is the result of a 6 ns delay and a 8.7 dB reflector ratio. An amplitude versus frequency display is shown in Figure 1-25 comparing the single reflector with a simulated multipath signal delayed 6 ns producing fades spaced each 167 MHz as can be seen in the signal bandwidth.

The diagnostic probe was placed on a 12 km test path and Figure 1-26 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 1-27 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 1-28. Three correlograms were taken at about 30-minute intervals in Figure 1-29 showing the time variability of the multipath signal.

Under the project MM Wave Attenuation Model, a review was completed on the quantitative picture (that is, models vs. experiments and theory), upon which estimations are based for the transparency in four atmospheric millimeter wave window ranges. The windows are located around 35, 90, 140, and 220 GHz and their frames are set up by molecular resonance absorption of H_2O (centered at 22, 183, and 325 GHZ) and O_2 (centered at 60 and 119 GHz) as illustrated in Figure 1-30. It appears that 150 GHz of the EHF band (30-300 GHz) are available for signal transmission. A closer look reveals that the windows are veiled by water vapor and suspended hydrometeors (haze, fog, cloud) and darkened by rain.

In the EHF window ranges, it is possible to formulate simplified expressions for specific (dB/km) and total (dB) radio path attenuations. Water in both liquid and vapor states

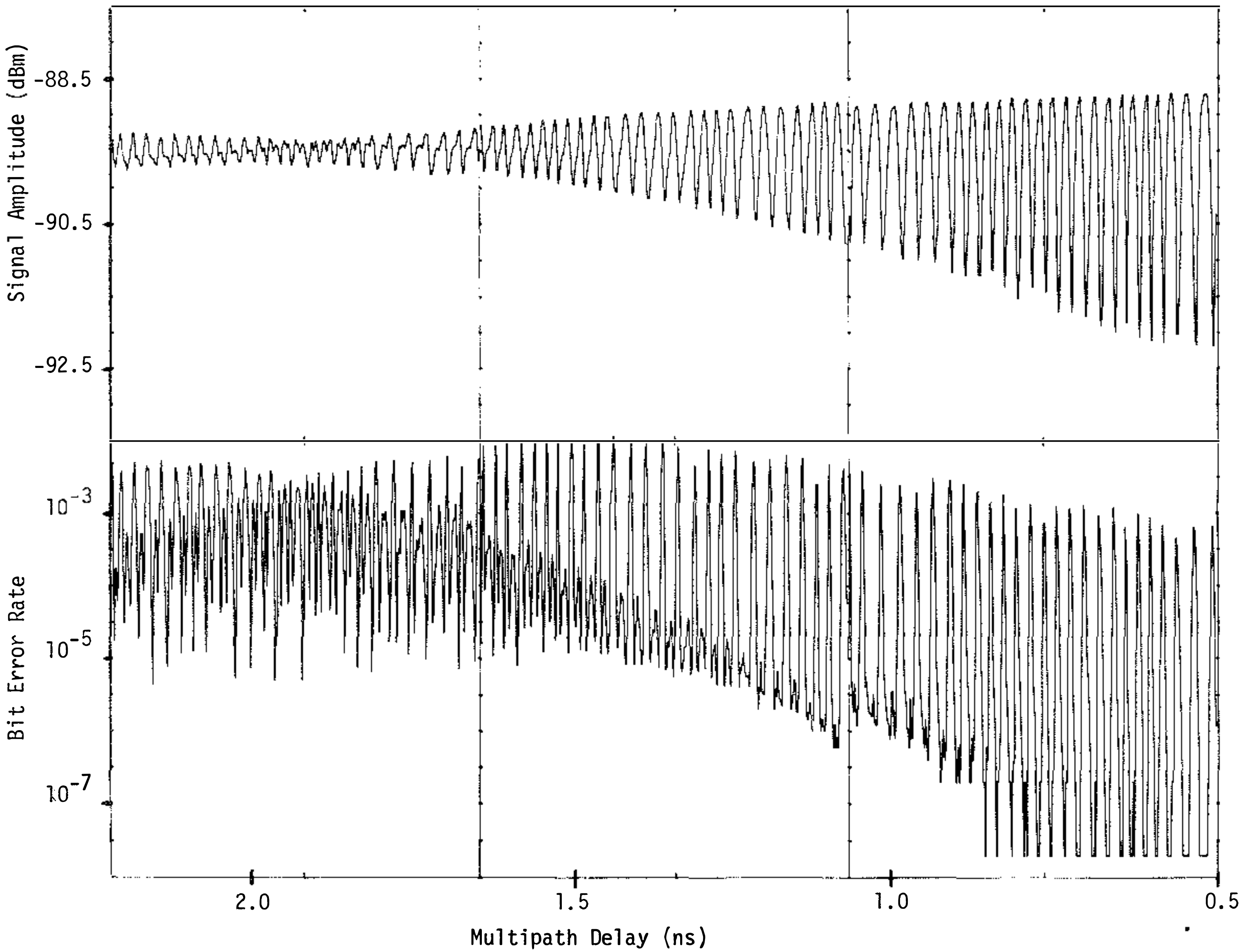


Figure 1-22. A plot of relative signal amplitude and bit error rate (BER) as a function of time displacement (ns) of a second reflector. (rf - 30.3 GHz, bit rate = 500 mb/s).

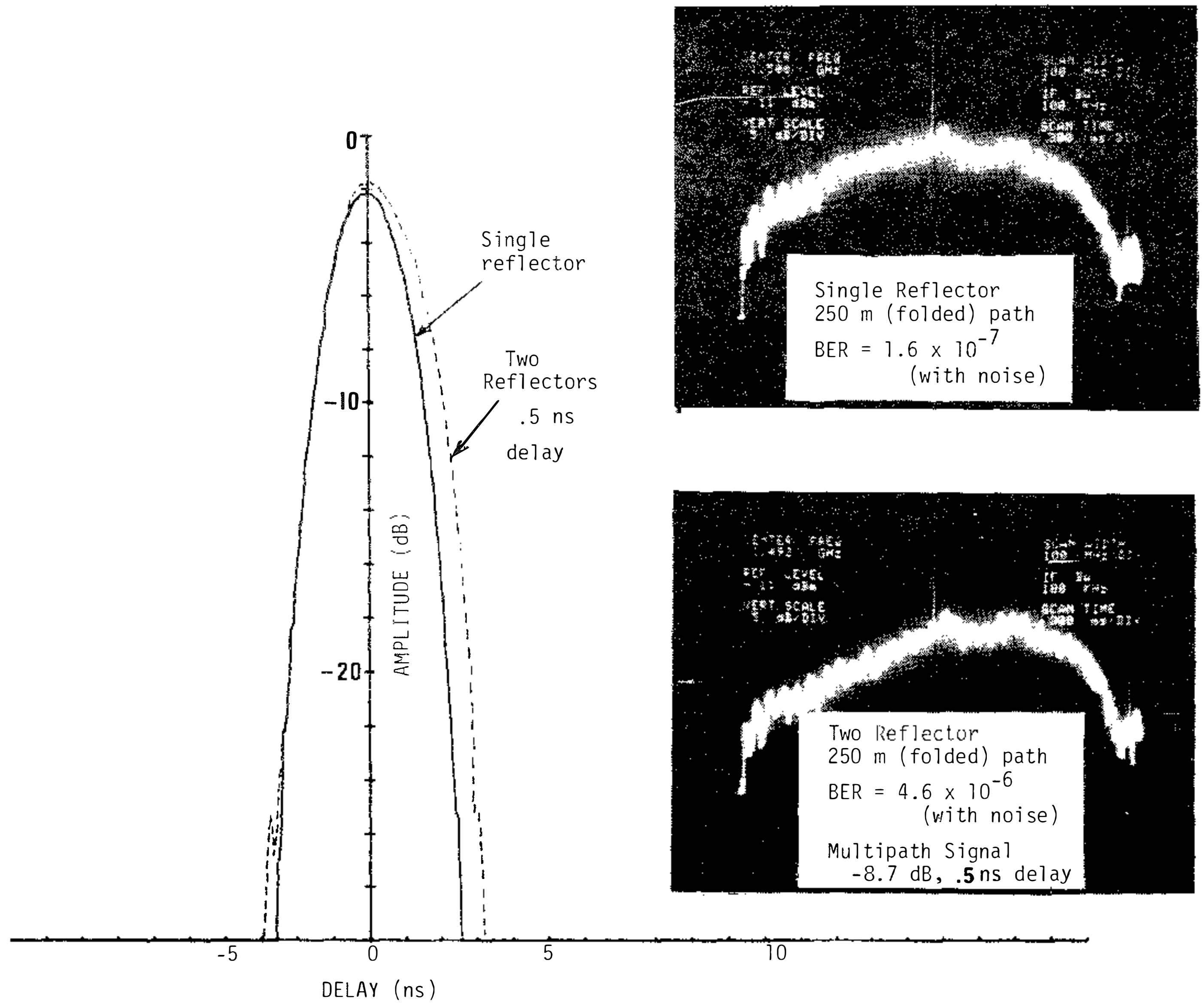


Figure 1-23. Probe impulse response curves and amplitude dispersion scans for a single reflector (no multipath) and two reflectors (multipath at 0.5 ns delay).

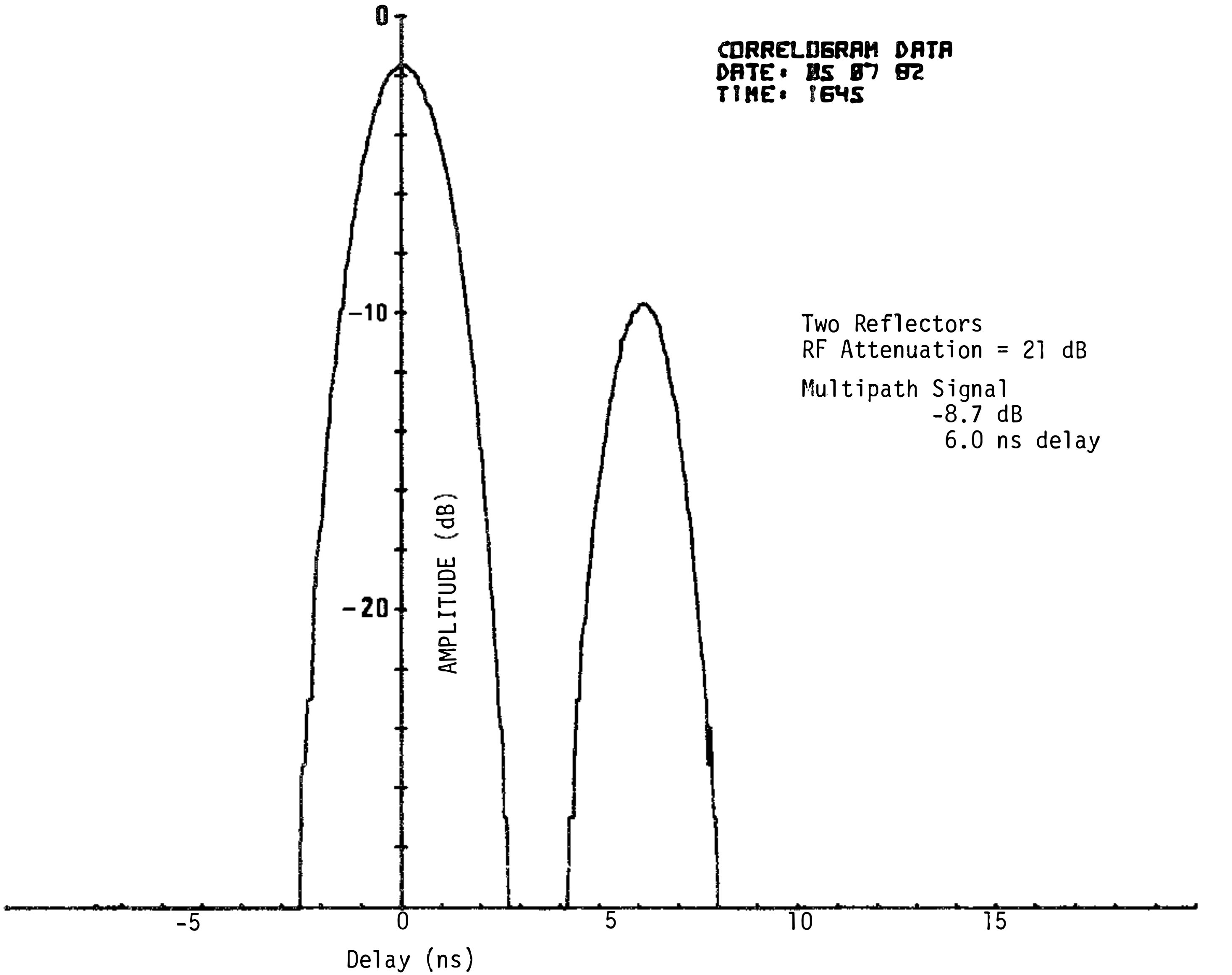
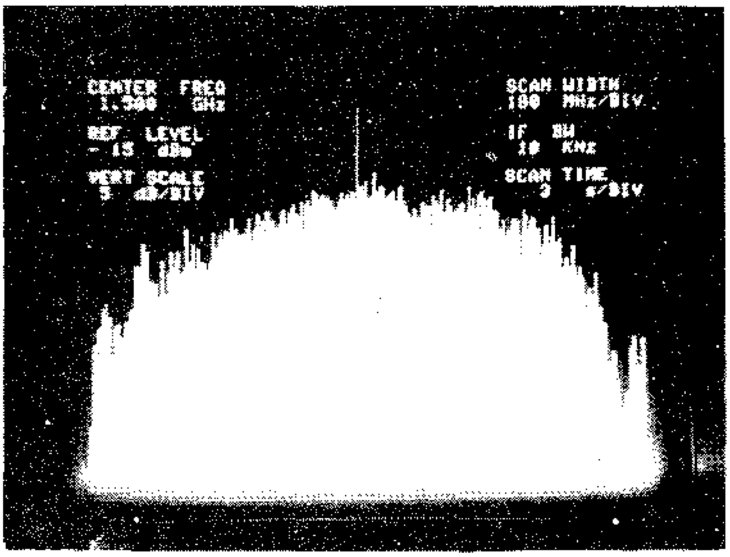
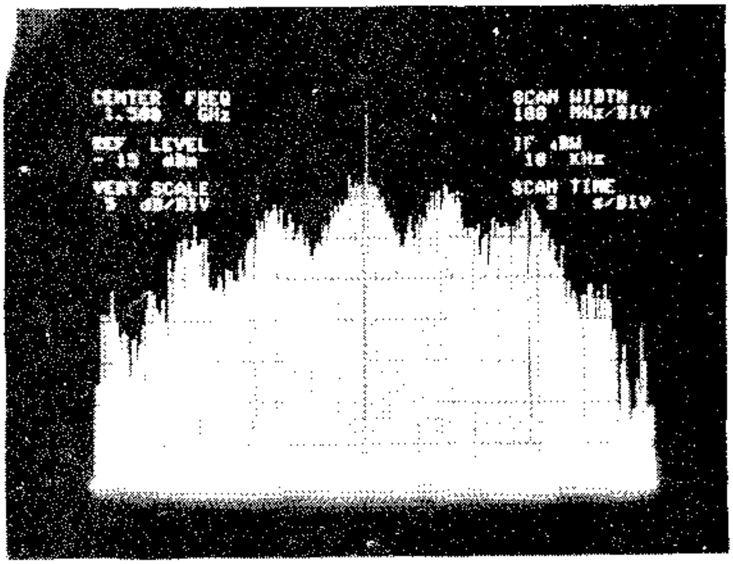


Figure 1-24. Impulse response from two reflectors. Relative amplitude of second reflectors is -8.7 dB with 6.0 ns time delay.



a) Single Reflector 250 m (folded) path
RF Attenuation = 40 dB
BER = 1 x 10^{-6}



b) Two Reflectors 250 m (folded) path
RF Attenuation = 40 dB
BER = 2 x 10^{-4}
Multipath Signal -8.7 dB, 6 ns delay

Figure 1-25. Plots of the 1.5 GHz sub-carrier amplitude for a single reflector and with added reflector at -8.7 dB in amplitude and 6 ns time delay.

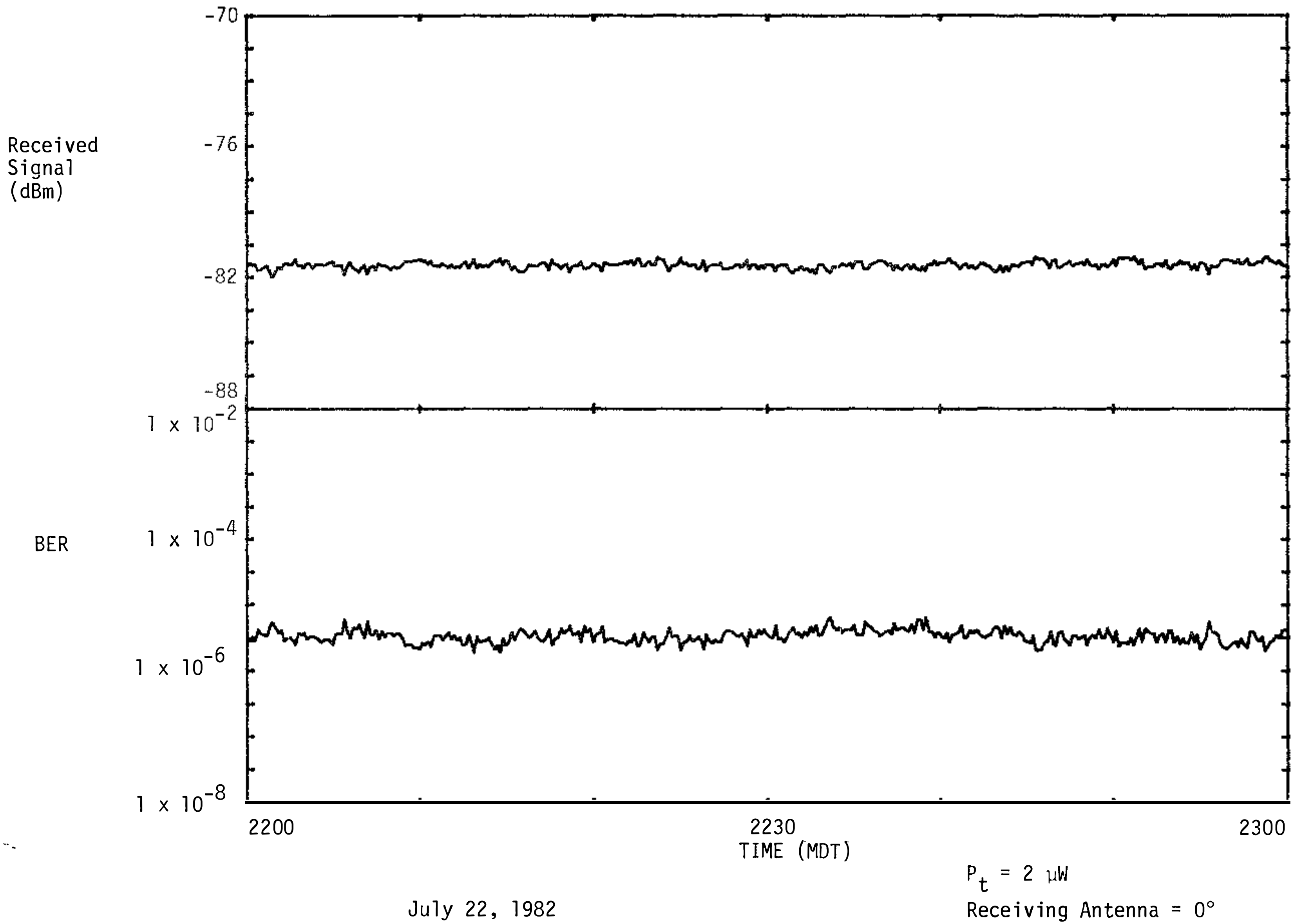


Figure 1-26. A plot of received signal level and BER for a calm period on the 12 km path with 30.3 GHz probe.

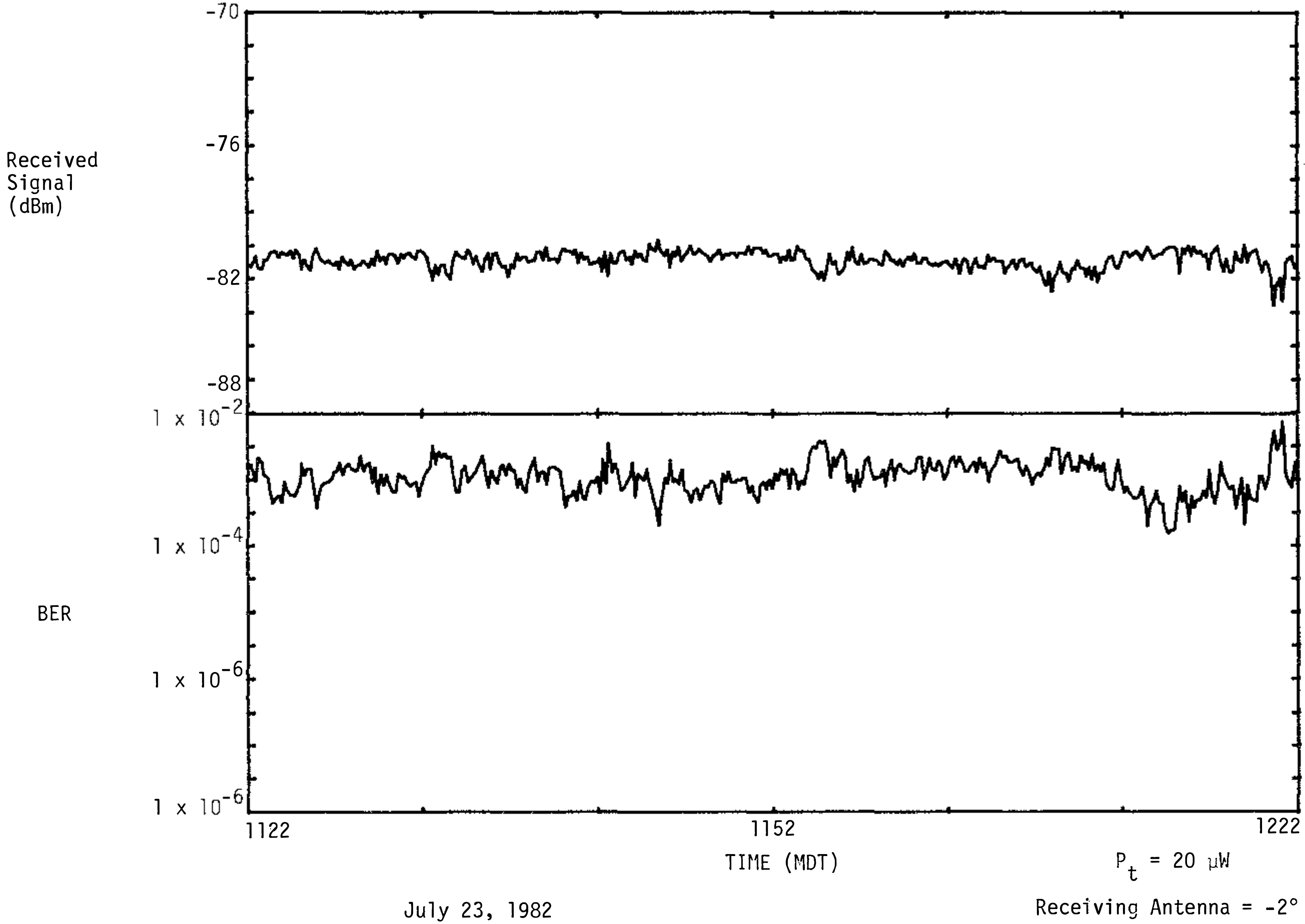


Figure 1-27. A plot of received signal level and BER for the 12 km path with the receiver antenna at -2^{o} elevation.

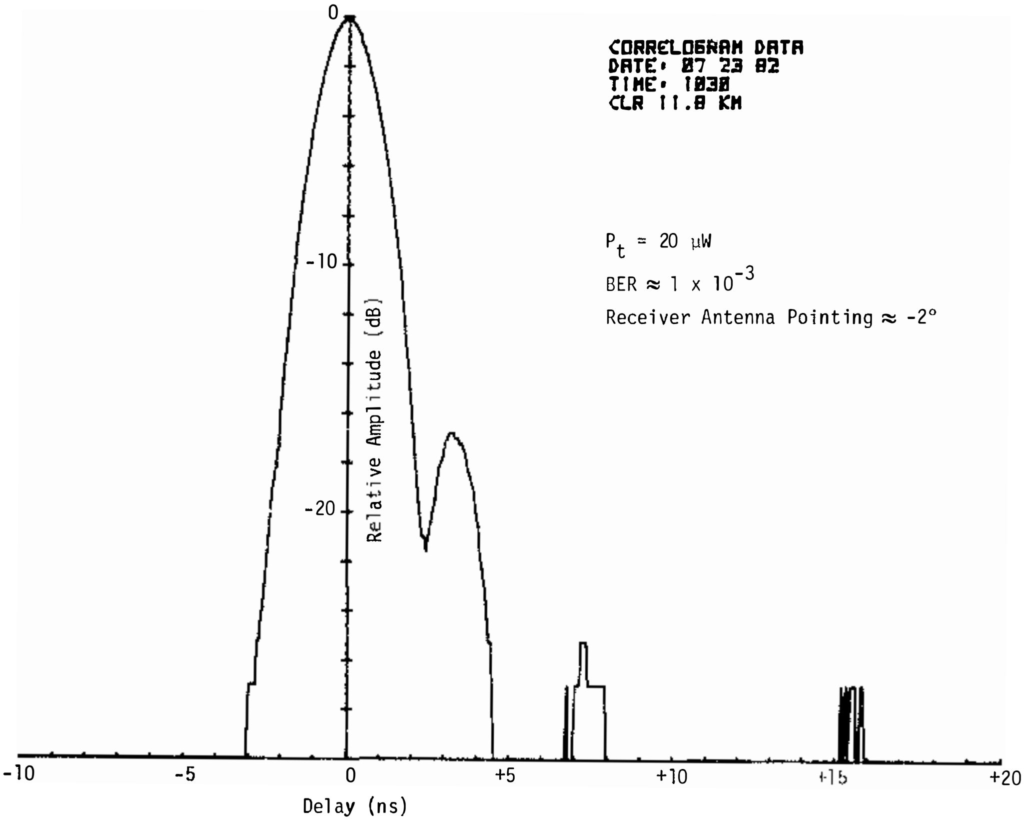


Figure 1-28. An impulse response curve showing the direct signal and a multipath signal delayed 1.5 ns.

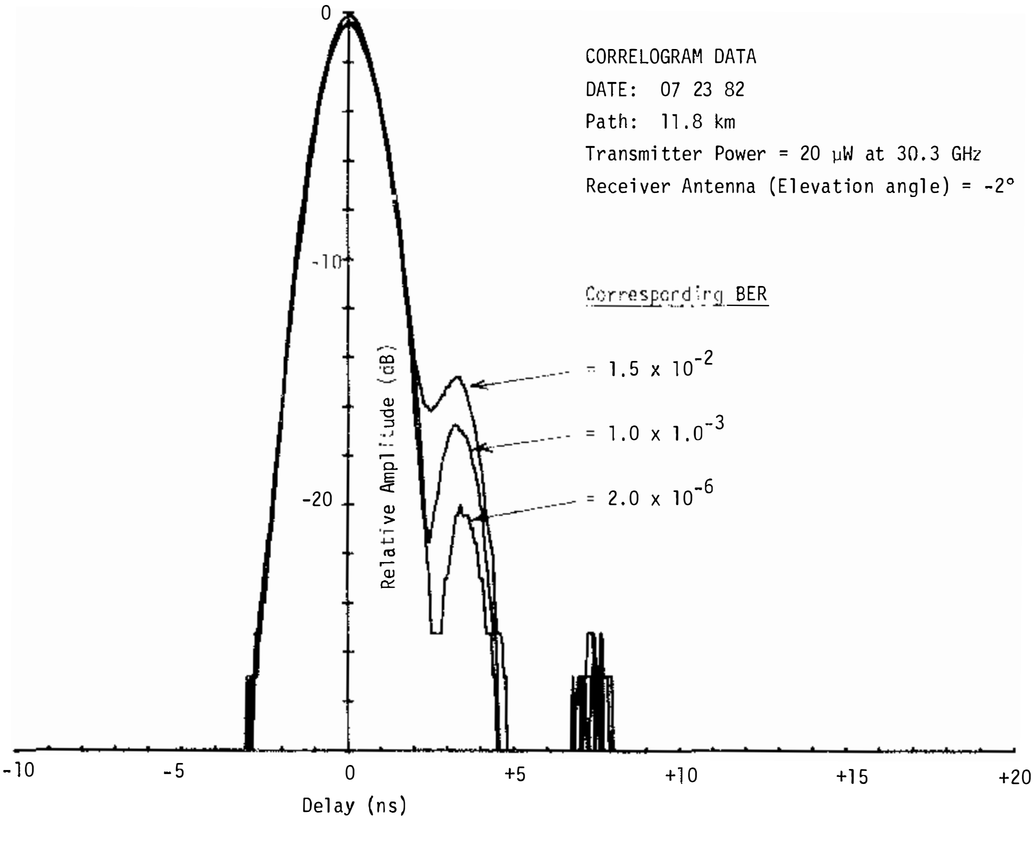


Figure 1-29. Three impulse response curves showing the effect of an atmospherically induced phase shift between the direct and multipath signals.

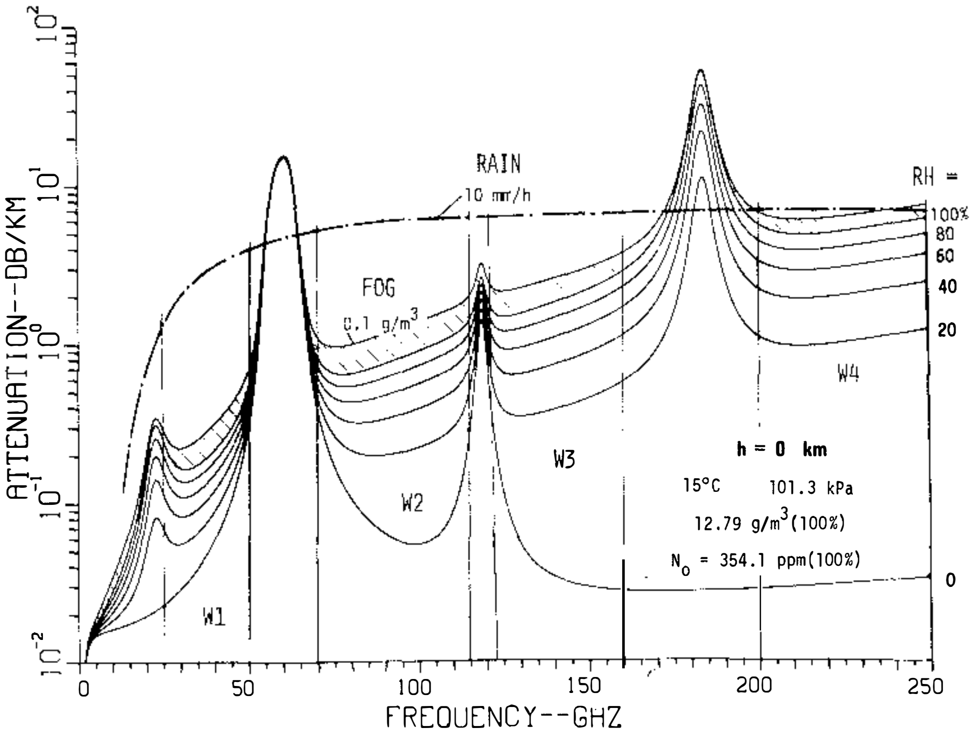


Figure 1-30. Specific attenuation at sea level over the frequency range 1 to 250 GHz for various relative humidities (0 to 100%) including fog (about 300 m visibility) and steady rain (R = 10 mm/h). The refractivity N_o is for saturated air.

obscures window transparencies for ground-based system applications. Magnitude and frequency-dependence of H_2O attenuation are distincly different for the same number of absorbers (1 g/m^3) in water, rain, hydrosol, moist air, and pure water vapor forms as depicted in Figure 1-31. The three atmospheric phase states lie between the extremes of continuum-type water (curve 1) and resonance-type vapor (curve 5) absorption spectra. Specific attenuations for rain, suspended hydrometeors, water vapor, and dry air were parameterized in terms of rain rate R (mm/h), water and vapor concentrations w and v(g/m^3), pressure p(mb), and temperature T(K). Elaborate, lengthy calculations which require specific drop size distributions, the complex refractive index of water, spectral data for 30 H_2O and 48 O_2 lines, etc., have been reduced to simple equations. They allow rapid estimations of window transparencies provided the meteorological variables of a radio path are available. The theoretical basis for water vapor continuum absorption was analyzed in more detail since it has been a long-standing source for speculations in the correct modeling of moist air behavior.

The cumulative zenith attenuation through the total atmosphere requires height profiles of R-w-pTv-distributions. Ten synthetic atmospherics from arctic to tropical climates have been analyzed. The example in Figure 1-32 is for the U.S. Standard Atmosphere. Air-mass-specific coefficients for zenith window attenuation and delay effects due to dry air, total precipitable water vapor (PWV), and water contents were obtained for arctic, standard, and sub-tropical atmospheres. The calculations are performed "layer-by-layer" in a spherically stratified model atmosphere encompassing 48 slabs between sea level and 30 km altitude.

An invited AGARD paper entitled the "Atmospheric propagation medium between 45 and 75 GHz" by H. Liebe (Conf. Proc. CP-331, 4/1-12) treats the unique oxygen absorption properties of the neutral air mass in great detail including the mesospheric Zeeman effects. Bandwidth limitation of this medium have been analyzed by employing various short-pulsed ($\leq$ 1 ns) test signals and Fast Fourier Transform (FFT) algorithm.

The physical propagation model developed by the Institute provided the basis for a statistical study entitled "Climatological influences on system performance at selected U.S. locations" covering 18 population centers in the United States. An example of gaseous absorption variability (clear air) is depicted in Figure 1-33. Rain presents the most serious limitations to system performance. Costly design decisions hinge on adverse weather statistics. For example, rain rate extremes for the value not to be exceeded by more than one hour during a year (0.01% reliability), lie in the continental U.S. between 7 (Arizona desert) and 115 mm/h (south Florida). This means a difference of about 1:20 in dB for designing a system with the same reliable performance. This study provides valuable data for assessing the feasibility of considering millimeter wave systems in various parts of the U.S., since, even with technological advances, the adverse weather effects remain the ultimately limiting factor for system applications.

In a project whose objective is to develop a Rain Rate Model, a survey of rain effects, primarily attenuation associated, is being conducted as part of an effort to assess the feasibility of using portions of the upper SHF and lower EHF spectrum in military tactical situations involving point-to-point terrestrial links. It has been tentatively decided to subdivide the survey in the following manner:

1. Rain Effects at Millimeter Wavelengths
   - A. attenuation
   - B. polarization sensitivity and depolarization
   - C. scattering and interference

2. Rain Effects on Communication Links in the Tactical Environment.

Part 1 will concentrate on the theoretical aspects of the problem, and Part 2 will concentrate on the operational aspects of the problem with the most likely applications in tactical environments.

As an example of some of the theoretical aspects that must be considered at these frequencies, Figure 1-34 shows the specific attenuation (attenuation per unit length) for surface rain conditions that might occur in a tropical situation (West Palm Beach, Florida), a temperate situation (Washington, D.C.), and a desert situation (Yuma, Arizona) for rain rates expected 0.01 percent of an average year. Note that this figure, having used only locations in the United States, will most likely not be representative of worldwide extreme conditions, but it does give an indication of frequency and climatic behavior.

In the Millimeter Wave Laboratory Studies project the physical basis for modeling millimeter wave propagation effects can be improved by performing controlled laboratory experiments. Assessing individual contributions to specific attenuation is difficult from measurements in the actual atmosphere. Reliability, precision, and scale of supporting meteorological data compromise the quality of most field observations. Three key elements were completed to serve a definitive study of millimeter wave attenuation by moist air. They are:

- o computer-controlled spectrometer (see schematic in Figure 1-35)
- o high humidity simulator (RH $\leq$ 101%)
- o atmospheric EHF propagation model.

The Millimeter Wave Laboratory Studies project continued to perfect the spectrometer performance for 140 GHz attenuation measurements. The data acquisition is now fully computer controlled, and two test runs over 10 days each have been completed. Most of the software has been developed for running the experiment and for data reduction and plotting of several thousand data pairs. An example is given in Figure 1-36.

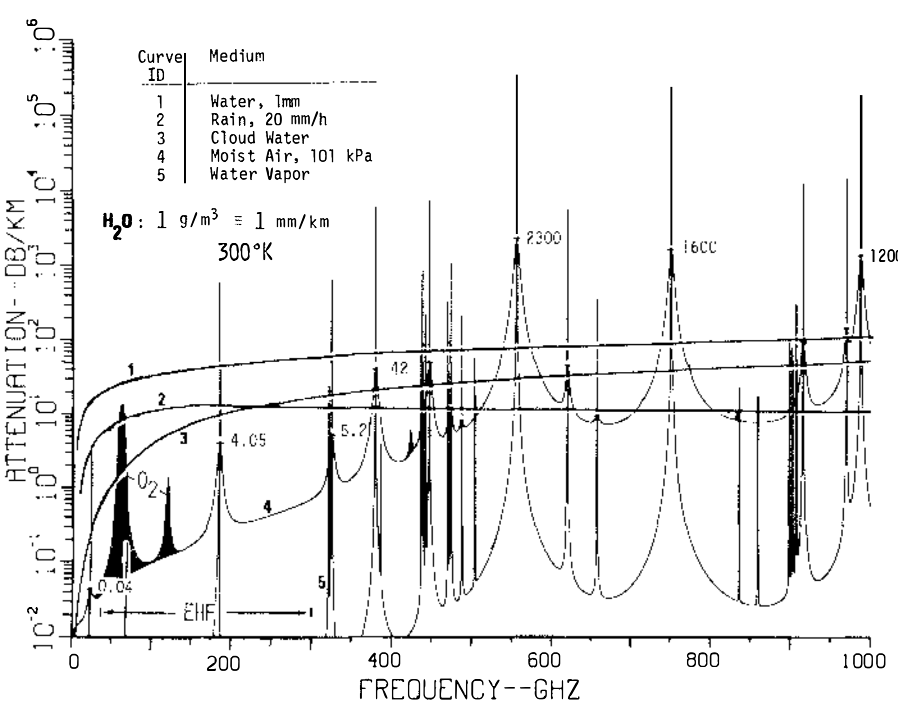


Figure 1-31. Normalized specific H_2O millimeter wave attenuation for 1 g/m^3 at 300 K displaying five phase states: water (1), rain (2), suspended hydrometeors (3), moist air (4), and pure water vapor (5).

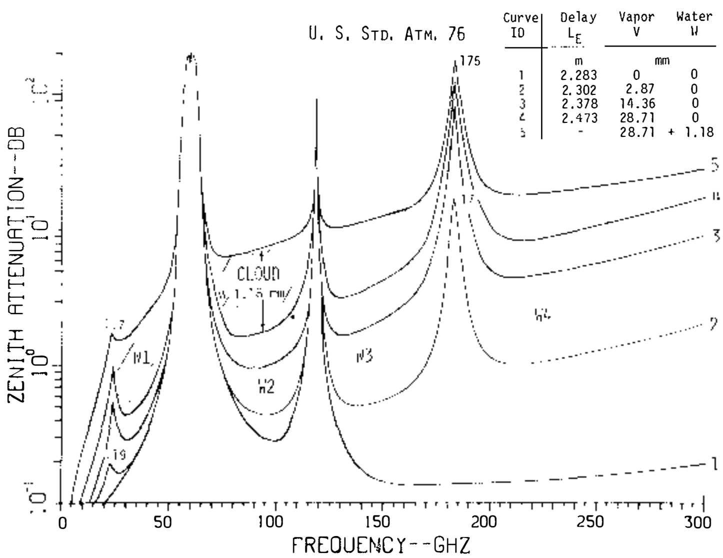


Figure 1-32. One-way zenith attenuation through the U.S. Standard Atmosphere 76 over the frequency range 5 to 300 GHz in 2.5 GHz steps for dry (1), moist (2), humid (3), and saturated (2.87 cm PWV) air (4); and for (4) containing a rain-bearing cloud with 1.18 mm liquid water content (5).

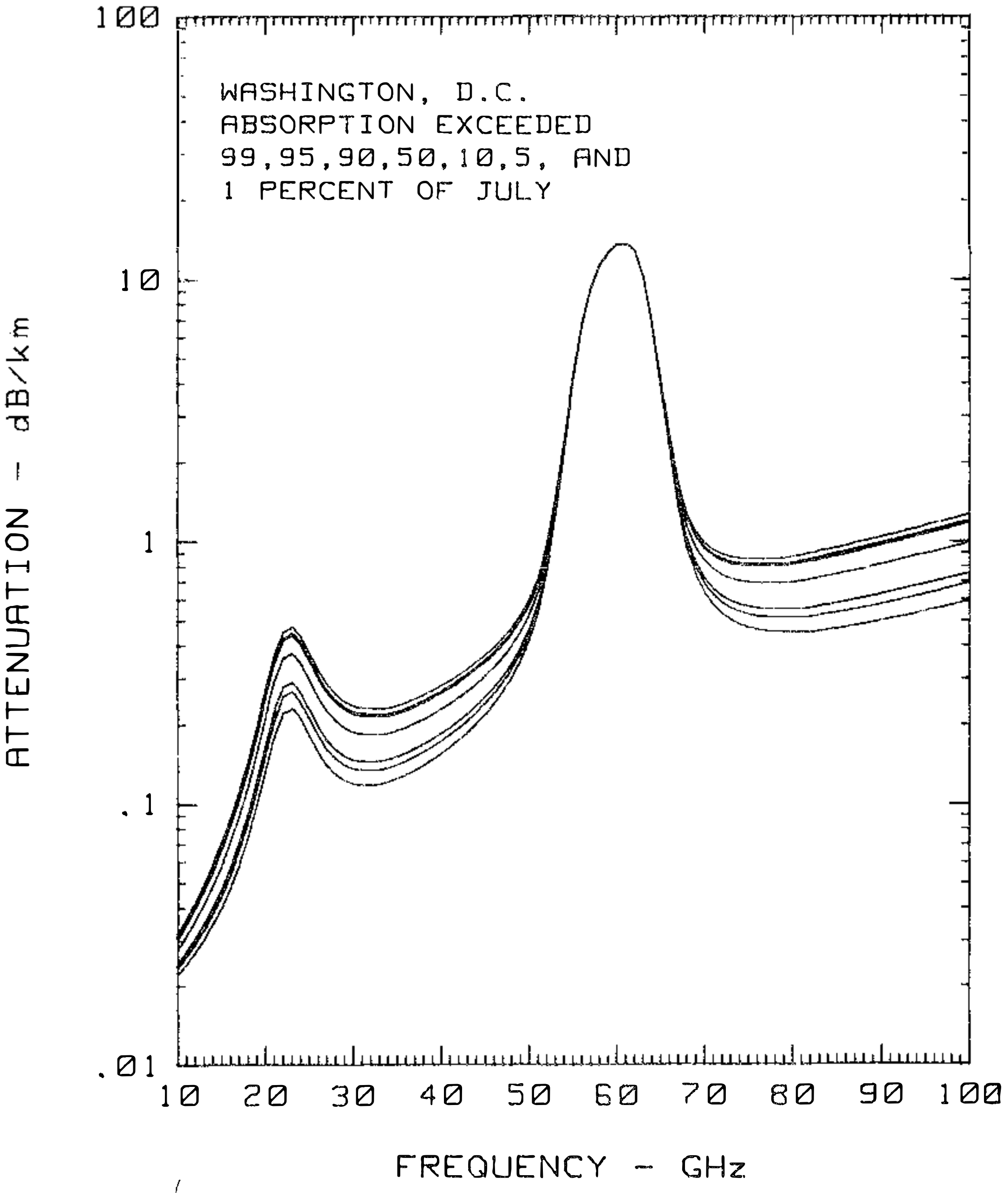


Figure 1-33. Statistical terrestrial path attenuation in clear air over the frequency range 10 to 100 GHz for the worst month (July) in Washington, DC.

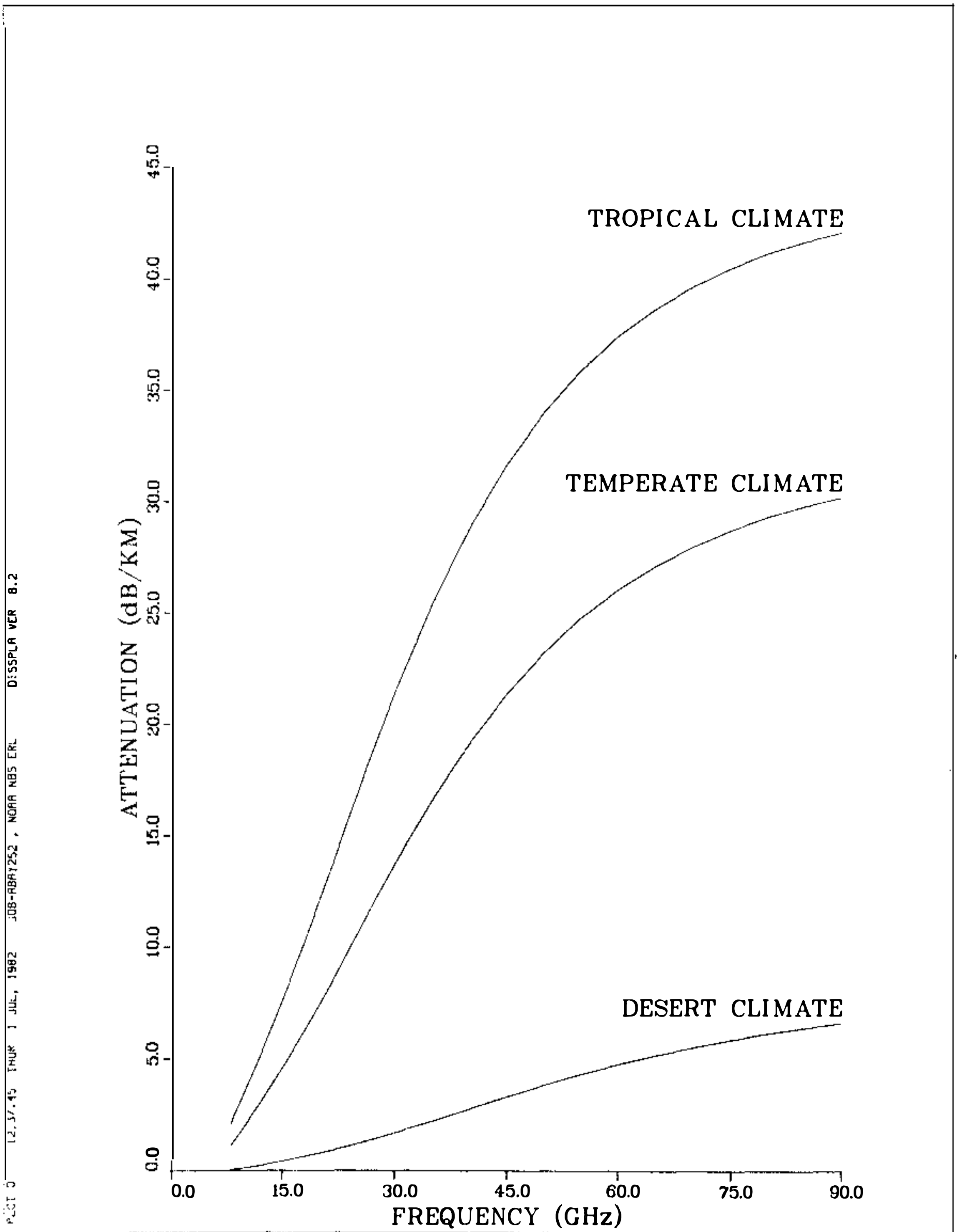


Figure 1-34. Variation of specific attenuation with frequency in the USA for locally heavy rain rate conditions, expected 0.01 percent of an average year.

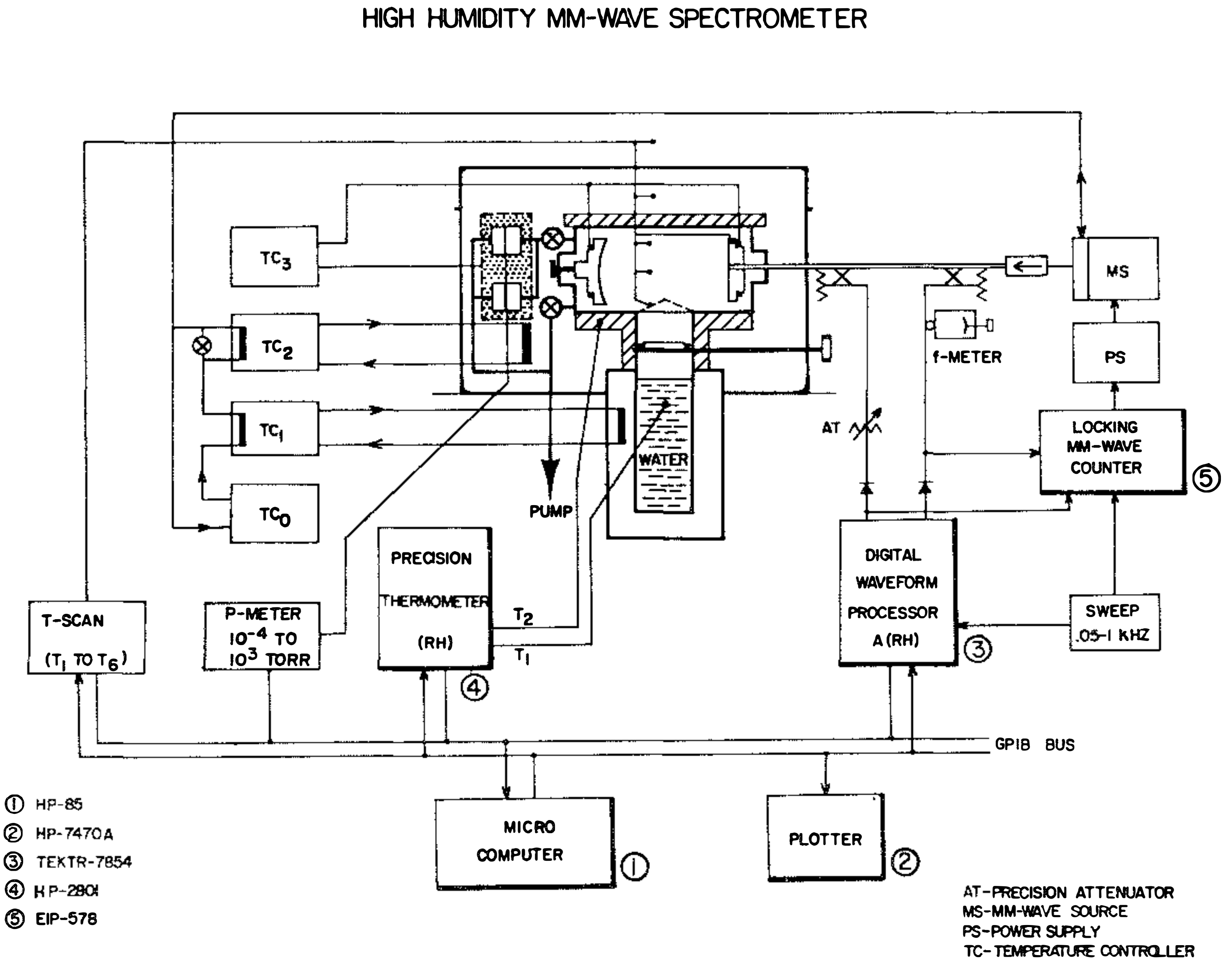


Figure 1-35. Schematic of millimeter wave spectrometer for measuring absolute attenuation of moist air (RH = 0 to 100%).

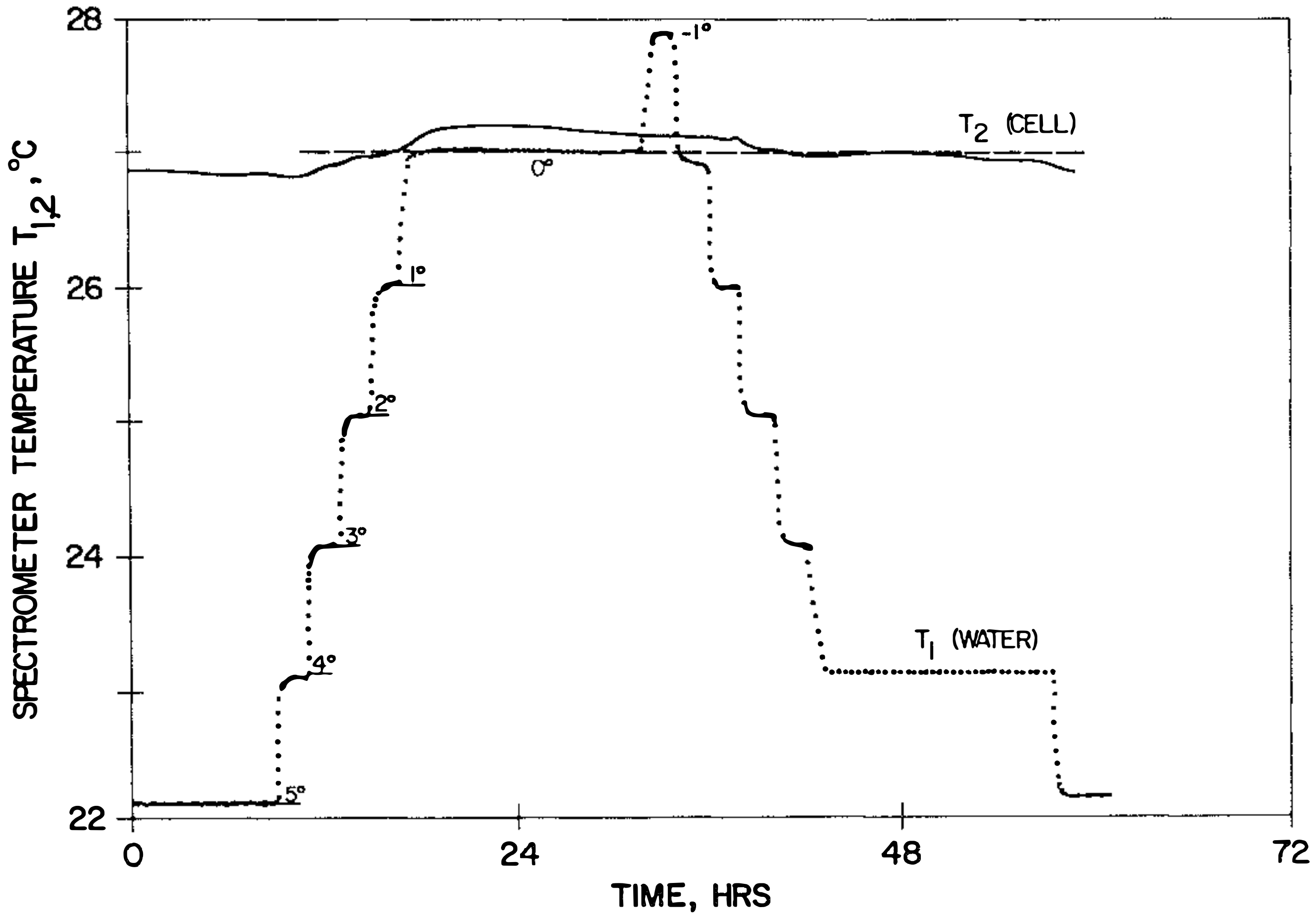


Figure 1-36. Example of 3-day data run to simulate various humidities in spectrometer cell.

A final report entitled "Molecular absorption test at 35 GHz" was published as NTIA Report 82-96 describing in detail the experimental and analytical efforts for estimating possible excess absorption in sea level air due to various trace gases (e.g., H_2O_2, HNO_3, NO_2, N_2O). This report was the result of the Trace Gas Attenuation of Air project.

As part of the Vegetation Millimeter Wave Propagation project, a measurement program was conducted in FY81 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 FY81 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 FY82 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, Texas, 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. For certain paths, a comparison of the orchard data to the Colorado data was possible and showed quite similar results as expected since propagation at trunk level and through branches and stems is little affected by climate.

The results obtained in April regarding vegetation losses as a function of foliage depth is shown in Figure 1-37. Plotted is the vegetation loss per tree in dB relative to the number of trees on the path as a function of frequency and 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 level. The significant finding is the rapid roll-off of loss per tree as the number of trees in the path increased. Even for the defoliated state the losses at the 1 meter height are less than at 4 and 6 meters although the opposite was true from a visual observation. No branches or twigs were in the path at the 1 meter height and the grove was completely devoid of underbrush. Propagation at 1 meter in this case was via edge diffraction and surface reflection whereas at branch level narrow apertures of line-of-sight and multiple scattering provided the path to the receiving antenna.

Several sets of data were recorded to measure the received signal level with the transmitter moving along the perimeter of the grove with the receiver at various locations in the grove. One of these runs is shown in Figure 1-38 where the receiver was located at a depth of 720 meters into the grove 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 1-38 were recorded. The highest received levels for each frequency occurred in the line-of-sight portion of the scan where greater than 1st Fresnel 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 is the general high signal levels when the path was non-line-of-sight considering the distance and number of trunks which obstructed the path.

A second measurement series was conducted in August which repeated the April measurements to determine the added losses and propagation differences that occurred with the leaves present. At the time of this writing, the August data have not been reduced.

Of the models tested the transport theory predictions best fits the data. The roll-off of vegetation loss with increasing depth was predicted by this model with good agreement. The higher attenuations at short ranges are primary coherent scattering components but at greater depth, incoherent scattering components remain.

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 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

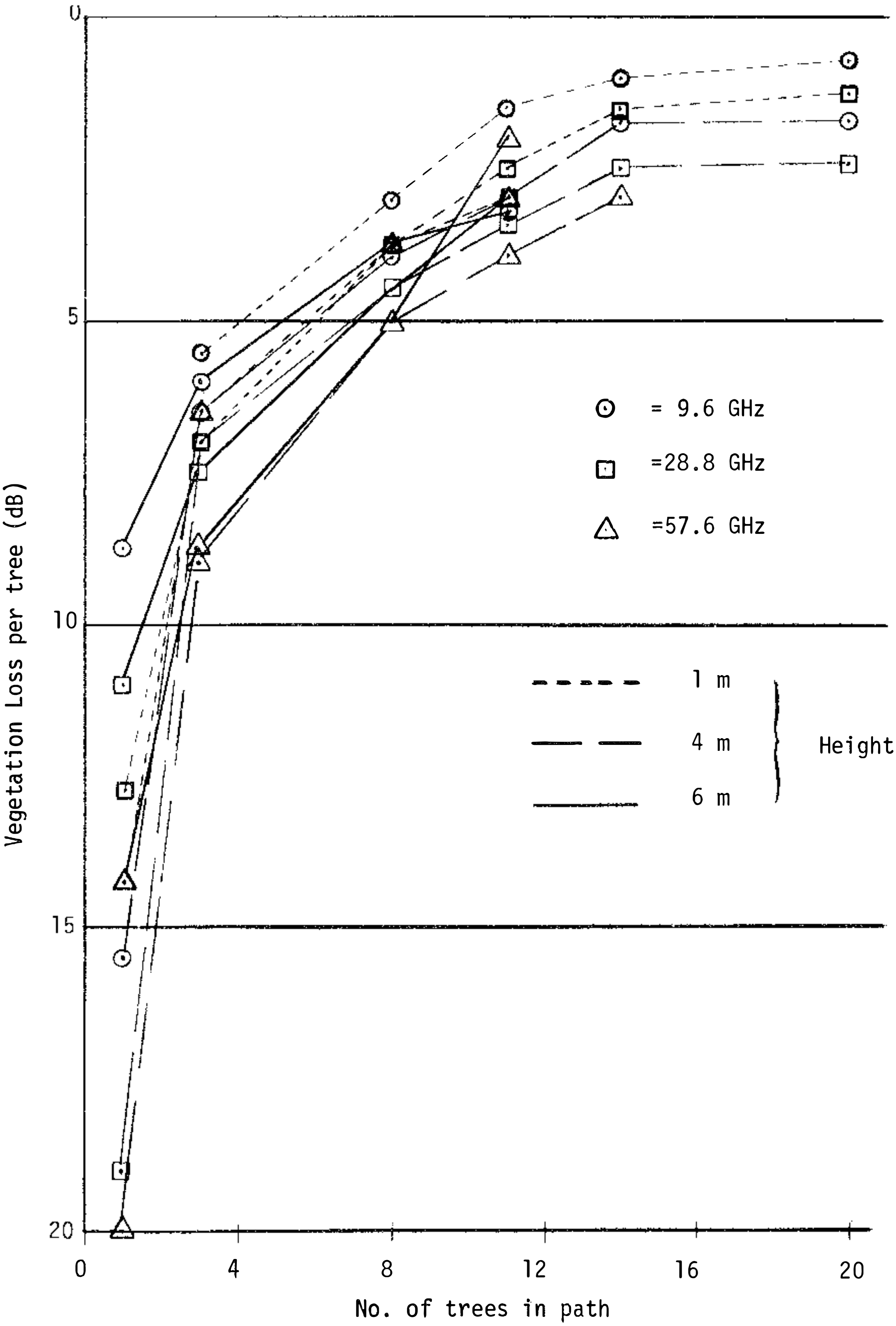


Figure 1-37. A plot of vegetation loss per tree relative to number of trees in path as a function of frequency and terminal height above ground with trees in a defoliated state.

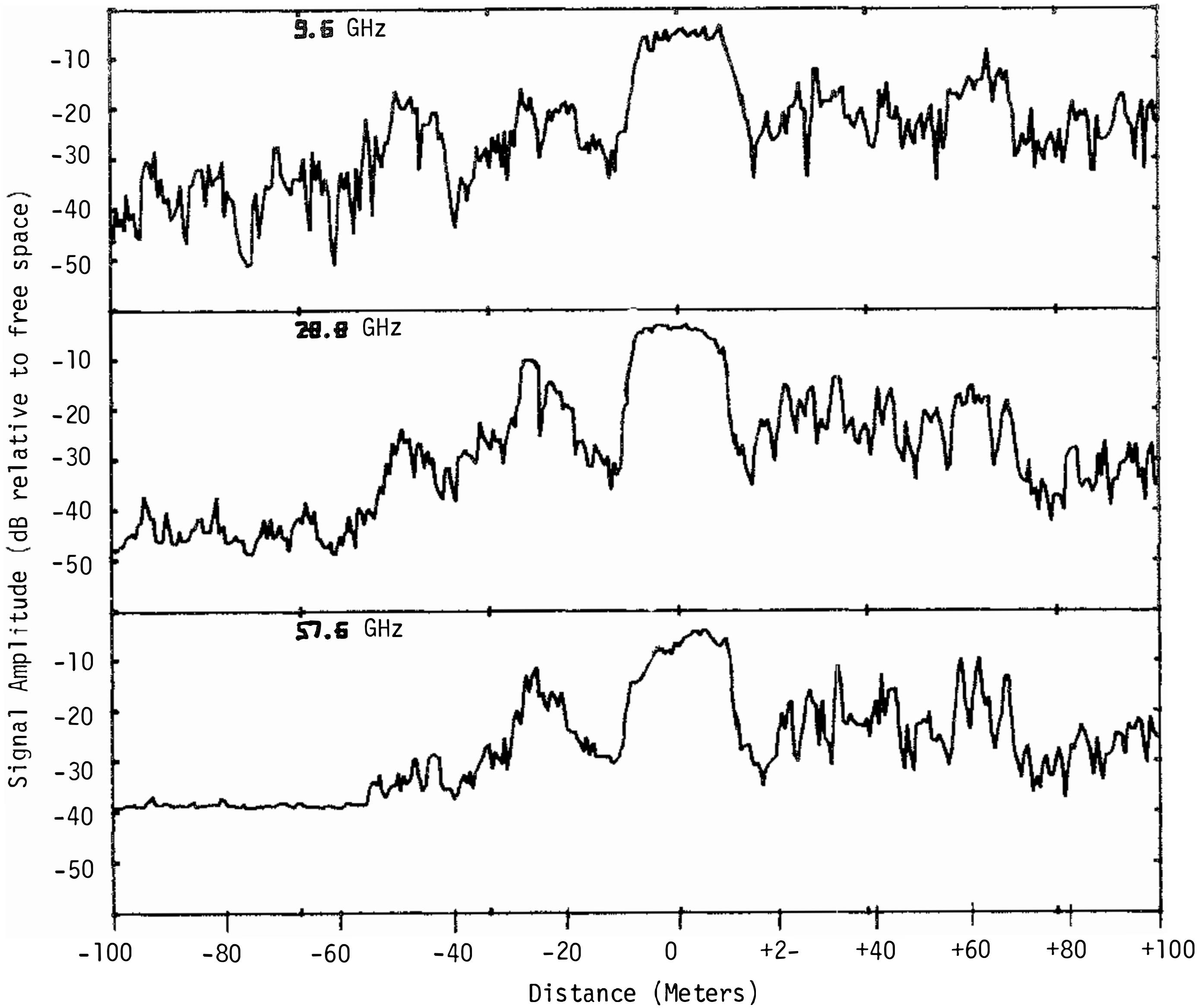


Figure 1-38. Received signal amplitude for 9.6, 28.8, and 57.6 GHz, with the transmitter moving along an arc at the edge of the grove and the receiver at a location 720 meters into the grove.

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 kilometer in the center of the Denver metro area using vertical, horizontal, and crossed antenna polarization. Figure 1-39 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 (nonurban) area to aid in separating ground multipath (asphalt road or street) from other reflecting paths. Figure 1-40 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 which 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 decreasing with increasing frequency.

By means of a horizontal angle scan with 1 degree beamwidth receiving antennas, the angle of arrival of signals propagated down a street surrounded by buildings was plotted. Figure 1-41 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 degrees is the line-of-sight signal and all other signal peaks are reflection 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 degree antenna beamwidths a 25 mb/s link could run with little intersymbol interference.

Army-owned 60 GHz handheld communicators were also used in this exercise. Voice quality was always good when frequency lock-up was achieved but the long time required to lock up, due mostly to signal fades and off angle signals, caused difficulty in establishing a contact. Several non-line-of-sight contacts were made from a single reflection from buildings or objects along the street over about a 400 meter path, all with good voice reception.

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 the National Telecommunications and Information Administration, 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.

In order to aid the prospective user, and in particular the prospective modeler, with background material on atmospheric and terrain effects of the propagation medium at these frequencies, ITS has undertaken a bibliography and article synopsis as part of the Millimeter Wave Model literature survey. The bibliography and synopsis should be available early in Fiscal Year 1983.

There should be nearly 1000 papers, reports, and books that are actually incorporated into the bibliography. All of the papers, reports, and books included in the bibliography were surveyed to determine their potential value to a propagation effects modeler, on the basis of their titles and abstracts. If those appeared promising, the actual paper, report, or book was examined. Even some of these were not adjudged to be as valuable as others, so that finally only 60 papers and reports were selected for the brief commentary and synopsis section.

For convenience to the reader and prospective millimeter-wave-region propagation models, it is planned to subdivide the bibliography into the following propagation-related topics:

1. Ray Tracing Effects
   - A. Refractive Index
   - B. Ray Tracing and General Wave Equation Solutions of Interest
   - C. Angle of Arrival
2. Transfer Function Effects
   - A. Line-of-Sight and Terrain Multipath
   - B. Vegetation
   - C. Diffraction
   - D. Gaseous Absorption, Delay, and Dispersion
   - E. Unstable and Stable Clear Air
     - 1) Turbulence
     - 2) Stratification and Ducting
   - F. Inclement Weather

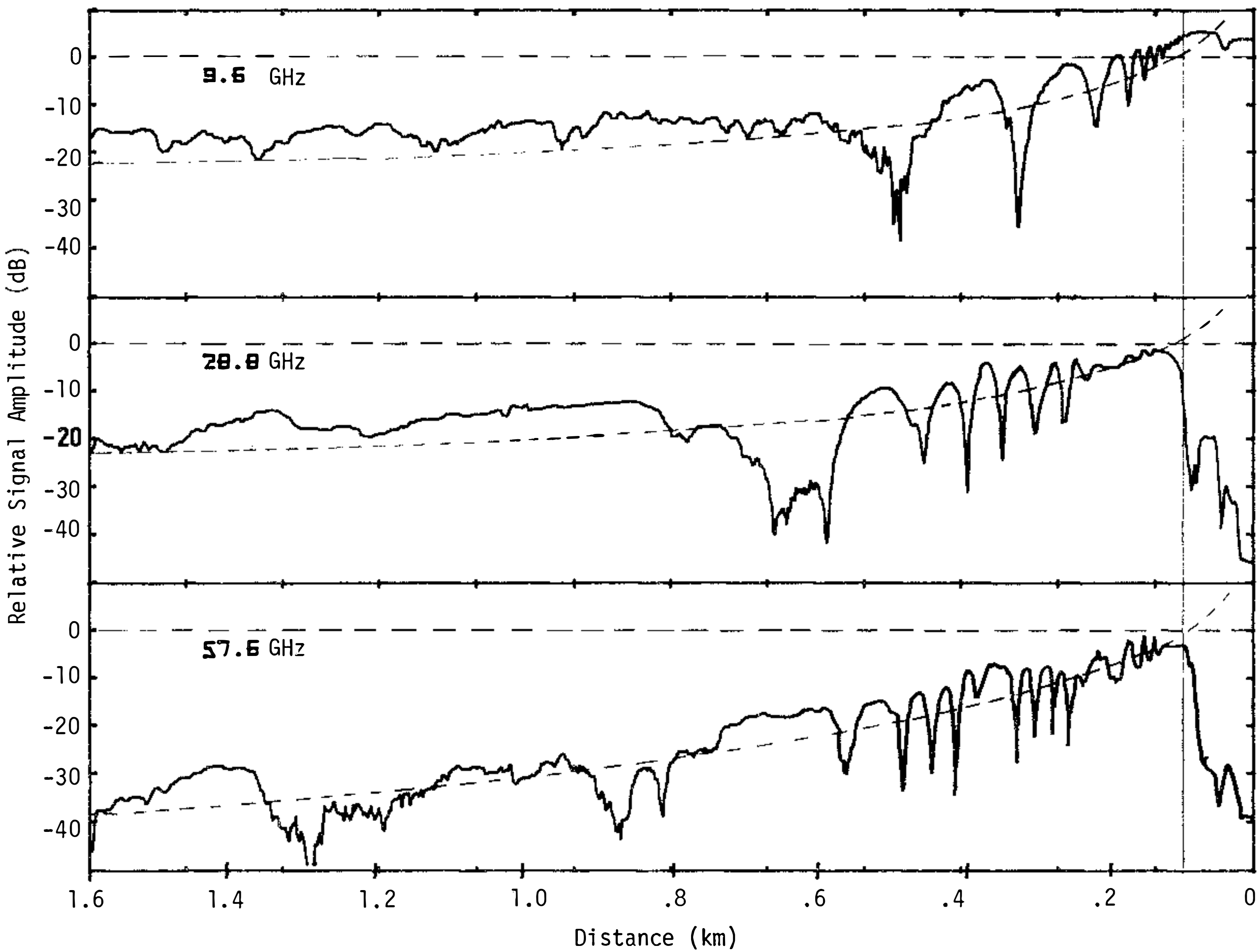


Figure 1-39. Signal amplitude recorded as a function of distance between the transmitter and receiver along a street in the Denver metro area.

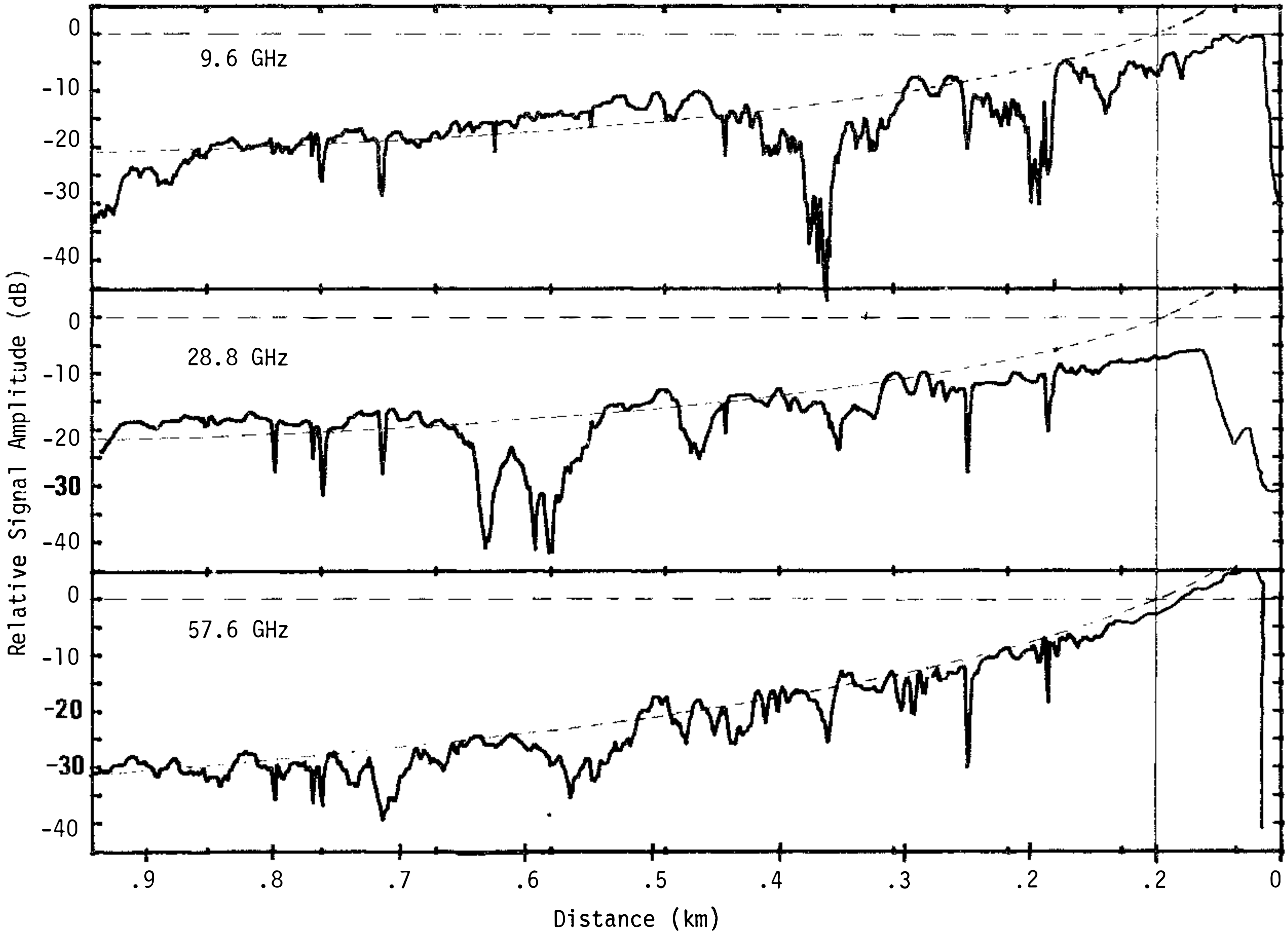


Figure 1-40. Signal amplitude recorded as a function of distance between the transmitter and receiver along an asphalt road in a rural area.

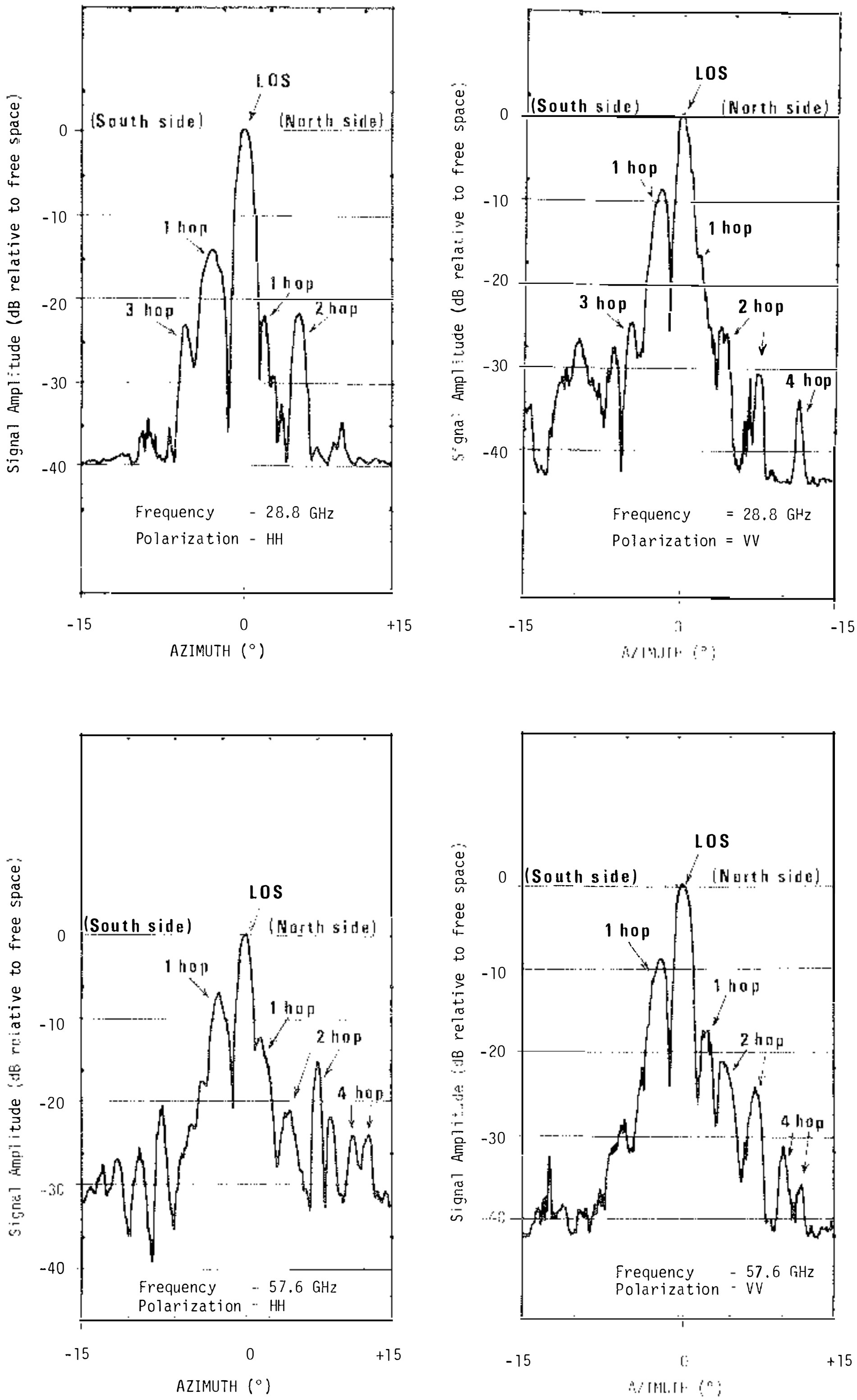


Figure 1-41. Signal amplitude as a function of azimuth scan for horizontal-horizontal and vertical-vertical antenna polarizations at 28.8 and 57.6 GHz. These recordings are for a 485 meter path down a street in the Denver metro area and show the effect of reflections from buildings.

1) Rain, Clouds, and Other Hydrometeors
2) Sand, Dust, and Smoke

G. Depolarization

3. Atmospheric Noise Effects

4. Miscellaneous Articles

In 1973, the first version of the Dutton-Dougherty model for prediction of the distribution of attenuation due to clear air gases, clouds, and rain for use on microwave, earth-satellite links was published at ITS. This model was refined in 1977 and 1978 and compared with data available at that time, which also included prediction distributions for several different locations. At that time, the concept of year-to-year variability of the attenuation distributions at a given location became an integral part of the Dutton-Dougherty (DD) model.

The 1977 version of the DD model predicts the probability, $P(A > \tau_f)$, that a given attenuation, τ_f at frequency, f, is exceeded during a year, and that this value was limited to

$$P(A > \tau_f) \geq 0.0001, \qquad (a)$$

or 0.01 percent of a year. The parameter A represents some random value of total earth/space attenuation. For many users, however, even higher system availabilities (the complement of P) than that represented by (a) are required. For this reason it became desirable to attempt to extend the DD model to the 0.001 percent level, or

$$P(A > \tau_f) \geq 0.00001. \qquad (b)$$

This work was performed as part of the NASA Propagation Studies project.

Through a derivation process involving a spherical convective storm model, and realizing that practically all storms are convective between the 0.01 percent and 0.001 percent levels in the U.S.A., an extrapolation procedure to the 0.001 percent level can be obtained. Figure 1-42 shows the prediction to 0.001 percent. There are five prediction curves (solid curves) on the figure for Washington, D.C. The middle curve is the median prediction curve, the inner two curves surrounding the median curve cover the 90 percent confidence interval in year-to-year variability, and the outer two curves cover the 99 percent confidence interval in year-to-year variability of the prediction. Two years of data (1977-1978) are shown as the dashed curve on Figure 1-42 for comparison.

The present, or "standard" version of the DD model uses a distribution of raindrop sizes in a cubic meter of air given by expressions which are in the exponential form of the classic Marshall-Palmer (MP) drop-size distribution, but with half the intercept value. Attenuation per unit length, or specific attenuation $\alpha(f,h)$, due to rain can be calculated from liquid water content $L(h)$, of a cubic meter of air at height, h, via expressions of the form

$$\alpha(f,h) = c(f)[L(h)]^{d(f)} \quad , \qquad (c)$$

where c(f) and d(f) are frequency-dependent coefficients. Comparisons have been made with several other methods for modeling specific attenuation and drop-size distribution. For example, Figure 1-43 shows the five prediction curves for the same conditions at Washington, D.C., as in Figure 1-42, except that the specific attenuation is derived from the procedure of R.L. Olsen, L., D.V. Rogers, and D.B. Hodge (The aR^b relation in the calculation of rain attenuation, IEEE Trans. Ant. & Prop. AP-28, No. 2, pp. 318-329, March 1978), and the full MP drop-size distribution (i.e., with the full intercept value). The results of Figure 1-43 tend to indicate that the DD model Figure 1-42) gives tighter bounds, and just as good a prediction, based on available data (the dashed curve in both Figures 1-42 and 1-43) as do other alternative methods.

The objectives of Southern California Propagation Study addressed somewhat lower VHF and UHF frequency range. 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 for Telecommunication Sciences has provided the FCC with the following specific items of information:

(1) a review of the propagation phenomena involved that is based on available theoretical and empirical studies and interference reports;

(2) recommendations as to paths, recording sites, and transmitting sites required to obtain needed data;

(3) recommendations as to signal sources;

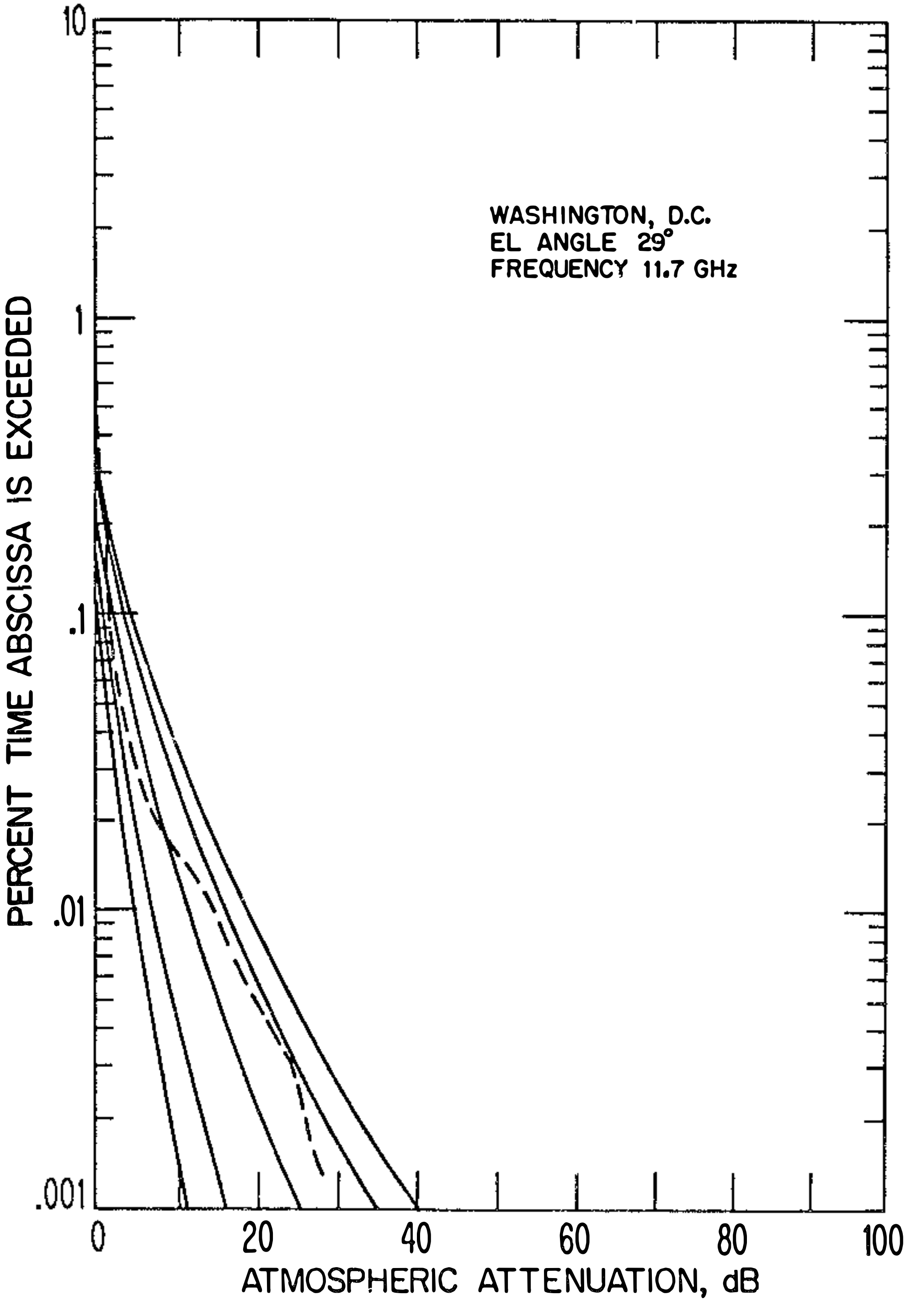


Figure 1-42. Comparison of the DD model obtained by extending to 0.001% of a year for Washington, DC, at an elevation angle of 29°, and a frequency of 11.7 GHz, with two years of data (1977-1978) observed for the same conditions at Greenbelt, MD.

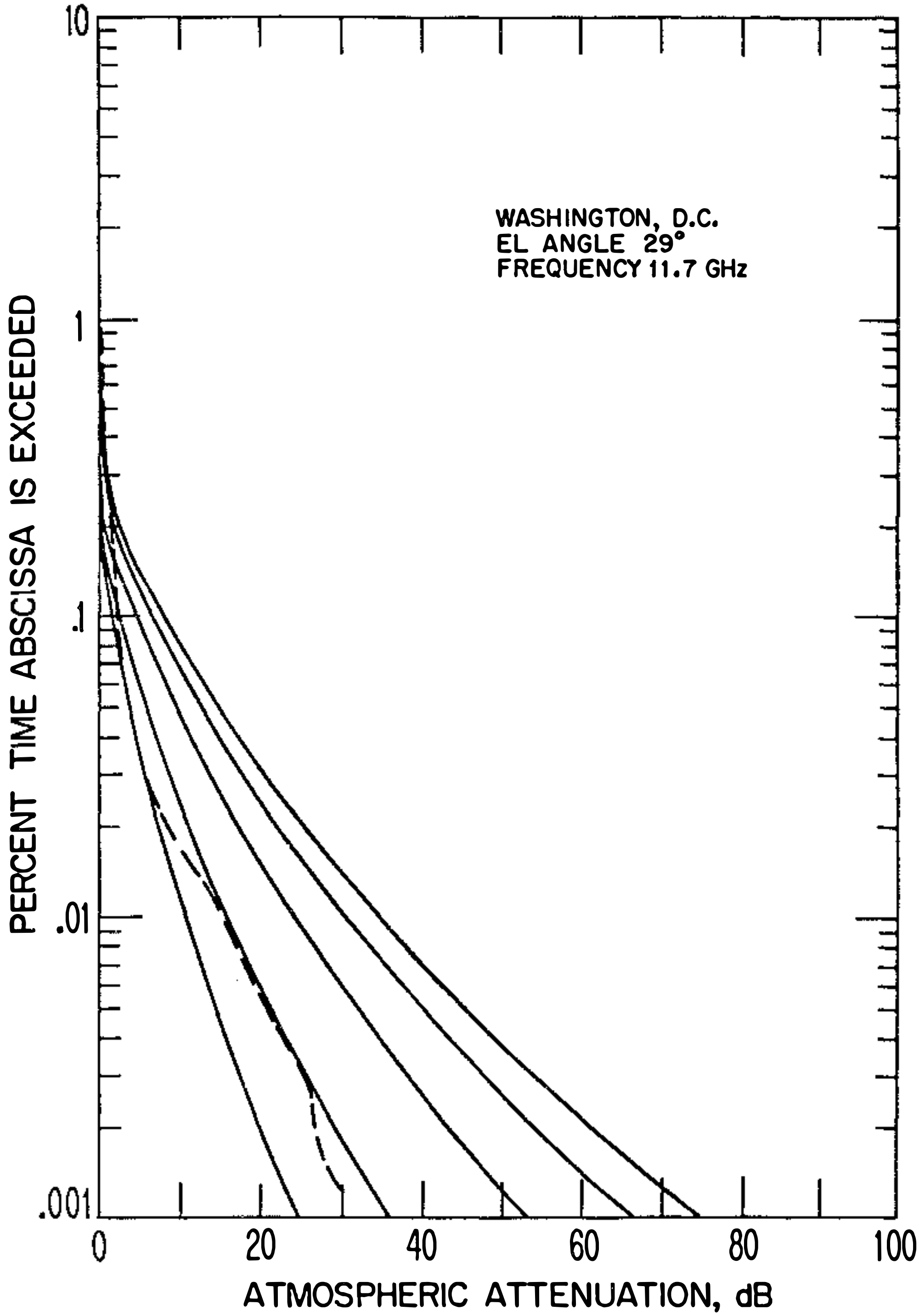


Figure 1-43. Comparison of the DD model using the Olsen et al. specific attenuation coefficients and the full MP drop size distribution with the same data and for the same conditions of Figure 1-42.

(4) recommendations as to desirable data sampling rates, amount of on-site data reduction, and statistical parameters to be recorded for reduced data; and

(5) recommendations as to meterological 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 1-44 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 1-8 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 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 1-8. Received 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.

With the data we expect to explore the correctness and pertinence of existing models such as that reported by the CCIR or, perhaps, to devise new, more extensively applicable models. One approach, for example, would be 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.

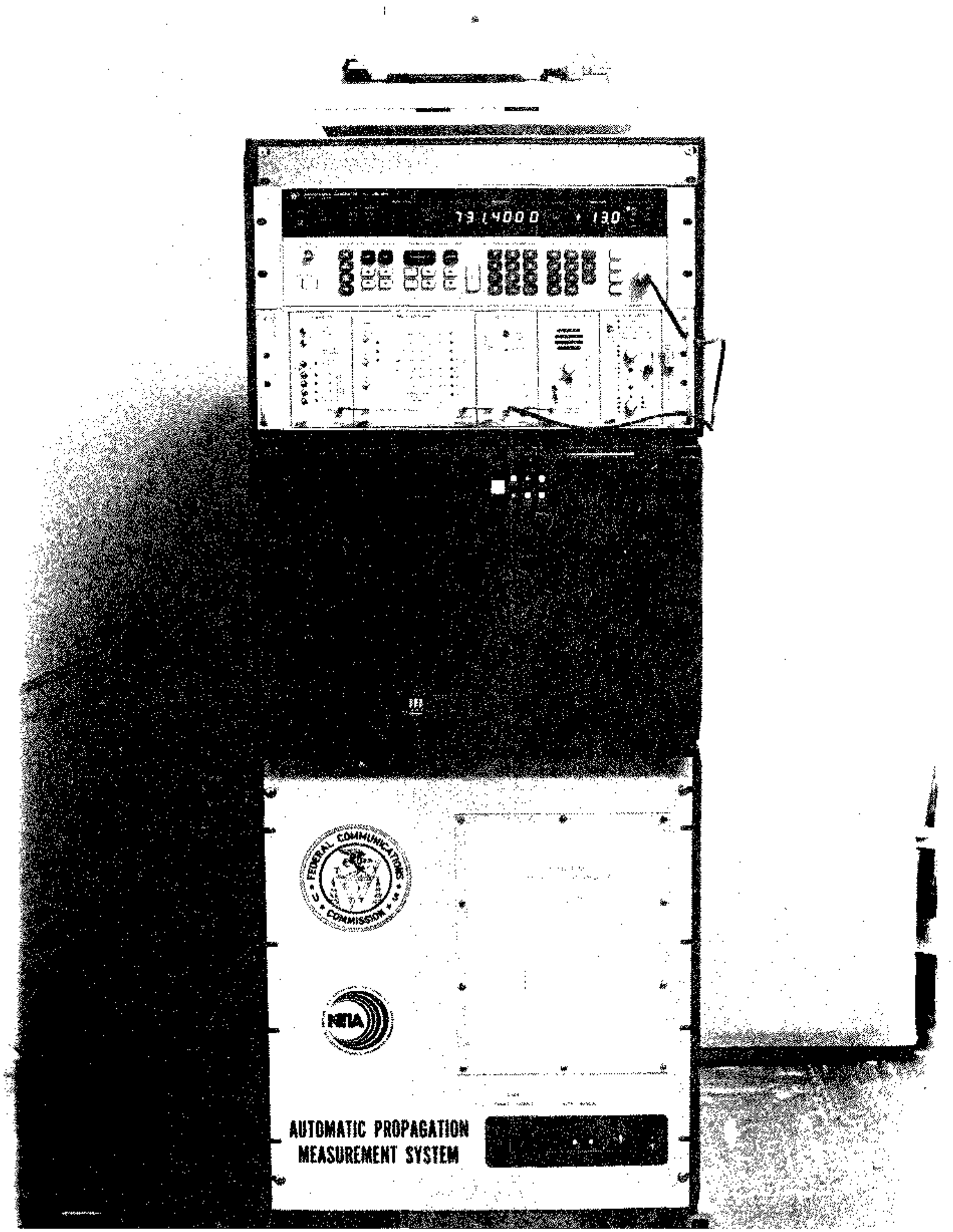


Figure 1-44. The Automatic Propagation Measurement System. Three of these are being used in the Southern California Propagation Study.

One can imagine several protocols for establishing the required link. One that comes immediately to mind is presently used in the "meteor burst communication" systems which 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 therefore immediately transmits its message before the meteor trail has had time to disperse.

There are two main aspects to this project. One of these 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. And, 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.

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 1-45 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% reliability, the one line of text will be received within 15 s in the morning and within 42 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 which is 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% 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, etc.) and some study of unusual propagation mechanisms (i.e., off-path reflection or ducting, etc.) 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.

At the HF portion of the spectrum, the Ionospheric Communications Analysis Prediction Program (IONCAP) is the most recent of the prediction programs developed at the Institute for Telecommunication Sciences (ITS). The computer program is an integrated system of subroutines designed to predict high-frequency (HF) 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.

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 TIME MIDPOINT BETWEEN MASTER AND REMOTE	AVERAGE INTERVAL BETWEEN BURSTS (SEC)	USER-DEFINED 75 MS (SEC)	WAITING TIMES NOT EXCEEDED FOR 99.00% OF THE TIME FOR THE GIVEN MESSAGE TIME: 50 MS (SEC)	100 MS (SEC)	200 MS (SEC)	400 MS (SEC)	800 MS (SEC)	1600 MS (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 1-45. Meteor-burst communication model input parameters (a) and output parameters (b).

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 (HF) circuits which have 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:

1. 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.

2. 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.

3. Explicit sporadic E modes have been added to the program. The model is composed of subparts which have been derived from and tested against measurements over the past 30 years.

4. 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.

5. An MUF model has been added which 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.

6. The distribution of tranmission 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.

7. Some modifications to the antenna models have been made, the most significant being for vertical antennas which are electrically short.

8. 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.

As part of the HF Antenna Simulation project 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.

Radio waves under consideration here have been reflected from the ionosphere and thus have traveled a considerable distance. This allows the problem to be viewed as two parts: (1) the local effect of the ground at the transmitting site on the antenna, and (2) the local effect of the ground at the receiving site on the antenna. Further, the assumption of plane-wave reflection is justified for this sky-wave case.

The analysis of the antenna models was broken into two logical subdivisions:

(a) the exterior (radiation) problem, which deals with the interaction of the antenna with the propagation medium; and

(b) the interior (circuit) problem, which deals with the interaction of currents, voltage, etc., within the antenna system itself.

The solution to the interior problem is implemented as precalculated curves or as measured curves where available. The exterior problem is implemented using the equations as developed by ITS. For arrays of dipoles, the practice of expressing the array equations as that of the resonant dipole element and a reduced array factor is used. This procedure results in a computer code which is quite stable and fast in running time. There are no matrix inversion routines nor any use of the complex arithmetic routines.

The work during this year consisted of developing the theory and subprograms for traveling wave antennas and of writing a report on the theory and use of the antenna module. The traveling wave antenna analysis considered a terminated sloping wire, terminated sloping V, the rhombic antennas, and several arrays of rhombics. The antenna 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 of the use and limitation of each particular antenna type. Comparisons of computed patterns with published patterns are given where available.

The report is intended to be documentation of antenna models intended for use with the HF sky-wave systems performance program (IONCAP). It is not intended to be a general antenna design guide or user's handbook. The general antenna equations are included here and all radiation equations are derived here. Thus, the report could be used as a reference to derive equations for other wire antennas. The radiation resistance equations are not derived here but are selected from the literature. The major elements of this work are:

(1) A direct correlation between the equations and the computer code.

(2) The derivation of all radiation pattern equations and comparison with published equations if available.

(3) The clarification of the use of the radiation resistance equations and reference to their source.

(4) The clarification of the normalization of the reflection coefficients and their use with the ground reflection factors. (This problem has been recurring for 50 years.)

(5) The simplification of the models for use with the prediction program and the resultant stability of the computer code.

(6) The accuracy of the patterns for use with the prediction program.

The chief limitations of the work are:

(1) Those cases when the antenna is placed close to the ground. This problem arises for smooth ground sites because of the approximation of free space of perfect ground that is used for the radiation resistance. For realistic antenna sites, local variations in the site parameters are important and cannot be included in general routines as provided here. A table of this effect for horizontal dipoles over perfect ground is included in the report.

(2) The use of the models outside the design limits of the antenna. This is not always apparent when a frequency complement cover in a large band is used. Some attempt has been made to assure that the antenna will appear to perform poorly outside its intended region when compared to performance within the designed range. But no claim to absolute accuracy of the pattern outside its design range is made.

Possible areas of improvement to this work are, first, incorporation of antenna types not included here, and, second, improvements to the solution of the interior problem, mainly radiation resistances, as used here. Methods such as those using numeric integration and matrix inversion techniques such as the three-term theory or the many method-of-moment programs are not really improvements to the work here but rather are alternative and sometimes more accurate approaches. Patterns generated by these methods or from measurements can, of course, be used by the prediction program by the precalculated antenna file option.

The Institute for Telecommunication Sciences has developed a polar ionospheric model that can be used to specify and predict the structure of the high-latitude ionosphere as part of the Polar Ionospheric Modeling project. This model, and applications of it, have been described in a report by Rush et al., 1982 (NTIA Report 82-94). Currently, the model is being used as the basis to develop improvements in the predictability of the F2 region critical frequency, foF2, during the sunrise period in the north polar regions of the globe. Particular emphasis is given to relating differences in foF2 observed during the sunrise transition in Europe to differences observed in foF2 during the subsequent sunrise transition in North America. The objective of the work is to develop a method to improve the prediction of foF2 in the polar regions around local sunrise that is based upon observations of foF2 ascertained at remote locations. In FY82 a method was developed that allowed for the incorporation of certain high latitude ionospheric features into the IONCAP HF prediction program.

Ionospheric predictions programs have been developed at ITS and are widely used for prediction of radio propagation characteristics. The currently used methods rely on numerical coefficients to specify ionospheric parameters which can be both slow and costly in evaluation. Also, the current methods do not include ground-to-air HF communications. A program has been created that requires less cost and includes ground-to-air predictions as part of the Ground-Air Propagation project.

The general approach to economizing the operating speeds of the HF predictions program HFMUFES was to precalculate as many parameters as possible for a given area of interest. The ionospheric parameters such as foF2, h'F2, fOES, etc., were precalculated for a grid of points which would encompass 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. Also precalculated were the statistics associated with the parameters used to characterize the ionospheric communication path.

The ground-to-air communications capability is based on a ground-air program developed at ITS, and is currently used in MF predictions. The initial 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.

Using the original programs and the methods developed under this project, a comparison was made to assess the accuracy degradation. In the ionospheric predictions section, using a 4 degrees in latitude, and 5 degrees in longitude grid, the differences were less than 10% in the areas the program was tested. One would expect the largest errors in a geographical area where the parameter gradients were steep and parabolic in shape. To compensate for this possibility, the density may be varied thus reducing the error to an acceptable level. The ground-to-air portion of the predictions were tested over different ranges of height, distance, and frequency. The errors observed over the ranges of the test were less than 10% and it appeared that this would be consistent across the ranges of applicability. The time enhancement for the shortened mode was approximately a 10 to 1 increase in speed over the old model and this was consistent for all lengths of paths tested.

Because of the heavy reliance in HF propagation prediction programs on numerical coefficients to represent the ionospheric parameters, the Institute is undertaking a program to improve the accuracy of these coefficients as part of the Ionospheric Mapping project. The numerical coefficients provide global maps of specific ionospheric parameters. Maps of monthly median ionosperhic parameters valid for the entire globe form the basis for a number of empirical and statistical models of the ionospheric electron density. The accuracy of such models is therefore tied directly to the accuracy of the maps of the ionospheric parameters. Maps of the critical frequency of the E region, foE, the critical frequency of the F1 region, foF1, and the critical frequency of the F2 region, foF2 have been employed in one form or another to determine ionospheric structure, HF propagation conditions, and transionospheric propagation factors. Studies have been reported describing how the global maps of monthly median ionospheric parameters can be modified with daily ionospheric observations in order to more realistically represent the daily variations in ionospheric structure.

The global maps of ionospheric parameters are generated from numerical coefficients obtained by performing a spherical harmonic analysis on observed monthly median values of foE, foF1, and foF2. The resultant accuracy of the maps is dependent upon the geographical distribution of the data that were used in the generation of the coefficients. The data, foE, foE1, and for foF2, that were used in developing the global maps were obtained from between 100 and 150 vertical incidence ionosonde stations that operated throughout the world. These stations provided observations that permit a reasonably accurate map of the ionospheric parameters at these locations for which data were available. At locations for which data were nonexistent, such as for ocean areas, the accuracy of the maps is questionable.

It has long been appreciated that the uncertainties in the maps of foF2 are the largest source of potential error in any ionospheric model that utilizes global maps of median ionospheric parameters. This is due principally to the fact that the F2 region is the most variable of the ionospheric regions displaying large changes on both temporal and spatial scales. The variations in the F2 region are the manifestation of complex interactions between neutral and ionized constituents at ionospheric heights, the dependence of F2 region phenomena upon the geomagnetic field, and the influence of the magnetosphere on the ionosphere. The variability of the F2 region renders it difficult to extrapolate observations of foF2 at one location to another location with a degree of accuracy that is commensurate with extrapolation procedures employed for the E and F1 regions. In order to rectify this situation somewhat, it was decided to employ a theoretical model of the ionosphere to generate values of the F2 region critical frequency in low and mid-latitude parts of the world where observations of foF2 are unavailable. The values of foF2 determined from the theoretical model were then combined with actual observations of foF2 and, in some instances, with values of foF2 determined from the existing sets of coefficients. These data then formed the basis for re-generating the numerical coefficients that yield global maps of the F2 region critical frequency for specific months. The resultant maps provide a means to specify foF2 on a global basis that is consistent with observation and with the physical understanding about the structures of the low and mid-latitude F2 region and the causes of its large-scale variations.

Figure 1-46 shows how well the theoretical model can be made to fit median measurements of foF2 observed at Auckland, New Zealand, in September 1978. The details of the mapping work have been published in a report by Rush et al., NTIA Report 82-93, and will also appear in Radio Science.

It is often useful to have ionospheric propagation predictions presented in a form to assist in the estimate of geographic coverage of a given frequency at a given time and with a specific antenna. Predictions such as the MUF, circuit reliability, signal-to-noise ratio, and median field strength could aid HF broadcasters and others if presented in a geographic latitude-longitude matrix display for specified areas of the world. The work reported here is the result of the Area Coverage HF Prediction project to develop such a geographic latitude-longitude display of ionospheric propagation predictions.

The task consisted of development of a procedure to generate a geographic area coverage representation of ionospheric characteristics given a specific area. The area is identified by either a code which targets a predefined geographic area or by specification of the latitude and longitude boundaries of

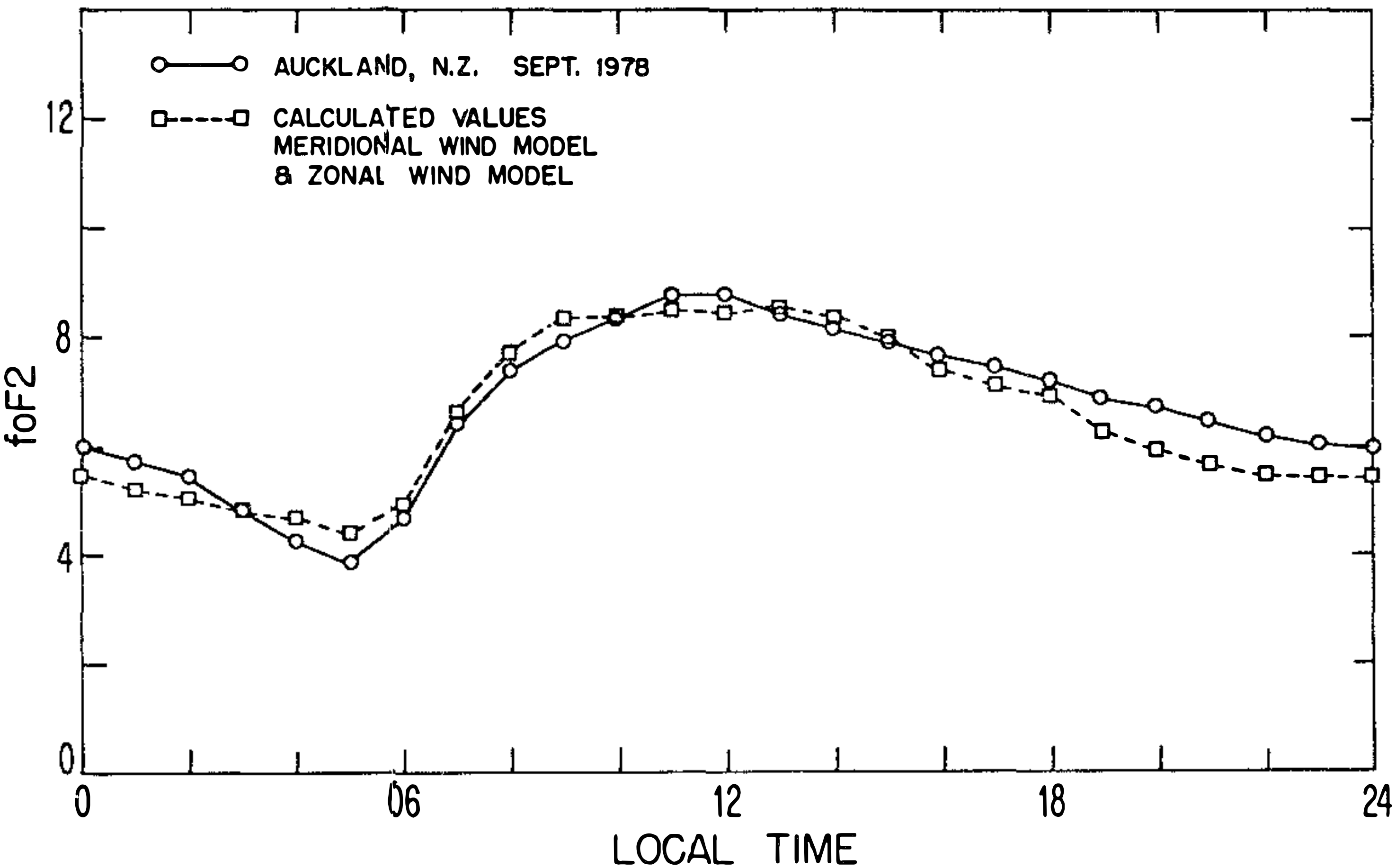


Figure 1-46. Comparison between median values of foF2 observed at Auckland, New Zealand, and values calculated using the theoretical model for September 1978.

the area. The ionospheric propagation predictions are computed at the boundary locations of the grid and at incremental locations within the grid. The area coverage representation consists of the display of these predictions on a matrix grid for each frequency and each hour for a specified month and antenna. The area coverage representation, therefore, consists of the predictions of several point-to-point communication paths on a rectangular grid.

The implementation allows the flexibility to identify the construction of rectangular grids where: (1) a specific transmitter location is used to communicate with each receiver location on the grid, (2) each location on the grid is considered a transmitter and is used to communicate with a specific receiver location.

IONCAP program is used to compute the ionospheric propagation predictions for this effort. The procedure consists of development of a processor to generate the input to the IONCAP program based on the specific grid to be constructed and a processor to generate the geographic grid from the IONCAP predictions. There are distinct advantages to this procedure. The IONCAP program is a point-to-point communications program and does not directly construct area coverage grids. The input processor generates the geographical area as a set of point-to-point communication paths that IONCAP can use without major modification to the IONCAP program. The IONCAP program is utilized more effectively by evaluating a particular point-to-point path at all specified hours and frequencies rather than all point-to-point paths at a single hour and frequency. It is also more efficient to compute all desired propagation predictions (i.e. Maximum Usable Frequency (MUF), field-strength, and signal-to-noise ratio) for a particular path rather than the prediction of each parameter for all paths. That is to say, the IONCAP program does not compute the predictions in the same order as is needed by the geographical area coverage model. The output processor, therefore, reads the IONCAP predictions and generates the desired area coverage grid.

A procedural flow diagram of the area coverage model is represented in Figure 1-47.

There have been several extensions to the basic area coverage model made at the request of the sponsoring agency. These modifications and extensions include: (1) An error detection capability to detect user input errors and issue an appropriate diagnostics. (2) Multiple output option extension to allow the user the capability to obtain several different output types without recalculating predicted values. (3) Multiple frequency extension to allow the user the capability to analyze a particular area coverage grid at several frequencies during the same computer run. (4) Multiple hour extension to allow the user to evaluate diurnal coverage capability in the same computer run. (5) Evaluation of constraints that restrict the maximum number of latitude and longitude locations within the grid and restrict the number of output option, frequency, and time permutations.

The Institute continued work on the development of a new MF propagation model in FY82 under the MF Propagation Studies project. The higher power AM stations south of the U. S. border have caused interference to some U.S. AM broadcast stations. Current accepted prediction models tend to underestimate field strengths in the Western Hemisphere. To remedy this, the Institute in cooperation with the Federal Communications Commission established MF monitoring sites at Cabo Rojo, Puerto Rico, to actually observe signals from the more southerly South American stations. This capability provides data with sky-wave reflection points below 30° north geomagnetic latitudes which, in the long term, will 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.

At the field sites, sky-wave signals from several South American AM stations are being observed on highly directional Beverage antennas. Only storage tapes are being shipped periodically to the Institute for analysis. Figure 1-48 shows a typical plot of field strength (dBu) versus local time by consecutive monitoring day (midsummer) at the Cabo Rojo site. By using an antenna model developed by the Lawrence Livermore Laboratories and on-site field strength readings of known transmissions, observed AGC readings are being transformed into field strength values. Figure 1-49 shows the horizontal antenna pattern, at an angle of arrival of 7°. The Beverage antenna monitoring the signals is shown in the previous Figure 1-48. The off-base site angle is 14° for the particular signals.

NTIA Report 82-19 entitled "Fading Signals in the MF Band" was written by A.D. Spaulding. This report develops methods that can be used to assess the interference potential to U.S. MF operations from emitters outside the U.S. In this report, computer algorithms are developed which determine the actual overall fading distribution of one or a combination of two fading signals, when the short-term fading of each is given by a Raleigh distribution and the long term fading of median values is given by a log-normal distribution. Also, a simple approximate means of determining the distribution of the median value of a signal given by the sum of any number of fading signals is developed. As an example, Figure 1-50 shows the cumulative distribution resulting from two signals, both with the same mean and both with a 6 dB fading range. The distribution for one signal with the same mean and fading range is given for comparison. Also shown is the distribution resulting from two signals, one with a mean 10 dB below the other and with the larger signal having a 6 dB fading range and the smaller signal a 12 dB fading range.

Further theoretical research was carried out with application to through-the-earth communication with trapped miners in the ELF and VLF bands as part of the Subsurface EM Waves pro-

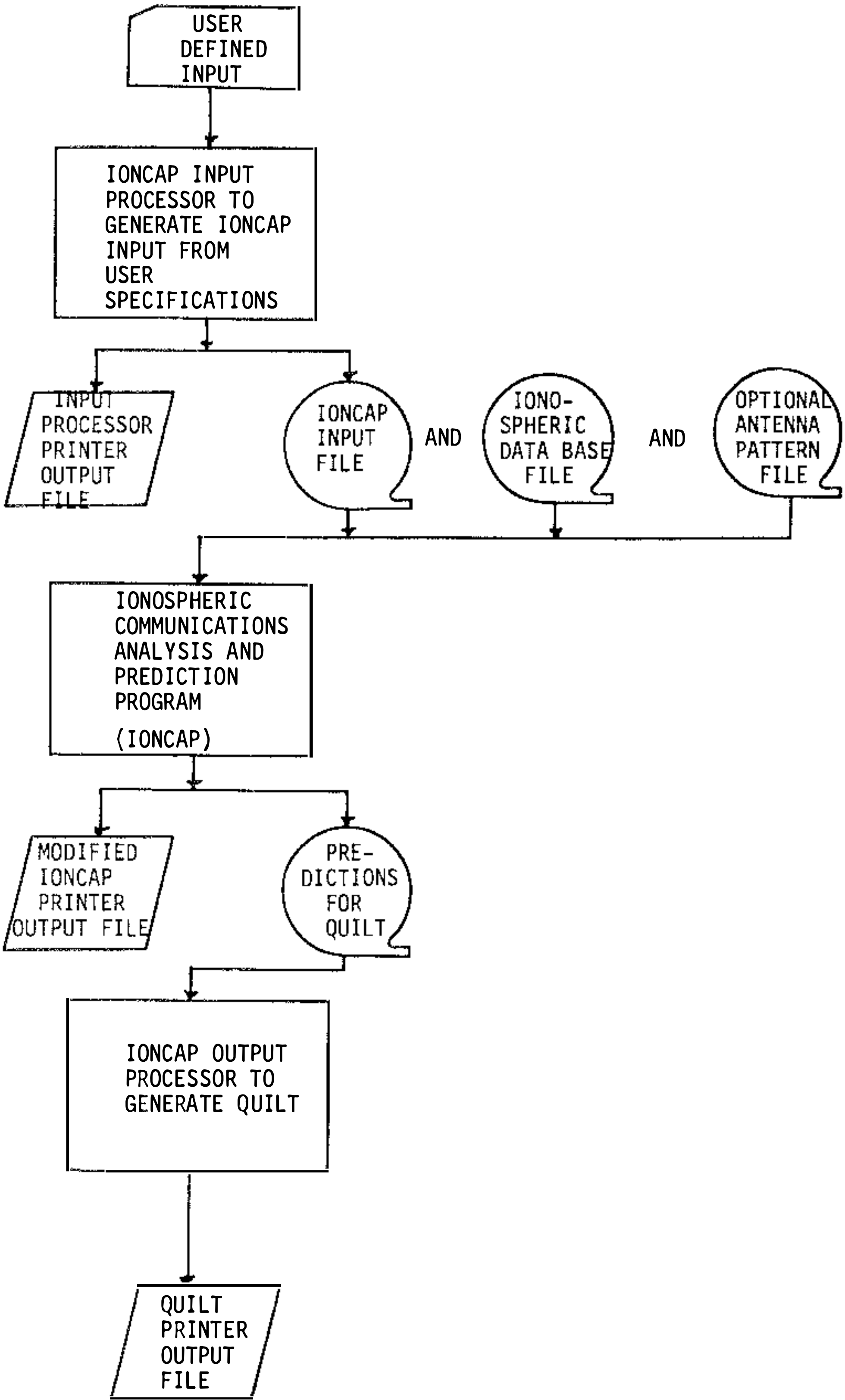


Figure 1-47. QUILT procedure flowchart.

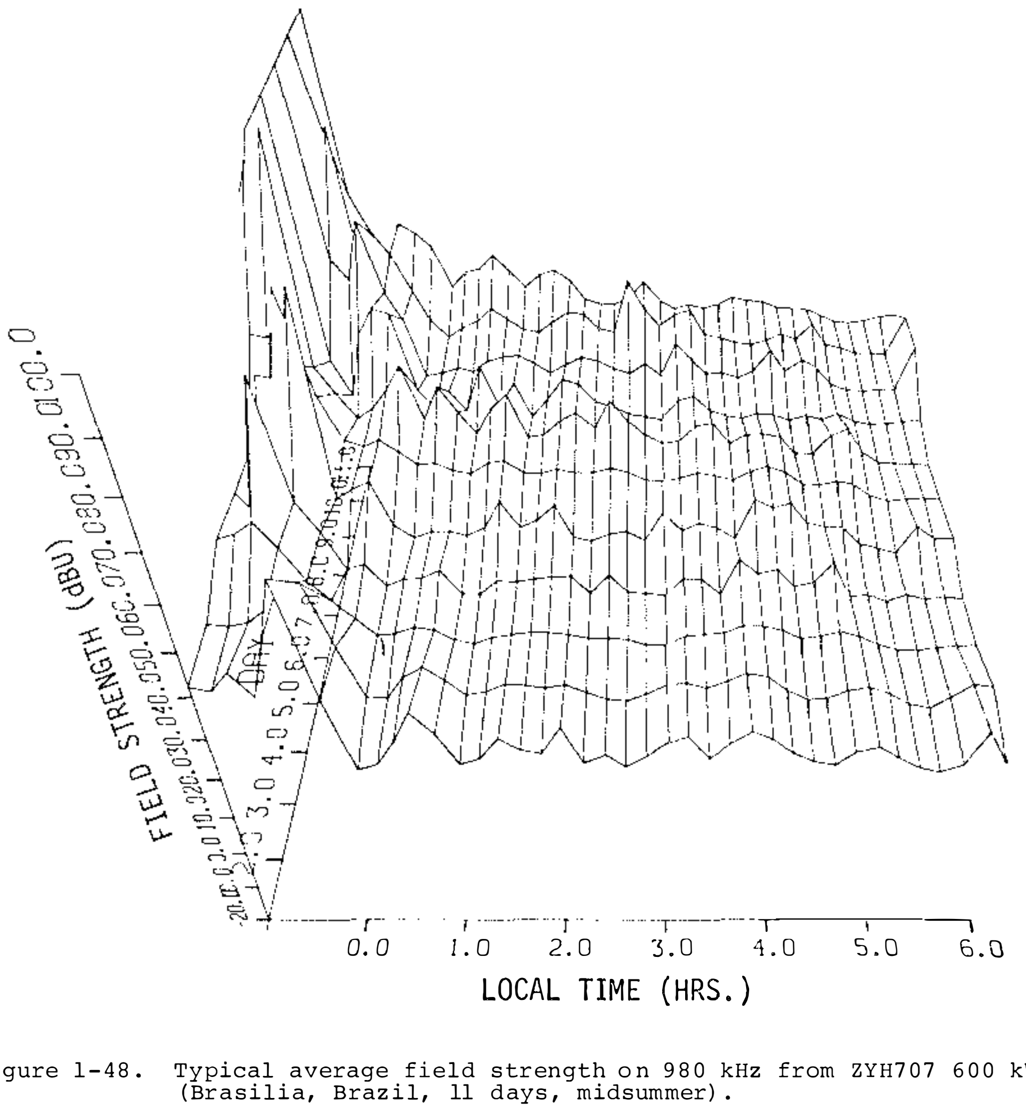


Figure 1-48. Typical average field strength on 980 kHz from ZYH707 600 kW (Brasilia, Brazil, 11 days, midsummer).

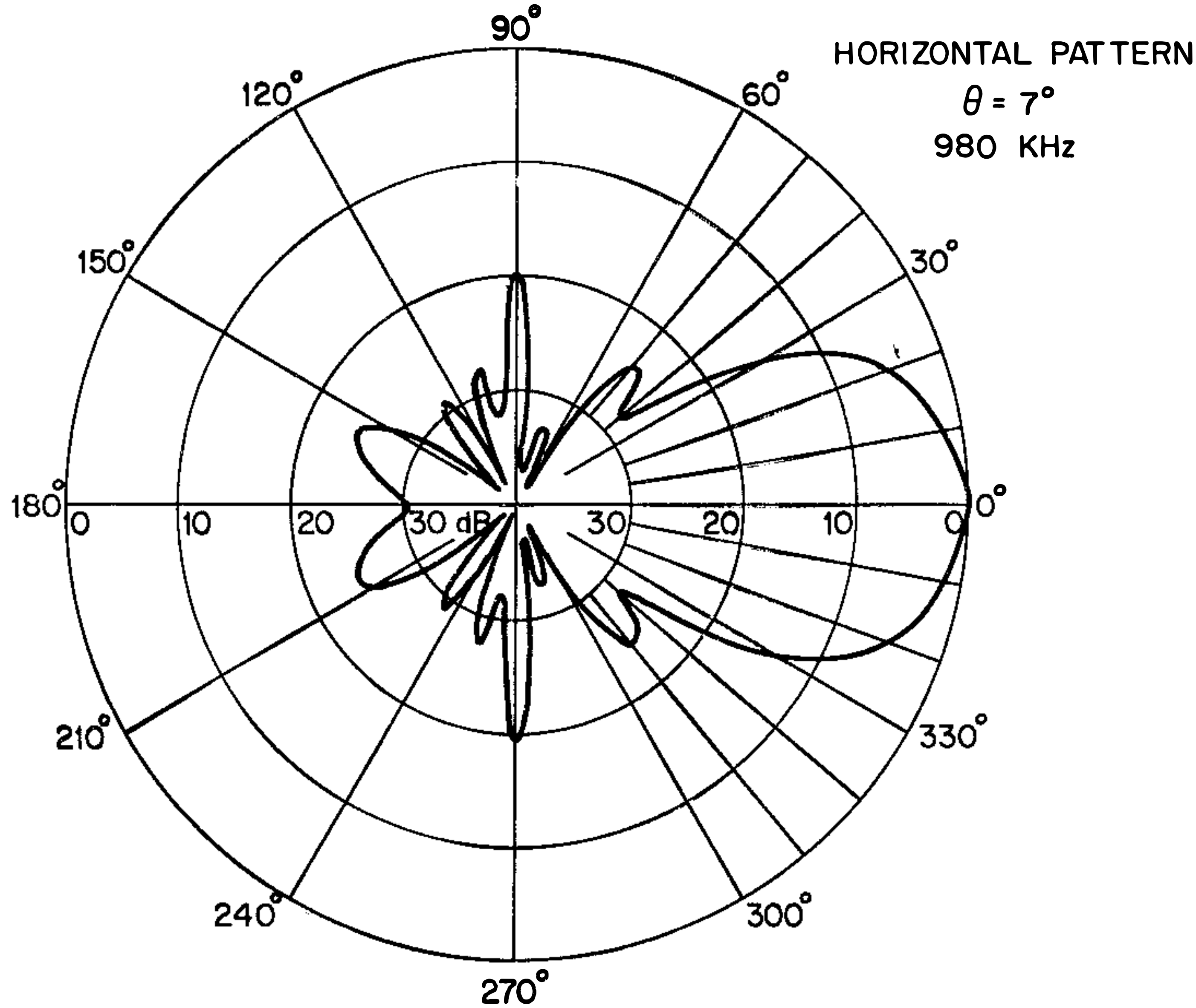


Figure 1-49. Horizontal pattern for a Beverage antenna at 980 kHz with an angle of arrival of 7° and a ground with conductivity of .002 Mhos/m.

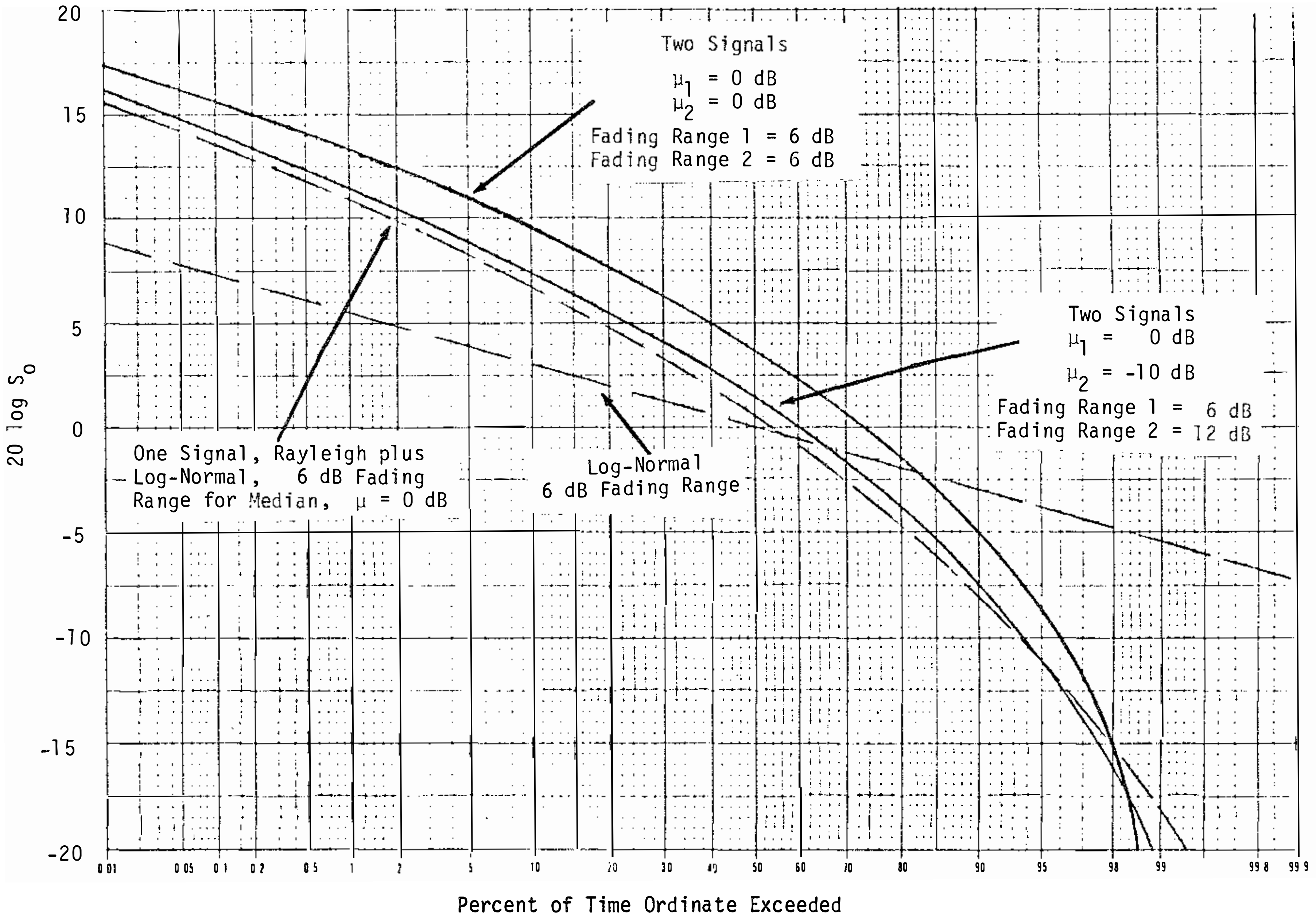


Figure 1-50. Cumulative distribution, Problem [5 > 50], of the sum of two fading signals.

ject. Extensions to earlier work were made in the areas of interference from atmospheric noise and improved modeling of earth attenuation. The properties of the vertical magnetic field component of atmospheric noise have not been previously well understood, and this is the dominant interferer in transmission between horizontal loops. Several theoretical models were analyzed in an attempt to explain the magnitude, frequency dependence, and spatial properties of vertical magnetic noise. The attenuation of through-the-earth signals as predicted previously by a homogeneous earth model is not in good agreement with recent transmission experiments by the Bureau of Mines. A two-layer model with high conductivity at the surface was analyzed and found to be in better agreement with experimental data.

The Institute for Telecommunication Sciences has played a major role over the years in various aspects related to ionospheric modification by high-powered HF radio waves. The Platteville high-powered HF facility, owned and operated by ITS, was the first facility to be used to demonstrate the impact of high-power HF radio waves on the structure of the ionosphere. In recent years, the ionospheric modification program at the Institute has emphasized the role played by ionospheric modification of the performance of ionospheric-dependent telecommunication systems as part of the Ionospheric Heating project. Specific studies are being undertaken to determine the degree that irregularities in the ionospheric electron density resulting from high-power HF radio waves influence HF, VHF, and UHF radio wave incident upon the irregularity region. Emphasis is being given to assessing the pertinent geometrical dependencies between the geomagnetic field configuration and the location of the ionospheric irregularities relative to transmitter and receiver locations in ground-based telecommunication systems. The program of study is being undertaken to determine the degree of interference to terrestrial systems that can result from irregularities in the ionosphere created by both man-made and natural methods.

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 represents the preliminary planning and research needed to initiate a measurement program for the Defense Nuclear Agency. This project is a companion to another which involves the development of a new theoretical prediction method and its implementation in a computer program. The theoretical work is actually an extension to an existing ground wave propagation model-program WAGNER.

Ground wave prediction methods that are based on the smooth earth assumption are adequate for most needs at MF and lower frequencies. When higher frequencies are of interest, terrain features and path inhomogeniety can be very important. The analytical solution of ground wave propagation over irregular and inhomogeneous terrain is impossible because the surface of the earth cannot be described by some function. The solution to this problem must rely on numerical techniques. Program WAGNER represents one of these solutions; it is based on an integral equation formation of the problem. As long as the elevation change is not too abrupt nor the frequency too high, WAGNER can predict the transmission loss over realistic, irregular, and inhomogeneous terrain.

The extension to the program WAGNER (the companion project) is the inclusion of a slab over the ground that can have a conductivity and permittivity different from the ground. The purpose of the slab is to permit the modeling of sections of forest, urban areas, or snow cover on a path.

There is very little collective experience regarding ground wave propagation at HF since it is an uncommon application. HF is usually chosen for medium- to long-range communications using sky wave modes of propagation. The choice of ground wave limits the range to relatively short distances, such as a hundred kilometers; but this is the intended application. As noted earlier, the irregularity and inhomogeneity are important, so program WAGNER appears to be the best approach to the solution of radio engineering problems using HF ground wave. Before WAGNER can be considered fully useful for this application and to be sure that the new slab feature is corect, validation measurements are needed. That is the primary purpose of the HF ground wave measurements. A secondary purpose is to develop some engineering guidelines that involve the application of WAGNER where a slab is needed. For example, how thick a slab and what values of conductivity and permittivity should be used to model the urban section of some path.

The basic information needed from a measurement program is the field strength versus distance along a radial centered on the transmitter. In addition, for selected distances on some of the measurement paths, height-gain measurements are considered essential. This is a measurement of the field strength versus height and will be important information when comparing predictions and measurements, especially in a slab. A minimum set of path types that should be measured are given below in Table 1-9. These paths will probably be located in both the United States and Germany.

Table 1-9. A Minimum Set of HF Ground Wave Measurement Paths

1) relatively smooth and flat,
2) similar to 1, but with an urban section,
3) smooth to rolling with complete forest cover,
4) similar to 3, but partial forest cover,
5) rough with a forest section,

6) smooth to rolling open ground,

7) same path as 6, but with snow cover, and

8) rough open ground with snow cover.

The methods of making the desired ground wave measurements as well as the need for ground conductivity and permittivity measurements have been examined this year.

The field strength measurements will require the discrimination of the ground wave and sky wave modes of propagation. One technique that has been chosen is to measure the angle of arrival of the test signal. This will require a sophisticated receiving antenna. The receiving system will include a microprocessor for control and data recording to allow increased measurement capability. The bit error rate will be recorded along with the field strength by using a known pseudo-random-sequence. Four frequencies will be measured simultaneously.

There are a variety of methods available to measure the ground conductivity and permittivity. None of them is considered as a standard nor are they all applicable in this case. The method chosen must be independent of the propagating wave used for the field strength measurement, but the results must be valid for the exact frequency used. The method or measurement chosen must be reliable at HF. These requirements eliminate all but the wave-tilt and the two-loop mutual impedance techniques.

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. Sky-wave predictions were used in our study to determine the optimal seasonal and solar-activity epoch groupings for use in the development of high-frequency broadcast schedules. The results indicated that the current seasonal schedule is optimum as far as seasonal grouping is concerned. A study was also undertaken to determine the number of frequencies required to cover a given broadcast area. The results were published in NTIA Technical Memorandom 82-75. Table 1-10 provides a typical summary found in the Memorandum. Typically, it was found that, for 80% of the time, one frequency can serve an entire area. Two frequencies are needed 18% of the time and three frequencies are needed only 2% of the time. The times at which more than one frequency is required for broadcast coverage correspond invariably to times of maximum sunlight on the radio circuit or when a transition occurs between the transmitter site and the area involved. These results were determined under the assumption of a constant gain antenna of 15 dB. Results of studies using more realistic antenna configurations are to be described in a separate publication.

Table 1-10. Frequency With The Highest Reliability (R) And The Range Of Frequencies With Reliabilities Greater Than 0.95 For Broadcast Transmission From Tehran to CIRAF Zone 29 During December, Solar Minimum And Solar Maximum Conditions

Tehran to Zone 29

December Solar Minimum

UT	Frequency with Highest R (±0.01)	Range of Frequencies With R > 0.95
02	3.9	3.9 - 4.8
04	7.2	3.9 - 7.2
06	11.8	9.6 - 11.8
08	11.8	7.2 - 15.3
10	11.8	7.2 - 11.8
12	11.8	6.1 - 11.8
14	9.6	3.9 - 9.6
16	4.8	3.9 - 4.8
18	3.9	3.9 - 4.8
20	4.8	3.9 - 4.8
22	4.8	3.9 - 6.1
24	4.8	3.9 - 6.1

02	4.8	3.9 - 4.8
04	9.6	3.9 - 9.6
06	15.3	9.6 - 17.8
08	17.8	9.6 - 17.8
10	17.8	9.6 - 17.8
12	15.3	7.2 - 17.8
14	11.8	3.9 - 11.8
16	7.2	3.9 - 7.2
18	4.8	3.9 - 6.1
20	6.1	3.9 - 6.1
22	7.2	3.9 - 7.2
24	6.1	3.9 - 6.1

As a result of actions taken at the General World Administrative Radio Conference of 1979, A world Administrative Radio Conference (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-waves (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 assure that U.S. positions at the HF Broadcasting WARC are based on sound technical decisions, the Institute is developing an automated method 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 aspects as power required and protection ratio to effect broadcast operations to be simulated using the best available information.

The U.S. Coast Guard Consulting project provides "quick reaction" radio propagation predictions and short-term studies as needed by the Coast Guard for the operation of their large network of HF and VHF communication systems. In addition, seasonal propagation charts are provided at regular intervals to help support the AMVER (Automated Mutual-Assistance VEssel Rescue) 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 studies begun last year and continued through this year involves coverage problems along the Tennessee River in the Second U.S. Coast Guard District. Several of the VHF sites used for communication with vessels on the river do not perform well. The result is that several sections of the river are not covered. So far the Institute has provided some specific path predictions and topographic information. This year, a method of computing the basic transmission loss between a fixed site and a river section has been developed. The result is a plot of the basic transmission loss as a function of position along some locus (in this case a river section). Figure 1-51 is a map of the Tennessee River with two "problem" sections indicated as A and B. Then in Figure 1-52 is an example of our computations. This graph shows the basic transmission loss for the first 50 km of section A (zero is at the north end of the section).

Propagation at or near vertical incidence presents a difficult antenna design problem due to the relative low frequency required for skywave communications at short distance and the desire to operate using antennas as small as possible. The analyses performed under this effort will provide 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 Communication Electronic 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 Analyses and Predictions (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 half-wave 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.

Also included in this project is a task that will give the users of IONCAP the ability to have many input and output formats without rerunning the IONCAP program. The output portion of the task required the generation of a structured computer file which would allow access by an output program. An interactive output program was generated which takes requests from the user and accesses the above file and outputs the "information" in the prescribed format.

The development and implementation of a processor to generate input to the (IONCAP) program provides the methodology for individuals to interface with the IONCAP 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.

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 involved the VHF-UHF range, but this past year most of the work has been in the LF-MF range. Many computations were done to aid in the preparation of a new handbook for the non-directional beacons. Along with this effort a sky-wave program was combined with a ground wave program to produce tables of distances at which the two components are equal and, also, where the ground wave exceeded the sky-wave by 10 dB. A report was written explaining the methods used and the various parameters that were included. The FAA is publishing the report.

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

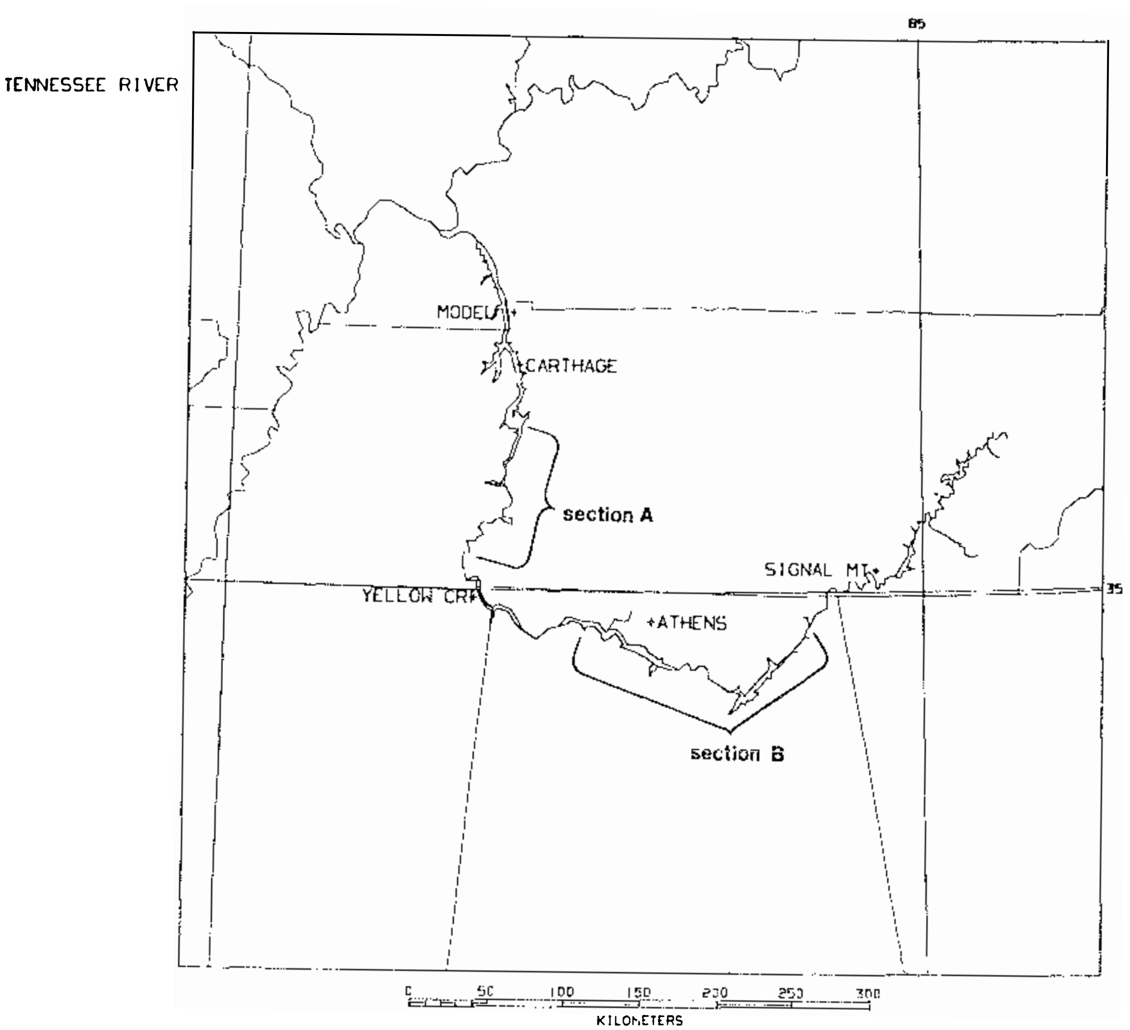


Figure 1-51. The Tennessee River and the existing VHF high-level sites. The two "problem" sections are indicated.

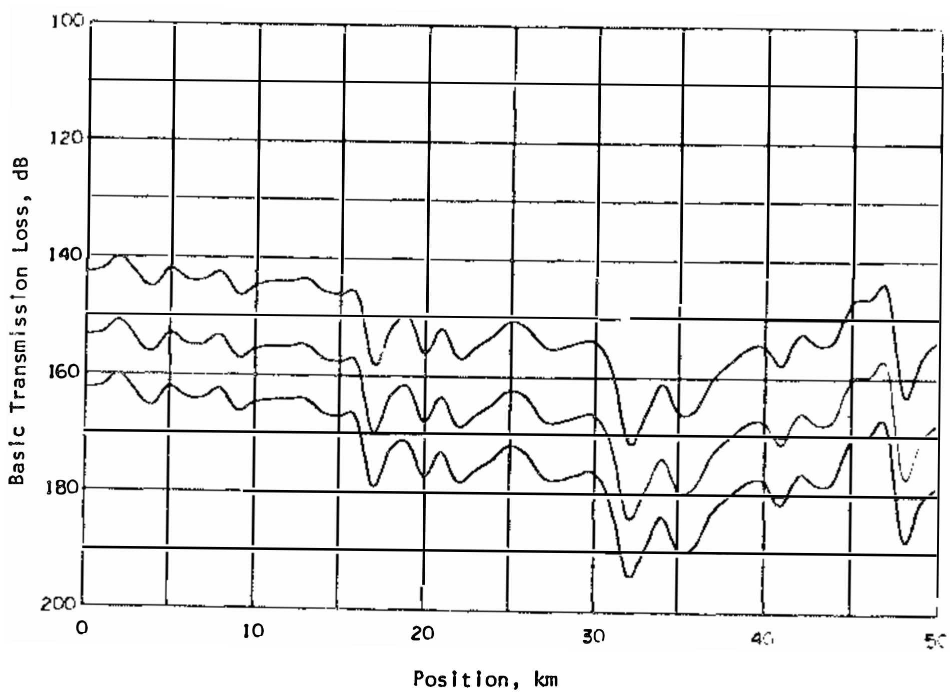


Figure 1-52. Basic transmission loss between model and river section A for 10% (upper), 50% (middle), and 90% (lower) confidence.

Federal Aviation Administration (FAA), with respect to frequency planning and management in the aeronautical frequency bands. Specific issues related to actions of the World Administrative Advisory Conference (WARC) were studied, and several informal letter reports were issued to the FAA.

The initial work on this project resulted in the publication of "An atlas of basic transmission loss for 0.125 to 15.5 GHz" by M. E. Johnson and G. D. Gierhart, FAA Report No. FAA-RD-80-1, August 1980. Based on this work and subsequent analyses, a revision of CCIR Recommendation 528 entitled "VHF, UHF and SHF propagation Curves for Aeronautical Mobile Service" was prepared and submitted to U.S. Study Group 5. The project was completed in November 1981.

The Bureau of Reclamation Telecommunication Analysis Services project allows Bureau of Reclamation telecommunication planners to use available time-share computer programs at ITS. The programs are useful for making radio propagation predictions using Bureau of Reclamation parameters such as transmitter and receiver location coordinates, antenna heights and gains, transmitter power, receiver sensitivity, and desired communications reliability. By utilizing the programs, the Bureau of Reclamation can optimize the siting of their radio systems and analyze trade-offs between transmitter power, antenna gain, etc.

CHAPTER 2. SYSTEMS AND NETWORKS

The Systems and Networks program subelement is a combination of the Systems Engineering-Evaluation and the Advanced Communication Networks subelements reported in the previous annual report. The objectives of this overall subelement are:

(1) to provide system-oriented studies that are user-oriented where the user is a Federal mission agency;

(2) conduct programs of applied research and analysis of advanced communication systems and networks in support of NTIA and other Federal agency requirements.

SECTION 2.1. SYSTEMS ENGINEERING DESIGN AND PERFORMANCE EVALUATION

The objective of this program subelement is to provide system engineering studies that are user-oriented where the user is the Federal mission agency. The studies are generally directed toward defining system requirements, system design and evaluation, cost trade-off, development of performance criteria or standards, and user-acceptance criteria. The engineering work needed to carry out these studies takes the form of analyses, measurements, and performance evaluations with the results published in NTIA reports or, when applicable, in technical journals. Federal agencies use the results in planning, designing, specifying, procuring, leasing, and operating telecommunication systems.

Section 2.1.1. addresses those projects which are categorized as terrestrial radio system performance and monitoring studies and tests; Section 2.1.2. presents those projects which deal with communication systems and services engineering; and Section 2.1.3. deals with the standards activities.

2.1.1. Terrestrial Radio System Performance and Monitoring Studies and Tests

This activity is directed toward the design, evaluation, acceptance, operation, and upgrading of existing or proposed radio systems operated by the Federal Government. The projects generally result in recommendations for system design changes and/or system upgrading or for new monitoring and control methods.

Wideband Radio Over-the-Horizon Link Design. To improve the efficiency of designing beyond-the-horizon radio links, ITS will provide an automated, interactive set of desk-top-computer programs which will permit workers with moderate skill levels to perform the calculations necessary for the design of beyond-the-horizon microwave links for both FM/FDM and PCM/TDM systems. The programs are to be provided with documentation which will permit them to be easily operated, understood, modified, and updated.

The models used cover beyond-the-horizon links operating between 40 MHz and 10 GHz. The models will not cover any of the ionospheric modes which are occasionally operative at the lower end of this frequency range. The programs will not cover mixed modes of radio propagation such as are observed in cases where diffraction and tropospheric scatter modes occur alternately or at the same time.

To achieve the objectives, four major tasks were undertaken:

1. Appropriate engineering models were found.
2. Design of the basic architecture of the software was prepared.
3. Component programs were developed and tested.
4. Programmer and operator documentation was prepared.

The programs are being written in HPL for a desktop computer with 48 kilobytes of working memory. The peripheral equipment consists of a flexible disk drive, a printer, and a plotter.

Some of the calculations done by this software fall into the following categories:

1. Earth Geometry
2. Path Profile and Ray Paths
3. Terrain Reflection
4. Single Obstacle Diffraction
5. Rounded Obstacle Diffraction
6. Multiple Obstacle Diffraction
7. Smooth Earth Diffraction
8. Irregular Terrain Diffraction
9. Tropospheric Scatter
10. Path Loss Variability
11. Equipment Sizing and Diversity Configuration
12. FM/FDM Channel Quality and Unavailability
13. PCM/TDM Channel Quality and Unavailability

The project is sponsored by USA CEEIA and is approximately 80% complete.

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 will be 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 analysis 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 20% complete.

Advanced DEB IV EFAS. The objective of this program is to design and develop an intelligent second generation transmission monitoring and control system (TRAMCON) in support of the Digital European Backbone (DEB), formerly called Enhanced Fault Alarm System (EFAS). The system is to be used to monitor several digital microwave terminals and relays within a network. The monitoring system is intended to provide the system operators with sufficient alarm and parameter data to isolate degraded conditions and faults at remote locations. Interactive displays are the core of the system that will assure efficient communication system operation.

Progress to date has included the specification and procurement of the computer systems that will form the intelligent nodes in the system, and an architecture for the software and displays has evolved. Further efforts are in progress to develop the deployment of these systems to cover the Defense Communication System in Europe. Also, early efforts have been made on the evaluation of distributing the network intelligence down to the remote terminals, to be investigated during the last quarter of CY 82.

It is anticipated that the second generation system will be developed, tested, and installed on a segment in Europe for evaluation by late next year.

The project is sponsored by USAF, ESD.

System Monitor Automated Remote Terminal (SMART). The objective of this program is to design and develop an intelligent monitoring system for digital microwave communication stations. The work is being done in conjunction with the aforementioned TRAMCON system development project. The intelligent monitoring system, or SMART, will be located at each station in a communication system. It will monitor all site and equipment functions and report the status of these functions to the central TRAMCON computer. Each TRAMCON computer will monitor up to 25 stations. The reason for the interest in developing a remote monitoring unit with some data processing capability is to improve the speed of reporting of problems or failures of station communication equipment which, in turn, will improve the continuity of service of these important defense communication systems.

Progress to date has been the development of a technical specification for the microprocessor-controlled SMART and the preparation of a procurement package for the hardware. Delivery of the equipment is expected before the end of the calendar year, with software development to start at that time. Installation of the equipment in a test status in Europe is expected to occur near the end of CY 83.

The project is sponsored by USAF, ESD.

DRAMA Radio Performance Tests. In support of the U.S. Air Force, Electronic Systems Division, propagation measurements and performance testing were conducted in conjunction with a new digital microwave radio system. The communications equipment has been developed under the Digital Radio and Multiplexer Acquisition (DRAMA) Program, and is planned to be used in the Digital European Backbone (DEB) network throughout Europe.

The test objectives for this project were established in the DEB Test and Evaluation Master Plan (TEMP) with respect to specific radio propagation conditions. These are:

a. Test Objective 1. Ascertain the susceptibility of the DRAMA radio to frequency selective fading.

b. Test Objective 2. If the DRAMA radio is unacceptably susceptible to frequency selective fading, ascertain if the conditions that cause this propagation related problem are present on DEB links in Europe.

To meet these objectives, ITS conducted two phases of a measurement program which are briefly described below.

Phase 1. A "first article" DRAMA radio was installed at the Pacific Missile Test Center (PMTC/U.S. Navy) at Point Mugu, CA. The test link was selected because of the known meteorological conditions that develop along the southern California coast during the summer and early fall months. Elevated ducting layers develop frequently during this time of year, creating multipath propagation (and its correlary of frequency selective fading). This phenomenon will seriously degrade the performance of a microwave radio system unless it is compensated for in some manner.

The DRAMA equipment was installed to operate over an established link between PMTC and San Nicolas Island (105 km), at a frequency of 8.07 GHz. Data transmission was from the island terminal (elevation 274 m) to a receiver site at Laguna Peak (elevation 427 m). The receive terminal was configured for space diversity reception with vertical antenna separation of approximately 30 m. A psuedo random bit stream (PRBS) clocked at a rate of 12.9 Mb/s was used as a performance test signal on both of the mission bit streams (MBS) in the DRAMA equipment. One of the MBS signals was monitored at the receiver site, measuring the bit error rate (BER) and the distribution of synchronous errored-seconds from the output of the diversity switch combiner.

The propagation channel conditions were monitored with the ITS Channel Probe instrument, operating at 8.6 GHz over the same diversity paths and antennas. This instrument measures the effective impulse response of each diversity path simultaneously, and thus shows the multipath structure of the received signal directly in the time domain [Hubbard, R. W. (1979), Investigation of digital microwave communications in a strong meteorological ducting environment, NTIA Report 79-24, August]. In addition, the received signal spectra from each of the DRAMA receivers was measured in the same time frame (one per second) as the impulse response data. In this manner, the data provided a second-by-second record of the propagation conditions and digital performance. These records were augmented with radiosonde data showing the refractive index profile over the test link (taken by PMTC twice daily). An example of the refractive index data is shown in Figure 2-1. The figure illustrates that the refractive layer changes elevation as a function of time, and can also be tilted with respect to the earth's surface. The relative elevations of the radio terminals are indicated on the ordinate of the figure.

A digital data acquisition system was used in this phase of the testing, which is shown in block diagram form of Figure 2-2. The figure indicates other signals that were recorded, including the received signal levels (RSL) and radio status and alarm signals.

The performance tests were conducted during August 1981. The results showed conclusively that the DRAMA system is susceptible to frequency selective fading. An example of the recorded impulse response and received signal spectra is shown in Figure 2-3, as read directly from a digital data tape into a digital signal analyzer. The figure illustrates both the multipath in the impulse response functions, and the frequency selective (in band) fading of the received spectra. The analyses showed that in this multipath environment, the DRAMA radio would fall short of performance expectations, based on a measure of time availability from errored-seconds with a BER greater than an established threshold of 1×10^{-6}.

Phase 2. To answer Test Objective 2, two future DEB links in West Germany were selected for testing in Phase 2. DRAMA equipment was not available for this part of the program, so the radio measurements were limited to propagation data only. The ITS 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.] was installed in duplex with operating communication systems. The testing was begun in October 1981, and continued until mid-December 1981. Most of the data was recorded from the tests over a 90 km link that spanned the Rhein River Valley. It was anticipated that refractive layering would develop during the month of October rather consistently, based on previous meteorological data. However, unusual rainy weather prevailed during October and November 1981, and as a result only three refractive inversion events were recorded during the test period. Two of these events were observed over the first link, and a later one over the second test link (a 72.5 km path over forested, hilly terrain).

Meteorological data were measured during this phase by a team from the Air Force Geophysics Laboratory (AFGL). Both tethered and launched radiosonde equipment was used to measure the refractive index profiles, usually at two different locations along the radio path. An example of a sounding made at Landau, West Germany, at 1030 LST on November 4, 1981 is shown in Figure 2-4. Note that the refractive layer is very similar to those measured at PMTC (Figure 2-1). The elevations of the test link terminals are indicated on the ordinate of the figure.

Results of this testing concluded that the same ducting-layer conditions that produced the degraded multipath performance of the DRAMA equipment at PMTC will exist at times on European DEB links. The impulse response measurements showed the presence of atmospheric multipath in correlation with each ducting layer that was detected with the meteorological instruments. In addition, multipath data were observed on several other occasions that were reasonably well correlated with the passage of strong weather fronts in the region. Analyses of these events indicate that the multipath was a result of (normally small) surface reflections (seen consistently in the impulse data) that were enhanced by slow changes in the near

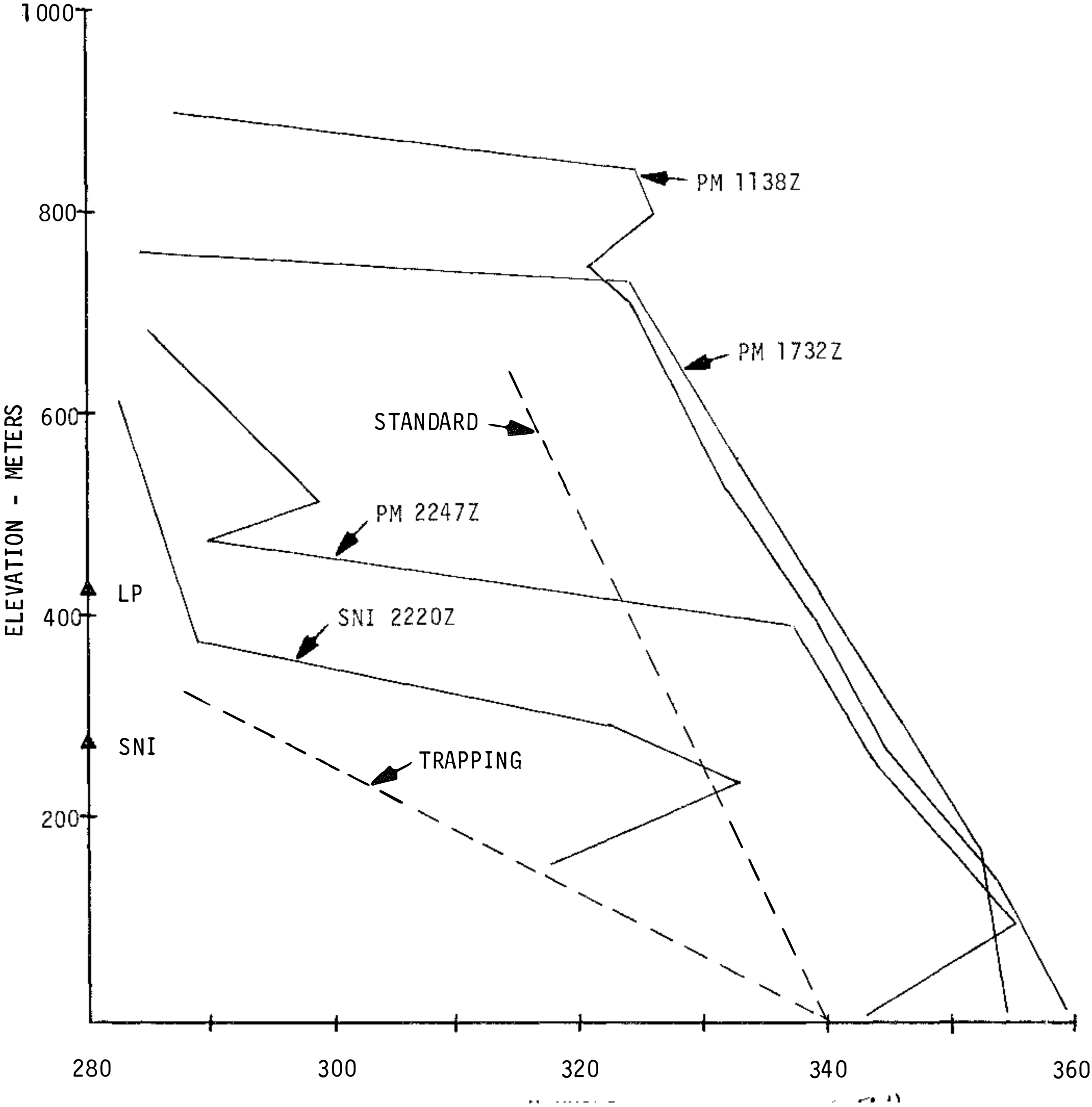
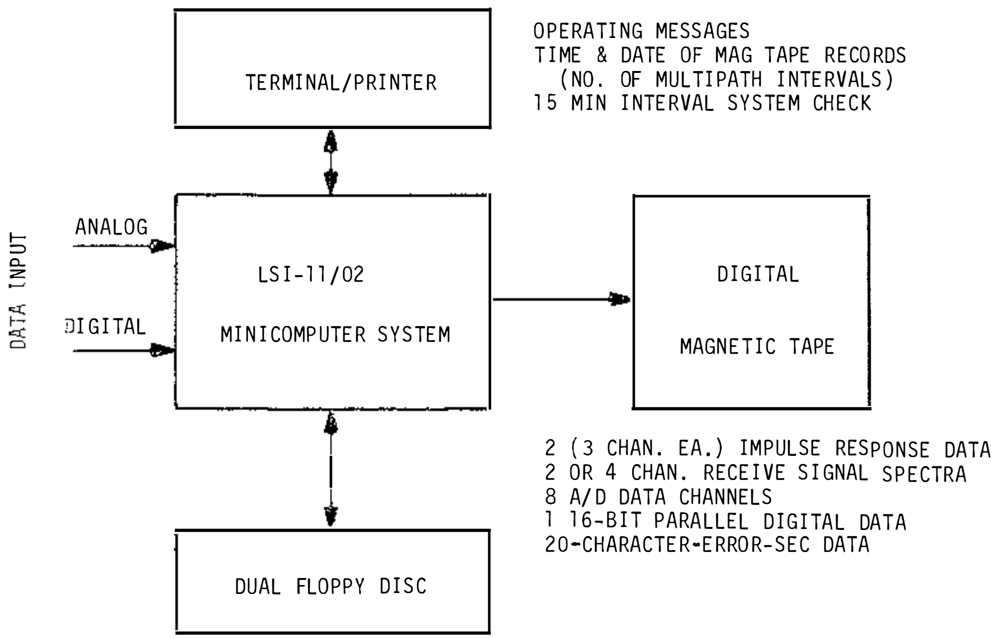


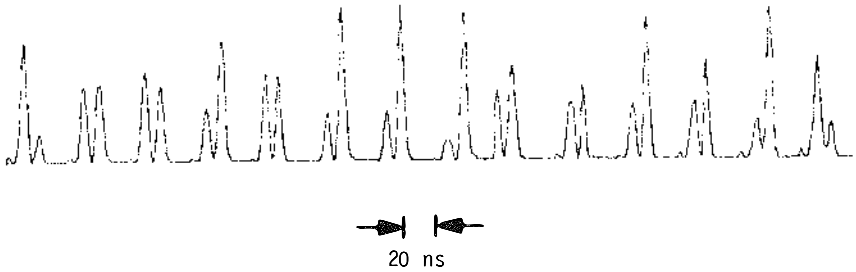
Figure 2-1. Refractive index profiles measured at Point Mugu (PM), and San Nicholas Island (SNI), CA, on August 19, 1981.



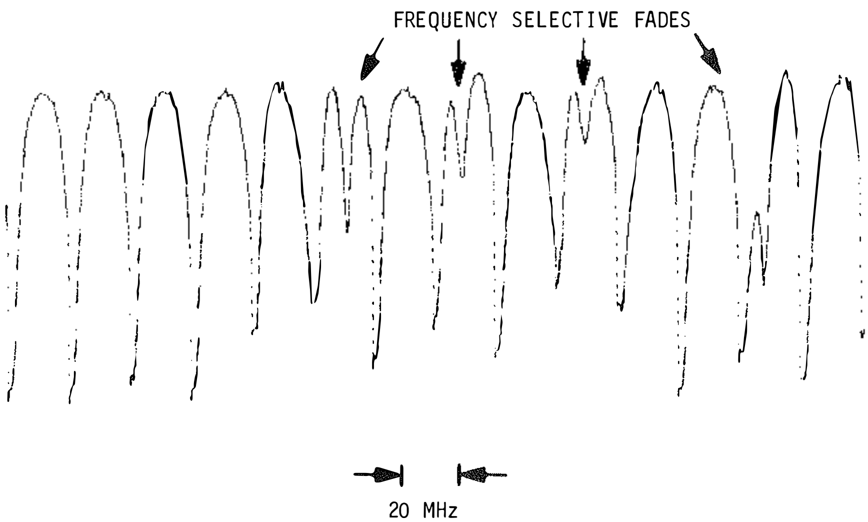
All data were recorded on the digital magnetic tape, using 5 sec data blocks. Each data block was formatted as follows (the sampling rate for the analog signals is shown in parentheses):

1. Date and Time
2. Channel Impulse Response (2 kHz)
3. Received Signal Spectra (100 Hz)
4. RSL and other Analog Signals (10 Hz)
5. DRAMA Radio Status and Alarm Signals
6. Synchronous Error-seconds Data

Figure 2-2. Block diagram of the digital data acquisition system used in the Phase 1 tests at PMTC.



(a) The power impulse response function of the transmission channel.



(b) Received signal spectrum of the DRAMA PRBS test signal.

Figure 2-3. An example of the simultaneous measurement of the channel impulse response function and the received signal spectrum. Each data sample is taken in a 1 sec time frame. A dominant two-path propagation mode is seen in the impulse data, with the resultant frequency selective distortion in the received signal spectra.

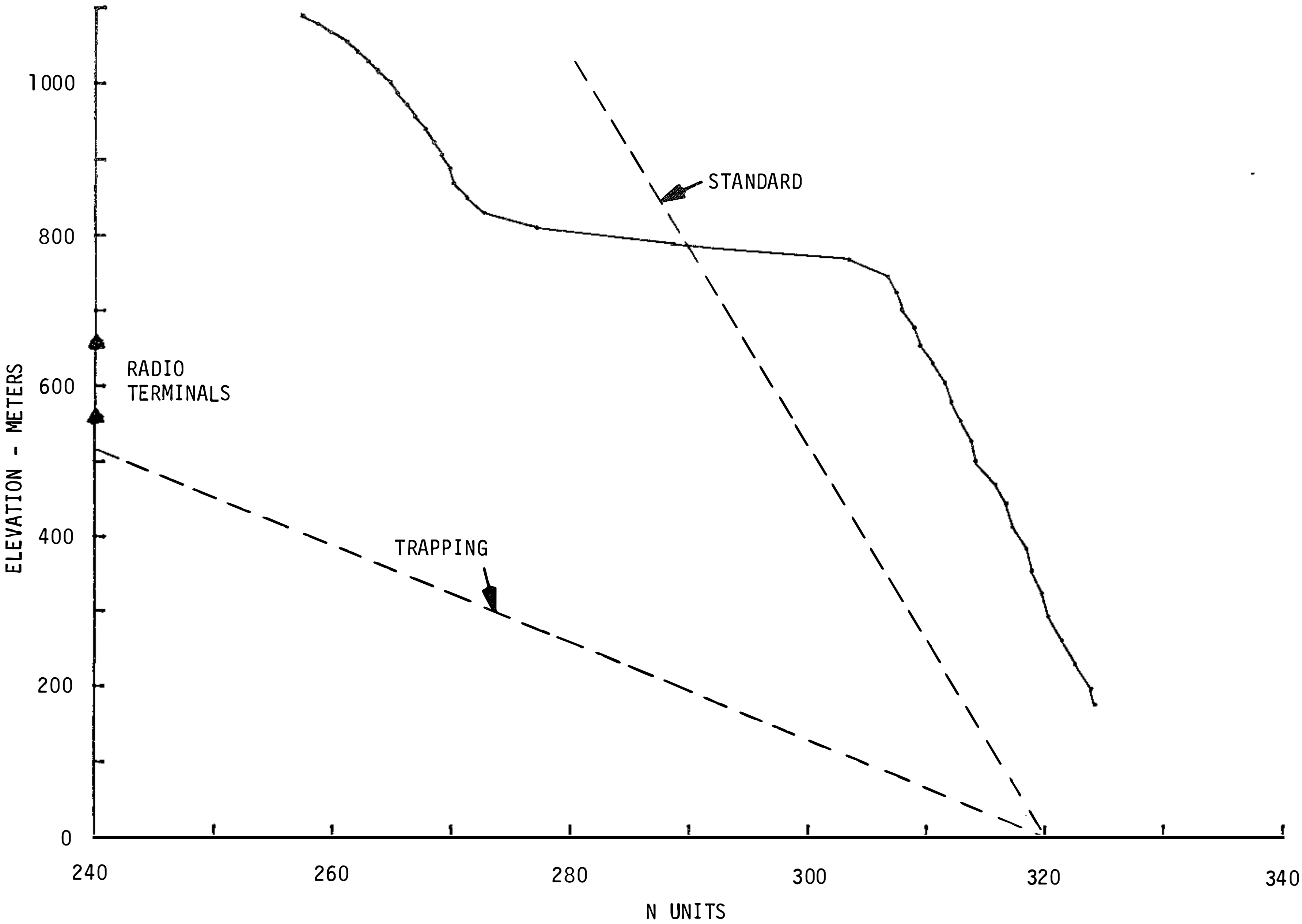


Figure 2-4. An example of the refractive index profile measured at Landau, West Germany, at 1030 LST on November 4, 1981.

standard gradient of the refractivity. These results were derived from reflection path geometry applied to the link profiles, using the measured refractive gradients.

A draft report was prepared and submitted to the sponsor in March 1982, in which the results of both test phrases were presented. The results answered both test objectives in the affirmative. The final report is in preparation, and will be issued prior to the end of FY 82.

Additional testing, which will include performance improvement techniques such as adaptive equalization and diversity combining, are planned to be conducted in the early part of FY 83.

Technical Support to the MEECN System Engineer. This is a continuing program which supports the MEECN (Minimum Essential Emergency Communications Network) System Engineer, at the Defense Communications Agency (DCA). Another phase of interoperability testing of the U.S. Navy and U.S. Air Force components of the MEECN was performed at NOSC, San Diego, CA, and a "Quick-Look" report written and sent to apprise the sponsor of emerging test results. Because of complex test objectives and other equipment commitments, it is expected that additional testing will be conducted in FY 83. The data from both test phases (FY 82 and FY 83) will then be analyzed, compared with each other and with that of earlier tests, and a final test report will then be written.

U.S. Army Tactical Communication Systems - Digital Message Device Group Tests. The purpose of this project was to (a) determine the possible improvement of specific performance capabilities of a Digital Message Device Group (DMDG) HF modem using the ITS Ionospheric Channel Simulator, and (b) prepare a final report on the results of the channel simulator measurements.

The DMDG is a frequency-shift-keyed (FSK), burst-communications, HF modem. After a first set of measurements was completed on the KY-879/P modem, and a report written, manufacturing design modifications were made, based on those results, and the modified prototype sent to ITS for testing. A second set of measurements was then made and a final report written on the results of that set of measurements.

As a consequence of the design changes and, based on the data of the second set of measurements, the following list of abbreviated results may be drawn:

1. The error-free range of the level of an ideal signal, at the demodulator input, has been increased from 44 dB to more than 75 dB. Consequently, demodulator additive and nonlinear distortions are now effectively absent.

2. Tolerance to demodulator Doppler distortion has been increased approximately $\pm$ 160 to $\pm$ 250 Hz under nonfading channel conditions.

3. With respect to channel thermal-noise distortion, performance has been improved as much as 3 dB.

4. The modem is now essentially immune to fading distortion for frequency spreads (approximate fading rates) of $2\sigma_1 \leq 25$ Hz, and therefore, is essentially immune to fading distortion on nearly all HF ionospheric channels.

5. The modem design changes increased its tolerance to demodulator Doppler distortion from approximately $\pm$ 160 to $\pm$ 250 Hz under typical channel fading conditions.

6. With respect to channel thermal-noise distortion, under typical channel fading conditions, the modem improved its performance as much as 4 dB.

7. The design changes in the modem significantly improved its performance with respect to channel differential-delay (multipath) distortion under typical channel fading conditions. However, the modem still fails to meet the U.S. Army differential-delay specification.

8. The modified modem is essentially immune to channel differential-Doppler distortion for differential frequency shifts of $\nu_2 - \nu_1 \leq 30$ Hz. It is therefore essentially immune to differential-Doppler distortion on nearly all HF ionospheric channels.

9. The performance of the modified modem with respect to channel fading CW interference at the space frequency is substantially better than its performance with respect to channel thermal noise with the same power in the combined mark and space filter bandwidths for unknown reasons.

10. The 267-baud keying rate of the modem is substantially higher than optimum, as shown by its excellent performance with respect to frequency-scatter distortions (conclusions 4 and 9) and by its very poor performance with respect to time-scatter distortion (conclusion 7).

11. The demodulator in the modified modem delivers some messages with fewer than or more than the correct number of characters. The probabilities of short and long messages increase with increasing conditional character error probability and approach unity as the character error probability approaches unity. This deficiency is not necessary and should be corrected.

2.1.2. Communication Systems and Services Engineering

The Systems Technology projects described in this section are either established or planned communication systems and services. The services are procured or leased by mission agencies, and the engineering described here pertains to the evaluation, performance criteria, measurement methods, or new technology required for the efficient and cost-effective acquisition of those services. The projects described are: Boise National Forest

Telecommunication Plan, Region 2 Telecommunication Master Plan, and Defense Nuclear Agency Information Sciences.

Boise National Forest Telecommunication Plan. The objective of the program is to perform a study of the telecommunication needs of the Boise National Forest to be included in a forest telecommunication plan. This plan addresses the issues of resource sharing with other Federal and state agencies, management of co-used electronic sites, and management of the information resource within the forest management structure. The needs of the forest are established through interviews of personnel at the Forest Supervisor's office and the District Ranger's offices. The needs are compared with available technology and alternative concepts are derived from these comparisons. With alternatives, many attributes may be evaluated for each and an optimum choice made for the system to be implemented.

A telecommunication plan is being prepared for the forest and will be available by year's end. An electronic site management document is currently in draft form and it, too, will be available in the same time frame.

The project is sponsored by the U.S. Dept. of Agriculture, U.S. Forest Service.

Region 2 Telecommunication Master Plan. The objective of the program is to study current and future Region 2 Forest Service information transfer needs and to extrapolate these needs into a telecommunication master plan. The plan is to include technical alternative solutions and the relative trade-offs between each alternative. The telecommunication plan will be described in a formal NTIA report. Information on the operational requirements of the 12 national forests in the region was obtained through interviews of personnel in each of the Forest Supervisor's offices. The basic elements of information transfer are described in the report and identified and a matrix of alternative solutions for these elements was developed. This allows a synthesis of a system to be tailored for a variety of conditions and circumstances.

An organizational structure is described in some detail for effecting the integrated management of telecommunications and information resources within the Forest Service management structure.

A NTIA report has been prepared and is going through the review process in anticipation of publication.

The project is sponsored by the U.S. Dept. of Agriculture, U.S. Forest Service.

Datacommunication System Architecture. The Institute is participating in a network and computer architecture program with the Defense Nuclear Agency (DNA). DNA operates and maintains both computational capability as well as network interconnect for themselves and their contractor base. DNA is in the process of upgrading both systems and has solicited the support of ITS as technical advisors.

2.1.3. Standards

The current ITS project pertains to a technical and economic assessment of the interface requirements and applications of an emerging technology. The standards will affect the Federal, international, and industrial communities. The project described is: Data Terminal Equipment (DTE)/Data Circuit Terminating Equipment (DCE) Standards.

DTE/DCE Standards. A new study was undertaken for the National Communications System (NCS) to provide technical and economic assessments for the application of optical waveguide cables and technologies to the interface requirements for DTE/DCE. The standards for interconnection have traditionally been the EIA-RS-232-C and more recently the EIA-RS-449. Physical circuits have generally been accomplished through a large number of paired-copper cables--as many as 24 wires (24 AWG copper) for the RS-232-C and even a greater number for the RS-449. A number of the electrical and physical properties and data rate limits of the above standards are shown in Table 2-1.

One basis for the examination of alternative physical interfaces such as optical fiber cable has been the interface requirements for the Integrated Services Digital Network (ISDN). Physical layer interface specifications have been requested through the CCITT Study Groups XVII or XVIII to meet the requirements for the ISDN and in particular for a Universal Physical Interface (UPI).

Objectives for a DTE/DCE physical interface include:

1. Support of present and future digital data networks and data applications.

2. Providing physical interconnection of terminal equipment to modems and network termination of the Public Data Networks (PDN).

3. Use of a minimum number of interchange circuits--no more than two circuits in each direction.

4. Provisions for path length exceeding 300 m (NCS has chosen 1000 m to provide for long term universality and to meet other Federal objectives).

Progress on a number of tasks for this program has included the following:

1. A technology and economic data base has been developed both for copper cable (coaxial interchange circuits) and for optical fiber cable. Power budgets for optical fiber cables have been calculated based on manufacturers' available optical cables matched to optical transmit/receive modules. Table 2-2 presents the results for a number of different optical fibers with varying waveguide core diameters and for the attenuation coefficients for the specific cables.

Table 2-1. Data Rates and Path Length Specifications--Existing EIA and CCITT Interface Standards

BACKGROUND

- Limitations of existing, operational DTE/DCE standards:

Standard	Max. Bit Rate	At Max. Path Length	Trans. Medium
EIA RS-232-C ①	20 kb/s	15 m	Wire pairs (Unbalanced)
EIA-RS-423 ② *	100 kb/s 3 kb/s	13 m 1200 m	Wire pairs (Unbalanced, balanced receiver) Wire pairs (Unbalanced, balanced receiver)
EIA-RS-422 ③ *	10 Mb/s 100 kb/s	13 m 1200 m	Wire pairs (Fully balanced) Wire pairs (Fully balanced)
CCITT V.35	48 kb/s	Ltd. by trans. line	Wire pairs (Hybrid)

*EIA RS-423 and 422 define electrical specifications for the parent standard, EIA RS-449.

Notes:

① Equivalents are V.28 (RS-232-C)

② Equivalents are V.10 (RS-423 or X.26)

③ Equivalents are V.11 (RS-422)

- Needs for next-generation standards:
  - increased bit-rate/path-length product
  - improved BER (not quantified in earlier standards)
  - decreased number of interchange circuits (physical trans. channels)
  - more efficient transmission medium to meet functional requirements of OSI Reference Model, CCITT/ANSI "mini-interface," and universal physical interface (ISDN)
  - reduced effects due to ground potential differences, also minimize high level transient voltage interference.

Table 2-2. Optical Power Budgets for Commercial Digital XMTR/RCVR Pairs as Function of Commercial Optical Cable Parameters
(Transmission Conditions: dc to Min. 10 Mb/s (NRZ) Over 1 kilometer at BER $\leq 10^{-9}$)

	Parameter	Unit																
I	Fiber Core Diameter	μm	50		100					200								300
II	Fiber Numerical Aperture	--	0.20-0.22		0.30					0.21 -0.22	0.30			0.33-0.36		0.40	0.50	0.22
III	Max. XMTR Optical Power Coupled into Fiber	dBm	-14	-17	-10.7	-14	-8	-13	-16	-3.5	-2	-11	-4	-6.5	-7	-5.5	-20	-4.9
IV	Cabled-Fiber Attenuation	dB/km	3		7					6	10					6	15	8
V	Optical Power Out. 1-kilometer Cable	dBm	-17	-20	-17.7	-21	-15	-20	-23	-9.5	-12	-21	-14	-16.5	-17	-11.5	-35	-12.9
VI	Output Coupling Losses (2 db) & Degradation Budget (3 dB)	dB	5		5					5								5
VII	Max. Optical Power Available at RCVR	dBm	-22	-25	-22.7	-26	-20	-25	-28	-14.5	-17	-26	-19	-21.5	-22	-16.5	-40	-17.9
VIII	RCVR Threshold	dBm	-28.2	-35	-40	-27	-24	-33	-33	-20	-31	-27	-27	-28.2	-23	-31	-48	-28.2
IX	Excess Power Margin for Above Configuration	dB	6.2	10	17.3	1	4	8	5	5.5	14	1	8	6.7	1	14.5	8	10.3
	Matched XMTR/RCVR mfr.	--	A,O	L,N	M	J	C,O	F,N	G	D	B	J	P	A	H	I	K	A

Notes: All modules and fibers are commercially available (April 1982).
Fiber geometry selected to match XMTR output coupling specs., per module mfrs.
Fiber attenuations are lowest available (at modest cost) for stated geometries.
Power coupled into fiber (ROW III) considers all source-to-fiber losses for given source and fiber geometries.
Multiple XMTR/RCVR listing given only where mfr. specifies multiple fiber geometries.
With one exception all XMTR/RCVR pairs are rated to max. BW range 16-50 Mb/s, NRZ, and power values reflect this max. BW. For max. 10 Mb/s, all above values will be higher.
Mfr.. "A" exception to 10^{-9} BER spec.; $<10^{-8}$ is quoted at 50 Mb/s. 10^{-9} should be achieved easily at 10 Mb/s; mfrs. "N" and "O" quoted at BER = 10 - 15.

2. Physical interchange circuit costs have also been tabulated as shown graphically in Figure 2-5. It is to be noted that these prices are for single circuits. Costs for a multicircuit interface would be in multiples of the tabulated costs.

3. "Draft specifications" for optical fiber DTE/DCE interchange circuits have been prepared by ITS and submitted to the EIA TR30.1 committee (signal quality). Such "draft specifications" are modified as a result of comment and discussion at a succession of such meetings.

Further submissions will include offerings to the appropriate ANSI, ISO, and CCITT Standards Groups.

A follow-on program has been requested by NCS to continue the DTE/DCE interface work towards a U.S. input into the International Standards Committees.

SECTION 2.2. SYSTEM PERFORMANCE STANDARDS AND DEFINITION

The three projects described in this section deal with the development and application of national and international telecommunication standards. The first project 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 project supports U.S. participation in the development of international standards, particularly those dealing with public data networks and the Integrated Services Digital Network (ISDN). The third project supports the Interdepartment Radio Advisory Committee (IRAC) in its development of radio emission standards. A common objective of the three projects is to facilitate private sector development and Federal procurement of digital telecommunication sources.

Data Communications. The overall goal of NTIA's Data Communications project is to promote competition and innovation in the data communications industry by giving users a practical way of comparing the performance of competing services. This objective is being pursued, in cooperation with other Federal and industry organizations, through the development and application of user-oriented, system-independent data communication performance parameters and measurement methods. Results are being promulgated in the Federal Government form of Federal Telecommunication/ Federal Information Processing Standards, and in industry in the form of American National Standards.

Two related data communication performance standards have been developed. The first specifies a set of user-oriented performance descriptors or parameters. That standard was approved as Interim Federal Standard (FED STD) 1033 in 1979, and has since been adapted for proposal as an American National Standard by a task group of the American National Standards Institute (Task Group X3S35). The ANSI standard was approved by a formal ballot of ANSI's Data Communications Subcommittee, X3S3, in March of 1982. It is expected that when that standard, X3.102, is officially promulgated by ANSI, it will replace Interim Federal Standard 1033 as a joint Federal Telecommunication/Federal Information Processing Standard. Interim 1033 has already been applied successfully in several Federal procurements of public packet switching services.

The second standard, proposed Federal Standard 1043, specifies uniform methods of measuring the FS 1033/X3.102 performance parameters. An initial 1043 draft was completed in 1980. It is following a review path similar to that followed by FS 1033, with ANSI approval targeted for early 1984.

The standard performance descriptors and measurement methods being developed in NTIA's Data Communications project will promote competition and innovation in the data communications industry in two ways:

1. By providing a "common language" for relating user performance needs with the capabilities of offered systems and services.

2. By providing a practical method of determining actual delivered performance.

In view of the strong procompetitive and deregulatory emphasis of recent Federal telecommunication policy initiatives, such capabilities are urgently needed now.

The Institute's FY 82 Data Communications project had two major objectives:

1. To complete and document a series of experimental measurements designed to demonstrate actual use of the 1033/1043 standards in characterizing the end-to-end performance of a modern packet switching network--the Defense Communications Agency's ARPANET.

2. To plan and initiate a series of public data network measurements utilizing portable, microprocessor-based test sets conforming to the 1033/1043 standards.

Figure 2-6 illustrates the specific performance parameters defined in the ANSI version of Federal Standard 1033, proposed American National Standard X3.102. A total of 21 parameters are defined: 17 "primary" parameters and 4 "ancillary" parameters. The primary parameters are specific measures of speed, accuracy, and reliability associated with three primary data communication functions: access, user information transfer, and disengagement. The ancillary parameters express the influence of user delays on the primary "speed" parameters, and provide a quantitative method of "factoring out" such influences. For further information, see Seitz, N.B., K.P. Spies, and E.L. Crow (1981), Data communication performance measurement--A proposed Federal standard, Proc. NTC '81, Nov. 29-Dec. 3.

Figure 2-7 illustrates the basic hardware configuration tested. The measurements were conducted between two host computers attached to the ARPANET: one located at NTIA/ITS in

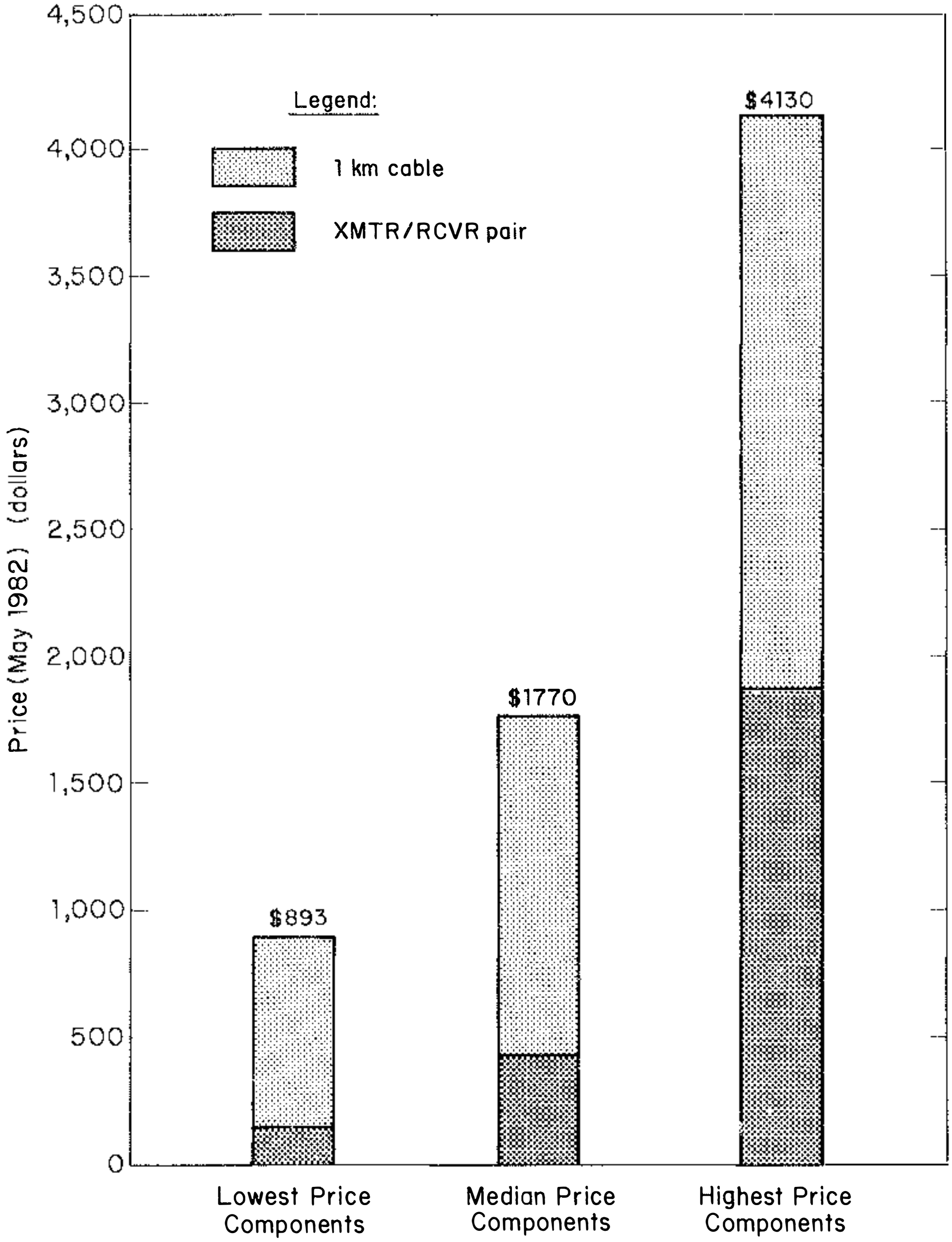


Figure 2-5. Prices for 1 km optical interchange circuit.

FUNCTION	PERFORMANCE CRITERION: SPEED	PERFORMANCE CRITERION: ACCURACY	PERFORMANCE CRITERION: RELIABILITY	PERFORMANCE TIME ALLOCATION
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 BLOCK ERROR PROBABILITY BLOCK MISDELIVERY PROBABILITY EXTRA BLOCK PROBABILITY	BIT LOSS PROBABILITY BLOCK LOSS PROBABILITY	USER FRACTION OF BLOCK TRANSFER TIME
	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 2-6. Summary of ANSI performance parameters.

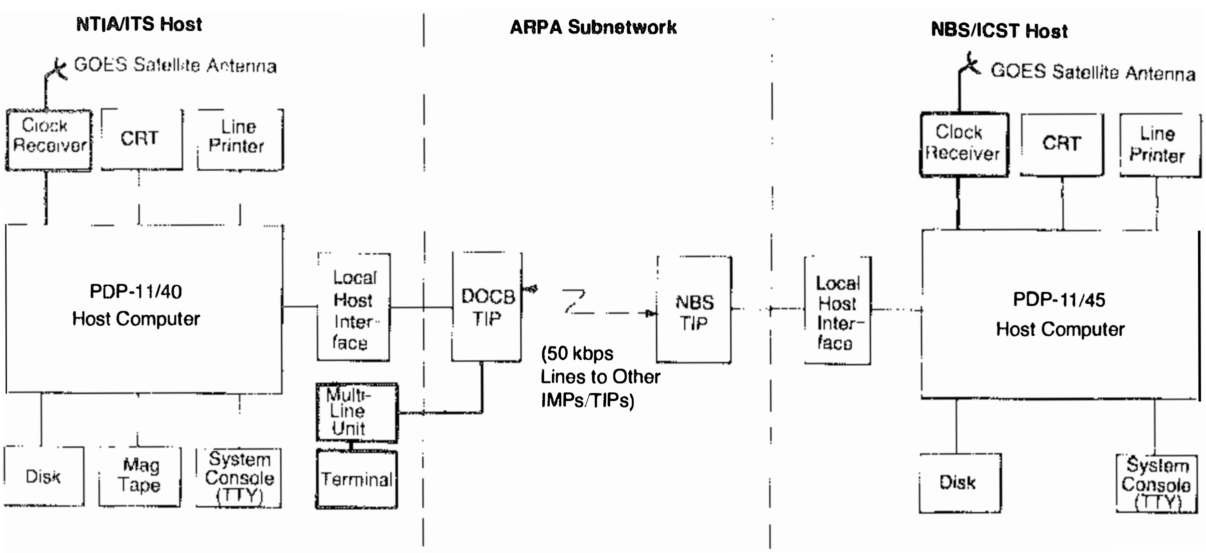


Figure 2-7. ARPA network test configuration.

Boulder, CO, and one located at the National Bureau of Standards' Institute for Computer Sciences and Technology (NBS/ICST) in Gaithersburg, MD. The two hosts were similar general-purpose minicomputers with the usual attached peripherals. Special-purpose test equipment consisted of two satellite clock receivers, which provided a synchronized time reference to the two host computers, and an ancillary data terminal which was used to remotely control activities in the NBS/ICST host.

Figure 2-8 shows the logical flow of information, and the associated measurement events, within each host. The end user in each case was an application program executing under the host computer's Operating System (OS). The OS was connected with the local Terminal Interface Processor (TIP) via the standard ARPANET Network Control Program (NCP). The measurement events consisted of Open, Close, Read, and Write system calls, and the associated "function complete" system responses, which were monitored by the application program at its software interface with the OS. This choice of measurement points distinguished the user-oriented performance measurements reported here from earlier ARPANET measurements, which focused on the subnetwork.

Figure 2-9 illustrates the general operation of the ARPANET measurement programs. Two types of measurement (application) programs were provided at each host site: a Transmit program, which served as the "calling user" and the source of user information; and a Receive program, which served as the "called user" and the information destination. During each test, the active Transmit and Receive programs progressed in synchronism through three consecutive phases of operation: a pre-exchange phase, associated with connection establishment or access; an exchange phase, associated with actual user information transfer; and a post-exchange phase, associated with connection release or disengagement. Two basic types of tests were conducted: access/disengagement tests and user information transfer tests. During the access/disengagement tests, many successive connections were established and released, with only a single block of user information transferred during each. During the user information transfer tests, only one connection was established, but many user information blocks were transferred before its release.

The measurement results reported here are based on a total of 44 separate ARPA network tests, conducted over a two month period in late 1981. These tests included over 3,000 access attempts and over 3 million transferred bits, and involved systematic variations in key measurement variables such as direction of transfer and time of day. The measurement results are fully described in a pending NTIA Report [Wortendyke, D.R., N.B. Seitz, K.P. Spies, E.L. Crow, and D.S. Grubb (1982), User-oriented performance measurements on the ARPANET: The testing of a proposed Federal standard].

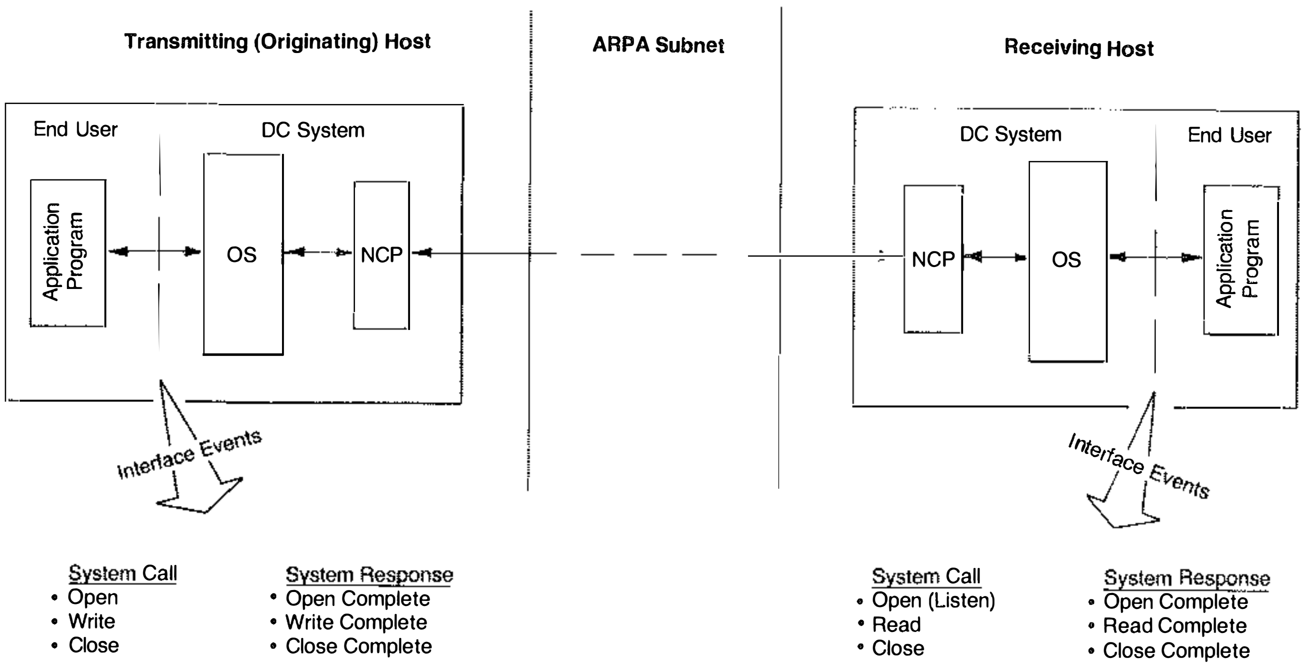


Figure 2-8. Logical data flow within the host computers.

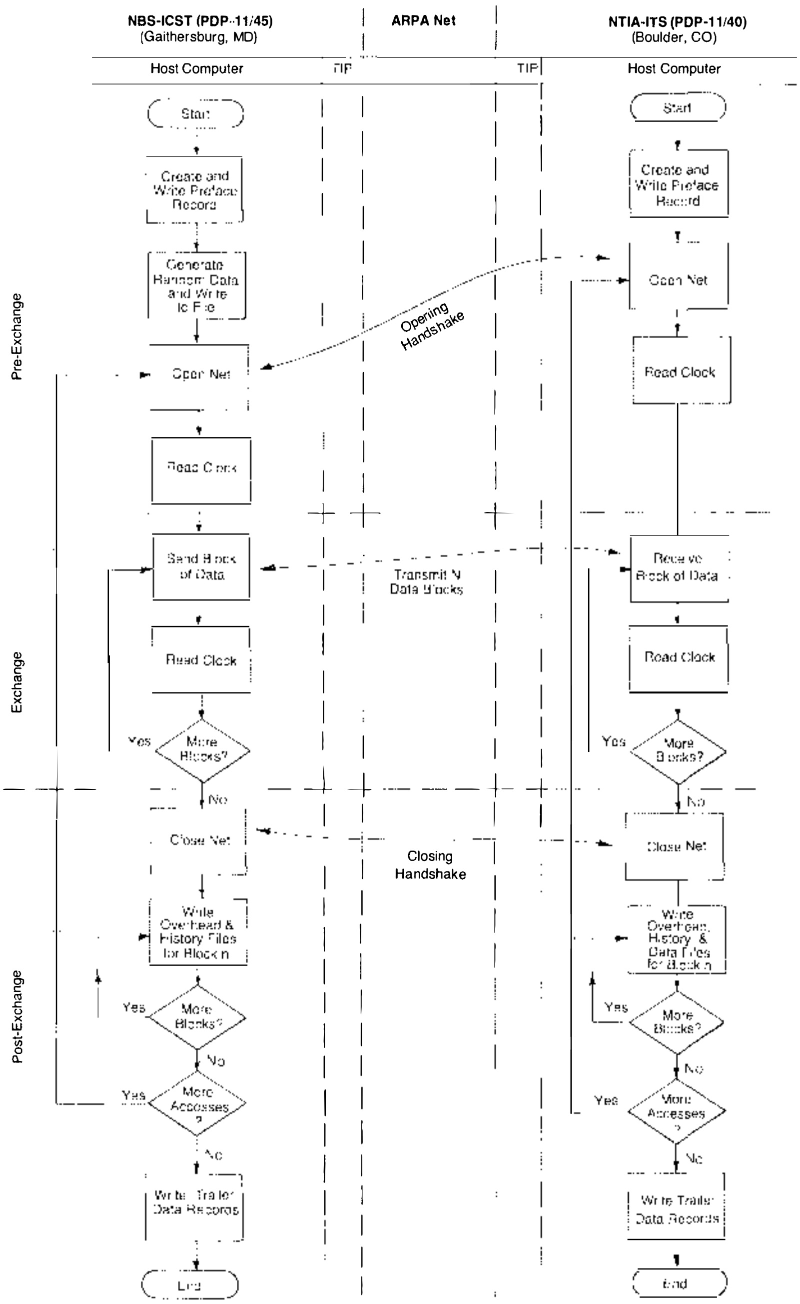


Figure 2-9. Flow chart of on-line data extraction programs.

Table 2-3 summarizes the measurement results in qualitative terms. As one would expect in measuring a modern packet switching network like the ARPANET, the majority of the tests ran faultlessly, with no deviation from the normal flow path of Figure 2-9. Shown in the table are the relatively few exceptions. The measured values for the 1033/X3.102 accuracy and reliability parameters were largely determined by these anomalies.

Figure 2-10 is a histogram of measured values for the performance parameter Access Time--the time between user issuance of an Open request and the start of actual user information transfer. The measured values for this parameter ranged between 602 ms and 24.1 s, with a mean of 1.8 s and a standard deviation of 1.02 s. (One astounding value of 12.1 min was omitted from these calculations to avoid unduly biasing the results.) The one-way Block Transfer Times measured were one-tenth to one-half the average Access Time, depending on block size, and were substantially less variable.

Figure 2-11 shows the distribution of measured values for ARPANET Disengagement Time--the time between user issuance of a Close request and successful disengagement. The ARPANET measurements quickly demonstrated a distinct assymmetry in the values for this parameter between the user originating disengagement (the source user in this experiment) and the other (nonoriginating) user. The average originating user Disengagement Time was 12 ms; the average nonoriginating user Disengagement Time was 2.5 s.

The reason for the substantial difference between the originating and nonoriginating user Disengagement Times measured in the ARPANET experiment is evident from a consideration of the nature of the disengagement function at each interface. Disengagement of the originating user is a simple local function which is accomplished entirely within that user's host computer. In contrast, disengagement of the nonoriginating user requires first the transmission of a Close message from the originating NCP through the network to the nonoriginating user; second, that user's issuance of a Close request; and finally, issuance of a Close Complete response by the nonoriginating host operating system.

Figure 2-12 summarizes the ANSI X3.102 performance parameter values measured in the ARPA network experiment. A comparison of these measured results with results previously reported reveals some significant differences between the performance delivered to a typical ARPANET end user and the performance of the subnetwork. Performance delays observed at the end user interfaces were two to four times greater than the corresponding subnetwork delays, and the observed throughputs were proportionally lower. It appears that most of the additional delay is introduced by communication support software in the hosts (e.g., the NCP's and the operating systems) rather than by the user programs themselves.

The measurement results obtained in this experiment confirmed that transmission errors are extremely rare in the ARPANET. However, the loss of user data in transit between application programs is relatively common. Such failures appear to be caused by hardware and software "crashes" and subnetwork delays in addition to the previously reported "tardiness" of ARPANET hosts in accepting transferred messages. Data loss was by far the most serious network imperfection observed during these measurements. That one phenomenon completely determined the measured service availability values.

Although the performance values obtained in this experiment are of interest in themselves, the primary purpose of the experiment was to verify the proposed standards and demonstrate their use in a realistic measurement situation. Application of the 1033/1043 standards to the ARPANET proved to be quite feasible, and relatively few significant changes to the proposed standards were required. In almost every case where differences between the Interim Federal Standard 1033 performance parameter definitions were examined, the measurement results demonstrated that the latter definitions were preferable. Future implementations of the measurement standard will be facilitated by the tools and techniques developed in this experiment--in particular, a standard, machine-independent FORTRAN computer program for reducing extracted measurement data to corresponding values for the FED STD 1033 performance parameters. That program is now available for use by other organizations, and is being fully documented in an NTIA Report which will be available early in FY 83.

The second major objective of NTIA's FY 82 Data Communications program was to plan and initiate a series of public data network measurements utilizing portable, microprocessor-based test sets conforming to the 1033/1043 standards. Figure 2-13 illustrates the basic test configuration. The on-line extraction of measurement data is accomplished by two similar microprocessors--one emulating a host computer and one emulating a remote data terminal which accesses the host via a public data network. The host emulator is connected to each public data network via a commercially available X.25 front end and a 9.6 kbps leased telephone line. The terminal emulator is connected to each public data network via conventional dial telephone service.

Test software in the two micros is similar to that used in testing the ARPANET, with two exceptions. First, the end user (application) programs are designed to communicate data interactively, rather than unidirectionally, during a test to more closely approximate the user/server interactions during a typical remote-access data processing session. Second, the terminal emulator software is designed to support, and passively monitor, sessions in which the operator at the terminal end serves as the communications end user.

A teletypewriter, colocated with the host, can be used to control and monitor the remote terminal via a conventional toll telephone connection in cases where the terminal user

Table 2-3. Summary of Observed Anomalies

IDENTIYING NUMBER	TEST NUMBER(S)	NATURE OF ANOMALY	CAUSE (IF KNOWN)	REMEDIAL ACTION (IF ANY)	PERFORMANCE EFFECT
1	77	DOCB TIP "crashed" during an A/D test sequence.	Routine TIP maintenance procedures.	TIP restart. See next item.	Access Denial (timeout).
2	78/79	Systematic disappearance of first 1 or 2 blocks transmitted during an A/D test sequence.	NTIA/ITS NCP altered by TIP "crash" during previous test.	Host software restart.	Block Loss.
3	94	Systematic disappearance of all transmitted blocks beginning at the middle of an A/D test sequence.	Probably a host software failure - NBS system "crashed" soon after test.	Host software restart.	Block Loss (all blocks transmitted between failure and test termination).
4	95	Destination host refused connection (and source program received a denial response) after 67 trials in an A/D test sequence.	Destination NCP "crashed."	Host software restart.	Access Denial (system blocking signal).
5	97	Random loss of blocks during an A/D test sequence.	Unknown. Destination host was under very heavy local use.	None. Problem did not persist.	Block Loss (three random blocks in a 160-block sequence).
6	97	12-minute access time observed on one trial in a 160-trial A/D sequence. Access ultimately established. Remaining access times normal.	Unknown. Destination host was under very heavy local use.	None. Problem did not persist.	Access Denial (timeout).
7	Not Assigned	Host down at initiation of test.	Various (e.g., hardware failures, software "crashes").	Host hardware maintenance or software restart.	Access Outage. This was a very common occurrence.
8	Not Assigned	TIP down at initiation of test.	TIP program failure.	TIP restart (via remote action).	Access Outage.
9	Not Assigned	Host and TIP disconnected at initiation of test.	TIP operator error.	Reconnect TIP/host cable.	Access Outage.
10	All UIT TESTS	First few blocks input by source are delivered to destination in two pieces (512 bytes 64 bytes + 448 bytes).	Unknown. May be a characteristic of the host flow control protocol.	None. Delivered bit sequence is correct; only block delimiters are changed.	Longer Block Transfer Times for first few blocks transmitted during UIT tests.

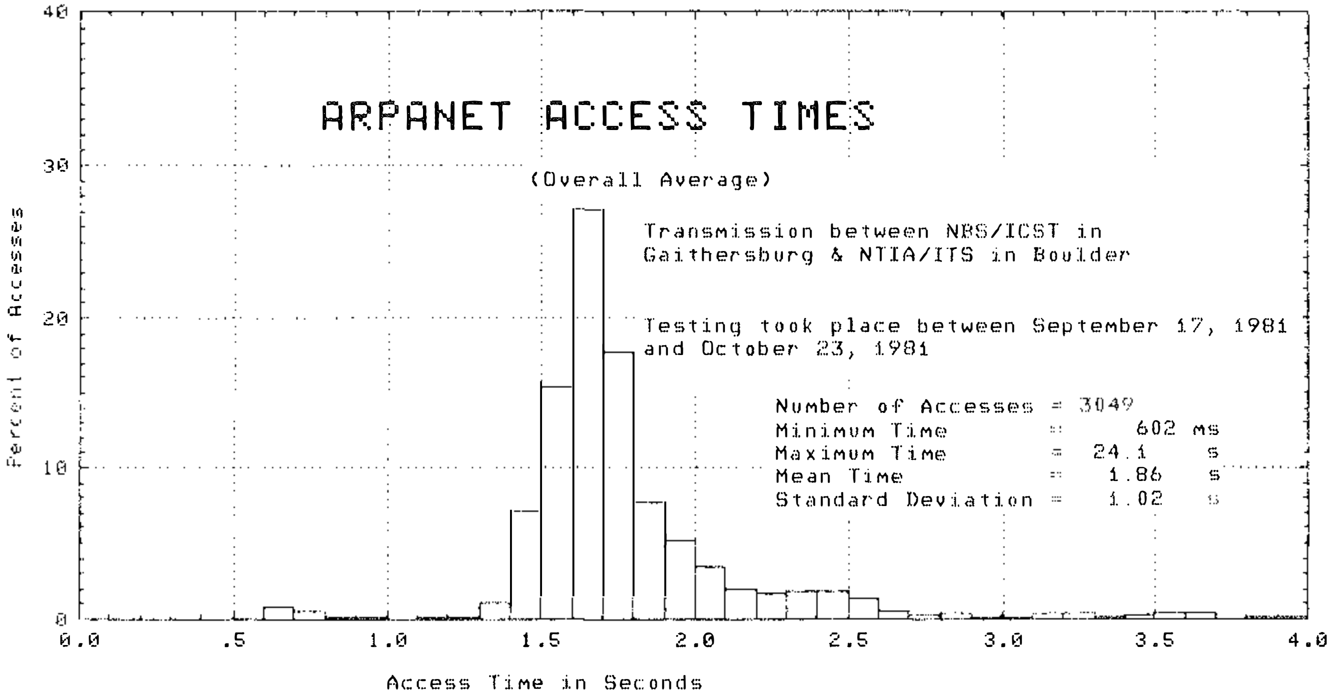


Figure 2-10. Histogram of access times - overall average.

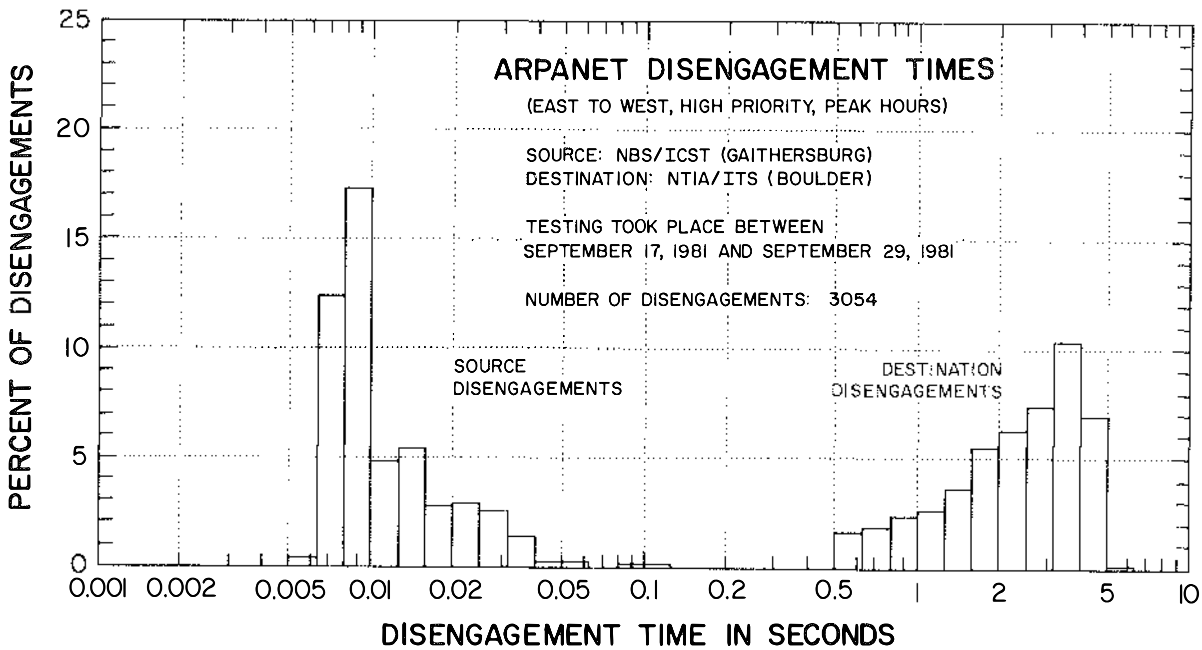


Figure 2-11. Disengagement time histogram.

SERVICE PERFORMANCE SPECIFICATION

Part A - Primary Parameters

Parameter	Condition	Value	Units
1. Access Time		1.8	Seconds
2. Incorrect Access Probability		0	*
3. Access Denial Probability		6.0×10^{-3}	*
4. Access Outage Probability		2.6×10^{-3}	*
5. Bit Error Probability		0	*
6. Bit Misdelivery Probability		†	*
7. Extra Bit Probability		0	*
8. Bit Loss Probability		2.0×10^{-3}	*
9. Block Transfer Time	(512-bit blocks)	709	Milliseconds
	(4096-bit blocks)	262	Milliseconds
10. Block Error Probability		0	*
11. Block Misdelivery Probability		†	*
12. Block Loss Probability		2.0×10^{-3}	*
13. Extra Block Probability		0	*
14. User Information Bit Transfer Rate		4872	Bits/ Second
15. Disengagement Time	Originator	12	Milliseconds
	Nonoriginator	2.5	Seconds
16. Disengagement Denial Probability	Originator	1.3×10^{-3}	*
	Nonoriginator	0	
17. Transfer Denial Probability		4.7×10^{-2}	*

Part B - Ancillary Parameters

Parameter	Condition	Value	Units
18. User Fraction of Access Time		0.15	*
19. User Fraction of Block Transfer Time	(East-to-West)	0.13	*
20. User Fraction of Sample Input/Output Time		0.13	*
21. User Fraction of Disengagement Time	Originator	0	*
	Nonoriginator	0.13	

*Note: The probabilities and user performance time fractions are dimensionless numbers between zero and one.

†Value not measured.

Figure 2-12. Performance measurement summary.

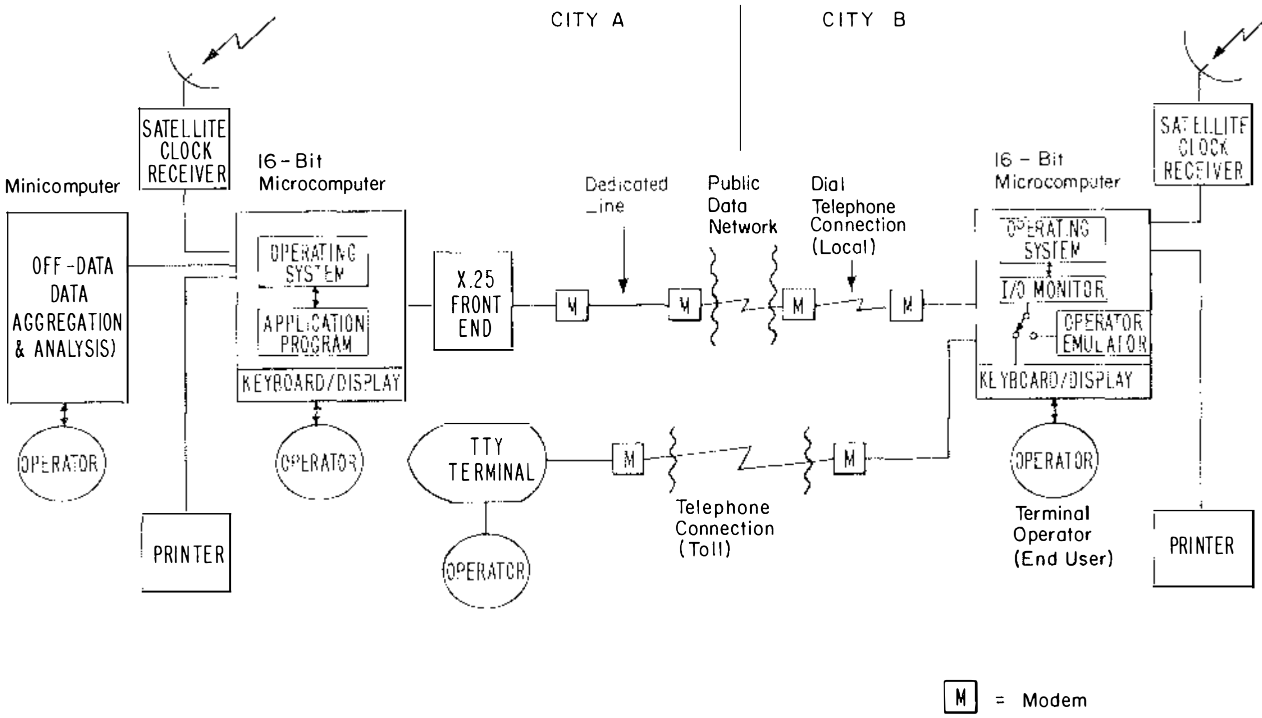


Figure 2-13. Hardware design for the measurement of public data networks.

functions are performed by the software operator emulator. Alternatively, the roles of the public data network and the toll telephone network can be reversed to permit testing of data transmission over the latter. A minicomputer connected to the host emulator is used to speed up the off-line reduction of measurement data.

Results of the public network measurements initiated in FY 82 will be published in an NTIA Report which will be available about the middle of FY 83. These results will promote the Data Communications project objectives in three ways:

1. By providing an initial characterization of public data network performance as seen by typical end users.

2. By encouraging data communication service suppliers to measure and report the performance of their own offered services in uniform, user-oriented terms.

3. By providing Federal agencies and others with a practical, relatively inexpensive method of measuring the user-oriented performance parameters.

Further information on the public data network measurement methodology and results can be obtained by contacting the Institute.

International Standards. Effective U.S. participation in the development of international telecommunication standards has become increasingly important in recent years. Among the reasons are:

1. Expanding World Markets. The worldwide telecommunication market for both services and equipment is growing explosively. Obviously, this implies substantial new market opportunities for U.S. suppliers.

2. U.S. Trade Balance. Import of telecommunications equipment by the U.S. continues to grow. Our growth rate of exports must at least equal that of imports if we are to maintain a favorable trade balance. This demands manufacturing to overseas specifications.

3. Growing Standards Impact. The telecommunication industry, worldwide, has entered a period in which international standards are often leading and shaping new network designs, rather than simply mandating existing practices. This change reinforces the need for active U.S. participation in international standards development.

The Institute's International Standards project is designed to enhance opportunities for U.S. firms to compete in international telecommunications markets by promoting the development of broadly based, functionally oriented, nonrestrictive international telecommunication standards.

The project involves three major functions. The first is to lead and support U.S. participation in key standardization efforts of the International Telegraph and Telephone Consultative Committee (CCITT) and its radio counterpart, the International Radio Consultative Committee (CCIR). This work is conducted under the auspices of the U.S. Department of State. The project currently provides ITS chairmanship for two U.S. CCITT preparatory groups and one international CCIR Interim Working Party (IWP). The responsibilities of a U.S. CCITT Chairman include the review, coordination, and approval of proposed U.S. contributions to CCITT; development of U.S. concensus positions on international standards issues; and leadership of the U.S. Delegations to international CCITT Study Group meetings. CCIR IWP Chairmen are responsible for the direction and coordination of international efforts leading to proposed CCIR Recommendations.

Figure 2-14 illustrates the structure of the United States Organization for the CCITT (U.S. CCITT). This organization, which is chartered by the U.S. Department of State, provides the mechanism by which U.S. contributions are coordinated and transmitted to the international CCITT. Each of the four traditional U.S. Study Groups, A to D, covers the work of several related international CCITT groups. The recently established Joint Working Party on the ISDN contains members from all four U.S. Study Groups.

Mr. Thijs de Haas of NTIA/ITS currently serves as the Chairman of both U.S. Study Group D and the ISDN Working Party. U.S. Study Group D coordinates U.S. inputs to two international CCITT study groups: Study Group VII, which develops recommendations for public data networks (e.g., Recommendation X.25); and Study Group XVII, which develops recommendations for data transmission over the public telephone network (e.g., modem Recommendations V.22, V.24, and V.27). The ISDN Working Party provides U.S. contributions primarily to CCITT Study Group XVIII, which is responsible for the overall development of the ISDN [Glen, D.V. (1982), Integrated services digital networks, standards, and related technology, NTIA Report 82-103]. The ISDN Working Party also plays an overall U.S. coordinating role in view of the probable impact of ISDN on existing telephone, telegraph, and data services.

Activities in Study Group D during FY 82 included work on CCITT Recommendations in the following areas: 2400 bps full duplex modems, the universal physical interface, the Open Systems Interconnection (OSI) reference model, message handling, and subaddressing in the numbering plan. Study Group D also developed contributions on ISDN related subjects. Meetings were held in October of 1981 and in April and August of 1982. International meetings of SG VII were held in Geneva, Switzerland, December 14-18, 1981, and in Melbourne, Australia, March 1926, 1982. An international meeting of of SG XVII was held in Geneva, Switzerland, on November 23-27, 1981.

Work in the ISDN Working Party included the development of Study Group XVIII inputs which helped shaped Draft Recommendations I.xxx (Reference Configuration for User/Network Interface), I.xxy (User/Network Interface Channel Structures and Access Capabilities) and I.xxw (General Principles and Characteristics of ISDN). Meetings were held in October of 1981 and in April and August of 1982. International meetings of SG XVIII were held in Munich, Germany, on February 17-25, 1982, and in Geneva, Switzerland, on June 16-23, 1982.

The Institute also provides chairmanship of international CCIR IWP 8/11, which is responsible for developing a new Recommendation for direct printing equipment in the Maritime Mobile Service. This Recommendation will incorporate improved radio circuit security and enlarged address capability. An IWP 8/11 meeting was convened in Rochester, NY, on May 4-12, 1982. An initial draft of the new Recommendation was developed and agreed to at

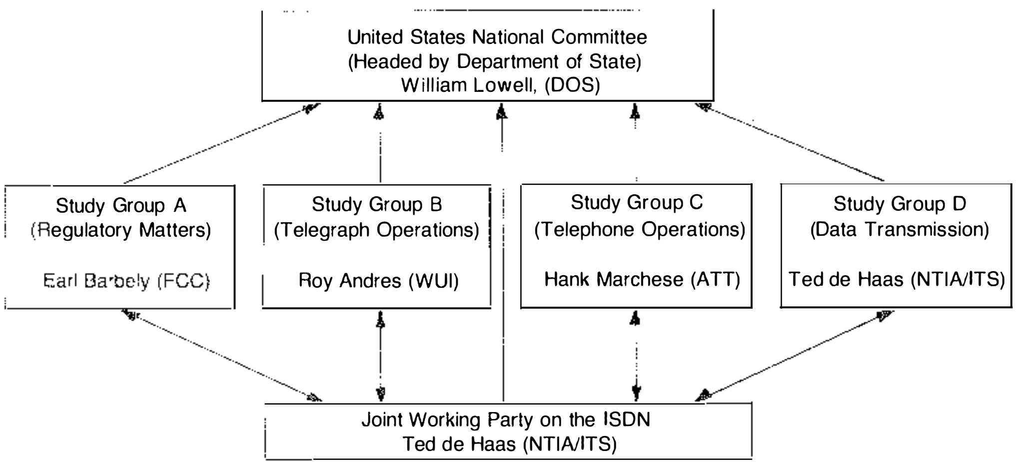


Figure 2-14. The structure of the U.S. CCITT and chairmen for 1981-1984.

that meeting. One more meeting will be scheduled during the Fall of 1982 or Spring of 1983 to finalize this work. An important task of the IWP is to provide positive identification of radio circuit terminals (as opposed to user terminals) to prevent the possibility of cross-connections on circuit establishment or reestablishment after interruption.

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 also broadens and strengthens U.S. input to the CCI committees by adding new contributors and expanding the "knowledge base" from which U.S. contributions may be drawn. This function is being accomplished by several means, including NTIA and open literature publications, tutorial workshops, and presentations at professional society and industry conferences. Specific FY 82 results included a comprehensive NTIA Report describing the history, organization, and operation of the CCITT [Cerni, D.M.(1982), The CCITT: Organization, U.S. participation, and studies toward the ISDN, NTIA Report 82-101]; several open literature publications on ISDN and related CCITT activities (in publication); a two-day Workshop on International Standards; and the development 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 (1981-1984) study period.

The basic purpose of the Cerni report is to summarize the organization and activities of the CCITT and the U.S. participation in it. Attention is focused on the ISDN studies in particular. The report is directed to the telecommunication (or computer) expert--engineer, regulator, manager, or user--who is unfamiliar with the CCITT and with its process of Recommendation development. Copies of this report may be obtained from the National Technical Information Service (NTIS).

The purpose of the ITS-sponsored Workshop on International Standards was to provide a forum for a broad-ranging U.S. discussion of current international standards issues. There were approximately 150 participants from Government and industry organizations, the latter representing common carriers, data processing equipment and service suppliers, telecommunications equipment suppliers, and communications users (e.g., the banking industry). The workshop focused on recent activities of the CCITT, particularly the ISDN, and included presentations by each of the four U.S. CCITT chairmen. Work of the International Organization for Standardization (ISO) and the U.S. Electronic Industries Association (EIA) and American National Standards Institute (ANSI) were also described, with emphasis on the process of participation and how to get involved.

The workshop consisted of eight sessions: (1) Organization and Working Methods of Standards Organizations, (2) U.S. CCITT Study Groups-Current Topics, (3) Impact of Standards--Why and How of Participation, (4) Integrated Services Digital Network-I, (5) Integrated Services Digital Network-II, (6) Open Systems Interconnection, (7) New Services and Facsimile, and (8) Signalling Systems. A summary record of the Workshop is in preparation. Attendee responses indicated that the Workshop was very well received. Many participants suggested that a similar workshop be held next year. Emphasis by industry speakers on more participation by users underscored the need for broad-based input to the standards-making process.

As part of the NTIA's international standards information function, the Institute has developed a computerized data base containing abstracts and identifier information on numbered White Contributions and Reports from all 15 CCITT Study Groups for the current (1981-1984) Study Period. The data base was developed primarily to assist ITS personnel in preparing for international meetings. Rapid access to these documents also assists NTIA in responding to industry and other-agency queries on standards matters. Plans to provide public access to the data base are under way.

Users can search the data base by using key words, study group names, contribution numbers, or questions assigned to the groups. It is also possible to search documents and print lists of document titles, document sources, or questions addressed in the documents. Future improvements to the system will increase its capacity and the speed at which the abstracts can be searched.

The third major function of NTIA's international standards project is to develop U.S. contributions to international standards organizations. Such contributions are normally undertaken on a very selective basis, in situations where NTIA/ITS has special expertise or resources not readily available to other U.S. participants. Two such contributions were submitted to international standards organizations during FY 82: one to CCITT, defining statistical methods of determining the precision of bit error probability and related performance parameter measurements; and one to the ISO, proposing a method of expressing Quality of Service at the boundary between the Transport and Session Layers of the OSI reference model. A CCITT Draft Recommendation on Quality of Service, reflecting the user-oriented approach of ANSI X3.102, was also prepared.

Figure 2-15 illustrates the general approach proposed in the CCITT contribution on measurement precision. Each curve expresses the relationship between the precision of a failure probability measurement (expressed as a confidence interval), and the number of failure occurrences (e.g., bit errors), for a given confidence level. The curves can be used either *a priori*, to determine the number of failure events which must be observed during a test to assure a given measurement precision, or *a posteriori*, to determine the level of precision actually achieved by a completed measurement. The Institute has

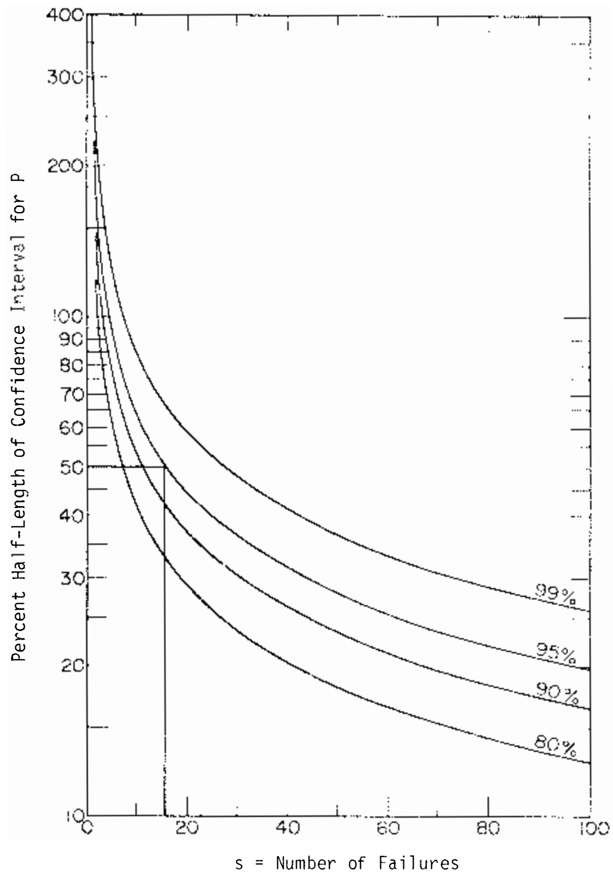


Figure 2-15. Relative precision in estimating P from large samples when number of failures is prescribed and successive observations are independent. Curve labels are confidence levels.

developed similar statistical techniques for determining the precision of time and rate parameter measurements, and will provide these results to the CCITT in future contributions.

Table 2-4 is a list of the user-oriented data communication performance parameters defined in ISO's proposed OSI Transport Service Definition Standard, DP 8072. These parameters were recommended to ISO's TC 97 SC 16 in a U.S. contribution prepared by ITS. They are a subset of the user-oriented performance parameters specified in Interim Federal Standard 1033 and proposed American National Standard X3.102, specialized and simplified to reflect two unique features of the OSI application: its restriction to connection-oriented services, and the need to signal values for the specified parameters across the transport service interfaces. The parameter definitions in the ISO DP closely correspond to the ANSI X3.102 definitions. It is anticipated that these parameters will also provide a basis and framework for a CCITT Recommendation on the specification of quality of service from a customer point of view.

Interdepartment Radio Advisory Committee (IRAC), Technical Subcommittee (TSC) Support. The IRAC provides spectrum management and frequency allocations for Federal agencies. This project provides support to chair the permanent Standards Working Group of the Technical Subcommittee. During this year the Standards Working Group completed the "Undesired Emissions from the Space Services" standard which was approved by the IRAC for inclusion in the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management. The Working Party on Electromagnetic Noise Created by Automotive Ignition Systems completed a review of experimental work sponsored by Army and submitted a recommendation that no new Federal standards be required for the control of such interference as measured by the degradation of radio communications within the vehicle. A recommendation for change of low-power, man-portable radio systems in the 162-174 MHz band

Table 2-4. Classification of Performance QOS Parameters

	Performance Criterion	
Phase	Speed	Accuracy/Reliability
TC Establish-ment	TC Establishment Delay	TC Establishment Failure Probability (misconnection/TC refusal)
Data Transfer	Throughput Transit Delay	Residual Error Rate (corruption, duplication/ loss) Transfer Failure Probability
TC Release	TC Release Delay	TC Release Failure Probability

was completed in order to conform more closely with FCC regulations and to make commercially available equipments comply with the standard. Work on measurement criteria for both Fixed Service Microwave Systems and the Radar Spectrum Engineering Criteria has continued.

SECTION 2.3. COMMUNICATIONS PROTECTION PROGRAM

The Communications Protection program was sponsored by NTIA and coordinated with NSA. This program was initiated as a result of Presidential Directive (PD-24). This directive designated the Secretary of Commerce as one of two Executive Agents. The Department of Commerce was designated as having the responsibility for protection of information in the following categories:

(a) Unclassified information transmitted by and between governmental agencies and contractors that would be useful to an adversary should it need to be protected.

(b) Non-Government information that would be useful to an adversary should he be identified and the private sector informed of the problem and encouraged to take appropriate protective measures.

The Department of Commerce (NTIA) is addressing the protection of non-national security related items that include:

- o Financial Information
  - -- planned changes in prime interest rate
  - -- Support of the dollar in foreign exchange markets
- o Commodity Market Forecasts
- o Supply of Critical Materials
- o Strategies for International Negotiations
- o Selected High Technology Information

The main threat to telecommunications is the relative ease with which it is possible to eavesdrop on common carrier terrestrial microwave and satellite communications. The techniques and equipment are readily available for industrial and foreign adversary eavesdropping.

The discussion of the Communication Protection related activities will be limited due to the classified nature of some of the projects. The following topics will be addressed to provide an insight into the general nature of the work which has been conducted during FY 82.

1. Boundary Studies
2. Boundary Measurements
3. National Telecommunications Plans Support
4. pFS 1026 Standard Authentication
5. Amateur Radio

Boundary Studies. The major thrust of the Boundary Studies program is to determine the maximum distance that common carrier microwave systems can be received. This problem presents some unique parameters that need to be evaluated.

First, the eavesdropper/interceptor does not need usable signal reception 100 percent of the time, and further, may accept reception for only one-half of the conversation. This latter situation may be forced on the interceptor because of the relative interceptor location and transmitter antenna orientation, geographical (distance) limitations, and/or topographical limitation again resulting from the physical transmitter location. A second item that impacts the propagation predictions is the antenna orientation of the desired transmitter with respect to the receiver location. It should be noted that a fixed location-interceptor will not generally be in the main lobe of the transmitting antenna. This then requires an extensive knowledge and cataloging of the antennas in use and their resulting antenna radiating patterns over a 360° azimuthal region. Third, special propagation models are needed that will give accurate measures of propagation losses under adverse conditions of path blockages, again emphasizing that the interceptor will consider reception of only a percentage of the transmission as acceptable for his purposes. Fourth, all significant terrain features must be available to assist in determining the particular propagation path loss.

The net result of the Boundary Studies is determination of the geographical limitations of an interceptor, given the interceptor's location and the transmitters of the common carrier transmitter locations under consideration. This study must also take into consideration the interceptor's receiving system in terms of interception antenna, front-end noise inputs, and the minimum required signal-to-noise ratio at the output.

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 Electromagnetic Waves by Multiple Knife-Edge Diffraction, NTIA Report 81-86, Oct. 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.

During this year, a report on Analytical Expressions for Gain Patterns of Microwave Common Carrier Antennas was published by ITS. This report described the analytical expressions of 924 transmit antennas that are currently in use by common carriers. The data are presented so the user can readily determine power gain for any antenna in the report and at the desired off-axis angle. All antenna gain patterns were reduced to a common format. Those antennas that exhibited common gain characteristic over the pattern and were within specified gain tolerances were grouped into sets. The group pattern then is represented by no more than 10 straight line segments that resulted in a smoothed radiation pattern envelope. This grouping then permits a more managable number of antennas that have been programmed for the software implementation.

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 topographic information for selected areas in the United States. This information coupled with transmitter and receiver antenna heights and types, transmitter power levels, and receiver sensitivity 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 are limited to one metropolitan area and two frequency bands.

Boundary Measurements. The classified Boundary Measurements studies conducted by ITS were under the joint sponsorship of NTIA and NSA. These measurements were a logical follow-on to the previously discussed Boundary Studies.

The objective was to obtain experimental verification of the computer propagation analyses program that was developed for the Boundary Studies.

This task made use of the extensive ITS background in development of measurement systems and propagation analysis. The measurement system selected for this measurement task is the Transportable Automated Electromagnetic Measurement System (TAEMS). TAEMS was developed for the Army Communication Command at Ft. Huachuca, AZ.

Specialized measurement approaches had to be considered because of the expected low signal levels that would be encountered in making boundary measurements. Special software programs were developed to control the measurements at specific times, at specified directions, and to provide automatic calibration of measurement equipment when required. The software programs were developed, equipment operation verified, and measurement approaches validated at the Boulder Labs.

A physical site survey of the proposed area was conducted by ITS and NSA personnel. All necessary measurement support requirements were reviewed. Special emphasis was placed on providing a means of transmitter tower identification. This was done by the common carrier providing a test-tone at a preselected voice frequency channel and having the ability to turn the tone on or off on command. This method of transmitter tower identification relies on having sufficient numbers of tone circuits, an adequate number of voice frequency channel assignments, different transmitter frequencies, and polarizations available to provide unique transmitter tower identification. Special care must be taken in areas where only repeaters are operating. In a repeater operation there are no drop or insert capabilities. The tone tag remains on the same voice frequency channel as on the previous transmission link. When this condition exists, only two variables remain for tower identification--the transmission frequency and polarization.

The measurement van (TAEMS) was then transported to the recommended site location. The measurement program was then started. The resulting measurement dictated that other receiver sights also be monitored. At all three sites measured, equipment outages were minimal and data was obtained under a wide range of weather conditions.

Upon return to Boulder, further measurements were taken under more idealized conditions (measurement van directly in the main transmitter lobe midway between two common carrier transmitters). This was done to provide reference measurement data.

An analysis of all the data was accomplished at the Boulder Labs. The results of the data showed good agreement (within measurement tolerances) with previously determined Boundary Studies. The Boundary Measurements were highly successful and served to further substantiate ITS theoretical propagation studies.

National Telecommunication Plan Support. The objective of this task is to provide support for National telecommunication plans directed toward finalizing efforts for common carrier protection, public key cryptology and special cryptographic analysis which includes the following major topics:

1. ITS protection standards efforts

2. Contractor results

3. Public key cryptographic systems, implementation and analysis.

2.3.1. ITS Protection Standards Efforts

During the past year the NTIA sponsored work relative to the DES (Data Encryption Standard) communications protection standards has primarily centered on information transfer. Several Government agencies requested, and were given, DES application engineering guidance for particular network scenarios. The guidance included an explanation of Federal Information Processing Standard Publications (FIPS PUBS) 46 and 81 (which defined the DES and its modes of operation), as well as Federal Standard 1027, which describes the required physical security attributes of a DES device. The interoperability requirements of proposed Federal Standard 1026 were also addressed.

Information transfer also involved the relating of ITS work accomplishments to those who might benefit. A presentation was made to the Department of Defense outlining ITS work, and recommending specific areas of protection standards work for the Government to pursue. As part of the Presidential Directive 24 mandate to inform the public, a technical paper entitled, "Federal Standards for Telecommunications Privacy and Security-Recent Progress," was presented to the 1982 Carnahan Conference on Security Technology.

The Institute's efforts in DES cryptovariable generation and distribution, which had included the preparation of two draft proposed Federal Standards, two comprehensive reports, and engineering prototypes which validated the proposed standards, were essentially halted after the imposition of a high security classification on the generated information. Further work would have included coordination with the Federal Telecommunications Standards Committee and the American National Standards Institute in refining the standards for approval and publication.

2.3.2. Contractor Evaluations of Analog and Digital Common Carrier Communication Systems Approaches

The protection of sensitive information over common carrier transmission links is a main area of interest. The most straightforward approach to providing protection is to combine modulo 2, a digital encryption sequence, with the digital information. This approach can be applied to either individual channels or the composite digital data stream. Bulk encryption systems are usually more efficient in terms of cost and operational considerations. However, analog radio systems may also be protected by specialized modulation systems found in the classified literature.

In order to obtain a more quantitive method of evaluation of protection, it was necessary to investigate the theoretical and practical applications of existing and proposed common carrier system approaches. To achieve this objective it was decided to award two contracts. The first contract investigated the theoretical comparisons of analog and digital modulation systems. This also included taking into consideration effects due to multipath, co-channel interference, fading, and delay distortion. Special emphasis was placed on digital systems because of the ease of providing privacy to the communication channel and the trend toward increased use of digital systems for new applications.

The second contract was directed toward documenting common carrier analog reference links, evaluation of cost and performance impacts due to conversion to digital links, and to design and analyze optimal analog and digital links to replace the current reference links.

Vendor offerings were reviewed for both terrestrial and satellite applications for existing applications as well as what equipment may be offered within the next three years. New areas of development for analog systems are primarily in the SSB/AM, increased companding to minimize transmitter bandwidth, and over-deviation for modulation system gain (FM systems) and better equalization approaches. New areas for digital systems included higher order modulation systems to meet minimum FCC channel requirements, TASI to take advantages of the natural pauses in voice channels, and low bit rate voice such as Adaptive Predictive Coding (APC) and Linear Predictive Coding (LPC). These latter two items will require further evaluations in terms of voice quality and tandum switching effects.

Co-channel operation effects, cost trade-offs, and fading effects have been reviewed. Cost advantages still favor analog systems, but maintenance considerations favor digital systems. The trend toward digital systems appears to be going at a much slower pace than originally anticipated. Each privacy requirement for common carrier communications will have to be evaluated on individual requirements. These study results will assist in expediting this evaluation.

2.3.3. Public Key Cryptography and ITS Implementation

A Public Key Cryptographic System (PKCS) is a method by which two parties can derive a common secret number quantity (e.g., a number or string of bits) without previously agreeing on anything in secret; i.e., all of the transactions are publicly disclosed. A PKCS depends upon asymmetric complexities in computation of mutually inverting operations. This curious aspect has been dubbed a cryptographic 'trapdoor.' In essence it means that, for some computations, one may proceed forward on a one-to-one mapping with relative ease and attendant small computational expense, but one is apparently faced with an enormous work factor to effect the inverse mapping in general, even though the unique inverse mapping exists.

It is believed that the various PKCS's deserve study as candidate vehicles for protected Data Encryption Standard (DES) cryptovariable transmission. Two PKCS's, the MITRE and the Rivest, Shamir and Adleman (RSA), have been studied.

2.3.4. Mitre Public Key

The MITRE Public Key Cryptographic System (MPKCS) is ideally suited to the ever-expanding world of digital communications.

The MPKCS requires both parties to derive secret numbers, x and y, which serve as exponents of a publicly disclosed element, α, of a finite field of 2^n elements. Exponentiation is performed modulo a GF(2) primitive polynomial (also publicly disclosed) of degree n. The first party calculates α^x and sends it to the second party. It is assumed that public disclosure also takes place. The second party computes α^y and sends it to the first party. Here it is also assumed that public disclosure takes place. The first party then exponentiates α^y to the x power and the second party exponentiates α^x to the y power. Both parties then obtain α^{xy}. An eavesdropper cannot compute α^{xy} without having x or y and x or y can only be obtained by solving for x or y given α^x or α^y. The asymmetric complexity is that given α and x one can easily compute α^x, but given α^x and α one cannot, apparently, easily recover x.

The Institute's work in public cryptography during the last year continued with extensive study of the MITRE Public Key Cryptographic System (MPKCS). The MPKCS appears to be an excellent cryptographic vehicle for protecting the transmission of Data Encryption Standard (DES) cryptovariables, i.e., keying variables and initialization vectors. Primarily, ITS has been carefully examining the strengths and weaknesses of the MPKCS under the threat assessment appropriate to NTIA's role in PD-24 activities. We have implemented the MPKCS in microprocessor software and successfully experimented with the system over unconditioned telephone lines at a moderate signaling rate. These experiments have provided valuable insight into the time-critical aspects of using the MPKCS.

A report was written on the results of this study and was classified.

2.3.5. Rivest, Shamir, and Adleman (RSA) Public Key

The Publication of "New Directions in Cryptography" by Diffie and Hellman has generated an increasing amount of research on public key cryptosystems. The system introduced by Rivest, Shamir, and Adleman is the subject of this project.

Briefly, the RSA scheme requires choosing two large primes, p and q, each about 100 digits long, and an encryption exponent E. Let n = pq. Then, to encrypt a message P, raise P to the power E and find the remainder upon division by n, or in symbolic form, the cipher text C is given by

$$C \equiv P^E \bmod n. \qquad (1)$$

Decryption depends on finding a number D such that

$$C^D \equiv P \bmod n, \qquad (2)$$

The numbers E and n are made public, while the members p, q, and D are kept secret. Anyone knowing D can find p and q. Thus, the basic security of the algorithm relies on the knowledge that factoring a number n which is a product of two larger primes is presently a very difficult problem.

One of the objectives of this project is to examine factoring methods to see if improvements are possible, and to look at other potential cryptographic weaknesses in the RSA algorithm. To date, no serious shortcomings have been found.

One report was published on the possibility of using improved Monte Carlo factoring techniques.

A memorandum was prepared on a discussion of the feasibility of proving the validity of an algorithm for distinguishing prime numbers from composite numbers.

Proposed Federal Standard 1026 Authentication Project. In January of 1977, the National Bureau of Standards (NBS) issued Federal Information Processing Standard Publication (FIPS PUB) Number 46 specifying an algorithm for encrypting digital data. The algorithm is known as the Data Encryption Algorithm (DEA); the standard as the Data Encryption

Standard (DES). The promulgation of the DES was a signal event in U.S. telecommunications as it marked the first time that the U.S. Goverment provided the public with substantial advice and guidance on a cryptographic matter.

But issuing the standard, it turned out, led to more questions than it answered.

The NBS quickly identified eight areas of primary concern:

1. The standard's architecture appears to some to favor a particular manufacturer's equipment line.

2. Encryption appears to some to portend a degradation of throughput.

3. The DEA appeared too complex to be effeced in software.

4. The DES appeared to provide inadequate security for some situations.

5. There appeared to be a lack of guidance for implementing interfaces to the DEA.

6. There appeared to be a lack of guidance concerning the 'wheres and whens' of using the DES.

7. There appeared to be a lack of administrative procedures regarding the procurement, testing, and validation of hardware which realized the DEA.

8. The export policy for DES hardware appeared undefined.

The NBS successfully tackled the principles of all of the eight points above. It is point number 5 that we are concerned with here. The DEA, as the acronym implies, is simply an algorithm. It converts, under control of a keying variable, a 64-bit plaintext word into a 64-bit ciphertext word in a reversible manner. This cryptographic technique is called an 'electronic codebook.' What FIPS PUB 46 does, is to unambiguously and completely specify the algorithm's rules. But it is a long way from a cryptographic algorithm to a cryptographic system. In recognition of this the Federal Standards Telecommunications Committee is pursuing the evolution and promulgation of Federal Standards which will advise and guide those responsible for integrating the DEA/DES into existing and planned networks on the proper interface procedures.

This effort has already resulted in the completion of Federal Standard 1027. Authored by the National Security Agency, this standard addresses the ancillary security requirements for physical protection for DES-based devices and also the electronic security measures and emanations security measures. Complementary to this standard is proposed Federal Standard 1026 (pFS 1026) which addresses interoperability and security requirements for the DES when used for data communications at the physical and data link protocol layers. It is in support of this proposed Federal Standard that ITS is conducting this project which is jointly sponsored by the National Communications System and the National Security Agency.

The project's essence is the melding of an established subset of the Advanced Data Communication Control Procedures (ADCCP) protocol and specific elements of pFS 1026. To our knowledge, this is the first in-depth look at meshing cryptography with an advanced data link layer protocol. It is anticipated that besides being a 'proof-of-principle' investigation, the effort will help the approval of pFS 1026 regarding its logical cohesion, completeness, and degree of ambiguity or lack thereof.

The test bed that is being created will consist of two Data Terminal Equipments (DTEs) and two modules which will serve as Data Encryption Equipments (DEEs) configured in a system architecture as shown in Figure 2-16. The pFS 1026 functions will be performed in the DEE; error correction and other link level protocol functions will be performed in the DTE. We are assuming errorless communication between the DTE and the DEE; however, we plan to study the effects of errors which occur between the DEEs. The testbed is built around a microprocessor programmed with a real time operating system so that moderate throughput rates can be attempted.

Spread Spectrum and Amateur Radio. The Federal Communications Commission (FCC) is considering allowing the Amateur Radio Service (ARS) to operate with spread spectrum techniques within three of the bands available to the ARS. Notification of the proposal is contained within General Docket 81-414. Needless to say, the question has sparked a great deal of controversy and comment both from neighboring band users who profess to be frightened about potential interference problems and members of the ARS who are themselves divided on the issue.

The issue is an extremely interesting one as no radio technique is surrounded by more mythology than is spread spectrum. This class of modulation techniques was swaddled in secrecy at its inception over three decades ago and still maintains its aura despite numerous open literature examinations and primers. Essentially, spread spectrum is any technique that demands a substantially greater spectral domain than that required by its information baseband. The two most common techniques are frequency hopping (FH) and direct sequence (DS). In an FH system members of a wide range of discrete frequencies are used for short 'dwell' times and thus the signal appears to hop about through an extended frequency domain. In a DS system, the relatively narrow spectral baseband is added to a wide spectral pseudorandom (and therefore deterministic or predictable) digital process. The baseband energy is then 'spread' over a wide frequency range.

The report is a study of the use of DS techniques for the ARS. The report will characterize the problem and attempt to bring all of the relevant information regarding the issues into one section. Another section will proffer a DS architecture for ARS communications.

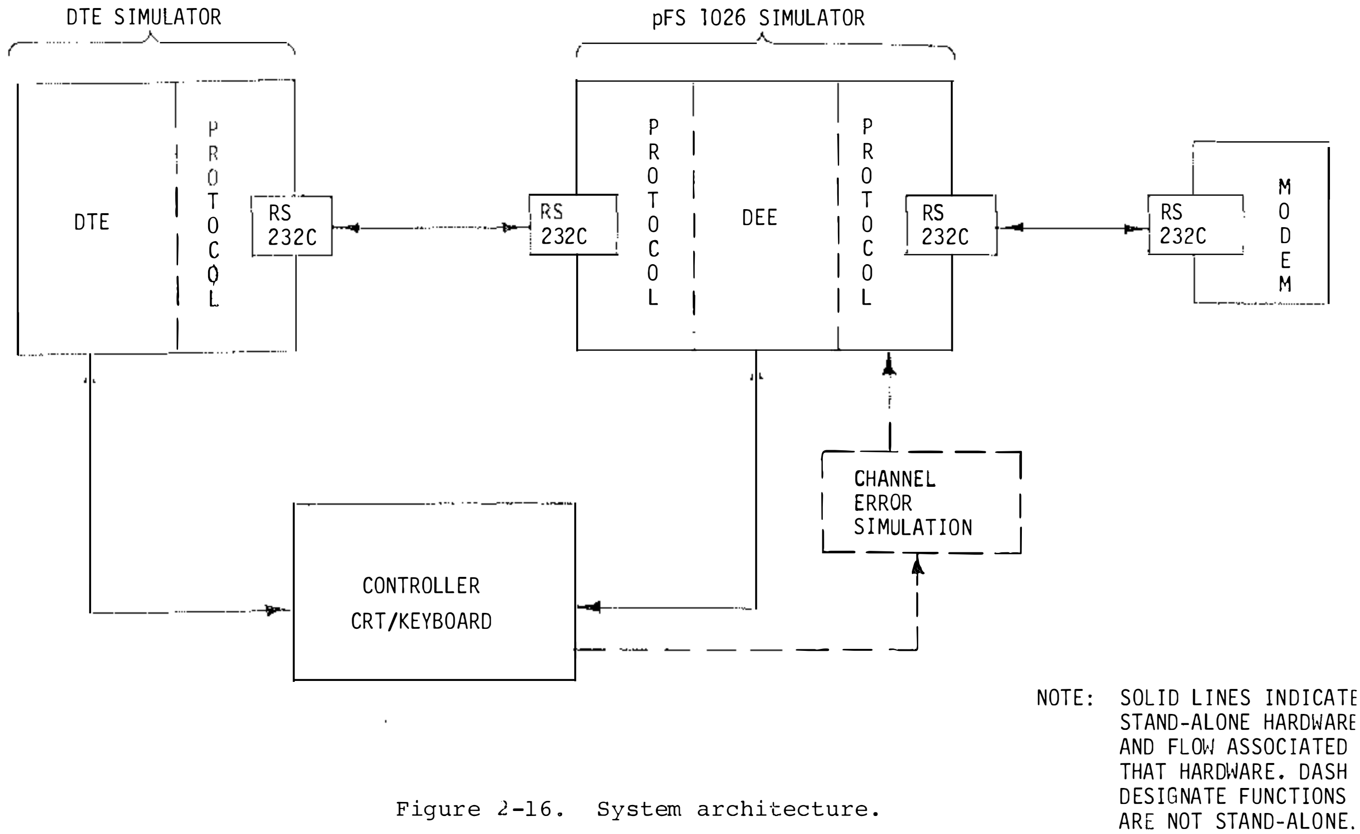


Figure 2-16. System architecture.

The report will be a concept level treatment only and is intended to advance ideas and concepts. Time consuming analysis is thus deferred for future work. The report will, however, contain a series of primers on various DS 'tools' such as sequence generation and characteristics and synchronization techniques following carrier and clock recovery.

Other issues to be considered are the monitoring and location problems. It is incumbent on the FCC that they monitor or be able to monitor transmissions that they permit and also be able to locate offending transmitters. Spread spectrum techniques pose some unique problems to the FCC in fulfilling their missions relative to these considerations and therefore we will devote some effort to studying the cost effective ways and means of monitoring and locating the proposed DS transmissions.

SECTION 2.4. SWITCHED NETWORKS

The Switched Networks Group of the Advanced Communication Networks Division is involved in a number of programs that, either directly or indirectly, relate to common carrier issues. These programs include work for other agencies such as the Department of the Army as well as the Domestic Common Carrier Program within NTIA. The NTIA common carrier program is oriented toward the development, promotion, and support of Administration policies concerning deregulation of the common carrier industry, increasing competition in the telecommunications industry, and stimulating innovative telecommunication services and productivity.

As the telecommunications industry moves in these directions, there is an increasing need in NTIA for the capability to 1) address those technical issues whose understanding is integral to the formulation of sound policy, and 2) resolve those technical issues which impede the implementation of such policy.

The objectives of the Switched Network Group activity regarding common carrier issues are twofold: first to obtain a technical understanding of the interactions between competing networks, and second to facilitate the interoperability of competing networks. A key aspect of these two objectives is to develop a full understanding of underlying technologies and methodologies. This is accomplished, in part, through the projects being undertaken for other agencies such as the Department of the Army. The technical expertise obtained by performing project-work for other government agencies is directly relatable to the Domestic Common Carrier Program of NTIA. Similarly, the NTIA common carrier work can be related to other agency work such as the Defense Switched Network (DSN) project which is concerned, in part, with the use of a mix of transmission media and a mix of vendors of transmission services in order to enhance the survivability of the DSN. Thus, the NTIA common carrier project and the other agency projects are mutually supportive.

The following paragraphs describe the NTIA common carrier work and the other agency work being conducted by the Switched Networks Group.

ENFIA Interconnection Technical Studies. The ENFIA (Exchange Network Facilities for Interstate Access) tariffs are the basis for present interconnections of the competing other common carriers (OCC's) to the A.T.&T. switched network. With the ENFIA interconnection, the OCC's access local switched telephone circuits from their intercity microwave network to originate and complete calls from their customers. The local switched circuits are provided by A.T.&T.

The first ENFIA interconnection arrangement is known as ENFIA A. Through this connection, an OCC accesses the local network on the line side of a serving central office (operating telephone company end office). On April 27, 1981, A.T.&T. delivered a proposal to the Federal Communications Commission for two new interconnection arrangements. Both arrangements, referred to as ENFIA B and C, provide somewhat different accesses than ENFIA A. In all cases, many technical and technology issues arose. The Institute performed studies of these technical issues for NTIA.

Requirements Analysis for the European Defense Communications System. The ITS is conducting a study for the U.S. Army Communications Systems Agency to perform a requirements analysis and network concept development for the European Defense Communications System (DCS). The objective of this study is 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: 1) the need to make critical telecommunications services survivable in a hostile environment (nuclear or conventional war, sabotage, or electronic warfare); 2) the need for increased interoperability of the DCS with other networks in order to enhance survivability and to extend geographical coverage; 3) the need for better grade-of-service for administrative, logistics, and command and control traffic; 4) the need to provide enhanced telecommunication services to meet new class-of-service requirements such as increased use of facsimile, increased data requirements, and possibly video; and 5) the need for new or enhanced features, some of which are unique to military telecommunication systems.

Figure 2-17 depicts the process for the mapping of system level requirements into network element specifications. At the top level one identifies user's requirements for service features such as abbreviated dialing, conference calls, priority preemption, etc., user's traffic requirements, and operator's requirements for network administration, operation, and maintenance (AO&M). Ideally, these would all be defined as inputs to the network designer. In the real world, however, some of these requirements are poorly defined at best. For example, traffic requirements for the future are typically poorly defined. The designer must therefore treat traffic quantities parametrically and design the network to have sufficient flexibility to grow as traffic requirements change. The mapping process continues by analyzing existing network technical characteristics and some nontechnical aspects such as economic, political, or regulatory factors. Using these requirements, characteristics of existing networks, and nontechnical factors as inputs, the network analyst then can define different alternatives for each of the issues or requirements that have been identified. Each of these alternative solutions may impact the major elements of a telecommunications network, namely switches, transmission facilities, terminals, system control, and possibly system aspects such as numbering plans. The objective in this project is to use this type of mapping process to identify how system level requirements (such as interoperability of the DCS with tactical systems) impact network elements such as multiplexers, radios, etc.

A recent report to the project sponsor discussed the users' and operators' requirements and summarized the characteristics of 44 different existing networks, both military and civilian, with which the European DCS could be made to interoperate. This Phase I report also summarized numerous issues related to the survivability and interoperability problems. Out of this long list of issues those judged to be most critical are now being addressed during Phase II (near-term) and Phase III (far-term).

The near-term issues are those issues whose solution will not require major new hardware or software development programs. The near-term issues being addressed are DCS interoperability with the TRI-TAC communications system, multipath fading with emphasis on the application of adaptive equalization or diversity techniques for radios used in the European DCS, vulnerability of high efficiency modulation techniques to jamming, and reconstitution issues.

Phase III is being conducted in parallel with Phase II. The Phase III study emphasizes the far-term issues, i.e., those that would require major new equipment development or major changes to existing networks. The issues being addressed in Phase III are differing network architectural concepts including Integrated Services Digital Networks (ISDN's), standards and protocols, and the development of mathematical models of survivability. The telecommunication networks of the 1990's will be driven, in part, by technologies that are in the R&D stage during the 1980's. A recent report to the project sponsor discussed some of the current developments and emphasized the role of the ISDN's as the direction in which the military networks of the 1990's might evolve.

The focus of both the near-term and far-term phases of the project is on developing requirements for new hardware R&D programs. Special emphasis is in the area of radio and multiplexer requirements since CSA has been assigned major responsibilities in this area by the Defense Communications Agency.

DSN Access Area Program. The Defense Switched Network (DSN) Access Area Program is a follow-on to the Access Area Digital Switching System (AADSS) program which was reported in the 1981 ITS annual technical report. The current program is also being conducted for the U.S. Army's Communication Systems Agency (CSA) at Ft. Monmouth, NJ.

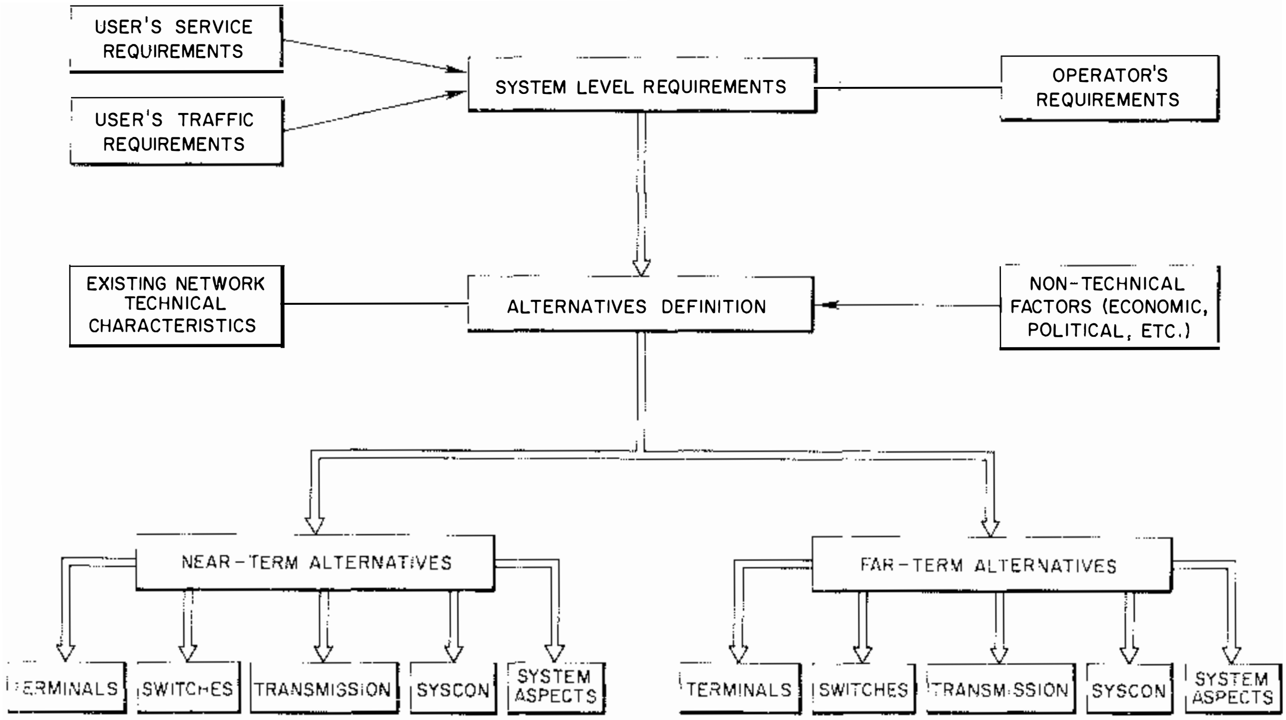


Figure 2-17. Mapping of system requirements into network element specifications.

The CSA is continuing the process of evaluating concepts and selecting preferred alternatives for the future DSN and the contiguous military base environments. The purpose of the current project is to begin the next logical step in the program, namely to validate the DSN-AA (DSN-Access Area) concept with "proof of performance" hardware. The ITS is to provide engineering support to CSA in the planning, development, and implementation of a demonstration network between Ft. Monmouth, NJ, and Ft. Huachuca, AZ, for evaluating certain critical aspects of the DSN-AA such as management and control interface requirements, interoperability with the Experimental Integrated Switched Network (EISN), cost, and risk factors. This scaled demonstration network and test facility is an important step leading to a large scale implementation of the DSN-AA.

In support of these objectives, ITS is to conduct three tasks for the project. These are: 1) formulate a concept validation facility (CVF) plan, 2) report on policies and actions impacting the DSN-AA, and 3) provide engineering support relating to industry contracts.

The first task, formulation of a CVF plan, provides for the planning and engineering support to CSA for formulating the objectives and designing experimental procedures. The intent is to test certain concepts and functional requirements of hardware and software in the DSN-AA program. This first task consists of four subtasks. These are to 1) define objectives that a CVF should achieve; 2) develop network management and control techniques using common channel signaling, along with a numbering plan; 3) prepare an implementation plan using the EISN and private line facilities; and 4) identify interfaces, protocols, and equipment needed to implement a CVF.

An interim report entitled "Defense Switched Network Access Area Concept Validation Facility Test Objectives" by R.F. Linfield and D.V. Glen has been delivered to the CSA for the first subtask. The report defines an assumed goal architecture for the DSN, then describes an initial validation facility so that limitations are apparent and then outlines objectives for the private line portion of the assumed architecture.

As explained in the report, the DSN is intended to replace the existing AUTOVON/AUTODIN network in the continental United States. The perceived threat at the time AUTOVON/AUTODIN was conceived in the 1960's was that potential enemy resources were inadequate to attack telecommunications directly. Today, this is no longer the case and placing switch nodes and other facilities in remote nontargetable areas no longer resolves all of the survivability problems. Distributing the switching functions to many more nodes and locating them closer to the subscribers reduces costs by reducing the backbone access costs. This DSN architectural concept is shown in Figure 2-18. This hybrid concept combines the strongest attributes of a circuit switched, software defined network (SDN), a circuit switched pri-

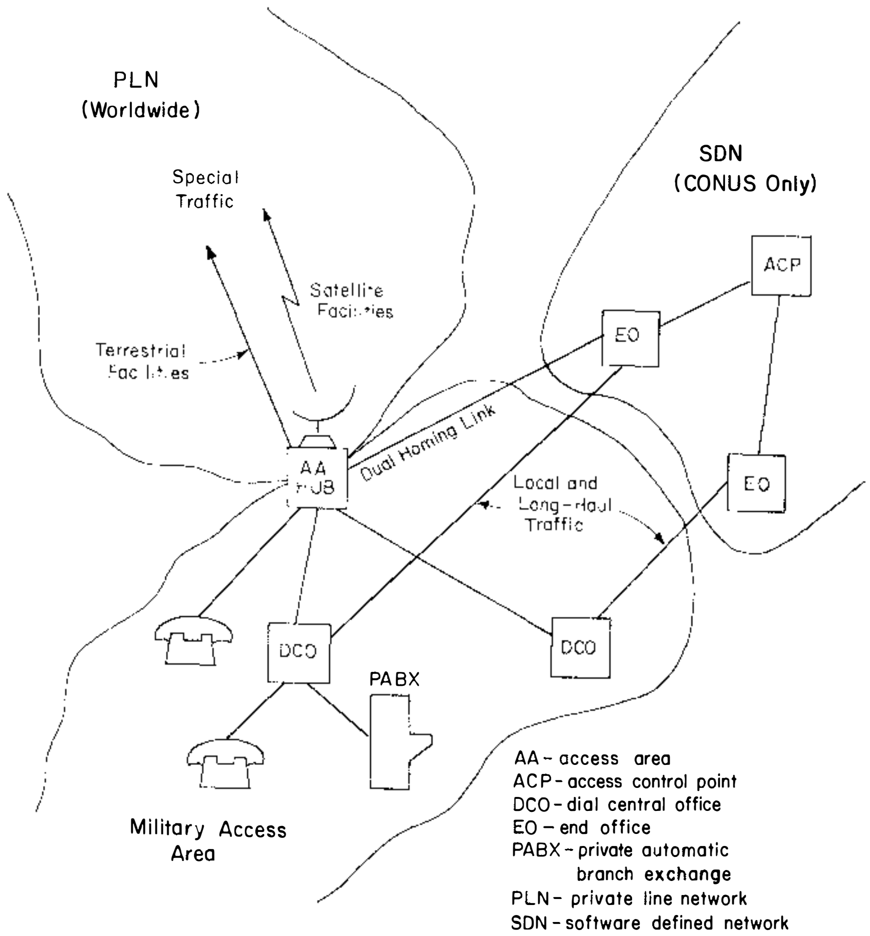


Figure 2-18. Planned DSN architecture in the CONUS.

vate line network (PLN), and a packet switched common channel signaling network.

The SDN portion of the DSN is an arrangement of hardware, software, and firmware elements imbedded within the Public Switched Telephone Network (PSTN). This SDN provides a special set of telecommunications services to the military user community under the control of a shared network intelligence accessed by common channel signaling.

The PLN portion provides telecommunication services between military access areas using military satellites, commercial satellites, and terrestrial lines leased from commercial carriers.

The EISN, which uses the WESTAR III satellite, will be used in the satellite portion of a scaled configuration of the DSN. The EISN consists of the WESTAR III, and an earth station interface and interface message processor to be located at Ft. Huachuca, Ft. Monmouth, and other locations intended to test components of a scaled DSN. Initially the CVF would exist only at Ft. Huachuca and Ft. Monmouth while the EISN involves up to five locations.

A potential CVF configuration of the DSN is shown in Figure 2-19. In addition to the EISN just discussed, terrestrial trunks and a private switched communications service are shown as part of a test configuration.

Work on the other subtasks is in progress.

The second task, concerning activities impacting the DSN-AA, consists of the Institute enabling the CSA to keep abreast of changing policies and regulatory and standards activities. For example, technical briefs describing standards activities in the area of public digital network access by the American National Standards Institute have been sent to the CSA. The technical briefs describe ongoing work in the area of Integrated Services Digital Networks (ISDN) and address which is pertinent to a numbering plan. Among other areas to be covered are regulatory actions and tariff revisions of the FCC and new legislation concerning telecommunications.

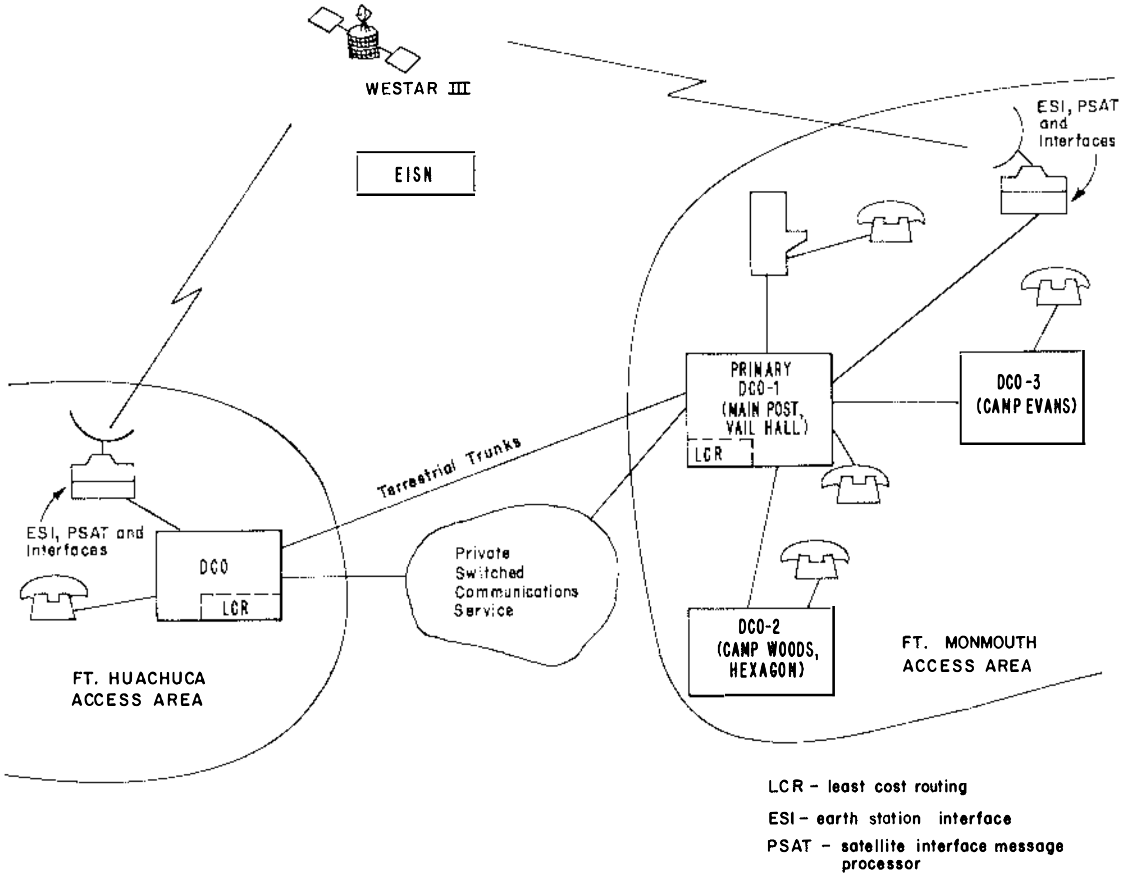


Figure 2-19. Potential CVF test configuration.

In Task 3, ITS conducts special studies, reviews and critiques contractor's reports, evaluates industry proposals, and attends program status reviews to assist the CSA in monitoring contractors that are engaged in DSN-AA studies.

SECTION 2.5. SPECIALIZED NETWORKS GROUP

Federal Government commitment, demonstrated in Research and Development supported primarily by the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA), to the development and growth, to free market independence, of a vigorous commercial satellite industry are clearly recognized. Today, there are well established services for domestic and international, large volume, geographically centralized services in the Fixed Satellite Services (FSS). The Broadcasting Satellite Service (BSS) has developed more slowly. At the 1977 World Broadcasting-Satellite Administrative Radio Conference (77 WARC-BS), a plan was drawn up for International Telecommunication Union (ITU) Regions 1 and 3 for assignments of frequencies and orbital positions for BSS in the 12-GHz band. Further, it was resolved that a Regional Administrative Radio Conference (RARC) would be held by 1983 to draw up a detailed plan for BSS in Region 2 (North, Central, and South America and Greenland). These plans and resolutions were adopted by the 1979 World Administrative Radio Conference (WARC).

The 1983 RARC for Region 2 must resolve the issues of sharing the Direct Broadcast Satellite (DBS) orbit and radio spectrum between 12.1 and 12.7 GHz. This conference will address the orbit and spectrum sharing issues and requirements of the countries in Region 2. The conference output can produce a very negative environment for the United States (U.S.) DBS industry unless favorable planning is accomplished. This can only be done if a strong case for the U.S. position is prepared in advance. Technical studies have been conducted (and will continue) to assist in determining the orbit-spectrum capacity and how it might be shared with the other countries in Region 2.

The 1979 WARC also resolved to convene another WARC in 1985 to decide which frequency bands for space services should be planned and to draw up a detailed plan for each of these frequency bands. The outcome from the 1983 RARC and the 1985 WARC will have major impacts on efficient use of the frequency and orbit resources by the United States.

Nearly two years ago, U.S. companies began submitting applications for license to construct and place in service direct broadcasting satellite services. By late summer 1981, 14 companies had filed applications with the Federal Communications Commission (FCC) for DBS services licenses; nine of these applications ultimately were accepted by the FCC. Private enterprise and market competition, therefore, are "pushing" the development and implementation of DBS service. On June 23, 1982, the FCC approved interim rules for licensing and operation of direct broadcast satellites. Spectrum allocated for DBS by the FCC--500 MHz in the 12.2 to 12.7 GHz band for downlink broadcasting and 500 MHz in the 17.3 to 17.8 GHz band for feeder uplinks--is conditional, pending outcome of the 83 RARC-BS for Region 2. However, this action will require users of terrestrial microwave systems (in the Fixed Services) operating in the 12.2 to 12.7 GHz band to move to other frequencies. During the past year, ITS supported the Interdepartmental Radio Advisory Committee (IRAC) Ad Hoc 177 Computer Users' Group and the FCC in development of computer-based interference analysis models to assist in planning for the 83 RARC-BS and for use during the conference. The Institute conducted studies to understand the extent of potential interference between the developing direct broadcast satellite service and the existing terrestrial microwave systems in the 12 GHz band. Support also was given to other offices in NTIA in preparation of Comments to the FCC Notice of Inquiry and Proposed Rulemaking, Docket No. 81-704, Released November 18, 1981, in the matter of Licensing of Space Stations in the Domestic Fixed-Satellite Service and Related Revisions of Part 25 of the Rules and Regulations (dealing with reducing required orbit spacing to 2 degrees for FSS satellites in geosynchronous orbit.)

Utilization of satellite technology by dispersed, low-volume users (thin-route applications in rural areas) can only be realized when lower-cost ground terminals are available. A jointly supported study with the Agency for International Development (A.I.D.) to define and encourage industry development of a low-cost, ground terminal system suitable for rural areas and other thin-route satellite communications applications was initiated in 1980. The emphasis of this study has been to define earth station designs and service capabilities which could allow reduced earth terminal costs.

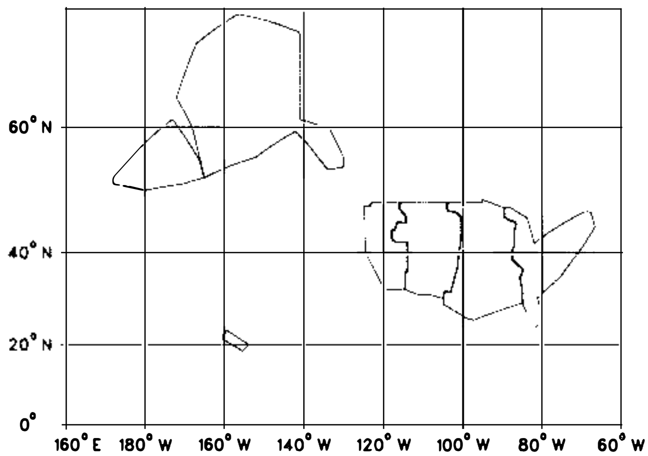
The earth station design and service requirements study has followed a parametric approach by establishing a matrix of options for technical characteristics of components of the earth station, such as the antenna size, the low noise amplifier noise temperature, and the high power amplifier output capabilities. 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.

The ITS Satellite Communications System work was comprised of two, NTIA-sponsored projects and the complementary project sponsored by the Agency for International Development, Department of State. These three projects, established for management tractability were: 1) Support to Preparation for the 83 RARC-BS, 2) Broadcasting-Satellite Service and Fixed Services Sharing, and 3) Support to the A.I.D. Rural Satellite Program.

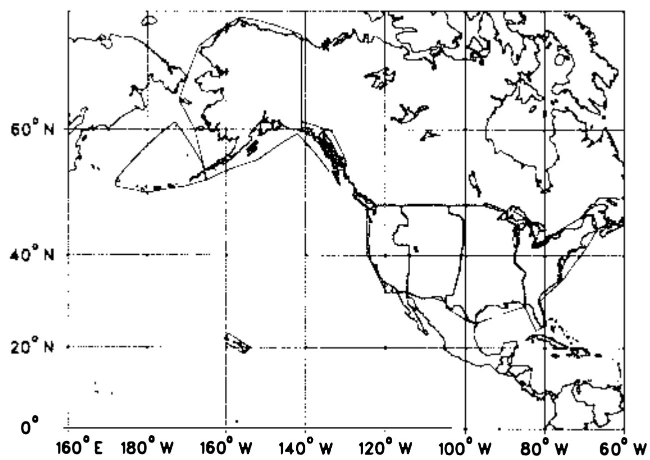
<u>83 RARC Preparation Support</u>. As noted earlier, the 1979 WARC of the International Telecommunication Union resolved that a Regional Administrative Radio Conference for the planning of the broadcasting-satellite service (RARC-BS) of the ITU Region 2 (North, Central, and South America and Greenland) be convened in 1983 and that a detailed frequency allotment and orbital positions plan be drawn up for the Region. The outcome of the RARC-BS will 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 Ad Hoc 177.

The SOUP (Spectrum-Orbit Utilization Program) that calculates the C/I (carrier-to-interference ratio) margins at the test points on the surface of the earth for the purpose of analyzing BSS scenarios has been further improved by the ITS in this fiscal year. The data file structure has been modified, and preparation of input data to run the program has been made simple and easy. Auxiliary programs that allow the user to append the data file easily have been added to SOUP. The data file for the polygon points (that define polygons that closely enclose service areas) have been improved by eliminating excessive overlaps between adjacent service areas and by including areas previously omitted from the service areas by some reason. A set of graphs showing the improved polygon points data file has been presented to Ad Hoc 177. As an example of data from this file, the polygons for U.S. service areas are shown in <u>Figure 2-20</u> along with a Mercator projection map of the same geographical areas with overlayed polygons for comparison.

The computer program FOOTPRINTS which was developed several years ago by ITS was revised to execute on the laboratory computer at ITS. The program automatically computes and plots earth footprints of satellite power density on a map projection of the earth's surface. An example is shown in <u>Figure 2-21</u>. Several improvements were added to the original program including more detailed map data, additional map projections and satellite transmitting antenna models, more footprints per map, and the plotting of service area polygons along with the earth footprints.



Polygons for U.S. service areas.



North American map with overlayed polygons for U.S. service areas.

Figure 2-20. Polygons for U.S. service areas and North American map with overlayed polygons for U.S. service areas.

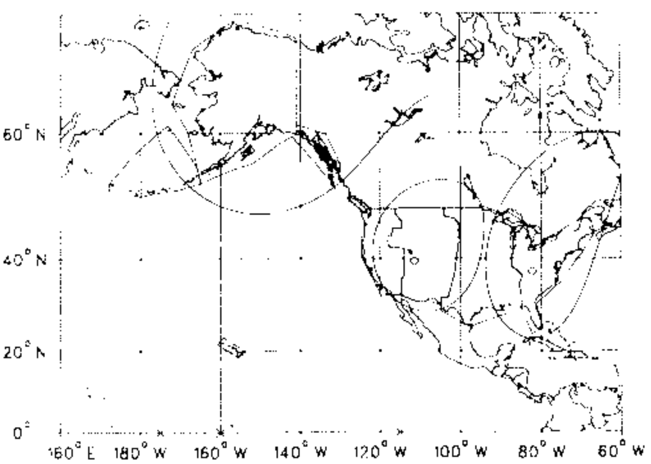


Figure 2-21. Satellite power density contours for Alaska, Mountain and Eastern service areas overlayed on North American map which includes polygons of U.S. service areas.

A specialized version of the program FOOT-PRINTS that executes in the batch mode was also developed. Instead of manually entering the satellite antenna information, the program uses the antenna parameters computed by program SOUP and stored in a data file. This saves time and reduces the chance of error when entering the input data.

The program ORBIT-PRINTS was once again made operational on the laboratory computer at ITS. The program calculates the contours of terrestrial-emitter power density measured at or near the geostationary orbit.

New capabilities also have been added to the SOUP. Now the SOUP is capable of analyzing scenarios with all the technical provisions specified by Appendix 30 to the ITU Radio Regulations (or the Final Acts of the 1977 WARC-BS). In addition, it can analyze scenarios using other antenna patterns such as the fast roll-off satellite transmitting antenna pattern and the improved earth-station receiving antenna pattern accepted by the International Panel of Experts. It can analyze either discrete-channel-allotment scenarios, or block-allotment scenarios, or the combination of both. A report describing the modified SOUP has been prepared.

Various broadcasting-satellite service scenarios (i.e., candidates for the frequency allotments and orbital positions plan) have been analyzed, and the results have been presented to the meetings of Ad Hoc 177. The analyzed scenarios include scenarios for testing the sensitivity to orbital positions, block-allotment scenarios developed by a member of Ad Hoc 177 and their variations, a scenario for Central and South America developed by the International Panel of Experts on Computer Software, a test scenario developed by Canadian delegates for testing and verifying the computer software systems.

Finally, ITS support to preparations for the 83 RARC-BS included Comments to the FCC Notice of Inquiry and Proposed Rulemaking, Docket 81-704, on the question of reducing orbit separation for domestic satellites in the Fixed Satellite Service. The comments developed at ITS were submitted to the Office of Federal Systems and Spectrum Management for incorporation into other Comments prepared by NTIA. The ITS Comments presented a summary of CCIR Recommendations pertaining to reference antenna patterns, giving particular attention to sidelobe characteristics and applicability in terms of the antenna diameter (D) to wavelength (λ) ratio. The Comments by the Institute also summarized CCIR Recommendations pertaining to circuit noise objectives for satellite telephone circuits. This summary suggested that relaxation of the total noise objective might be feasible, and, in turn, present allowances for total nonthermal noise and noise due to interference ought to be reexamined as ways of increasing (and maximizing) orbit-spectrum utilization.

Fixed Service and Broadcasting Satellite Sharing with Broadcasting Satellite Service. We previously discussed that a resolution was adopted at the 1979 WARC calling for a Regional Administrative Radio Conference for ITU Region 2 to be convened in 1983. This 1983 RARC is to divide the band 12.1-12.3 GHz in two sub-bands and allocate the lower sub-band to the FSS and the upper sub-band to the BSS, Broadcasting Service (BS), Mobile, except Aeronautical Mobile, and Fixed Services (FS). These assignments are part of the overall responsibility to draw up detailed frequency assignments and orbital position plans for the BSS for Region 2 in the band 12.3-12.7 GHz and in that portion of the band 12.1-12.3 GHz which it shall allocate to the BSS.

Under the provisions of Part 94 of the FCC Rules and Regulations, the band 12.2-12.7 GHz has been allocated to FS use and is to be potentially shared with both BSS and BS or reassigned to a different band. Part 94 of the FCC Rules and Regulations refers to the FS as a Private Operational Fixed Microwave Service. Therefore, one technical issue is the sharing and compatibility of these two services within this frequency band, which is the central topic of this project.

This research shows that the 12.2-12.7 GHz FS application primarily supports local network distribution as opposed to long-haul FS. Figure 2-22 shows the total U.S. deployment of FS systems on a path-by-path basis. Figure 2-23 expands the New York metropolitan area within Figure 2-22. It is unknown to what extent path engineering and power budgeting is performed on the design of the FS in this band, particularly for short paths less than several miles. But there are large numbers of users who operate well above -50 dBW/m^2 FS receiver power flux density (PDF) at distances less than 5 mi in which other users successfully operate at -70 dBW/m^2 and below. The assumed BSS PFD at the center of the service area in Region 2 falls in a range between -100 dBW/m^2 and -97 dBW/m^2. Figure 2-24 demonstrates these operating levels between the FS and **BSS**.

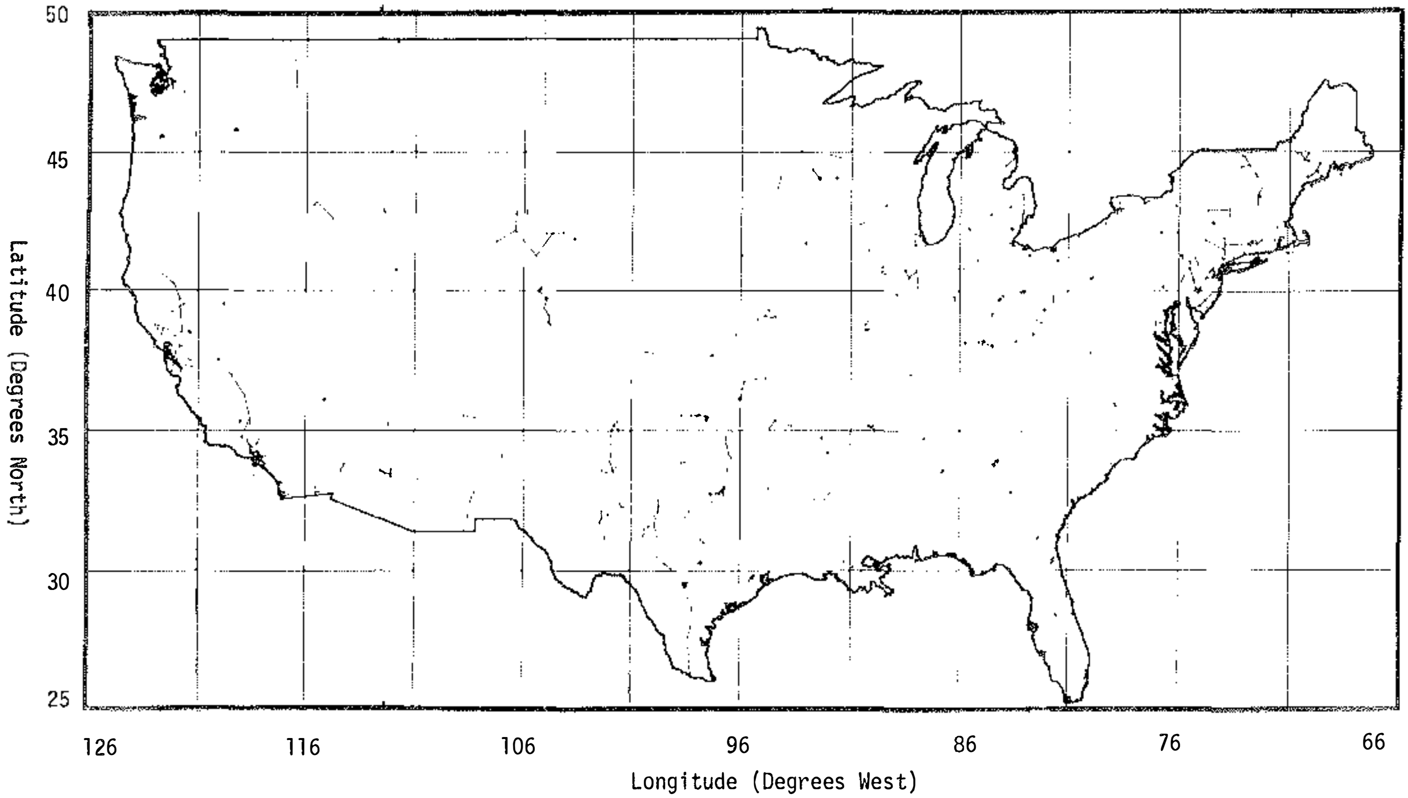


Figure 2-22. Private operational fixed microwave service in the United States for 12.2-12.7 GHz.

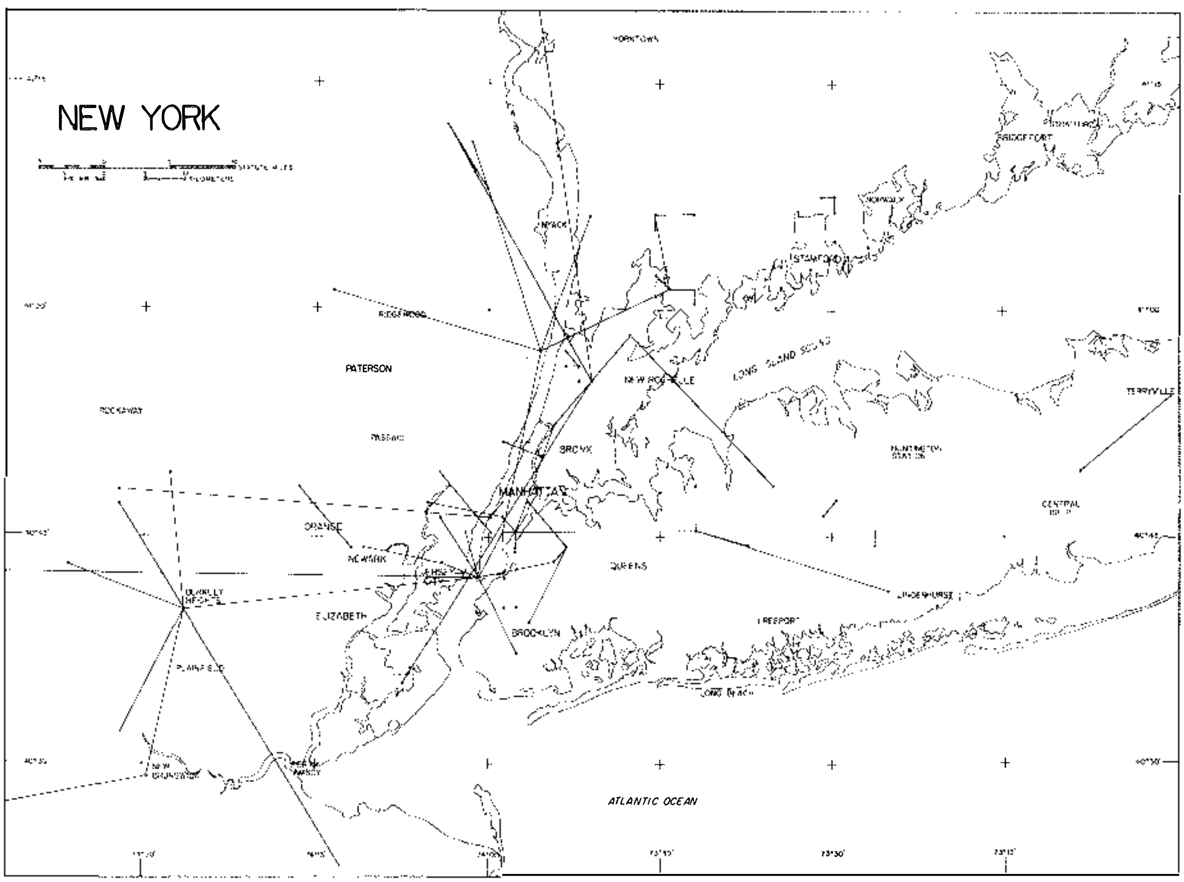


Figure 2-23. Terrestrial FS user connectivity for the 12.2-12.7 GHz band in the greater New York City area.

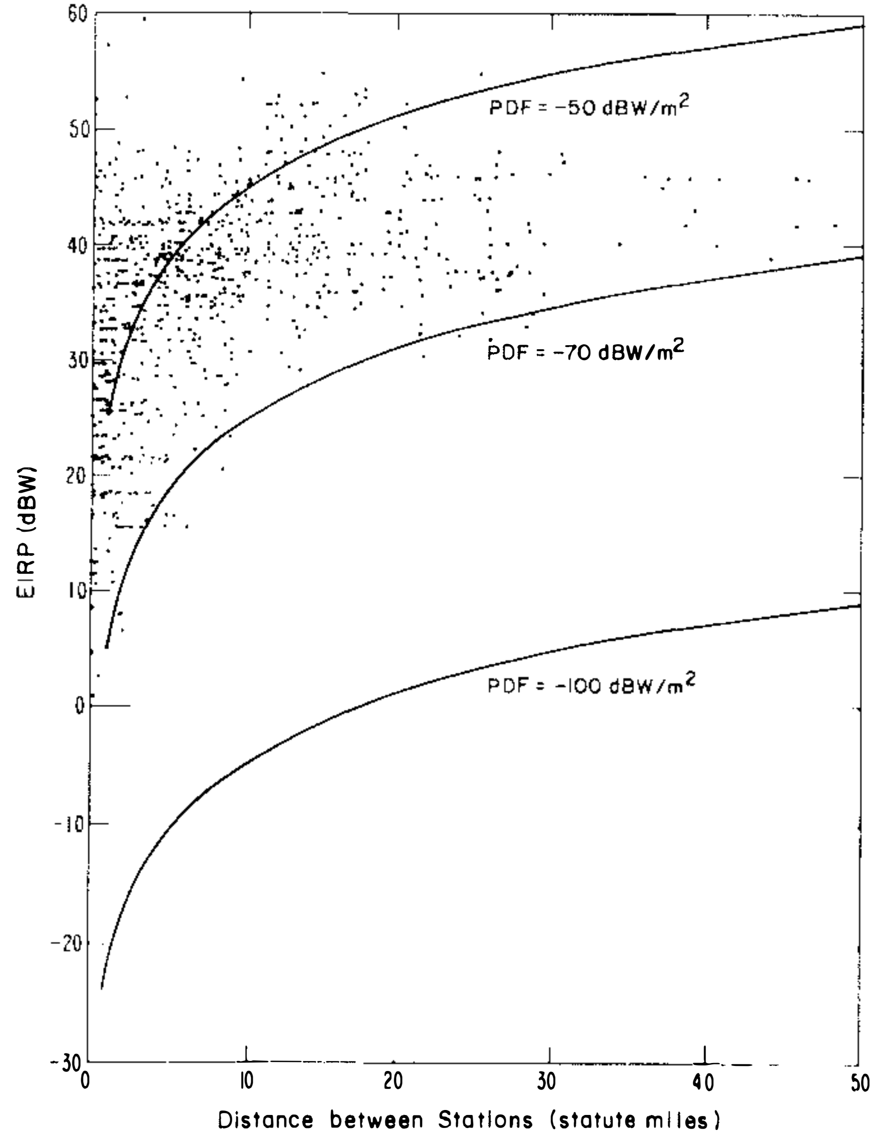


Figure 2-24. Comparisons of operating levels of FS and BSS systems in the 12.2-12.7 GHz band.

It plots all of the FS EIRPs versus station distances and then overlays the PFD curves for -50, -70, and -100 dBW/m^2. This clearly demonstrates the differences which exist between these two systems operating within the same frequency band, and quantifies these differences for RARC planners.

A.I.D. Rural Satellite Program. The Rural Satellite Program, established by the Agency for International Development, is a five-year, cooperative effort between the United States and a number of developing nations to develop and demonstrate the value of communications technology, particularly as realized through use of communication satellites, upon development efforts of developing nations. The establishment of reliable communications systems into rural areas of the developing world provides an important and essential capability which can be used (a) to improve methods of producing and distributing food, (b) to improve health and family planning services, (c) to stimulate productive work, and (d) to provide access to education.

This was the third year of technical support by the Institute to the Rural Satellite Program. Support during this year has been directed to development of an earth station design suited to thin-route communication requirements and purchase of an earth station for experimental tests to verify performance.

We took a unique approach to the problem of defining service requirements and system design characteristics for a small, low-cost, earth terminal for the Rural Satellite Program (thin-route) applications. Only general definition of service requirements for typical project applications could be provided. Therefore, we have followed a parametric, matrix plan in establishing service that can be provided by several candidate technologies noted below. The following assumptions and component parameter values have been used in the analysis of requirements and design:

a) Typical applications may be either mesh or star networks of like-capability remote earth terminals. A star network would operate with a central earth terminal assumed to be an INTELSAT Standard B or equivalent terminal in terms of G/T capability. The number of earth terminals per network is a parameter of the analysis.

b) Space segment service for the network will be provided by leased transponder which may be on an INTELSAT satellite (with either global or hemispherical beam coverage) or a regional or domestic satellite system, such as PALAPA (which will have shaped beam coverage including the area where communication service is to be provided).

c) Earth terminal antennas are assumed with aperture diameters of 3.0 m, 4.5 m, 6.0 m, 8.0 m, and 10.0 m.

d) Earth terminal receiving systems are assumed to incorporate a low noise amplifier with an operating temperature of 55K, 90K, 120K, 150K, or 200K.

e) The conditions of (c) and (d) above provide earth terminals with G/T ranging from 16.3 dB/K to 30.9 dB/K.

f) Telephony service will be provided using companded FM, SCPC technology, digitally encoded voice (i.e., CVSD or ADM) with QPSK modulation technology, or synthesized voice (i.e., LPC) with QPSK modulation technology.

g) Service capacity that can be supported by a quarter transponder (9 MHz) with combinations of technologies and earth terminal characteristics identified above have been determined.

Results of this analysis have been published in NTIA Report 82-99, dated March 1982 and titled "Parametric Approach to Thin-Route Earth-Station Requirements." An application example is shown below to illustrate use of the analysis results.

The most challenging situation arises if one were to use an INTELSAT satellite with global beam coverage and standard transponder gain. In such an application, receiver characteristics (uplink) for the satellite are G/T = -18.6 dB/K and maximum flux density is $-84.0\ dBW/m^2$ (for use of 9 MHz of transponder bandwidth). The satellite EIRP, transmitted toward earth, is 11.5 dBW. The values have been used to develop the information shown in Table 2-5.

Column by column, this table shows parametrically, the antenna diameter, low noise amplifier (LNA) noise temperature, earth station G/T, high power amplifier (HPA) power requirements, mesh and star network options, the number of circuits that can be supported by 9 MHz of transponder bandwidth (1/4 of a 36-MHz bandwidth transponder) and associated costs, when the voice service is single channel per carrier (SCPC) using continuously variable slope delta modulation (CVSD) digital voice encoding at 20 kbps and forward error correction (FEC) coding at rates R = 1/2 and R = 3/4 to reduce bit error rate to a corrected rate not to exceed 10^{-4}.

The first two sets of rows in the table deal with the standard transponder gain. The second two sets of rows are based on the global beam, high transponder gain which is 7.5 dB more gain than the standard gain. The first four rows of information are for systems with forward error correction coding (redundancy) at rate R = 3/4. The second four rows of information portray applications using FEC coding at rate R = 1/2. A similar pattern is followed for the applications using high transponder gain. The high transponder gain does not increase the capacity (number of duplex circuits provided by 1/4 transponder), but it does reduce, substantially, the required power capacity of the HPA. In fact, the communications capacity of 1/4 transponder decreases slightly due to increase in the required satellite EIRP per carrier to provide a slightly higher downlink C/N_o to achieve the required system C/N_o.

Consider the third row of information in the second section which is information pertaining to use of standard transponder gain and rate R = 1/2 forward error correction (100% redundancy). Note the required carrier-to-noise power density for digitally encoded voice, using CVSD, is C/N_o = 47.5 dB-Hz. The first column shows use of a 4.5-m antenna, the second column shows use of a 90°K LNA, and column three shows G/T = 22.5 dB/K, assuming receiving system noise temperature is 125°K (90K + 35K). Columns four and five show the HPA output power requirements are 29W and 3.6W for mesh and star network applications, respectively. Thirty-three duplex circuits could be supported by 9 MHz of transponder bandwidth in a mesh network, and 58 circuits could be supported in a star network (with an INTELSAT Standard B or equivalent capability earth station used at the hub of the star network). Finally, the last two columns portray estimated costs for the earth station components (excluding a shelter for the electronics equipment). These estimated costs of $56.2K for a mesh network earth terminal and $50.0K for a star network remote earth terminal are the minimum estimated costs when considering antenna sizes ranging from 3.0 m to 6.0 m. Estimated costs for earth terminals with smaller antennas are higher because larger capacity power amplifiers, which are very expensive, are required. The earth terminal with a 6.0-m antenna also is more expensive due to rapidly increasing cost for the antenna as diameter increases above 5.0 to 5.5 m.

Table 2-5. Tabulation of Antenna Size, LNA Noise Temperature, HPA Output Power, the Number of Circuits (Using One Channel per Carrier), and the Estimated Cost of Earth Station Components when the Satellite Resource is 1/4 Transponder on an INTELSAT Global Beam Coverage Satellite and Voice Encoding is Performed at 20 kbps

Ant. Size (m)	LNA Temp. (K)	G/T(dB/K)	HPA Power (W) MESH	HPA Power (W) STAR	Circuits per 1/4 Transponder MESH	Circuits per 1/4 Transponder STAR	Earth Station Cost ($ X 1000) MESH	Earth Station Cost ($ X 1000) STAR
---Standard Transponder Gain, FEC at R = 3/4 (Required C/N_o = 49.2 dB-Hz)---								
3.0	140	17.5	290	12	7	13	73.0	53.0
4.5	190	20.0	73	6	12	23	65.4	49.8
4.5	90	22.5	42	6	22	39	58.2	50.6
6.0	90	25.0	14	3	39	64	83.7	77.3
---Standard Transponder Gain, FEC at R = 1/2 (Required C/N_o = 47.5 dB-Hz)---								
3.0	140	17.5	195	8	10	20	72.0	48.0
4.5	190	20.0	49	3.6	19	35	62.4	49.2
4.5	90	22.5	29	3.6	33	58	56.2	50.0
6.0	90	25.0	9	2	58	95	78.9	76.8
---High Transponder Gain, FEC at R = 3/4 (Required C/N_o = 49.2 dB-Hz)---								
3.0	140	17.5	53	2.6	7	13	59.0	46.4
4.5	190	20.0	14	1.1	12	23	55.4	47.9
4.5	90	22.5	8	1.1	21	37	51.2	48.7
6.0	90	25.0	2.5	0.6	37	60	77.1	75.9
---High Transponder Gain, FEC at R = 1/2 (Required C/N_o = 47.5 dB-Hz)---								
3.0	140	17.5	36	1.7	10	19	53.0	46.0
4.5	190	20.0	9	0.8	18	34	50.6	47.8
4.5	90	22.5	5	0.8	32	56	51.0	48.6
6.0	90	25.0	1.7	0.4	56	88	76.7	75.8

The analysis reported in NTIA Report 82-99 was used to guide selection of technical characteristics for an earth terminal to be purchased by ITS. Technical specifications for purchase of the earth station components have been prepared, and competitive procurements are in progress. These components will be integrated by ITS staff into an earth terminal which will be used for experimental testing during next fiscal year to verify performance using leased satellite transponder resources.

ANNEX I
ITS PROJECTS FOR FISCAL YEAR 1982
ORGANIZED BY DEPARTMENT AND AGENCY

AGRICULTURE, DEPARTMENT OF

U.S. Forest Service

Project	Title	Leader
9104484	Boise National Forest Telecommunication Plan	Skerjanec
9104485	Region 2 Telecommunication Master Plan	Skerjanec

COMMERCE, DEPARTMENT OF

National Telecommunications and Information Administration (NTIA)

Project	Title	Leader
9101121	Best Spectrum Advocacy	Murray
9101123	Spectrum Trade-Off Research	Berry
9101124	Expanded FM Capacity	Adams
9102100	Common Carrier Technical	McManamon
9104120	Data Communications	Seitz
9104123	International Standards	Seitz
9104140	83 RARC Preparation Support	Jennings
9104142	FS & BS Sharing with BSS	Gates
9105100	Boundary Studies	Thompson
9105107	National Telecommunications Plans Support	Thompson
9107100	Technical Subcommittee Support	Hull
9107120	Spectrum Engineering Development	Berry
9107122	RSMS Operations	Matheson
9107123	RSMS Development	Matheson
9107124	Spectrum Resource Assessments	Grant
9107125	RSMS Upgrade	Matheson
9107126	HF/BC Computer Program Development	Rush
9108101	Modelling & Experimental Data Acquisition	Washburn
9108108	Millimeter-Wave Modeling & Experimental Data Acquisition	Rush
9108109	Southern California Support Analysis	Kissick

DEFENSE, DEPARTMENT OF (DoD)

Project	Title	Leader
9104372	Ionospheric Mapping	Rush
9104480	Boundary Measurements	Thompson
9104486	HF/VHF Propagation Studies	Teters
9104489	Impact of HF Heating	Rush

Air Force Systems Command (ESD)

Project	Title	Leader
9104468	Advanced DEB IV EFAS	Skerjanec
9104482	DRAMA Radio Performance Tests	Hubbard
9104492	System Monitoring Automated Remote Terminals	Farrow
9104501	Polar Ionospheric Modeling	Rush
9104502	AFGL Refractometer	Marler

Air Force Miscellaneous

Project	Title	Leader
9103441	MSR-Tl Multi Receiver System	Barghausen
9104431	AN/MSR-() Receiver System	Barghausen

Army Communication Command (USA/CC)

Project	Title	Leader
9104432	HF Antenna Simulation	Lloyd
9104447	Automated Troposcatter Path Loss Model	Hause
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

Army Communications-Electronics Command (CENCOMS)

Project	Title	Leader
9104423	Millimeter Wave Vegetation	Violette
9104467	Network Communication Model	Adams
9104472	Land Mobile Radio Network Communications Probability	Berry
9104478	Extended Range Communications Study	Kissick

Army Communications Systems Agency (CSA)

Project	Title	Leader
9104475	European DCS Requirements Analysis	Hoffmeyer
9104497	Defense Switched Network Access Area Program	Linfield

Army Research Office (ARO)

Project	Title	Leader
9104405	Millimeter Wave Attenuation	Liebe

Army Miscellaneous

Project	Title	Leader
9104446	DMDG Channel Simulation	Austin
9104449	Satellite Antenna Pattern Measurements	Carroll

Defense Communications Agency (DCA)

Project	Title	Leader
9101534	MEECN Simulation	Austin
9104491	Proposed FS 1026 Standard Authentication	Pietrasiewicz
9104498	DTE/DCE Standards	Gates

Defense Nuclear Agency (DNA)

Project	Title	Leader
9104464	Datacommunication System Architecture	Gates
9104500	HF Groundwave Measurements Phase I	Kissick

INTERNATIONAL COMMUNICATION AGENCY (ICA)

Project	Title	Leader
9104473	HF Propagation Studies/Voice of America	Washburn
9104505	HF Broadcasting/VOA	Rush
9104506	HF Broadcasting/BIB	Rush

NATIONAL AERONAUTICS & SPACE ADMINISTRATION (NASA)

Project	Title	Leader
9104457	NASA Propagation Analysis Program	Dutton

STATE, DEPARTMENT OF

Project	Title	Leader
9104411	AID Assistance	Jennings

TRANSPORTATION, DEPARTMENT OF (DoT)

Federal Aviation Administration (FAA)

Project	Title	Leader
9103489	Technical Support for Propagation and Spectrum Engineering	Hubbard
9103526	Air Navigation Aids	Johnson
9104469	FAA Radar Studies	Matheson
9104471	FAA Aircraft Calibration	Kissick
9104476	Instrument Landing System Interference Performance	Haakinson

U.S. Coast Guard (USCG)

Project	Title	Leader
9101532	Consulting USCG	Kissick

MISCELLANEOUS FEDERAL AGENCIES

Project	Title	Leader
9104428	Trace Gas Atten at 35 GHz	Liebe
9104477	Subsurface Electromagnetic Waves	Hill
9104487	Bureau of Reclamation Telecommunication Analysis Service	Haakinson

NONFEDERAL AGENCIES

Project	Title	Leader
9104483	RSMS Measurements at Goldstone	Matheson
9104490	RSMS Measurements/SPC	Matheson

OTHER

Project	Title	Leader
9102586	IONCAP Requests	Teters

ANNEX II
PROJECT INDEX

ANNEX III
ITS PUBLICATIONS - FISCAL YEAR 1982

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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, 1982) a full-time permanent staff of 85 and other staff of 13. In FY 1982, its support consisted of $3.7 million of direct funding from Commerce and $5.2 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 two of the eleven 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 three 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 which 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 the 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
MURRAY, John P. - Spectrum Advisor/Liaison	ITS.D7	5162	3013
SPECTRUM DIVISION			
RUSH, Charles M. - Acting Deputy Director	ITS.S	3821	3423
EM Transmission Measurement BARGHAUSEN, Alfred F. - Acting Chief	ITS.S1	3384	3451
Spectrum Use Measurement MATHESON, Robert J. - Chief	ITS.S2	3293	3420
Propagation Model Development and Application SPAULDING, A. Donald - Acting Chief	ITS.S3	5201	3415
Spectrum Management Analysis and Concept Development ADAMS, Jean E. - Chief	ITS.S4	5301	3461
SYSTEMS AND NETWORKS DIVISION			
McMANAMON, Peter M. - Acting Deputy Director	ITS.N	3570	2245
Switched Networks Analysis LINFIELD, Robert F. - Chief	ITS.N1	5243	2241
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 McMANAMON, Peter M. - Acting Chief	ITS.N4	3570	2245

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INSTITUTE FOR TELECOMMUNICATION SCIENCES

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    John P. Murray
  - **Special Technology Liaison**
    Roger K. Salaman
  - **SPECTRUM DIVISION**
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    Jean R. Mollard, Secretary
    - **EM Transmission Measurement**
      Alfred F. Barghausen, Acting Chief
      Ruth B. Hansen, Secretary
    - **Propagation Model Development and Application**
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    Harvey M. Gates, Associate Deputy Director
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