DEPARTMENT OF COMMERCE * UNITED STATES OF AMERICA *

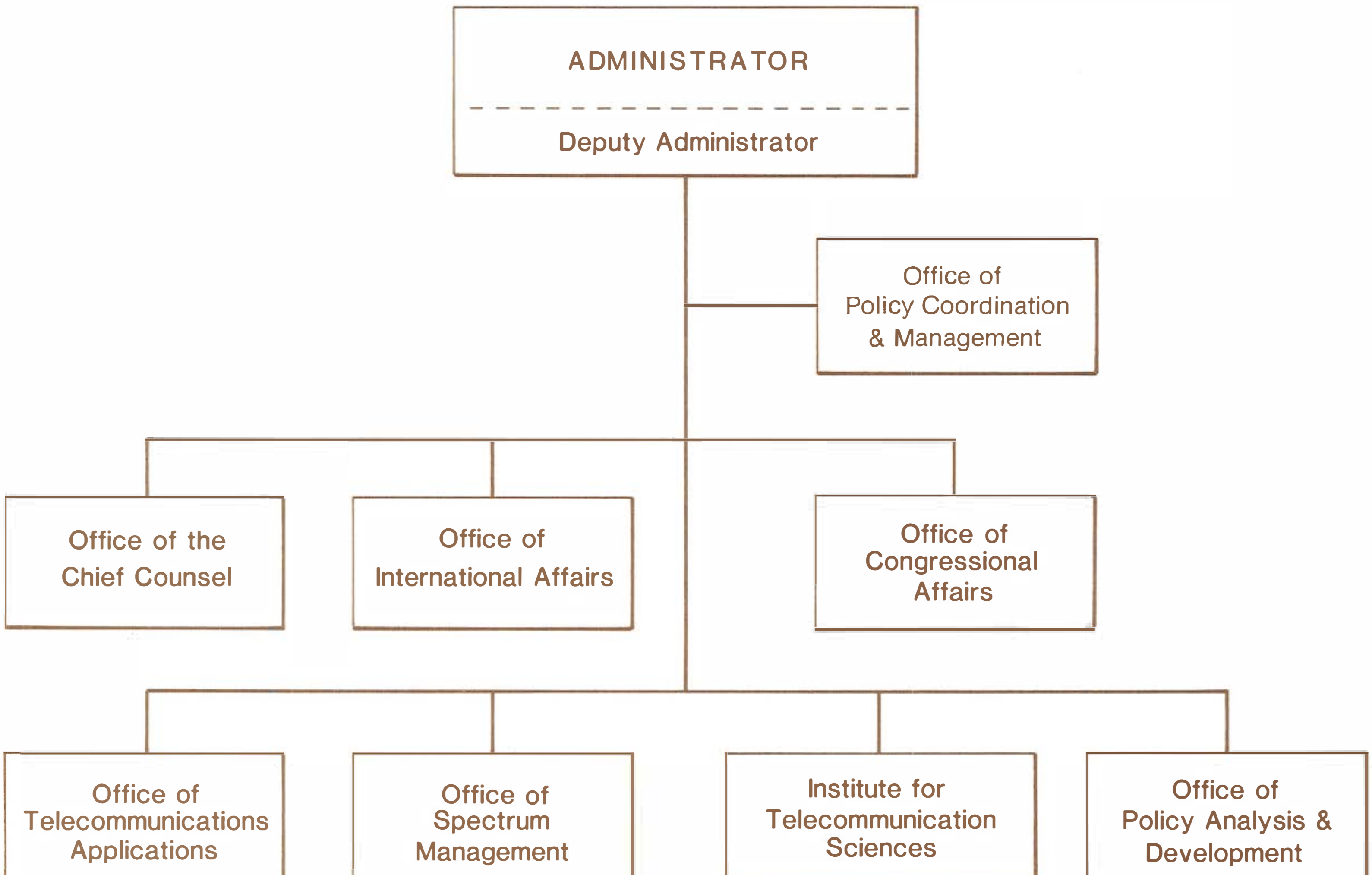
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

ANNUAL TECHNICAL PROGRESS REPORT 1984

For the period Oct. 1, 1983, through Sept. 30, 1984

U.S. DEPARTMENT OF COMMERCE

National Telecommunications and Information Administration



See inside back cover for ITS organization chart

ITS

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

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INTRODUCTION

The $175 billion telecommunications industry is at the heart of this country's move toward the information society. Scientific research and engineering are critical to continued U.S. leadership in this area. Research has been, and continues to be, conducted through cooperative efforts among U.S. industry, academia, and Government. This annual technical progress report summarizes significant fiscal year (FY) 1984 technical contributions made by the Institute for Telecommunication Sciences (ITS), the primary Government laboratory devoted to this field.

The Institute is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. Its mission is divided into two major elements: 1) to provide direct support to the NTIA Administrator (who is the President's principal adviser on telecommunications and information issues) and to 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 importance of this responsibility is illustrated by the fact that the Department of Defense alone will spend $1.1 billion for common carrier telecommunications equipment and services in 1985.

The technical work carried out by the Institute falls in two broad categories: Spectrum Research and Analysis, and Systems and Networks Research and Analysis.

The Institute's work in Spectrum Research and Analysis is directed toward improving our understanding of radio-wave transmission to enhance spectrum utilization and the performance of radio communication systems. Important results of this research are spectrum use concepts and models that lead to more efficient Federal and private sector use of radio frequency spectrum, and electromagnetic wave and propagation models that lead to improvement in radio system performance.

Systems and Networks Research and Analysis studies are directed toward developing domestic and international telecommunication standards, assessing the performance of Government and private sector telecommunication networks, and evaluating new technologies for application to future needs. These activities facilitate competition in the U.S. telecommunications industry, promote international trade opportunities for U.S. firms, and improve the cost effectiveness of Government telecommunications use.

In both categories, the Institute provides significant contributions to 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). Work in support of these international committees is reported within the succeeding chapters.

In summary, the Institute's science and research efforts are directed toward improving the United States' telecommunications technology base. Major technical programs are undertaken to find more effective and efficient ways to utilize our national spectrum resource and to improve the planning, use, and evaluation of Government telecommunictions systems. Concomitant with these efforts, the Institute provides a core telecommunications research capability that can be accessed by all sectors of our society. Institute research provides a technical foundation for Administration telecommunications policy development in national and international arenas.

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

The use of the electromagnetic spectrum, in telecommunications, has grown dramatically in the last four decades. This growth stems from population increase, new technologies, and new services. To accommodate this growth, the limited usable spectrum must be expanded to higher frequencies, and existing spectrum must be managed more efficiently. To these ends, the National Telecommunications and Information Administration, Institute for Telecommunication Sciences (NTIA/ITS) continues a historic program to better understand and use higher frequencies and to optimally manage the use of the spectrum within the framework of national goals and priorities. This program draws heavily upon interrelated projects and expertise in spectrum measurements and in electromagnetic (EM) transmission and propagation modeling/ predictions.

This chapter provides a brief overview of some specific projects conducted by ITS personnel. These projects are categorized topically into four sections. In Section 1.1 spectrum engineering work is described; Section 1.2 presents some spectrum resource assessments for the frequency bands from 947 MHz to 40.5 GHz; advanced instrumentation and spectrum measurement operations are presented in Section 1.3. Finally, in Section 1.4, EM transmission with its three subtopics of medium properties, models and predictions and propagation predictions are discussed.

SECTION 1.1 SPECTRUM ENGINEERING TECHNIQUES

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

The rapidly expanding global usage of the radio frequency spectrum resource has resulted in intensified competition among the 40 radio communications services for spectrum space to meet their present and anticipated future needs. In the United States, many critical radio bands are already congested, and this situation may well be aggravated as increased private sector competition heightens the pressure on the spectrum resource.

In 1982, the Senate Appropriations Committee requested NTIA to study Federal spectrum usage; the goal is to use the spectrum resource more efficiently. In response, NTIA prompted the Interdepartmental Radio Advisory Committee (IRAC) to direct its Technical Subcommittee (TSC) to define quantitatively terms related to spectrum efficiency. Working Group 13 (WG-13) was formed by TSC to produce the desired definitions, and the tasks in projects <u>TSC Support</u>, <u>Spectrum Efficiency Studies</u>, and <u>Spectrum Engineering Development</u> support the TSC WG-13 effort. The project leader of these projects is the Convener of WG-13.

The terms of reference of WG-13 are to: "Accomplish

a) A quantitative definition of the terms relating to 'efficient spectrum use';

b) A method of application and general formulation for evaluating spectrum efficiency. This should initially be applied to the Fixed Service in selected bands from 947 MHz to 40 GHz;

c) The development of a computer model for evaluation of the specific application examined in b;

d) An examination of typical outputs from the computer model for the specific application examined in c;

e) Repeat b, c, and d for Mobile in selected bands from 947 MHz to 40 GHz."

Working Group 13's initial response to this charge, "Defining Spectrum Efficiency: TSC Working Group 13 Progress Report," was approved by TSC and noted by IRAC in its February 14, 1984, meeting. The report distinguished between <u>technical spectrum efficiency</u> and <u>spectrum utilization effectiveness</u>. This latter term relates to the degree to which particular communications requirements are fulfilled, including service quality, reliability, cost-effectiveness, access, and security. Some of these factors depend heavily on economic, social, and political needs that are qualitatively, rather than quantitatively, related to important national goals.

It should be emphasized that technical spectrum efficiency is not the only--<u>not even the most important</u>--criterion for rating a communication system. Cost, response time, reliability, security, quality, and other characteristics are often more important, and they may be compromised by maximizing technical spectrum efficiency.

For example, cost is one of the most important reasons that telecommunications systems are designed with less than maximum spectrum efficiency. This is especially true for Government systems that are procured and operated with taxpayers' dollars, but it is also true for commercial systems. Point-to-point communications, such as telephone calls and business data communications, could be carried by wires, cables, or waveguides. These transmission media use no spectrum space at all, so using spectrum space to transmit point-to-point messages could be called spectrum inefficient. Yet almost all such communications that travel beyond the local area are carried by microwave relays or satellite transponders (spectrum-using systems) because these systems are generally cheaper than long-distance wire networks.

The technical regulations for UHF television provide another example of economics (and other social or political factors) overruling technical spectrum efficiency. When those regulations were developed, Congress and the Federal Communications Commission wanted to promote the development of UHF TV to provide greater diversity of programming. So the regulations ("the UHF taboos") protected UHF TV receivers that are very spectrum-inefficient. These receivers have little selectivity or interference rejection, because these require filters and other components that would make the receivers cost more.

In any application of a quantitative index of technical spectrum efficiency, the possible benefits of increasing spectrum efficiency must be measured against the economic costs of doing so.

Communications accessibility, or response time, is another desirable characteristic of communications systems that can be traded for technical spectrum efficiency. During many parts of the 24-hour day, a large fraction of the circuits in our nationwide telephone system are idle. This could be said to be an inefficient use of communications resources. The reason for the idle capacity is that the system is designed to hold the "blocking probability" to an acceptable level. That is, there must be a good chance that a person trying to make a call during a busy hour will not be blocked by a "circuit busy" signal. This can be accomplished only by providing more circuits than are necessary during most of the day so that the "peak load" can be handled.

In some Government systems, the difference between the peak load and normal conditions may be much greater, with an accompanying decrease in the apparent "spectrum efficiency." For example, communication systems used during emergencies or disasters may transmit hardly at all for long periods of time. But when disaster strikes, they must be instantly accessible and will carry heavy traffic to save lives and property. Many frequencies used by the Department of Defense are like this. An extreme example of accessibility overriding spectrum efficiency might be the "hot line" to Moscow. It's traffic-per-year ratio is probably very small, but instant accessibility is far more important.

In some Government systems, particularly defense systems, the messages must be secure from interception. Some techniques for engineering security (particularly those that prevent detection) require more spectrum than would be necessary for transmission "in the clear."

A characteristic especially important for Government communication systems is robustness. The systems must work in adverse, even hostile, conditions. Defense systems must pass orders and information even when deliberately jammed; radars and weapon guidance systems must continue to operate during electronic countermeasures; air traffic control systems must not be interrupted by severe weather. Robustness is often purchased with additional spectrum:

- deliberate redundancy is built into critical systems, so that one line of communications will always be open
- spread-spectrum systems are designed to combat hostile jamming
- frequency diversity is used to ensure that the message gets through. All these design strategies might be termed spectrum-inefficient if the definition is too simplistic. Working Group 13 has attempted to avoid such a simplistic definition, but for any definition, some critical communications systems may appear to be not spectrum efficient. Maximizing technical spectrum efficiency is not always the way to optimize Government operations.

One reason that the spectrum resource is limited, so that spectrum efficiency is necessary, is that electromagnetic signals can interfere with each other, thus destroying part or all of the information in the signals. Emissions interfere with a desired signal if:

- they are at a frequency that the receiver responds to
- they arrive at the receiver location with sufficient power
- they arrive during the time that the desired signal is being received.

These conditions show that the important dimensions of the spectrum-space resource are frequency bandwidth, physical space, and time.

Working Group 13, therefore, follows CCIR (Report 662) in defining the volume of spectrum-space used to be the product of (bandwidth)x(time)x(physical space) that is denied to other potential users.

Then, the technical spectrum efficiency factor (TSEF) is the ratio of the spectrum resource used by a state-of-the-art radio system that accomplishes the same mission as the evaluated system to the spectrum resource used by the evaluated system. Here, "state-of-the-art" means the best of the systems that either can be procured, or could be produced at a reasonable price. Mathematically, the technical spectrum efficiency factor is:

$$TSEF = (B_r \times T_r \times S_r)/(B_s \times T_s \times S_s),$$

where

B_r is the bandwidth the reference system denies to others,

T_r is the time the reference system denies to others,

S_r is the physical space (e. g., area) denied,

B_s is the bandwidth denied by the evaluated system,

T_s is the time denied by the evaluated system, and

S_s is the physical space denied by the evaluated system.

There is clearly much work to be done to apply the definition to any specific system or service. The necessary data may not all be available, and some may be probabilistic. Good engineering judgment will have to be applied to produce a formulation that is both computable and credible.

Even more engineering judgment will be necessary to specify what, in fact, constitutes "a practical, state-of-the-art system that accomplishes the same mission." However, making the required mission a part of the definition avoids many potential pitfalls in quantifying spectrum efficiency. For example, if the mission requires that a channel be instantly accessible at all times, then the reference system must have that reserved channel, and the appearance of spectrum inefficiency in the real system is avoided.

Working Group 13 is now applying the definition and calculating the technical spectrum efficiency factor for the fixed service, beginning with the 7-8 GHz band. Document WG-13-8, "Calculation of the TSEF for Fixed Terrestrial Services," gives calculation methods and formulas, along with sample calculations that show the sensitivity of the TSEF to some of the necessary simplifying assumptions. The first draft of this document was produced at ITS. Document WG-13-11, "Specification of Computer Program to Calculate TSEF in the Government Terrestrial Fixed Service," was also drafted as part of the ITS projects. Several necessary subroutines have been developed, and the computational software is now being produced by NTIA personnel in Annapolis.

Calculations of the TSEF from data in the Government Master File for the 7-8 GHz band are scheduled for the fall of 1984.

Efficient spectrum management requires application of technical expertise as exemplified by the Radio Frequency Assignments project. In this project the effects of atmospheric ducting, transmitter emission, and receiver bandpass characteristics on radar frequency assignments are evaluated for the Federal Aviation Administration (FAA).

The FAA uses a band of frequencies for their Air Surveillance Radars (ASR) that must be assigned across the country efficiently and with a minimum amount of interference between assignments. By using the ASR transmitter's emission and receiver's bandpass characteristics, the required distance separation between assignments for a given frequency separation can be estimated. Figure 1-1 shows a typical family of distance-separation versus frequency-separation curves between ASR-8 radars. The middle curve shows what separation is required to maintain a specified interference-to-receiver noise ratio for 50 percent of the time.

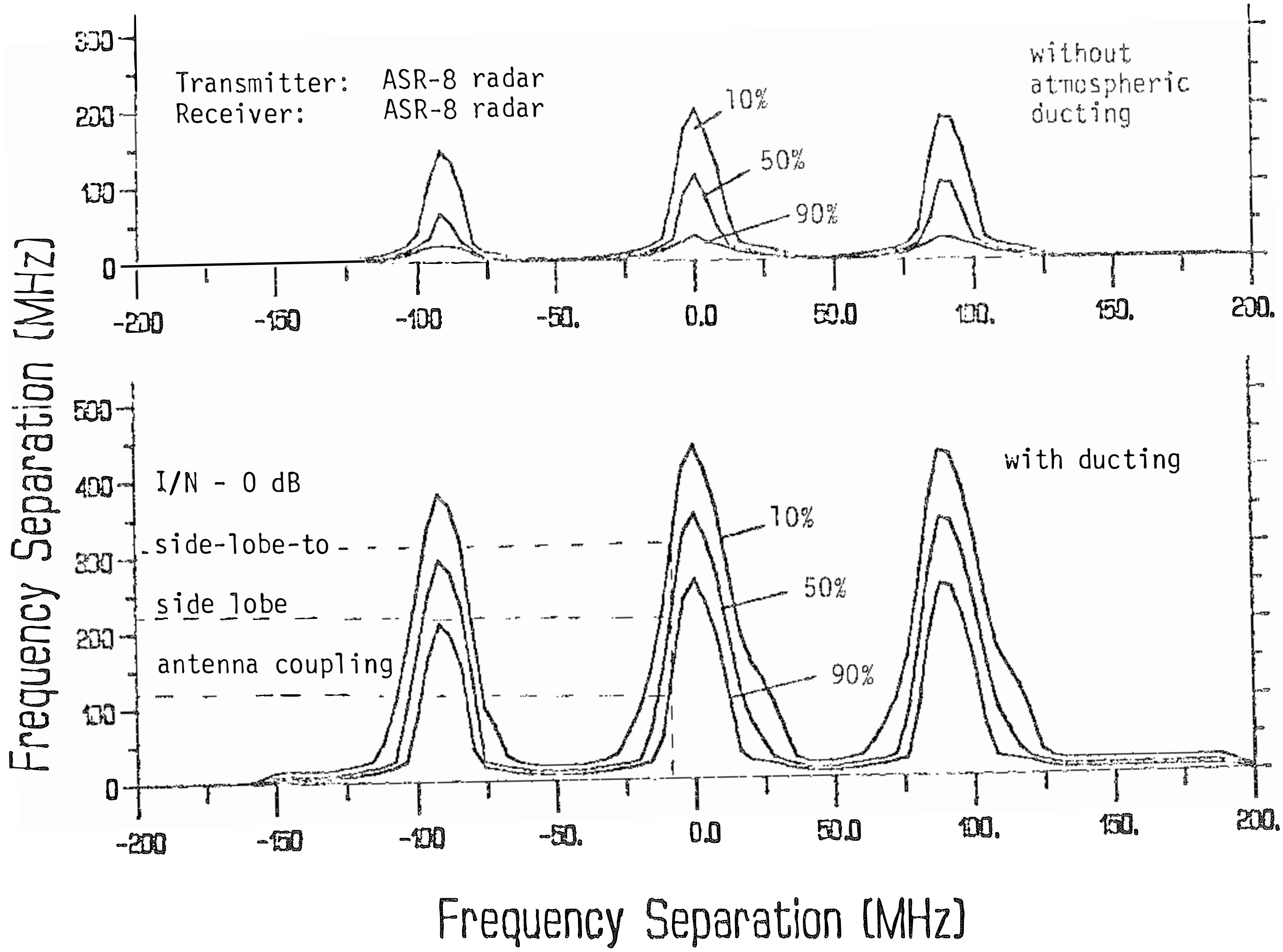
The top curve shows the separation required such that the specified interference-to-receiver noise ratio is not exceeded for 90 percent of the time while the bottom curve shows the separation such that the ratio is not exceeded for 10 percent of the time. By using these types of plots, FAA frequency managers can determine what frequency separation between carrier frequencies are required between nearby radars.

SECTION 1.2 SPECTRUM RESOURCE ASSESSMENT

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government use of the radio spectrum. Part of NTIA's responsibility is to: "...establish policies concerning spectrum assignment, allocation and use, and provide the various departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies". In support of these requirements, NTIA has undertaken a number of spectrum resource assessments. The objectives of these studies are to: assess spectrum utilization, identify existing and/or potential compatibility problems among the telecommunication systems that belong to various departments and agencies, provide recommendations for resolving any compatibility conflicts that may exist in the use of frequency spectrum, recommend changes to increase spectrum efficiency and improve spectrum management procedures, and help establish a long-range plan for spectrum use.

In order to ensure efficient and effective use of the spectrum, Executive Order 12046 and Department of Commerce Order 10-10 direct NTIA to develop, in cooperation with the Federal Communications Commission (FCC), a long-range plan for spectrum use. As part of this planning effort, several tasks have been initiated:

- Spectrum Resource Assessments (SRA) covering the bands 947 MHz-17.7 GHz and 17.7 GHz-40.5 GHz. (These SRA's are proceeding concurrent to the FCC Docket 82-334 which addresses identification of suitable spectrum for licenses displaced under Docket 80-603 by the Broadcasting Satellite Service (BSS) in the 12.2-12.7 GHz band.)
- Spectrum Resource Assessment covering the 2900-3100 MHz band.
- Spectrum Resource Assessment evaluating the use of narrow-band communications techniques.
- IRAC Technical Subcommittee (TSC) determination of a method for evaluating spectrum efficiency--TSC Working Group (WG)-13 has been tasked under IRAC documents 23191/1, 23199/2, and 23648/1 to complete this work. TSC WG-13 has defined a Technical Spectrum Efficiency



Example: F_r a frequency separation of 10 MHz between two ASR-8 radars and when ducting is present, interference is predicted to occur:

for 90% of the time at a distance of 150 n mi.
for 50% of the time at a distance of 230 n mi.
for 10% of the time at a distance of 320 n mi.

Figure 1-1. An example of statistical frequency separation-distance separation curves.

Factor and is proceeding with development of a related computer model. This efficiency factor concept will be applied where feasible to fixed and mobile systems in selected bands within the overall 947 MHz-40.5 GHz range.

Pertinent portions of the SRA's will be incorporated into the Joint NTIA/FCC Long Range Plan (LRP).

The Spectrum Resource Assessment of the Fixed and Mobile Services in the 947 MHz-17.7 GHz Bands is part of the tasking as given above.

On September 30, 1983, the FCC released the First Report and Order (FCC 83-393) in General Docket 82-334 to provide frequencies and revised rules for the reaccommodation of existing 12 GHz fixed microwave users. This was necessary because the 12 GHz band (12.2 to 12.7 GHz) has been allocated to the Broadcasting-Satellite Service on a primary basis, and Fixed Service and Broadcasting-Satellite Service cannot use the same frequencies in a geographic area due to potential interference. The First Report and Order also allocated spectrum in the 18 GHz band to Fixed Service.

On January 13, 1983, the Commission adopted and released a Notice of Proposed Rule Making (NPRM) (FCC 83-2) in General Docket 82-334 proposing spectrum allocations and standards for certain microwave bands. A major purpose of the NPRM was to propose changes in the Commissions's Rules to accommodate private fixed users who might be displaced from the 12 GHz frequency band by the allocation of band to the Broadcasting-Satellite Service. Earlier, the Commission had released a Notice of Intent (NOI) (FCC 82-286) in this proceeding to examine spectrum allocations and technical standards for certain Fixed and Mobile Services' bands between 17.7 and 40 GHz. The scope of the proceeding was expanded by the NPRM to include consideration of certain additional bands between 947 MHz and 17.7 GHz in order to provide a means for developing provisions to accommodate the displaced 12 GHz users. This concern prompted this special study of Government use of spectrum between 947 MHz and 40 GHz which would influence the continuing effort at long-range planning for effective and efficient use of the spectrum administered by NTIA.

In the United States, the spectrum from 947 MHz to 17.7 GHz has been divided into 88 separate bands. The effort here will be focused on the Fixed and Mobile Services, and there are 50 bands allocated to those services. These 50 bands are represented by 7917 MHz of spectrum. The 7917 MHz of spectrum is allocated to Government/non-Government shared, non-Government exclusive, and Government exclusive uses. Even though the allocation table may seem to allocate a band to Government or non-Government exclusive use, the band may actually be shared by action of a footnote to the allocation table. An example would be the three bands between 8025-8400 MHz. These bands appear to be Government exclusive bands. However, U.S. Footnote 258 states that, "In the band 8025-8400 MHz, the non-Government Earth Exploration-Satellite Service (space-to-Earth) is allocated on a primary basis. Authorizations are subject to a case-by-case electromagnetic compatibility analysis." By virtue of the footnote, this portion of the spectrum becomes a Government/non-Government shared band.

The 7917 MHz of spectrum containing Fixed and Mobile Services in the frequency range from 947 MHz to 17.7 GHz is allocated as follows:

Government/non-Government shared:

Shared by direct allocation, containing 744 MHz of spectrum	11 bands
Shared by footnote, containing 1403.5 MHz of spectrum	14 bands
Total shared, containing 2147.5 MHz of spectrum	25 bands (27 percent)

Government/non-Government exclusive:

Non-Government exclusive, containing 3,578 MHz of spectrum	14 bands (45 percent)
Government exclusive, containing 2,191.5 MHz of spectrum	11 bands (28 percent)

Major services in the remaining 38 bands that make up the allocations in the 947 MHz to 17.7 GHz spectrum range include Radiolocation, Aeronautical Radionavigation, Aeronautical Telemetering, Fixed-Satellite, Mobile-Satellite, Meteorological-Satellite, Broadcasting-Satellite, and Radio Astronomy Services.

The frequencies between 947 MHz and 17.7 GHz represent a large portion of the usable radio frequency spectrum and represent a very important and valuable asset as part of this resource. There is a need at this time to review the Government use, rules and regulations, and technical standards governing this portion of the spectrum in light of the Commission's NOI, NPRM, and Report and Order; the changes in allocations and standards implemented as a result of the 1979 World Administrative Radio Conference (WARC-79); and changes in market demands and applications of new technologies being addressed. Continued examination of Government spectrum requirements is necessary to assure that assigned mission functions are satisfied and that the spectrum is used efficiently.

A multiphase program to evaluate sharing potential in the 947 MHz-17.7 GHz frequency bands was undertaken as follows:

Phase I: The first phase involves the gathering of all information presently in NTIA files on assignments, uses, major systems, etc., in the bands involved. Sources for this information are the Government Master File (GMF), Non-Government Master File (NGMF), past SRA reports in this frequency range, other NTIA and Government agency reports, equipment manufacturers' system descriptions and reports, and any other readily accessible source with pertinent information to this study. This will lead to the generation of preliminary recommendations for the band's sharing potential.

Phase II: This phase will incorporate detailed information from each Federal agency represented in IRAC giving system/equipment counts, mission requirements, and projections of future use in all bands containing Fixed and Mobile Services from 947 MHz to 17.7 GHz. Based on Phase I recommendations, certain bands will be explored in more detail to assess the impact of band sharing. The concept of regional sharing as recommended in the Phase I report will be more detailed in the Phase II report.

Additional Phases: These phases will be conducted in particular bands as required. These assessments take into account new inputs such as new system design, other system changes, allocation changes, and Electromagnetic Compatibility (EMC) impact. They will continue until satisfactory solutions to the problems of sharing are obtained, or until the point when sufficient decisions have been made, such that further assessments are no longer necessary.

OBJECTIVES

To assist in the development of long-range spectrum management plans and policies, the following objectives were identified for this spectrum resource assessment:

- Review and document the existing and proposed uses of the bands between 947 MHz and 17.7 GHz by the Government and non-Government Fixed and Mobile Services, particulary emphasizing those specifically addressed in the FCC documents and including those that could be expected in response to the results of the WARC-79 and other international and national agreements.
- Assess the nature and scope of present and future potential compatibility problems between Government and non-Government planned uses of the spectrum.
- Evaluate the feasibility of increased sharing between Government and non-Government services without affecting critical Government needs.
- Recommend specific changes to the existing rules, regulations and frequency management practices that would improve overall management of the band.
- Identify and outline specific problem areas requiring additional analysis.

APPROACH

In order to accomplish the objectives of the 947 MHz to 17.7 GHz Spectrum Resource Assessment, the following approach was taken:

- Review the various FCC documents concerned with this band to determine the likely effect to Government radio services.
- Review the Final Acts of the WARC-79 and the NTIA Manual to determine the allocations to Fixed and Mobile Services and the regulations pertaining to the frequency bands of concern between 947 MHz and 17.7 GHz.
- Review the systems that are currently operating in the band, where they are deployed, and their technical characteristics by:
    - a. Using the Government Master File (GMF), the non-Government Master File (NGNF), previous NTIA reports, the System Review File (SFR), and other Government reports to identify frequency assignments and usage for Government and non-Government operations.
    - b. Contacting the Government frequency managers through IRAC and using surveys of major equipment manufacturers and users.
- Identify future systems proposed for the band by using data in the IRAC/Spectrum Planning Subcommitee's (SPS) system review process for Government systems and equipment.
- Review the compatibility analysis of systems within the 947 MHz to 17.7 GHz concerned with the Fixed and Mobile Services accomplished by other Government agencies and those analyses made in support of the IRAC system review process.
- Recommend specific changes or further studies relative to the existing rules, regulations, and frequency management practices that would improve overall management of the Government Fixed and Mobile Services in the bands involved.
- Identify remaining key issues that affect spectrum management of the Fixed and Mobile Services in the band and recommend follow-on activities to address these issues.

The study produced a comprehensive 364-page report that detailed spectrum use in the bands between 947 MHz and 17.7 GHz and made the following conclusions and recommendations.

Conclusions and recommendations are general in this Phase I report and are based on file data within NTIA and easily accessible file data from other-agency sources. The Phase II report will include more explicit data on future Government need for services in these bands and actual present-day system/equipment counts. It will be noticed in a number of bands there are recommendations for regional sharing of frequency asignments between Government and non-Government entities. These recommendations are general in nature and will be considered in more detail in light of all data available, particularly planned future use by the various Government agencies, in the Phase II report. However, the concept of regional sharing should be a serious consideration for the future since frequency assignments to a service in some bands tend to concentrate in certain geographic areas leaving other areas with few or no assignments.

General Conclusion

The forces influencing the allocation of spectrum resources by the FCC and the Federal Government are basically very different. Economic and political pressures by the private sector upon the FCC for increased spectrum resources establish a criterion for spectrum efficiency. The Government's requirements are dictated by planning requirements for national exigencies, and Federal Government's National Security and Emergency Preparedness programs, which complicates the efficiency of Government spectrum use. It is this difference in national planning concepts that establishes the basis upon which Government needs are satisfied and why sharing with non-Government entities requires special management and rules.

While there is a concept of geographical sharing between Government and non-Government entities presented in this report, if this concept should be pursued, the ramifications and implications upon existing and future Government and non-Government spectrum needs would require a detailed and vigorous examination. The National Table of Frequency Allocations is a representative document of the Government's detailed long-range planning requirements. However, it would facilitate planning if a regional concept were established. By designating geographical areas, sharing and nonsharing and the terms under which they could be accomplished could be more definitely specified. To accomplish this, private sector, long-range plans must be identified and addressed to make a comprehensive assessment of this important issue. The FCC liaison representatives to the IRAC and Frequency Assignment Subcommittee (FAS) have provided a needed and satisfactory procedure for coordination of civil and Government requirements in the past. This liaison must become even more effective in the future as pressure from both Government and non-Government users of the frequency spectrum become more demanding on this important national resource.

Specific Conclusions

Government exclusive bands--sharing not possible

- The 1710-1850 MHz band: This band is one of the most heavily used bands for Government Fixed Services. There are 41 systems presently in the systems review process, which is indicative of the anticipated growth in the band. Based on present assignments and the critical nature of the services in the band, it seems highly improbable there could be sharing with the non-Government sector.

- The 2200-2290 MHz band: This band is an important band for Government with many assignments to the Mobile Service for telemetering. There are also a considerable number of experimental assignments along with growing space research and fixed assignments. The band is actually now a shared band by footnote. With present nature of band usage and expanding space research use, this band does not lend itself well to increased sharing with non-Government users at this time. This band should be looked at in more detail in the Phase II report.

- The 4400-4500 MHz and 4800-4990 MHz bands: These bands are used by the military services for tactical communications both line-of-sight microwave and tropospheric scatter operations. There is some room for growth in these bands, but until future use is determined in the Phase II study, these bands should be held for Government exclusive use.

- The 7125-8450 MHz band: These bands are used mainly for Government fixed systems (87 percent). Most of the 13 subbands contain some type of satellite communications allocation, and this is a growth area in assignments for the future. Twenty Government departments and agencies have assignments in the bands (over 7700). The three bands for 8025-8400 MHz are shared with non-Government users for the Earth Exploration-Satellite Service by U.S. footnote 258. Because of the importance of the Government systems operating in the bands and the congestion already present in many areas of CONUS, there is little possibility of increased sharing with non-Government users.

- The 14.5-15.35 GHz band: Present assignments in the band are primarily to the Fixed Service (75 percent). The band has shown a 500 percent growth in assignments in the past 10 years. It is expected that this growth trend will continue in the near future. Although there is room for growth, until all information is in on future Government needs for this band (to be given in Phase II report), sharing possibilities cannot be determined.

Government exclusive bands--limited sharing may be possible

- The 1350-1400 MHz band: This band is primarily a radiolocation band with Fixed and Mobile secondary. Because of the importance of this band to the national defense, general sharing with the private sector is not practical. However, there are 25 states with no present assignments. After future proposed usage is known in the Phase II report, this band should be investigated for possible sharing opportunities in certain geographic areas with non-Government users.

Government/non-Government shared bands

- The 1427-1535 MHz band: This band is heavily used by the Government and non-Government for telemetering purposes. Provisions have been made for the Fixed Service on a secondary basis for the private sector. There doesn't seem to be a need to change allocations in this band at this time.

- The 1700-1710 MHz band: This band is used mainly by Government for meteorological-satellite data links. This band does have growth potential but the allocations are such that both Government and non-Government users can be accommodated without changes at this time.

- The 2290-2390 MHz band: The 2290-2390 MHz portion of the band is used mainly for Space Research (deep space only) assignments and has the least potential for increased sharing. The 2300-2390 MHz portion is basically a Government radiolocation band; however, radiolocation use of frequencies between 2310 and 2390 MHz is very sparse. There are 26 states in CONUS that do not presently have Government assignments in the 2290-2390 MHz band with another 9 that have only one. The 2300-2390 MHz portion of the band could support more fixed assignments and might be considered for a non-Government Fixed Service on a secondary basis as is presently allocated to Government. However, the impact of new Mobile Services should be evaluated before any changes in allocation are recommended.

- The 4500-4800 MHz band: The major assignments in this band are to the Government Fixed Services (75 percent). Tropospheric scatter systems that operate in this band are very important to the military for tactical communication purposes. The new fixed-satellite allocation to non-Government may pose some interference potential to existing systems. This band at present tends to have many assignments in a few geographic areas. There are 15 states with no assignments and another 9 with only one assignment. However, because of the importance of the troposcatter systems, limited sharing is desirable.

- The 8450-8500 MHz band: This is not a heavily used band by either Government or non-Government services. There are only 9 states with assignments in this band. There may be room for a non-Government Fixed Service on a secondary basis. There is some concern about adjacent channel interference for high power radars in the 8500-9000 MHz band but distance criteria can be developed to help in assignment placements. Further investigation is necessary before final decsion is made.

- The 10.6-10.68 GHz band: There are no Government assignments in this band. However, there are two Government assignments and one non-Government assignment in the lower adjacent band that can range tune into this band. There is an allocation to the non-Government Fixed Service on a shared primary basis with other services. At present there are only 12 states that have any assignments. It would seem that this band could be used by some of the non-Government fixed stations to be displaced from the 12 GHz band by the Broadcasting-Satellite Service. However, the new Digital Termination System (DTS) services will be the new growth area for this band.

- The 14.4-14.5 GHz band: The primary allocation in this band is to the non-Government Fixed-Satellite Service. Government fixed and mobile assignments are secondary. Though satellite systems are a growth area nationally, they have not significantly changed the number of assignments in the band over the past 5 years. However, this is misleading since there are 112 satellite-related systems that require bandwidths that extend into this band from the lower adjacent band. These wide-band assignments show about a 10 percent growth per year over the past 3 years.

Recommendations

The following are NTIA staff recommendations based on technical findings. Any action to implement these recommendations will be accomplished under separate correspondence by modification of established rules, regulations, or procedures.

Government exclusive bands

- After future needs have been fully explored in the Phase II report, it is recommended that the 1350-1400 MHz band be studied for possible regional sharing of non-Government Fixed and Mobile Services on a secondary basis.

- After future needs have been fully explored in the Phase II report, it is recommended that the 14.5-15.35 GHz band be studied for possible regional sharing of non-Government Fixed and Mobile Services on a secondary basis.

Government/non-Government shared bands

- It is recommended that the 2310-2390 MHz band be studied for the possibility of adding non-Government Fixed Services on a secondary basis if Phase II findings warrant for certain specified geographic areas

- It is recommended that the 8450-8500 MHz band be considered for non-Government Fixed Services on a secondary basis if Phase II studies show possible success.

- It is recommended that the 10.6-10.68 GHz band be considered as a band to be used for some of the displaced fixed stations from the 12.2-12.7 GHZ band. However, the new DTS services will be expanding rapidly in the near future and the 12 GHz users would have to be well coordinated with these new systems.

The concept of geographic sharing between Government and non-Government entities, while not completely new, is considered formally in this SRA. The concept is based on geographic use of assigned frequencies. As an example, in Figure 1-2 for the 1350-1400 MHz band the placement of Government systems is shown. While the Government systems in the band are very important to the national defense, it is felt that the geographic area as shown in Figure 1-3 could be shared on a secondary (noninterference) basis with the private sector.

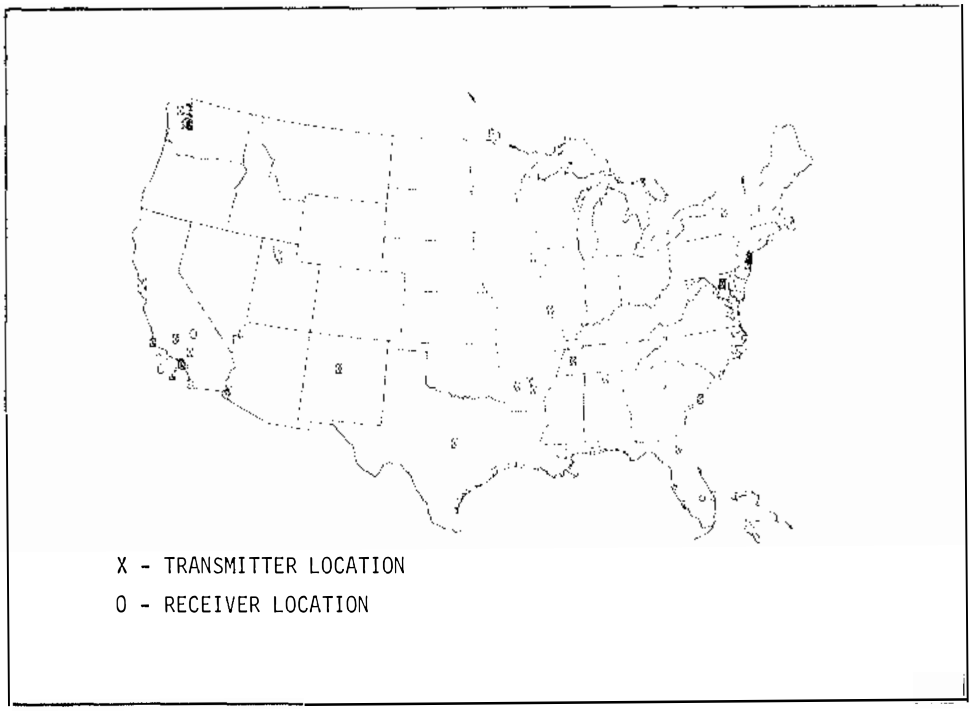


Figure 1-2. Transmitter and receiver locations for the 1350-1400 MHz band.

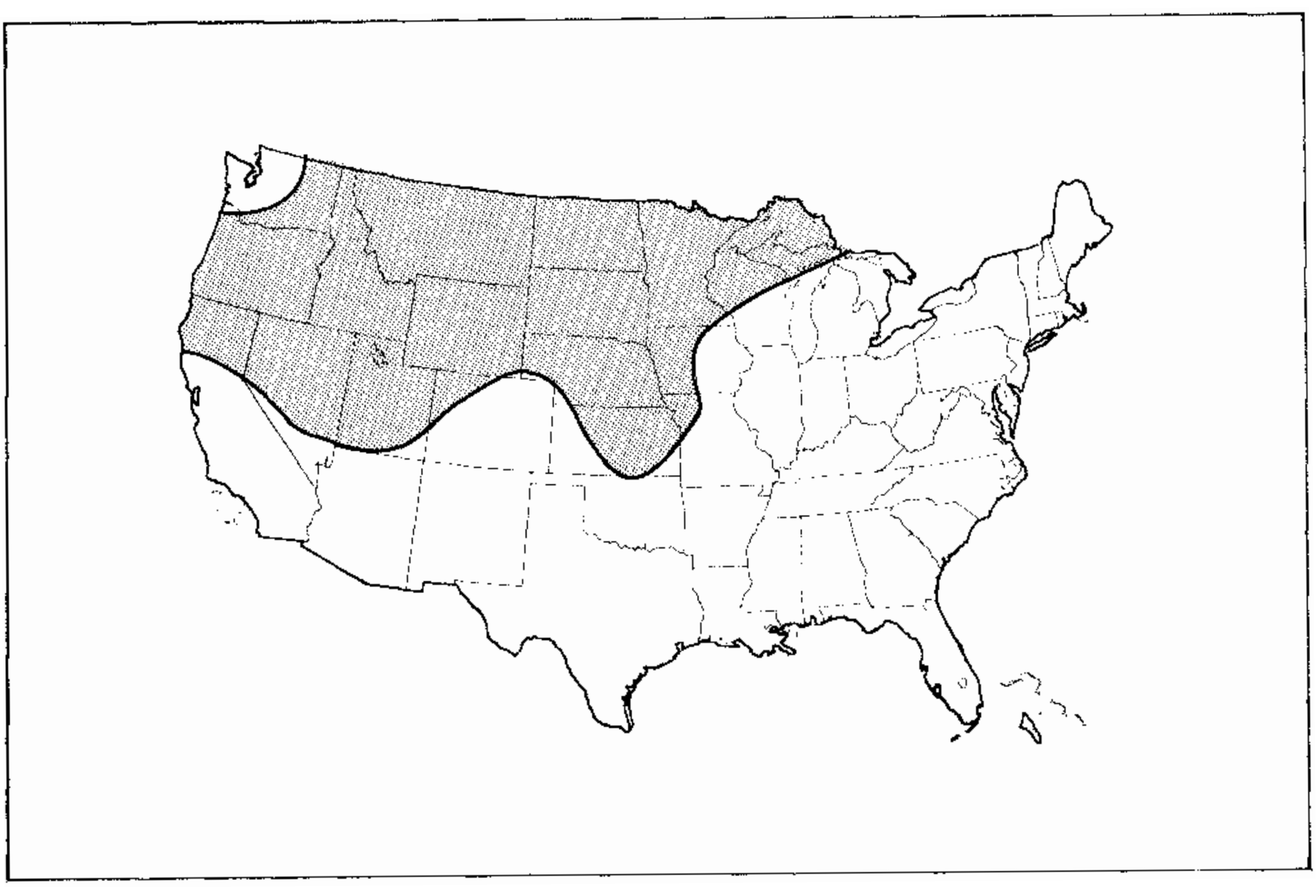


Figure 1-3. Geographic area (shaded) for possible sharing in the 1350-1400 MHz band.

SECTION 1.3 ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

NTIA in its role as frequency manager for the Federal Government is required to operate and maintain an instrumentation capability for performing spectrum measurements. The Radio Spectrum Measurement System (RSMS) is a computer-driven radio frequency (rf) measurement system in a mobile-home-style vehicle (Figure 1-4) that has been used by the Institute since 1973 in its spectrum measurement program. The program, in past years, included extensive measurements on general frequency band signal occupancy and emission spectra for particular transmitters. This year only a few measurements have been made, including:

- Land Mobile Radio (LMR) measurements in the Washington, DC, area
- ASR-8 radar emission spectra at Baltimore
- Measurements on Power Line Carriers (PLC) and Ground Wave Emergency Network (GWEN)
- Air Force radar system emission spectrum.

The first two measurements were made using the RSMS for a measurement system. The last two measurements were made using portable systems assembled for the particular measurements needed.

Measurement van operations were greatly de-emphasized this year to allow more effort to be committed to Measurement Van Development. The present RSMS was placed into operation by ITS in 1973 and has been used extensively each year since then. More recently, maintenance problems and an awareness of the advantages of newer systems led to an FY 82 decision to upgrade the RSMS with more modern instrumentation and computers. In FY 82, basic system design was accomplished for an upgraded RSMS. In FY 83, most of the major procurements were finished, equipment was received, construction was begun on most of the specialized measurement equipment, and the general outline of the software system was completed.

This year, in FY 84, the major emphasis has been in three areas: (1) the measurement system hardware has been completed, (2) the system software is being designed and tested, and (3) work on the vehicle systems has begun. The first field measurements are now scheduled for early in FY 85.

The RSMS Upgrade includes three main systems. A laboratory computer system in Boulder is being used for software development and will be used for data analysis and storage. In addition, this computer is being used to provide a general electronic office capability linking many terminals and shared resources. A second computer system will be used to operate the "radar" measurement system, while a third computer system will be used to operate the "LMR" receiver in the RSMS. Since independent systems are used for radar and LMR measurements, both systems can be operated simultaneously at high speed. In the event that one of the computers fails, the remaining computer can be connected to the system of greatest priority or shared between the two measurement systems to operate at lower speed.

Each of the three computer systems is identical, except that the laboratory system has a larger disc and many additional terminals. The computers have 512 K-bytes of memory, a graphics terminal with internal hardcopy capabilities, a 10 M-byte or a 28 M-byte hard disc, and a 1600 bpi 0.5 in magnetic tape unit for data storage and transport. Modems allow data to be transferred between Boulder, Annapolis, and the RSMS. In addition, these modems will allow the operation of the RSMS to be remotely monitored and controlled, which may substantially affect the amount of time personnel spend in the field. IEEE-488 interface cards provide a digital interface between the computers and the measurement systems, while DAC and ADC cards provide an analog interface to the measurement systems.

The radar receiver (Figure 1-5) allows measurement of signals in the 10 MHz-18 GHz range with processing bandwidth between 10 Hz and 30 MHz. It incorporates features to automatically ensure measurement quality control, including large-signal overload sensing and input attenuation autoranging, automatic tracking routines for the YIG preselectors, sensing contacts on many of the rf relays, and multiple amplitude calibration points using broadband noise diodes.

A block diagram of the radar system is shown in Figure 1-6. The system operates mostly as a standard multiconversion superheterodyne microwave receiver. The function of the spectrum analyzer is somewhat unconventional. In one mode, the intermediate frequency (IF) section of the spectrum analyzer is used to provide resolution bandwidths of 10 Hz-300 kHz. In another mode, the rf section of the spectrum analyzer is tuned across the 30 MHz wide, 478 MHz IF output. This permits measurements to be rapidly made at 1000 frequencies across the IF bandpass without retuning the measurement system front end, increasing the measurement speed as much as 20 times.

The radar measurement system contains special radar processing hardware, including peak hold detectors and pulse train separators. However, it was designed with enough flexibility to measure almost any signal in its frequency range. It is scheduled to be tested in the laboratory in January 1985.

The land mobile radio (LMR) system (Figure 1-7) is a second receiving system in the RSMS, which has been designed especially to make measurements on LMR signals and other similar narrow-band, channelized communication services. This system operates up to 1000 MHz with very high dynamic range (up to 130 dB without switching attenuation) and high rejection of signals on adjacent channels. Other LMR system design features include rectangular bandpass filters with bandwidths of 3 kHz, 7.5 kHz, 15 kHz, and 30 kHz and a measurement speed of 250 channels/second. Like the radar measurement system, it includes special hardware to

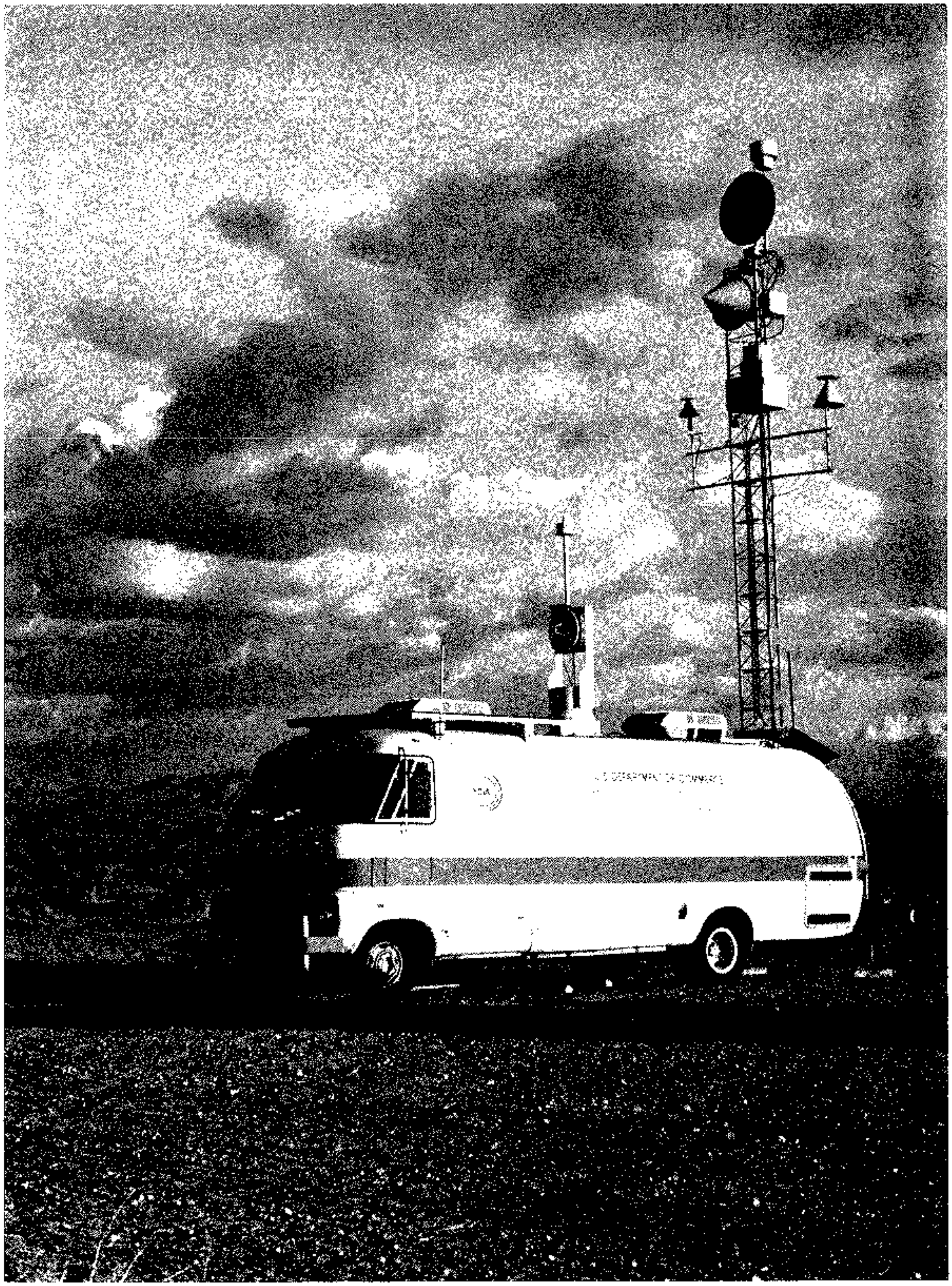


Figure 1-4. Exterior view of RSMS configured for site surveys.

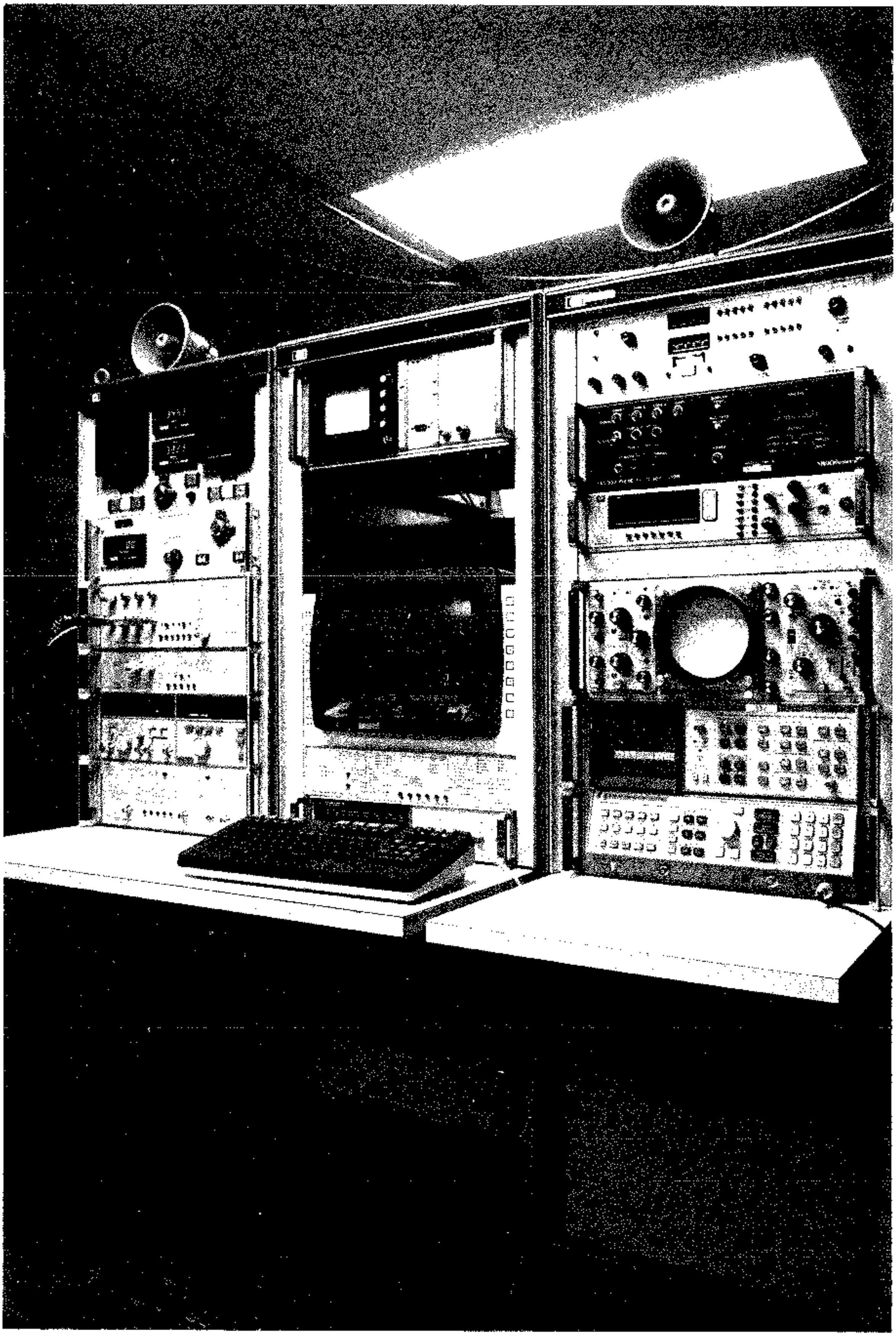


Figure 1-5. Upgraded RSMS radar measurement system (configured as three racks).

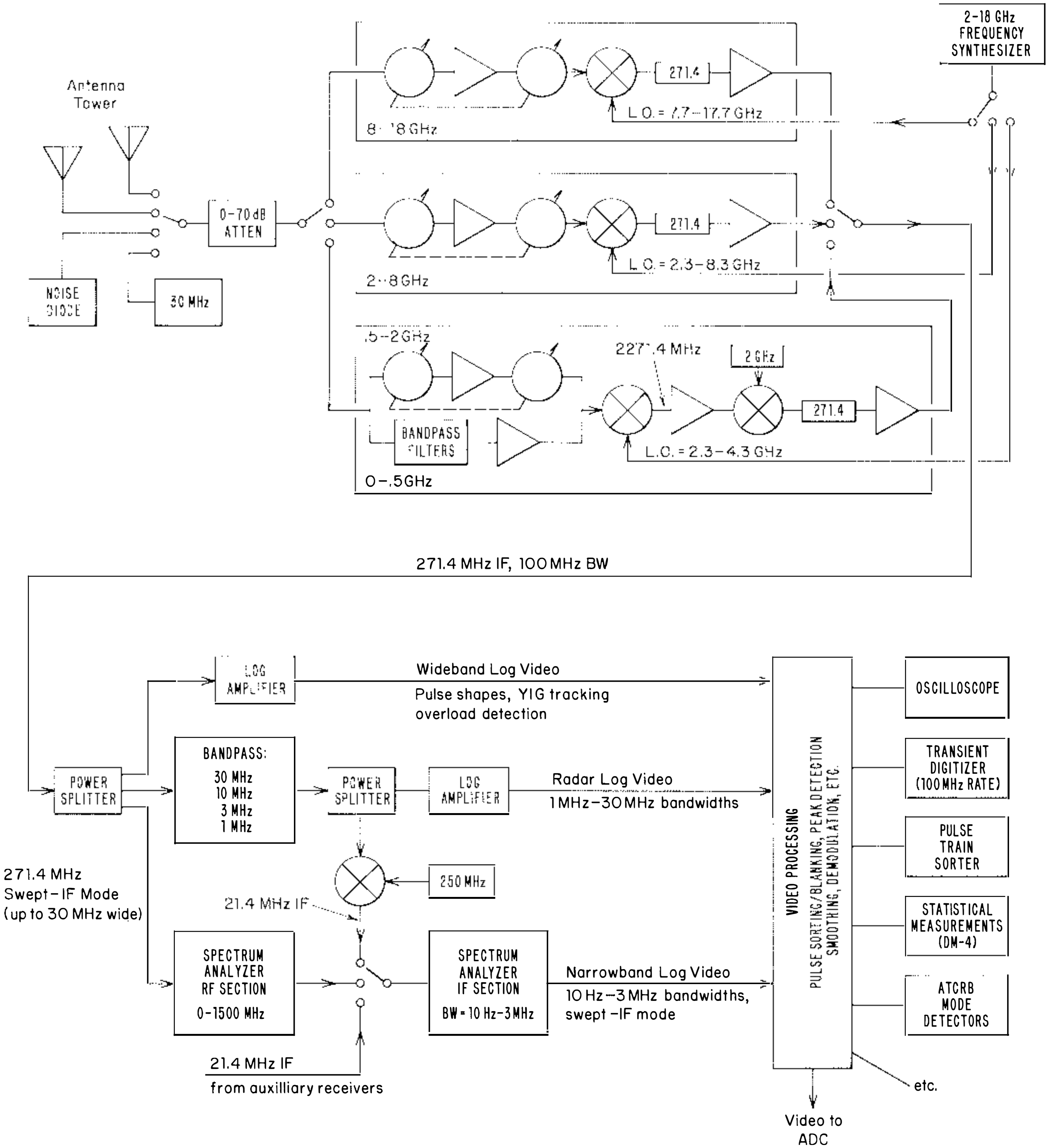


Figure 1-6. Block diagram of upgraded RSMS radar measurement system.

Figure 1-7. Upgraded LMR measurement system (configured as one rack and terminal).

detect possible overload conditions that might produce misleading information.

The left hand graph of Figure 1-8 shows the logarithmic amplifier response over a 120 dB dynamic range. An additional 10 dB range is available at the upper end to give additional protection against saturation and intermodulation, but is not calibrated. The right-hand graph shows an expanded view of the logarithmic amplifier ripples, which are calibrated out in 1 dB steps.

A block diagram of the antenna system for the radar measurement system is shown in Figure 1-9. The LMR antenna system is simpler, but follows the same design philosophy. This configuration was selected to allow easy modification as needed for specific experiments, as well as permanent antennas for many types of routine measurements. Four sets of cavity-backed spiral (CBS) antennas provide reception in the 1-12 GHz and 2-18 GHz ranges, using right-hand and left-hand circular polarization. PIN-diode switches on two of these sets allow rapid alternation between antennas aimed 90 deg apart, providing the basis for an automatic direction-finding capability.

For maximum sensitivity, a set of tower-top preamplifiers can be switched in for the 0.5-18 GHz range. If strong local signals do not permit the tower-top preamplifiers to be used, low-loss coaxial lines and a double-ridged waveguide bring the signals from the antenna tower with a minimum of signal loss. Broadband noise diodes are located at several locations throughout the antenna system, providing a known amplitude reference source for overall system calibration out to the antenna terminals.

We believe that the upgraded RSMS measurement systems will provide substantial advantages in field measurements, in data quality, and in the cost of field measurements. We are eagerly waiting to see how well these improvements work in actual operational deployment of the RSMS.

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

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

The Institute was also tasked to provide a Factory Acceptance Test Plan, Method, and Procedure that will be conducted by the Government to evaluate operational compliance with production requirements prior to field operational acceptance tests. This factory test was conducted on the first and second production units using the threat/ECM simulator designed and fabricated by ITS. The results of these tests, which were conducted and analyzed by ITS personnel, indicated some shortcomings in the production unit. One example was the discovery of the erroneous value of modulation depth being calculated. Another example was the discovery of errors in the formatting of the output data. Although many of the deficiencies in the MSR-T4 have been corrected since this testing was concluded, some still remain to be resolved.

Other technical support efforts by ITS for the AN/MSR-T4 procurement have included: (1) the analysis of the results of factory acceptance tests on units one and two, (2) the analysis of the results of factory system tests on units one and two, (3) acting as Government test director for the Computer Program Configuration Item test, and (4) the analysis of proposed changes to hardware and software of the system.

The Air Force also has tasked ITS to analyze the test results from La Junta and Nellis operational field tests and advise the procuring agency regarding compliance with specification requirements. The Air Force also requested that ITS participate in a series of Technical Interchange Meetings (TIM). The purpose of these meetings will be to develop plans for system enhancements to meet the recently developed requirements of the Air Force.

SECTION 1.4 EM WAVE TRANSMISSION

The radio wave portion of the electromagnetic spectrum may be adversely affected by propagation conditions in the medium constituted by the Earth's surface, the atmosphere, and the ionosphere. These conditions may be permanent or time varying (seasonal or sporadic), and the severity of the adverse effects is frequency dependent. The purpose of the EM Wave Transmission Program is to study conditions in the transmission medium and provide models and prediction methods for cost and spectrum efficient radio system design.

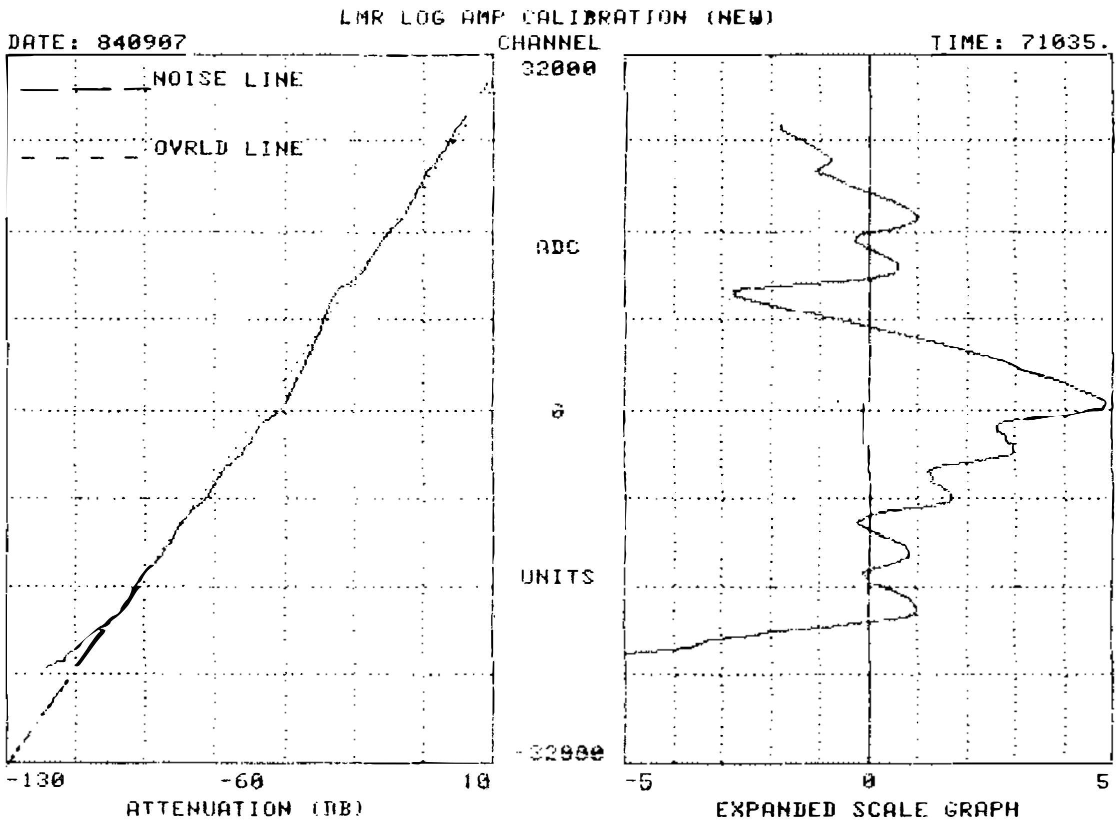


Figure 1-8. LMR logarithmic amplifier characteristics.

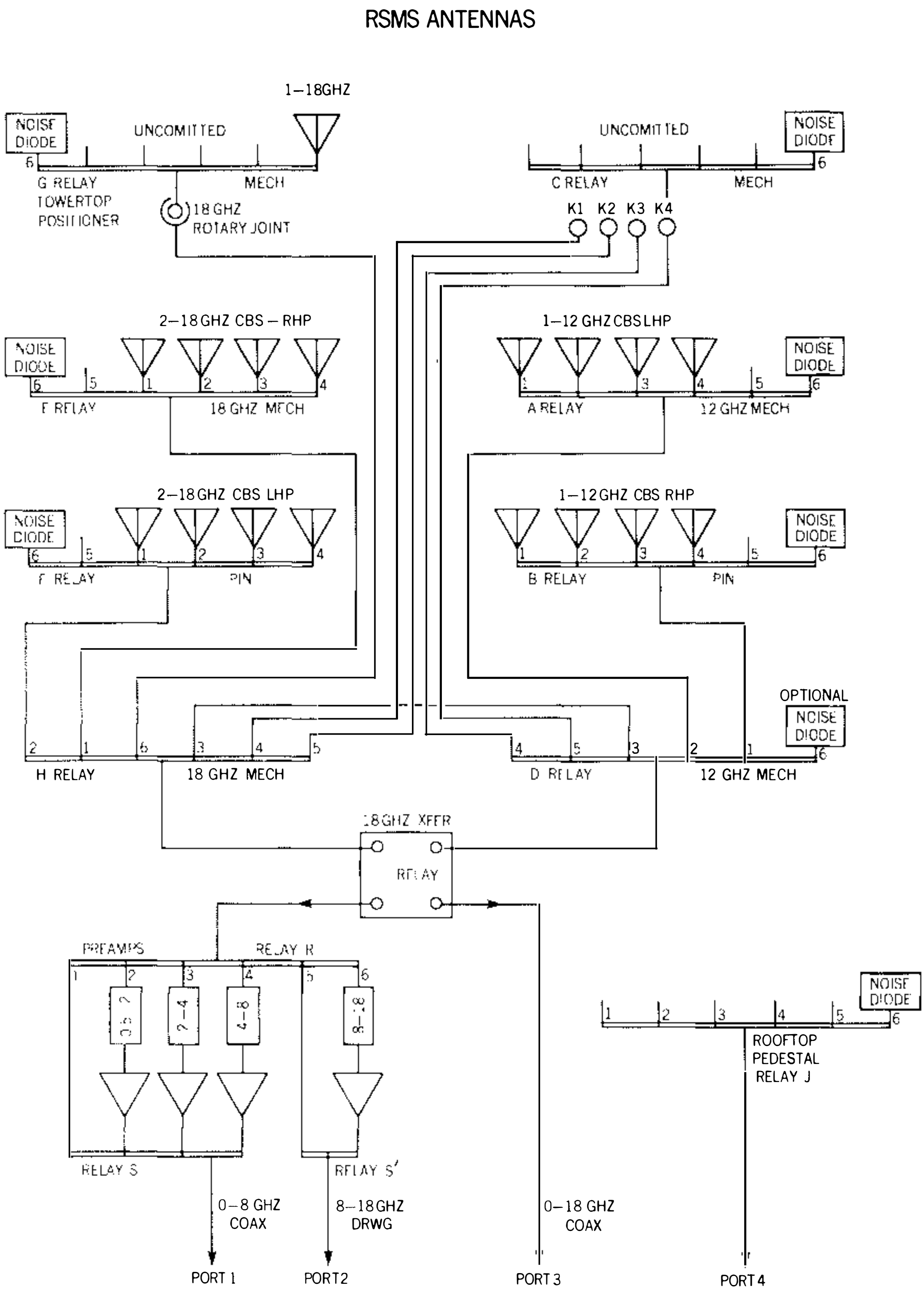


Figure 1-9. Antenna system block diagram.

Some of the specific conditions or phenomena which are related to radio wave propagation and were studied in the program this year are:

- o scattering by vegetation, terrain multipath, propagation over sea water, ground waves, diffraction
- o absorption by atmospheric gases, attenuation and depolarization by rain, refractivity and ducting in the atmosphere, electromagnetic noise
- o scintillation and penetration losses in the ionosphere, maximum usable frequencies and the effects of structural irregularities in the ionosphere, solar and geomagnetic field effects.

1.4.1 Properties of the Radio Wave Transmission Medium

Properties of the radio wave transmission medium determined empirically or by theoretical analysis and its effects on telecommunication systems are reported in this section.

In the project devoted toward Experimental Determination of Millimeter Wave System Effects, a mobile millimeter wave probe has been developed to be used as a diagnostic tool to evaluate the performance of links or networks in the 10 to 100 GHz band. This diagnostic probe is unique in that a rapid succession of channel impulse response measurements (up to 10 per min) can be transformed into the channel transfer function which fully describes the channel (hardware and propagation medium). One objective is to provide a link designer or a user with hardware performance criteria and system fade margin information on an atmospheric channel to predict the average number of hours per year a specified minimum link performance will be exceeded. Another objective is to perform measurements to characterize transmission paths with obstructions such as terrain, trees, man-made structures, etc. in terms of propagation modes resulting from refraction, diffraction, reflection, and/or absorption. The application for paths in this environment includes establishing non-line-of-sight communication links, remote sensing probes, terminal camouflage techniques, radiation level predictions, and covert operations.

The desirable feature of millimeter waves is the inherent bandwidth capability of 2000 MHz or more. Systems developed in the United States and Japan are already approaching these bandwidths. Problems encountered with very wide bandwidth millimeter wave channels through the atmosphere are much more complex than channels with narrow bandwidths and require a more thorough investigation.

The millimeter wave diagnostic probe (NTIA Report 83-128) gives emphasis to the application of high data rate digital links where the received signal characteristics are complicated by refraction, reflection, and/or diffraction, as well as attenuation enroute from the transmitter.

The primary instrumentation consists of a 30.3 GHz, 1000 Mb/s coherent QPSK or 500 Mb/s coherent PSK transmitter-modulator, a 2 GHz bandwidth receiver-demodulator with a 5.5 dB double sideband noise figure, and a baseband processor bit-error-rate (BER) detector. Built into this digital system is the capability of selecting a channel impulse response mode using cross-correlation of pseudorandom binary words that permit a 1/2 ns 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 that can be translated in terms of BER for path lengths up to at least 50 km. At 50 km, the excess signal-to-noise ratio is 20 dB using .91-m (3-ft) parabolic reflectors, for example, or 32 dB if 1.82-m (6-ft) reflectors are used.

The diagnostic probe was placed on a 27.2 km path along the Colorado front range (near Boulder) where the climate is characterized as not humid, but one where convective storms produce locally very high rain rates. Figures 1-10 and 1-11 display plots of bit-error-rate (BER) on the 30.36 GHz, 500 Mb/s channel with an associated received signal level (RSL) channel, the RSL of a narrow bandwidth 28.8 GHz channel, the RSL of both a vertically and a horizontally polarized (antenna) narrow bandwidth channel at 11.4 GHz, and a rain-rate channel. The data in Figure 1-10 show a typical 24-hour period in the late winter, and Figure 1-11 show a similar period during the summer. Significant in this comparison are the increased scintillation (signal fluctuation) levels and greater fade depths during the summer. These are caused by atmospheric turbulence due to convective heating and increased ray bending which result from nighttime atmospheric layering. The BER remains essentially constant with only a few errors occurring, seen by occasional dots on the plot, most of which were caused by power line transients rather than by the atmospheric path. No rain occurred on these days as indicated by the rain-rate channel. In Figure 1-12, a 96.16 GHz channel is displayed, in place of the 28.8 GHz channel, over the same path and in this 2-hour time series an example of atmospheric multipath fading is seen. Identifying these fades as primarily due to atmospheric multipath is possible because the fade rates, through constructive and destructive phase interference, are directly proportional to the rf signal ratios as a result of the fully phase coherent diagnostic system. The atmospheric fade is most pronounced at around 0200 h on the time series plot. Fades that occur simultaneously in all rf channels are a result of ray defocusing from an atmospheric gradient that bends rays away from the receiving antenna. Some of the signal variations in Figure 1-12 are defocusing, but a better example of focusing and defocusing is seen in Figure 1-13 around 0545 h. Note that some increase in BER occurs from multipath fading where channel distortion consists due to resulting intersymbol interference. However, most increases are due to the

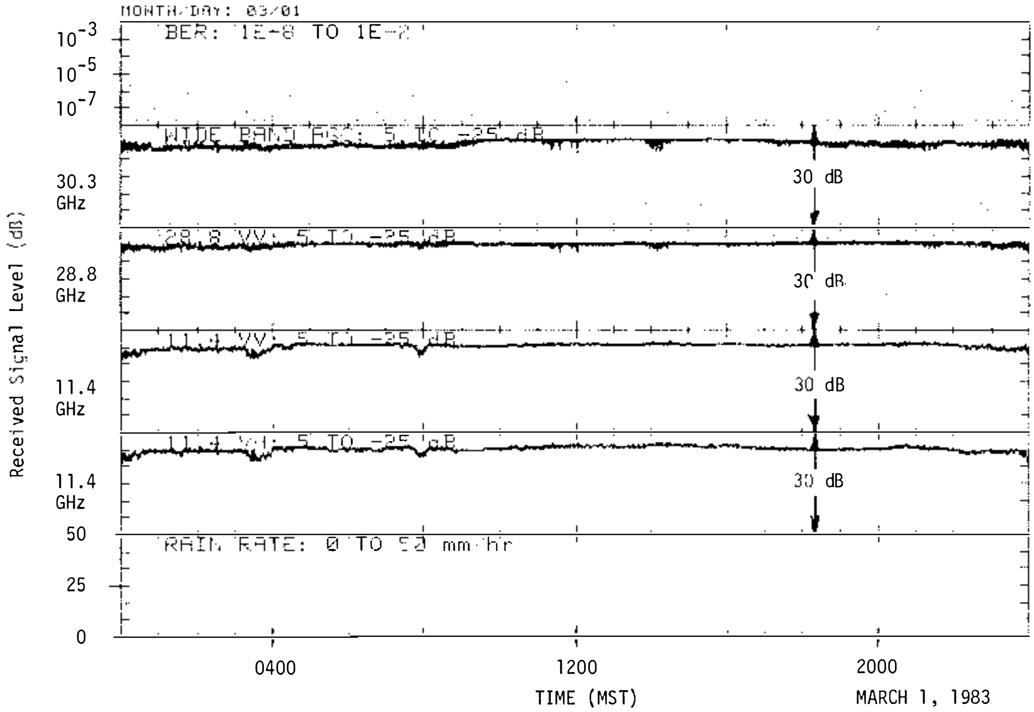


Figure 1-10. Typical winter record from the 27.2 km path showing bit error rates, received signal levels (11.4, 28.8, and 30.3 GHz), and rain rate.

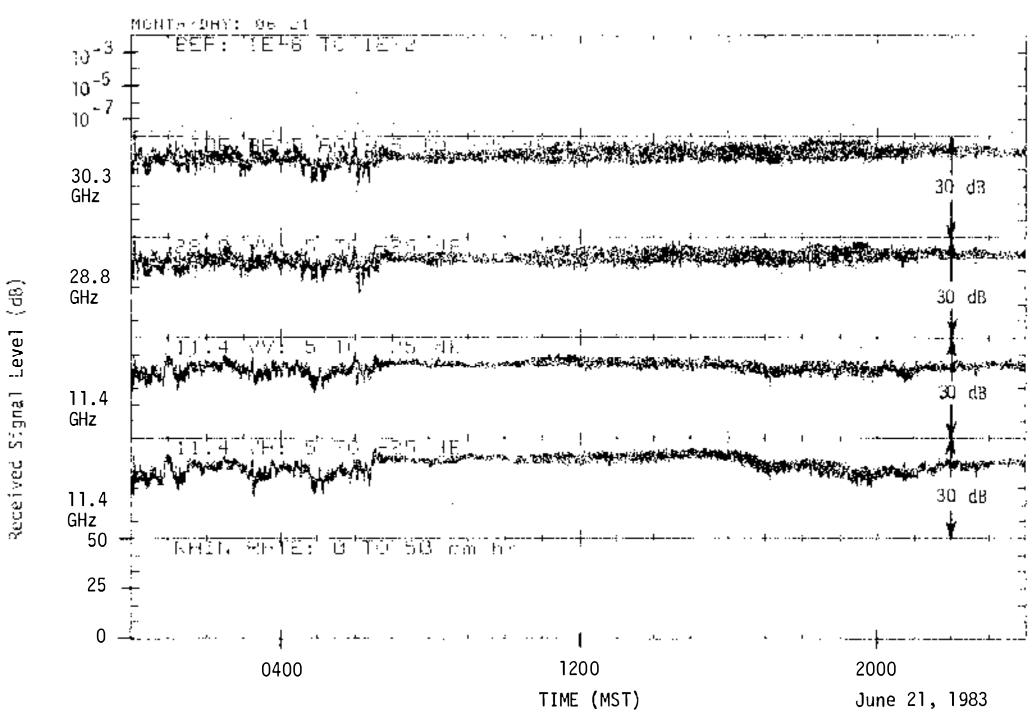


Figure 1-11. Typical summer record from the 27.2 km path showing bit error rates, received signal levels (11.4, 28.8, and 30.3 GHz), and rain rate.

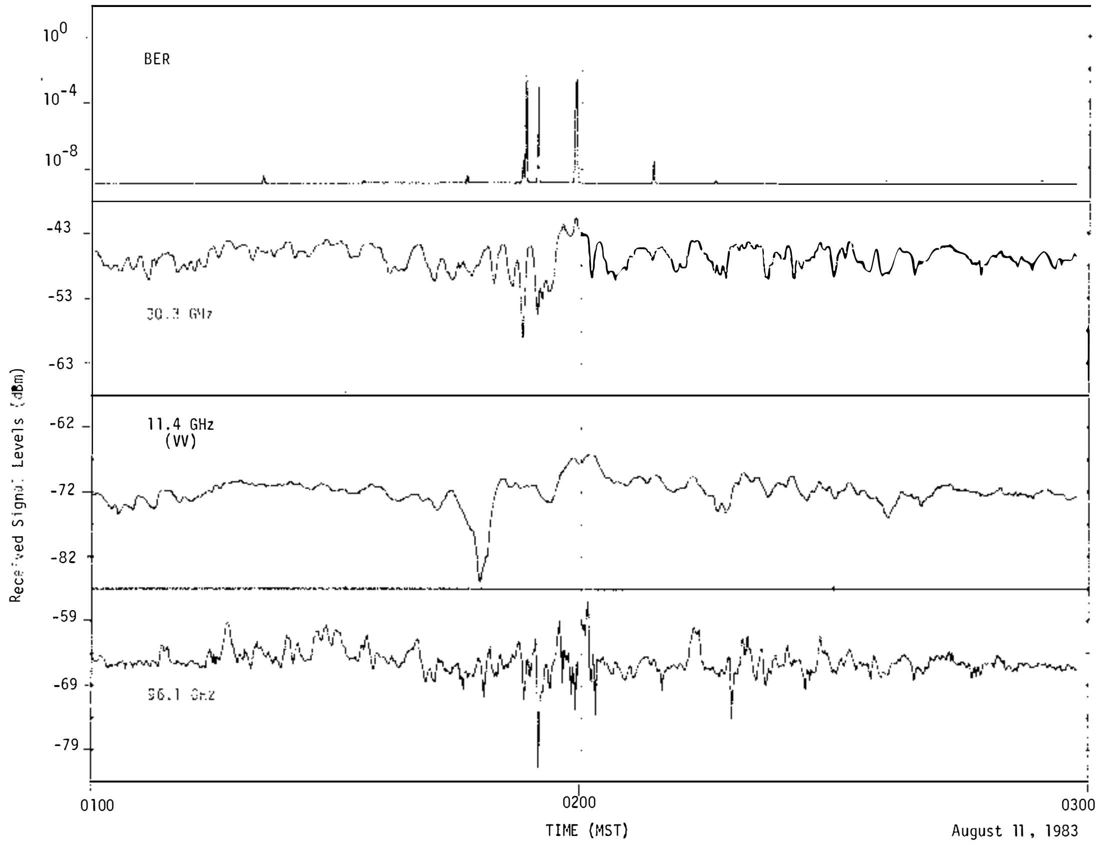


Figure 1-12. Time series during period of fading on the 27.2 km path.

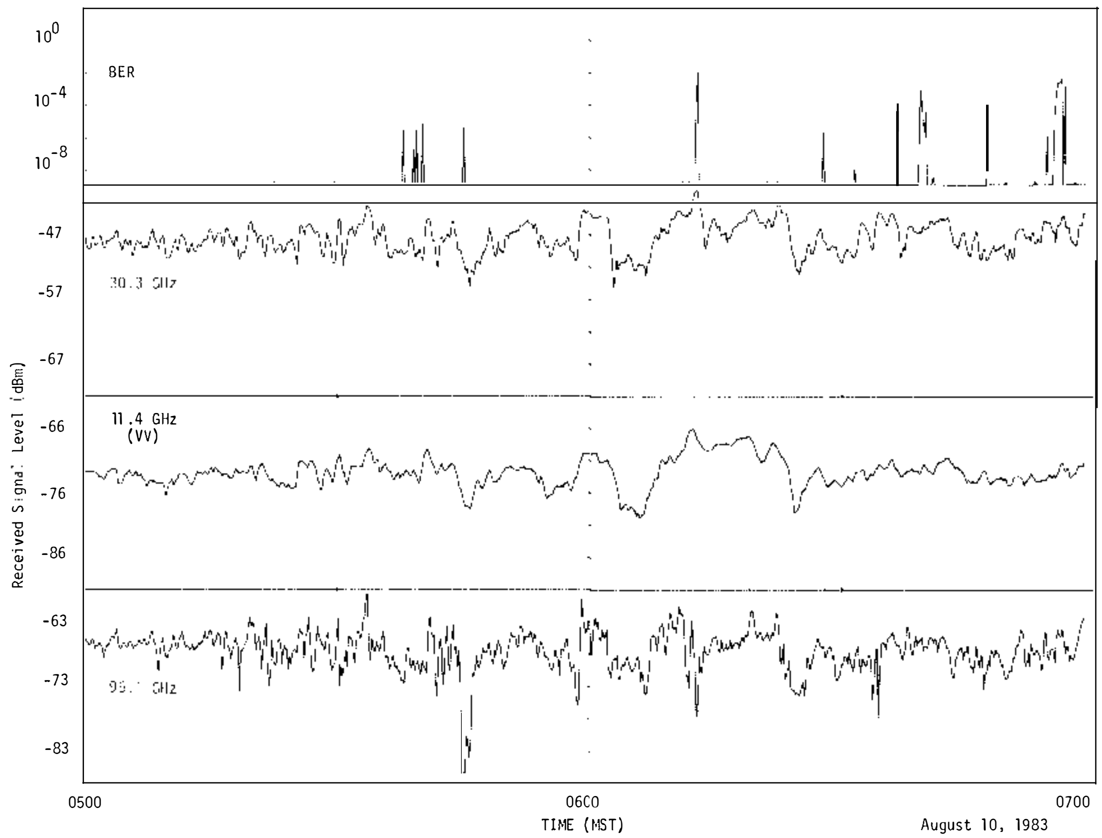


Figure 1-13. Time series during period of fading on the 27.2 km path.

combination of reduced signal-to-noise ratio and distortion. It is anticipated that fades caused by refractive ray bending will be more severe in humid climates and in areas further removed from the mountains because the atmosphere near the mountains is mixed by the downslope air movements.

For the same 27.4 km path, the effects of snow, fog, and rain were observed. A heavy, wet, snowstorm (temperatures at or above freezing) produced slightly greater signal attenuations than for a heavy, dry, snowstorm; a maximum of 5 dB in total loss was recorded at 30.3 GHz. The 96.1 GHz channel showed a sizable increase in absorption due to the greater water vapor content, and to date the loss due to each event has not been separated. Lower frequency channels experienced less loss with a maximum loss ratio of about 2 to 1 for the highest to the lowest frequency. No BER change was noted as a result of time delay scattering during snow. Fog attenuation was somewhat higher than expected being about 5 dB at 30.3 GHz for a maximum suspended water droplet content estimated at 0.5 gm/m^3, or about 100 m daytime visibility, which occurred over at least two-thirds of the path. Numerous rains permitted observations of relative drop-size distribution for a variety of seasons and storm types. An estimate of raindrop-size distribution can be obtained by comparing the attenuation ratios for the frequencies spanned (approximately 10 to 100 GHz). In order to develop rain models, drop-size distribution statistics are needed, and the use of 96.1 GHz has added an indicator of smaller drop-size effects that had not been previously available to verify theoretical distribution curves. Figure 1-14 shows results of a major rain event that occurred August 21, 1983. The reason that signal attenuation and rain rate are not correlated is that the rain-rate gauge is located at the receiver terminal. It was observed that the rain extended to both ends of the path, but the rate varied along the 27.4 km path. It is obvious that the ratios of attenuation vary between link frequencies, and this feature relates to drop-size distribution during the storms. A scatter plot comparison of the ratio of received signal levels between the 11.4 and 28.8 GHz channels is shown in Figure 1-15. The same comparison is made between 28.8 and 96.1 GHz in Figure 1-16. Data in this form are used to calculate drop-size distribution. The top curve in Figure 1-14 indicates the change in bit error rate for the 30.3 GHz 500 Mb/s channel as a result of rain attenuation.

Recent studies by ITS have indicated that if certain easily achieved design criteria are met, practical narrow-bandwidth transmission links would have few problems in climates similar to the climate of the Denver/Boulder, CO, area. Basically, this entails providing adequate fade margin for line-of-sight links up to 50 km in length at frequencies up to 100 GHz, excluding the molecular oxygen absorption band around 60 GHz. At 60 GHz, the absorption is about 15 dB/km at sea level and about 12 dB/km at 1500 m (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.

As the frequency of the channel through the atmosphere increases, the loss due to water vapor also increases. The actual attenuation produced by water vapor has been an uncertainty in models of the atmosphere at millimeter wavelengths. With the on-line computer and the meteorological data collected, it has been possible to precisely measure water vapor absorption, which should allow the model to be considerably improved up to 100 GHz. Water vapor absorption as high as 20 dB was seen on the 27.4 km path. A plot of measured water vapor pressure and total absorption is shown in Figure 1-17. NTIA Report 84-149 describes and analyzes the most recent observations taken using the millimeter wave diagnostic probe.

Specific efforts were directed toward Water Vapor Millimeter Wave Spectroscopy. Millimeter-wave water vapor attenuation rates in atmospheric air are expressed by

$$\alpha = 0.182\ f\ N''(f)\ \ dB/km\ ,$$

where the frequency-dependent absorption term N"(f) in ppm arises from the molecular spectra of H_2O and O_2 and the frequency f is in units of GHz. There has been a long-standing discrepancy between theoretical spectroscopic predictions and experimental α data obtained from both laboratory and field measurements. Marked differences occur in the window ranges located around 35, 90, 140, and 220 GHz. Since excess factors between 2 and 5 are involved, it has been speculated that unidentified absorbers related to H_2O (dimers, clusters, etc.) might be involved. Results for α from controlled laboratory studies have been reported [Liebe (1984), The atmospheric water vapor continuum below 300 GHz, Int'l. J. IR & MM Waves 5(2), 207-227], which help to clarify the water vapor excess problem.

The laboratory experiment was prepared to measure attenuation rates (α) under conditions reaching water vapor saturation. Details are given in the paper referenced above. Various anomalous absorption behaviors (i.e., high rates, extreme temperature dependences, hystereses in pressure, and temperature cycles) have been encountered during the studies. They could be identified as being instrumental, and they disappeared when condensation effects on the millimeter-wave active parts of the spectrometer were avoided. Several hydrophobic surface treatments were investigated to facilitate high humidity (relative and absolute) experiments with the spectrometer. Seventeen different cases were tested for absorption and desorption behavior of a vacuum chamber, employing various combinations of metal surfaces (stainless steel, aluminum, brass), coating materials (electropolish, gold plate, Teflon, HMDS, silicone, lacquer), and surface-to-volume ratios (0.3 to 1.7 cm^{-1}). Test

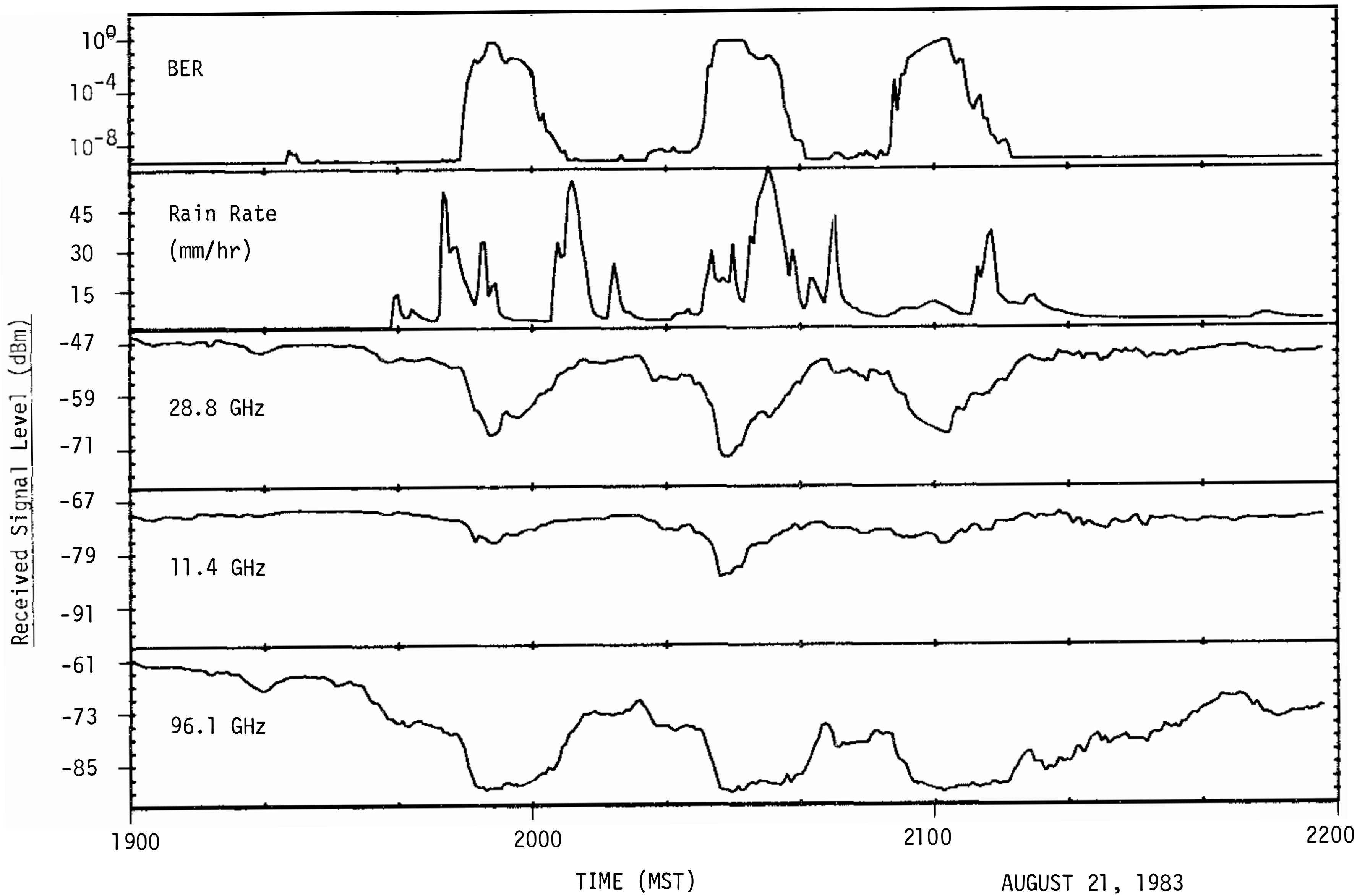


Figure 1-14. A plot of received signal levels, BER, and rain rate recorded on the 27.4 km path during a major rainstorm on August 21, 1983.

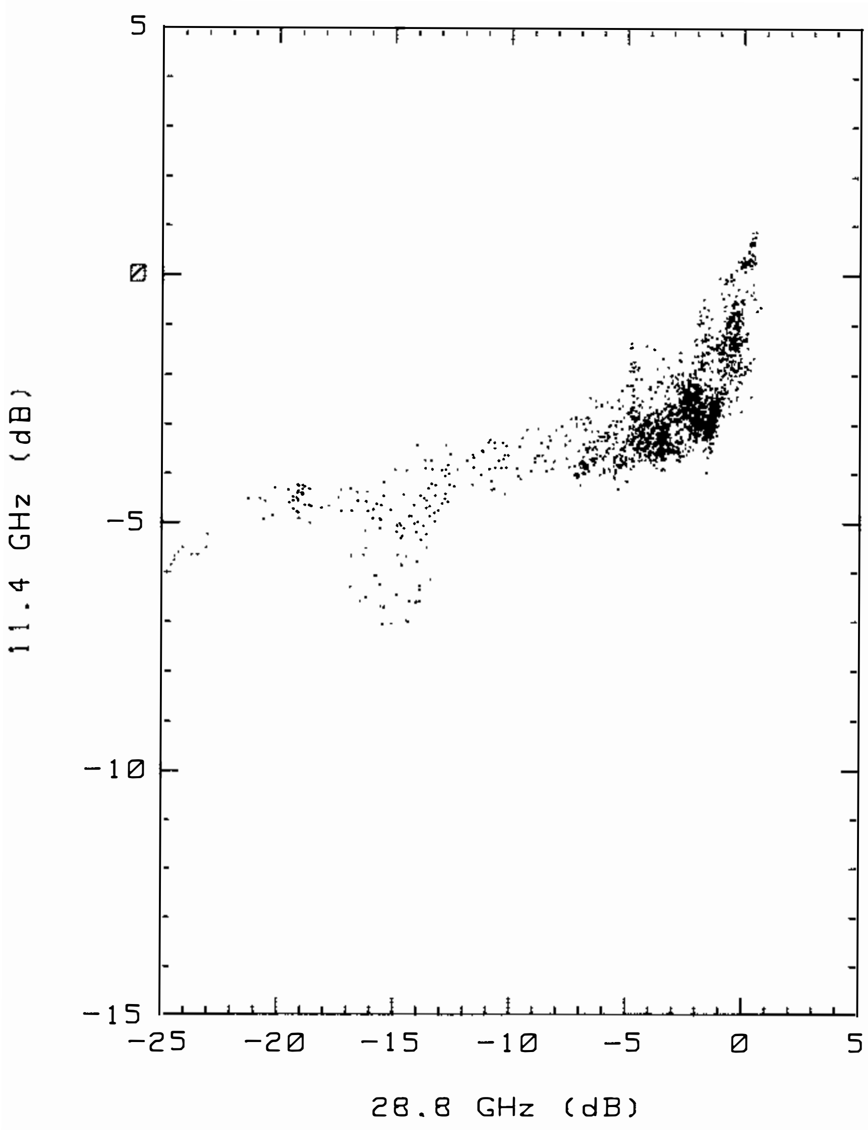


Figure 1-15. A scatter plot comparison of the ratio of received signal levels between the 11.4 and 28.8 GHz channels during rain on the 27.4 km path recorded September 19, 1983.

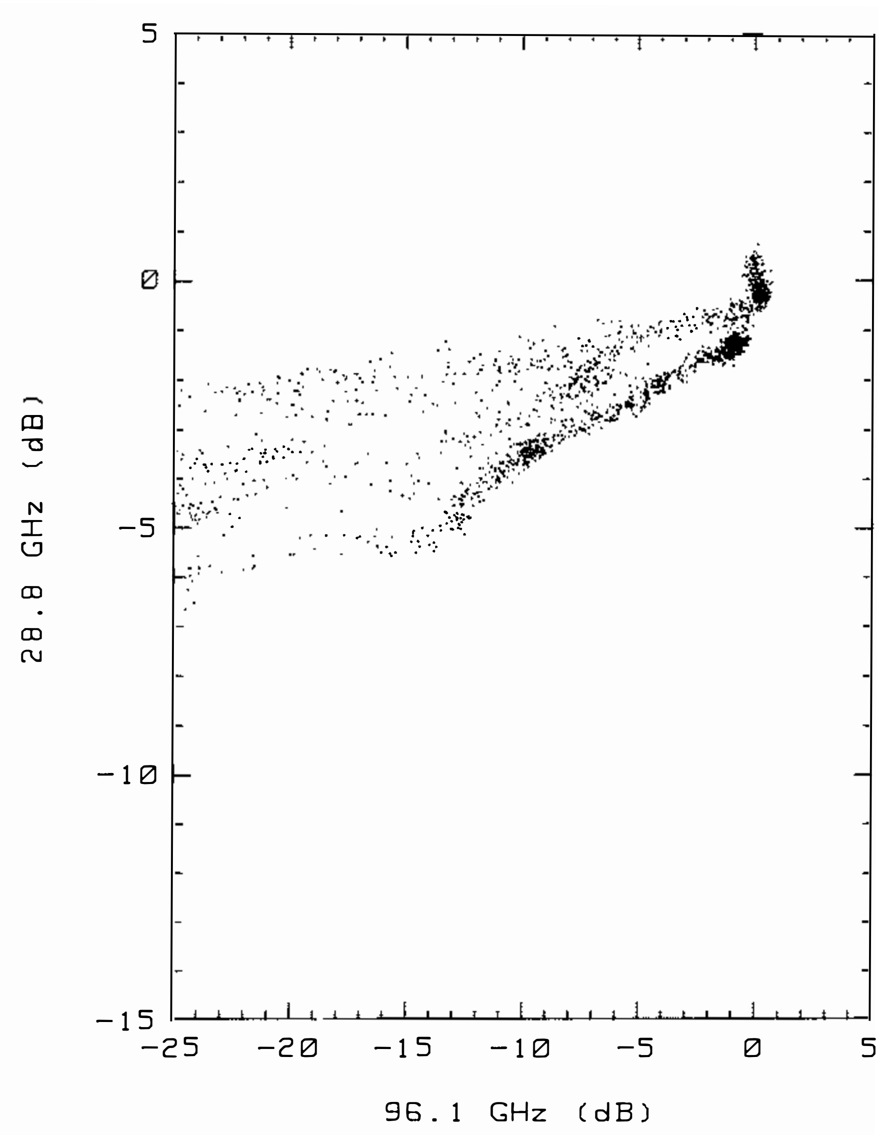


Figure 1-16. A scatter plot comparison of the ratio of received signal levels between the 28.8 and 96.1 GHz channels during rain on the 27.4 km path recorded September 19, 1983.

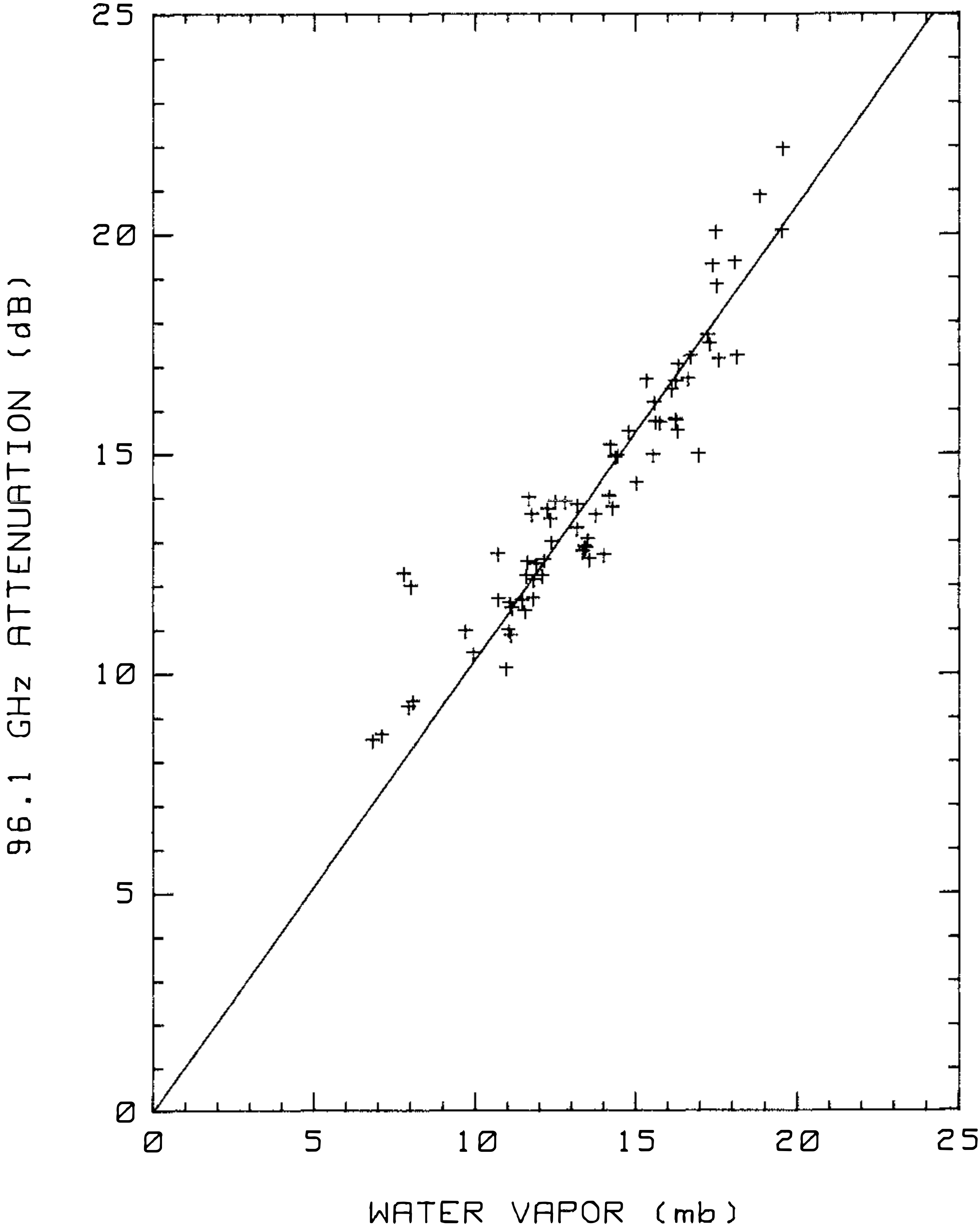


Figure 1-17. A plot of measured water vapor pressure versus total absorption at 96.1 GHz from data recorded on the 27.4 km path.

procedure and data are described together with a brief discussion of the findings in an article to appear in the October 1984 issue of Review of Scientific Instruments.

Uncorrupted attenuation results obtained at 138 GHz display in addition to air-broadening ($\propto ep$) a strong self-broadening component ($\propto e^2$). Pressure scans of the attenuation rate α were taken under conditions of relative humidity, RH=80 to 100 percent at two temperatures, 300° and 282° K. Nitrogen was used to simulate dry air. The data led to a moist air continuum spectrum

$$N_c'' = f(1.40\ ep\theta^{2.5} + 54.1\ e^2\theta^{5.5})\ 10^{-6}\ \text{ppm},$$

where vapor (e) and air (p) pressures are in kPa = 10 mb and θ = 300/T. Based upon this result, a practical atmospheric millimeter wave propagation model (MPM) was formulated that predicts attenuation, delay, and noise properties of moist air over a frequency range of 1 to 1000 GHz and a height range of 0 to 100 km. The main spectroscopic data base consists of 48 O_2 and 30 H_2O local absorption lines complemented by continuum spectra for dry air and water vapor. A typical example of the predictive capability of the MPM is exhibited in Figure 1-18.

A theoretical assessment of water vapor attenuation below 1 THz was accomplished on the basis of the rotational H_2O spectrum consisting of 2280 lines up to 30 THz. By subtracting all line contributions below 1 THz, the resulting difference was defined to be the continuum spectrum N_c''. Six line shapes proposed for pressure-broadening were applied to the full H_2O spectrum, leading to four different spectra N_c''. However, none of these is capable of describing the available experimental evidence in a satisfactory manner.

Two shortcomings of the MPM lie (1) in the missing confirmation for a physical basis of water vapor continuum absorption and (2) in an oversimplified treatment of atmospheric conditions entailing reduced optical visibilities at high relative humidities due to haze. The continuum N_c'' accounts for the so-called "excess absorption" and has been tentatively identified to be a far-wing response of the H_2O spectrum above 1 THz. Parametric studies are proposed to reap the benefits obtainable from the high humidity performance of the unique ITS spectrometer that has been developed, overcoming a great deal of difficulties. Experimental variables are frequency, pressure, temperature, humidity, aerosol composition, and concentration. In preparation for these studies, a phase-coherent 220 GHz frequency source has been developed with excellent performance characteristics--an example of which is displayed in Figure 1-19.

It is well known that vegetation such as leaves may scatter, absorb, or diffract radio waves. A Vegetation Studies project was conducted for the U.S. Army with emphasis on determining signal properties as a function of foliage depth in order to develop the best theoretical model for predicting link performance. In forested areas, the density of foliage was found to be nonuniform and difficult to describe in terms of depth. To remove the density variable, an evenly planted orchard would best permit a controlled measurement. Because of the tree size, foliage density, and humid climate, a pecan orchard near Wichita Falls, TX, was selected as best suited to the measurement requirements.

The first series of measurements was completed in April 1982 when the trees were in a defoliated state. In August, a second measurement series was conducted that repeated the April measurements to determine the added losses and propagation differences that occurred with leaves present. The results of these measurements are contained in U.S. Army Report CECOM 83-2 entitled "Vegetation Loss Measurements at 9.6, 28.8, and 57.6 GHz Through a Pecan Orchard in Texas." Figure 1-20 shows the vegetation loss per tree in decibels relative to the number of trees (no leaves and with leaves) on the path as a function of frequency at a 4-m 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-m height.

Because of the unusual propagation mode that occurred when diffraction scattering appeared to become dominant, directional properties of the arriving signals are most interesting. A series of receiving antenna azimuthal scans (beamwidths 4° at 9.6 GHz and 1° at 28.8 and 57.6 GHz) are presented for all three frequencies at 6-m terminal heights, for depths of 1, 3, 8, and 11 trees with leaves present, as shown in Figure 1-21. An unobstructed reference scan is superimposed on each data scan. These scans show a rapid loss of signal directivity, with increasing tree depth. This suggests that after only three trees the energy is scattered nearly equally from all the trees within the 30° scan.

Future work in this area is expected to entail the use of the millimeter wave diagnostic probe in the pecan orchard to better understand the diffraction paths by measuring time-delay spread components. Similar measurements to those in the pecan orchard are anticipated for conifer trees.

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

Measurements divided into two phases are in progress to study propagation characteristics at millimeter wavelengths in an urban-suburban environment: (1) signal loss on paths obstructed by a variety of structures found in the urban-suburban areas and (2) impulse response (time-delay spread) signatures for both line-of-sight (LOS) and non-LOS paths in

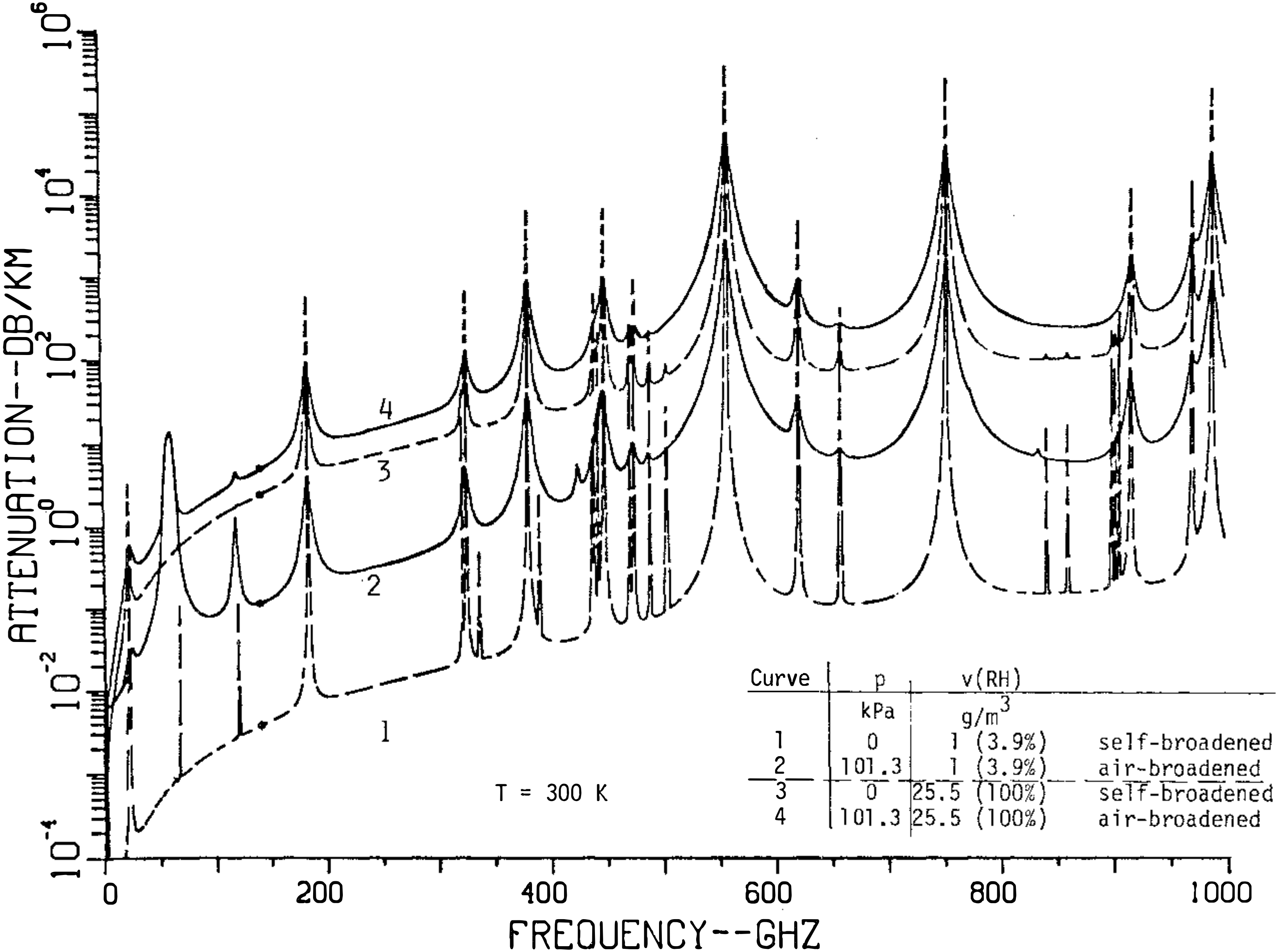
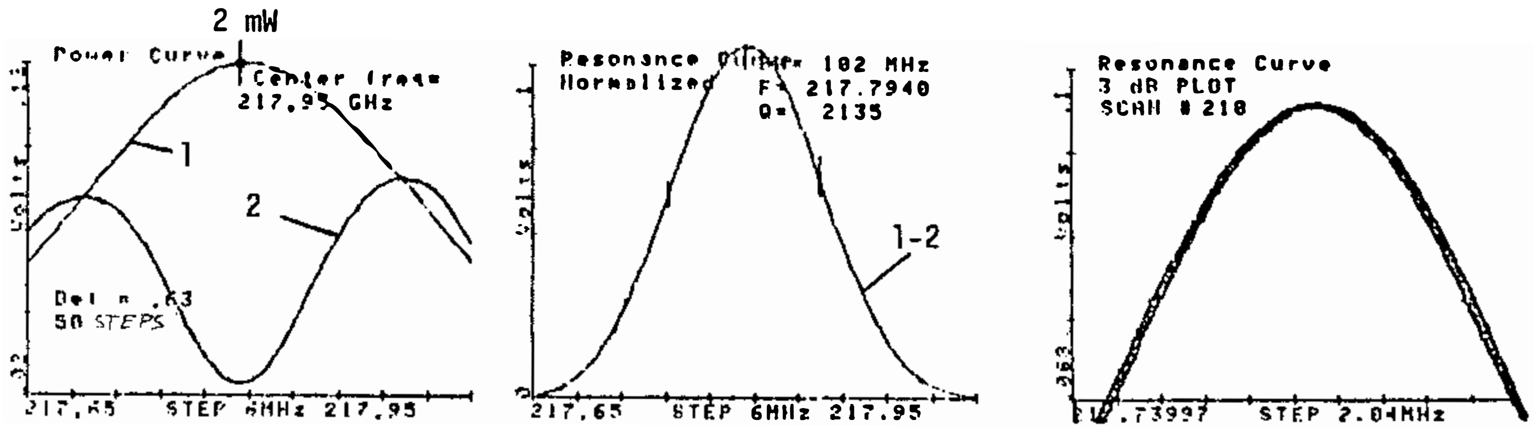


Figure 1-18. Predicted millimeter and submillimeter wave (1-1000 GHz) attenuation spectrum of pure water vapor and of moist air under sea level conditions.

220 GHz SYNTHESIZER



MENU:

Set klystron for
PEAK of power curve
DE-TUNE CAVITY
and press CONT
Power Curve
Center frequency 72.603
Multiplier= 3
Amplitude= .025164
Span set at +/- 500 MHz
Y axis (VOLTS)
MIN-.07 MAX .03
Number of samples= 50
Detector 3 dB factor= .63
CHANGE (Y/N)?

Tune cavity to
RESONANCE
and press CONT

Figure 1-19. Example of power curves from the MMW synthesizer:
(a) stepped-frequency mode under program control through wave meter centered at 217.794 GHz
(b) reduced resonance curve
(c) retraces of the resonance center for 210 (=3.5 h) scans each 50 steps.

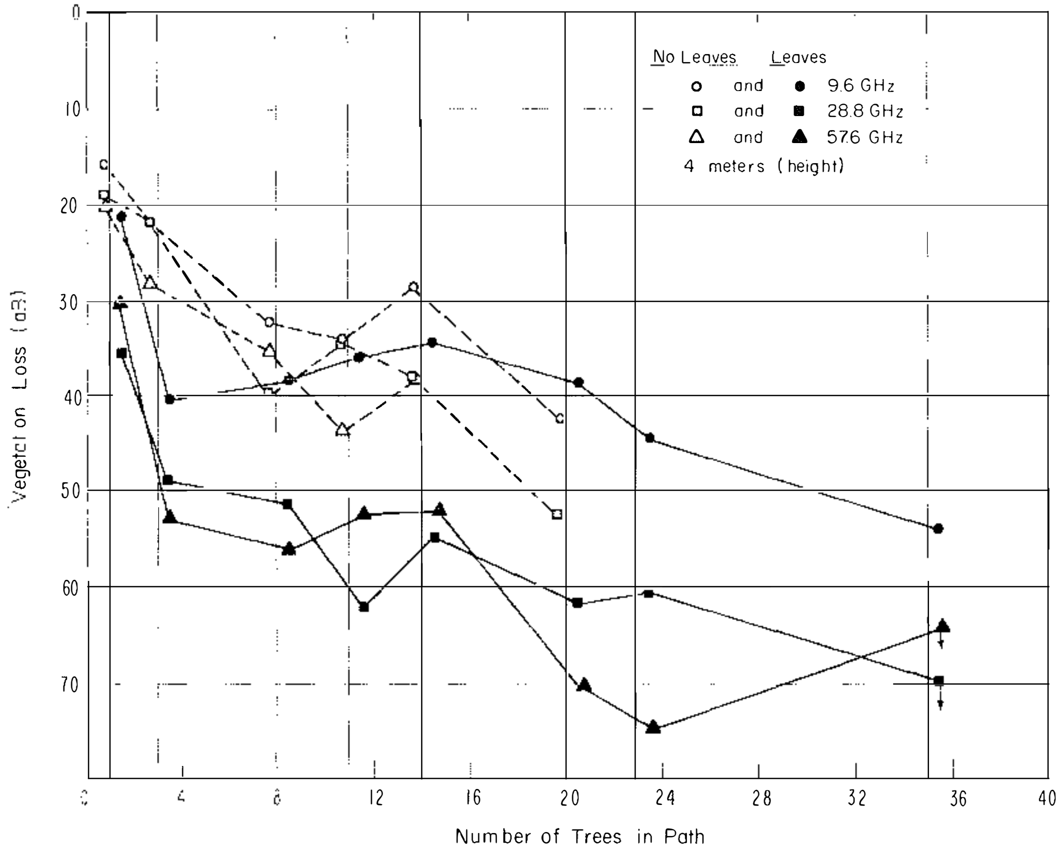


Figure 1-20. Average values of vegetation loss as a function of the number of trees in path for 9.6, 28.8, and 57.6 GHz at a 4 m height.

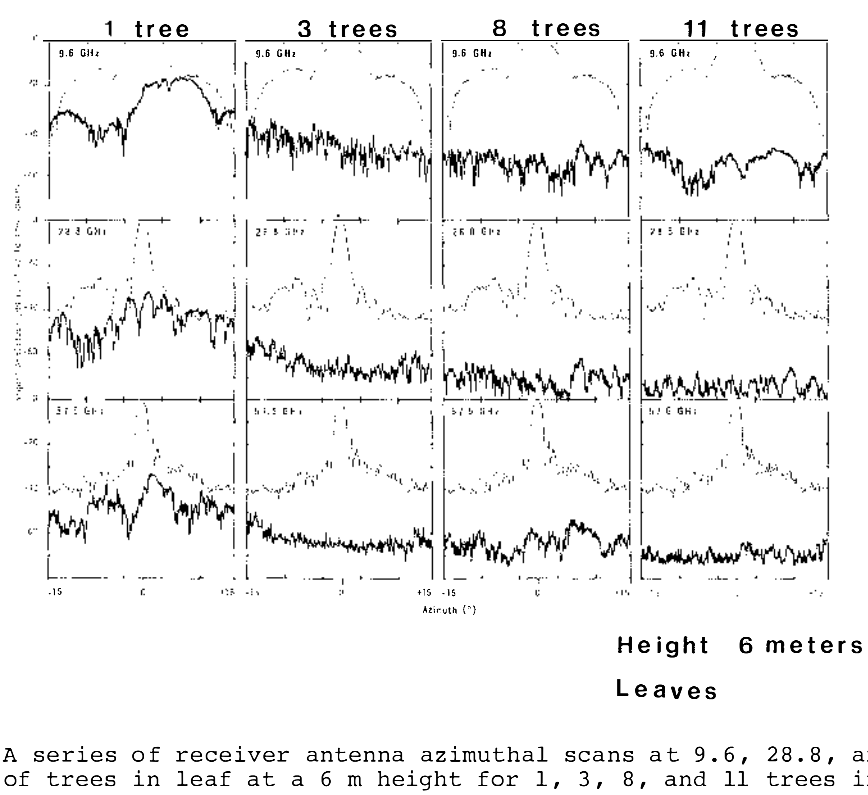


Figure 1-21. A series of receiver antenna azimuthal scans at 9.6, 28.8, and 57.6 GHz of trees in leaf at a 6 m height for 1, 3, 8, and 11 trees in path.

an urban area. Data obtained in the first phase will provide information pertaining to propagation modes and signal loss, through an obstruction, relative to free space as a function of the kind of material (wood, stone, brick, glass, etc.), depth, path geometry, and frequency. This information is useful in determining the probability of a pair of terminals establishing a non-LOS communications link given the performance parameters of the communications equipment. Also, the data acquired can be used to estimate the detectability of a signal if obstructions are used to screen unwanted propagation paths.

Information obtained in phase 2 (impulse response data) will assist in determining channel quality where time delay can be resolved to less than 1 ns (30 cm in path delay). Amplitude dispersion over a 1.0 GHz bandwidth will be recorded to measure frequency selective fade depths and to determine the coherent propagation bandwidth by noting the maximum bandwidth for flat fading. With the digitally modulated probe, bit error rates at 500 Mb/s attributable to intersymbol interference resulting from multipath signals are measured and used to compute bit error rates for a family of data rates.

Phase 1 was conducted using a three-frequency carrier wave (cw) probe operating at 9.6 (pilot channel), 28.8, and 57.6 GHz. Each channel has a sensitivity of approximately -132 dBm and an 80 dB dynamic range accomplished by use of specially designed filters and log amplifiers along with quality rf circuitry.

Measurements for phase 2 will employ the millimeter wave diagnostic probe which includes cw probes at 11.4, 28.8, and 96.1 GHz, along with a 30.3 GHz wideband channel. Both transmitting and receiving terminals are van-mounted with the receiving antennas attached to a computer-controlled, high torque positioner. Switchable linear antenna polarization is used at each terminal to compare results for each polarized mode as well as cross-polarized signal levels. One-meter (3-ft) dishes are used to measure energy reradiated from reflecting surfaces and energy penetrating building walls while recording data with the impulse probe to evaluate channel distortion in terms of time-delay spread. A 28 deg beamwidth transmitting antenna and a 3 deg receiving antenna are used to determine channel quality in the presence of streets and buildings simulating a condition where an omnidirectional antenna is used at one terminal.

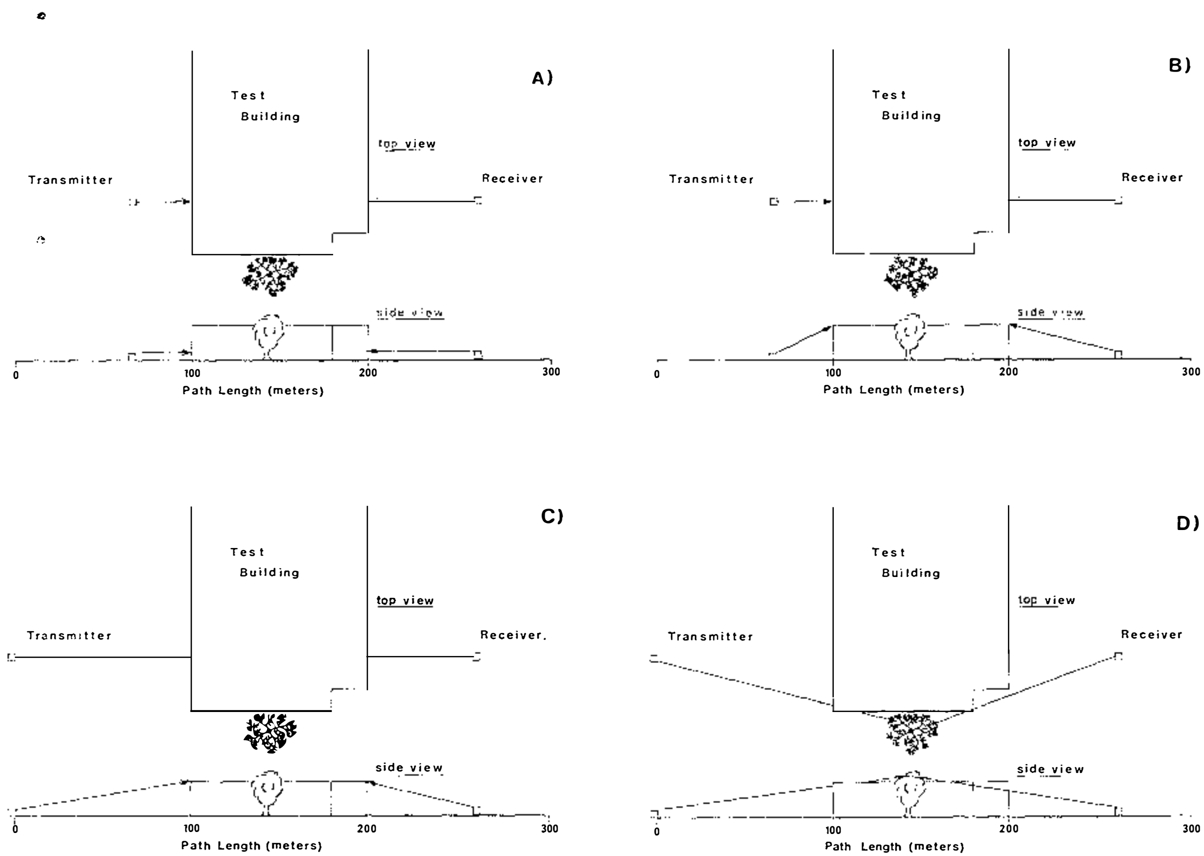
Two examples of data taken on phase 1 are contained in Figures 1-22 and 1-23. Figure 1-22 (test A) shows path geometry and signal penetration and diffraction levels for a building with exterior walls of prestressed reinforced concrete with a thickness of 20 cm (each) or greater. Direct penetration was almost nil at the 9.6, 28.8, and 57.6 GHz channels. (See the table in Figure 1-22.) In test (B) the antennas were pointed at the roof edge and a readily detectable signal occurred on the lower two frequencies presumably via a double edge diffraction mode. In test (C) the transmitter terminal was moved 100 m from the building and the over-the-top and down-mode levels increased. The common illumination of a cottonwood tree in leaf (test D) at the side of the building increased the received levels by about 20 dB from the over and down mode. Figure 1-23 (test A) shows results from measurements of an office building with predominantly glass walls. All windows were a chromatic coated glass which exhibited a surprisingly high signal loss almost equal to the loss measured through a commercially manufactured rf absorber. The doors of the building were similar in thickness (both double glazed with no other obstructions), however, not coated, but heavily tinted. The results in Figure 1-23 (test B) show almost no signal loss with a path through the glass doors on each side of the building and down the hallway; i.e., the measured values are approximately the same as a clear 75-m path.

At the somewhat longer wavelengths associated with high frequency, conditions of the upper or ionospheric portion of the propagation medium become important. The Institute is currently directing an experimental program to examine the feasibility of employing HF beacons to improve geolocation accuracies. The project, Beacon Assisted Technique to Locate Emitters Using Time of Arrival Differences, (BATTLETOAD), requires the use of high frequency transmitters, receivers, and ionosondes. The objective of the experimental program is to determine the degree to which the uncertainties in the ionospheric structure impact the inferred location of unknown HF emitters. In FY 1984, preliminary testing was undertaken with five receiver sites in California and Nevada, and three transmitter sites in California. Figure 1-24, shows site locations involved in this experiment. Ionospheric data were observed at Vandenberg Air Force Base. Preliminary analysis of the results indicates that the use of beacons to infer ionospheric structure and therefore reduce (or eliminate) the time delay associated with the passage of HF signals through the ionosphere can result in substantially improved geolocation accuracies.

A major experimental measurement program will be conducted in October 1984 using the net configuration illustrated in Figure 1-25.

Electromagnetic noise can be a limiting factor in any telecommunication system. Noise is often generated by man-made devices. Accordingly, Medium Frequency (MF) Signal and Noise Measurements were made of the electromagnetic interference (EMI) environment in a typical modern office building to ascertain the resultant interference levels.

An interest in noise environment prompted the investigation into the types of noise and frequency range of interference found in the modern office building. These areas typically include computer systems that range from microcomputers for local-office use, to minicomputers for larger interoffice systems, to mainframe computers in banking complexes and large data-handling facilities. Some older systems may generate radio frequency

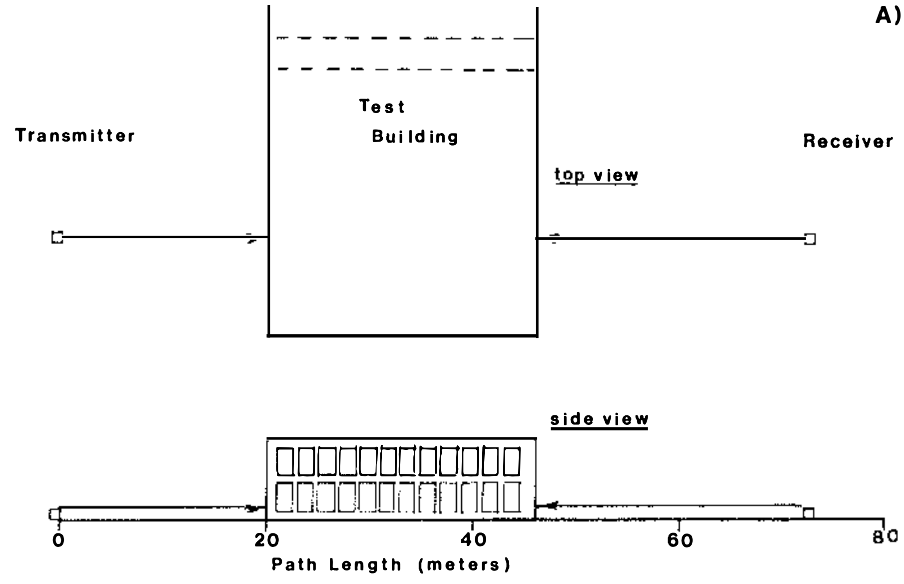


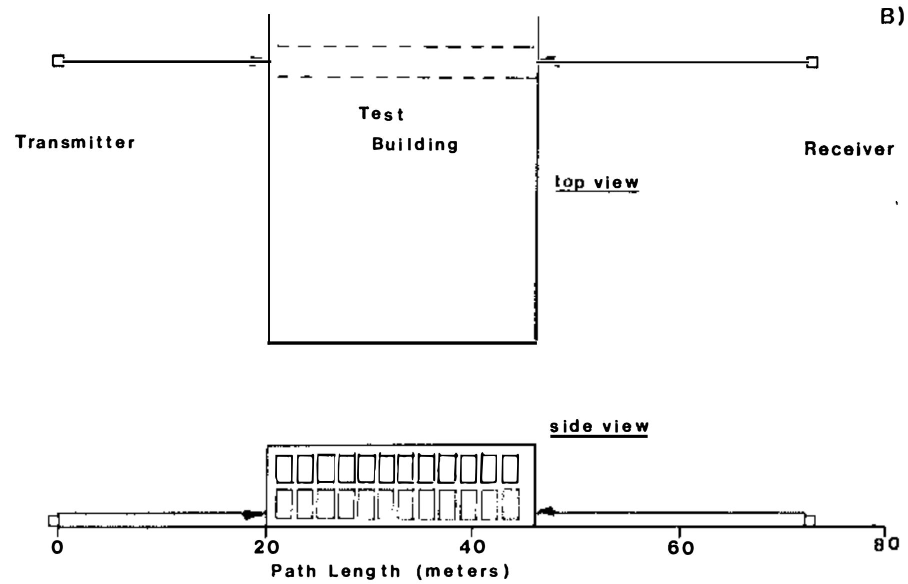
FREQUENCY (GHz)

	9.6	28.8	57.6
Signal level (dBm) A	-132	-132	-132 *
Signal level (dBm) B	-113	-117	-132
Signal level (dBm) C	-104	-104	-130
Signal level (dBm) D	-83	-84	-104

* -132 dBm is system noise level.

Figure 1-22. Test configurations and corresponding measured signal levels, using a building with solid concrete walls as path obstacle.





	FREQUENCY (GHz)		
	9.6	28.8	57.6
Signal level (dBm) A	-88	-90	-107
Signal level (dBm) B	-35	-32	-57

Figure 1-23. Test configurations and corresponding measured signal levels using a building with predominantly glass walls as path obstacle.

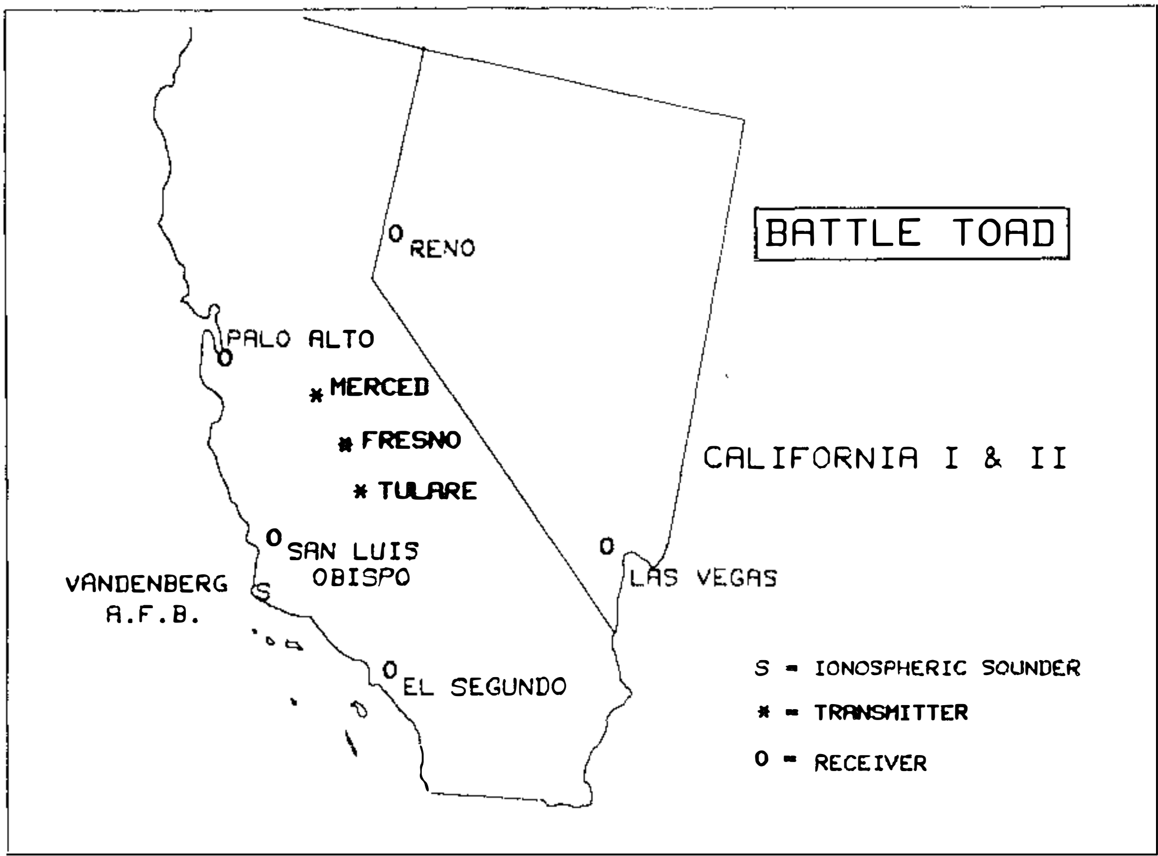


Figure 1-24. BATTLETOAD site locations.

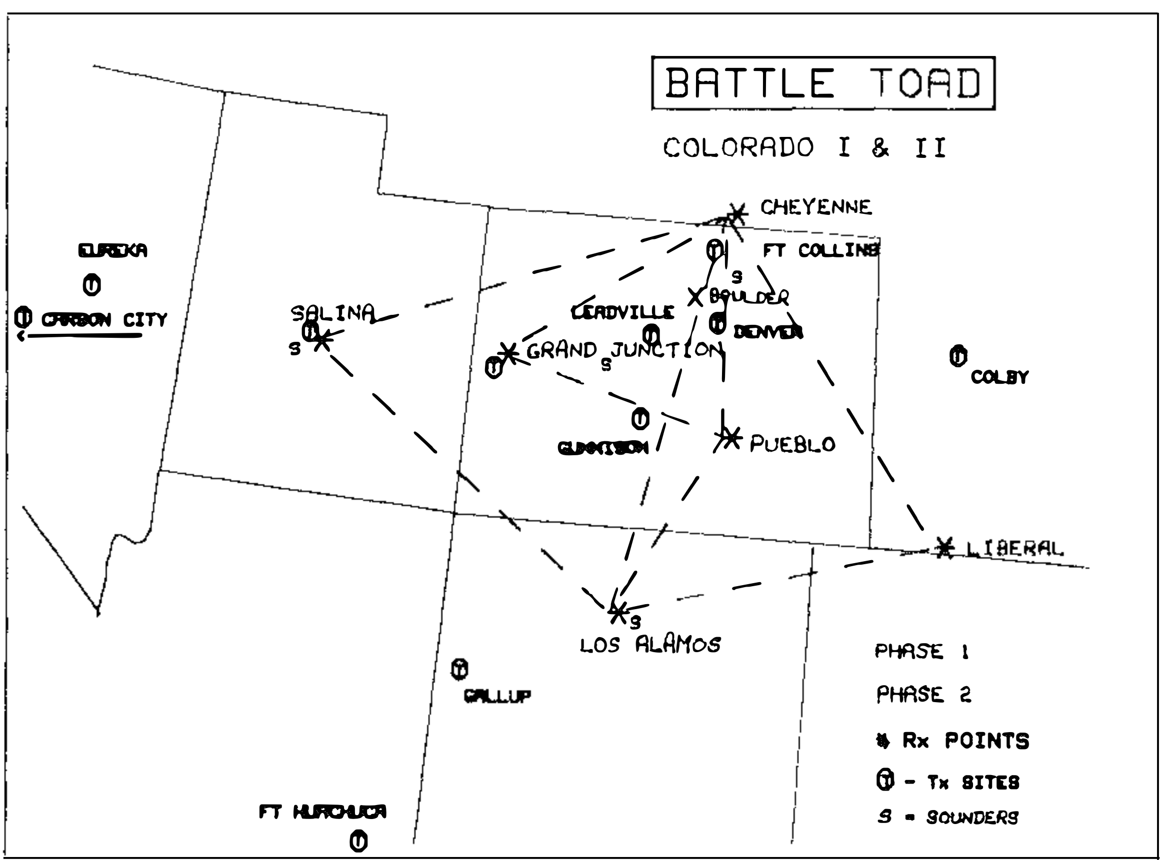


Figure 1-25. BATTLETOAD net configuration.

interference to a greater degree than the newer systems. One reason for this might be the greater sophistication in design of shielded enclosures. Another would be the greater use of low-power circuitry and improved circuit design which consume less energy and thus have the capability of radiating less energy.

Noise from outside the building can be anticipated. The frequency range of the spectrum analysis includes those frequencies used by carrier-current/receiver systems. Also, interbuilding digital communications have potential for introducing noise. Heating systems, elevators, and other contrivances using electric motors are a significant source of EMI.

Measurement Techniques

The measurement system consists of a low-frequency spectrum analyzer, a control computer, and a mass storage device. The system will be set up in at least two typical office buildings. Measurements will be made using a rapid digitizer with a bandwidth of at least 100 kHz. One burst of 40,000 samples will be taken at intervals of approximately 1 h and stored on magnetic tape. Tape capacity of at least 2 days will allow unattended operation throughout the nighttime hours.

Equipment

A low-frequency spectrum analyzer was chosen for the project. It is capable of "flash" digitizing the received energy in the low-frequency spectrum and performing a fast Fourier transform (FFT) analysis on the collected digital information. The digitized data can also be further analyzed using the "zoom" capabilities of the analyzer to look at a particular range of interest. It can output its raw data samples or analyzed spectra to the control computer for storage on magnetic tape, or allow the raw data to be reinserted at a later date for further analysis.

Measurement Plans

The project required a measurement system that could run unmanned for extended periods of time. This meant having a data storage device sufficient for at least 2 days of data. For this purpose a 1.3 cm magnetic tape drive was chosen that would allow nearly 3 days' data to be stored on one tape. The central processor was fast enough to interface between the spectrum analyzer and tape unit and a desktop computer was selected that also had good graphics capabilities. Figure 1-26 shows the completed measurement system.

Expected signal levels were derived from initial measurements of signal levels in our own office building. An active antenna was designed as a temporary probe for these estimates. It acted as a capacitive probe and was sensitive to E-field energy. Since interest primarily lies in H-field energy, searches are under way for a suitable loop device that will be reliably calibrated.

The measurements will be made at several typical office sites and analyzed to give information on expected signal levels. Some effort will be made to identify the sources of signals and noise to aid in our understanding of factors affecting this EMI environment.

1.4.2 Models and Performance Prediction Methods

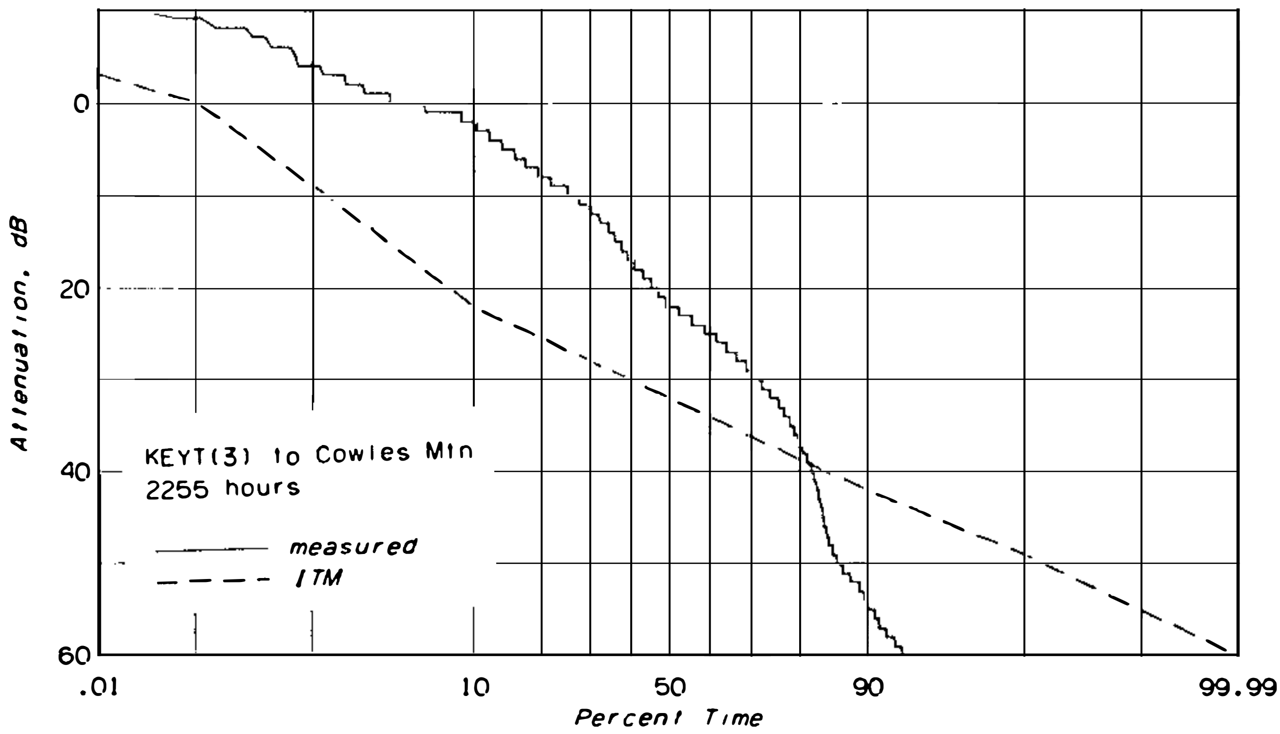
New technologies and services have created growing use of the higher frequencies in the radio spectrum. Digital systems, for example, require wider bandwidths that are available at the higher frequencies. At these frequencies, many factors such as hydrometeors, atmospheric gases, terrain features, and noise influence the reception of radio signals. This section describes the Institute's efforts toward modeling propagation in the presence of these influencing factors.

The VHF/UHF Propagation Studies project is a continuation of the Southern California Propagation Study that was begun several years ago. The purpose of this study is to measure and model the effects of ducting. Atmospheric ducts that are found in the coastal regions are often present and extend over great distances. If a transmitting antenna lies near or within the duct, its signal can become trapped by the duct and will propagate with less than free-space losses over long distances. The results caused by some ducts are interference from transmitters far away from their victim receivers.

A measurement program initiated several years ago has three receiver sites located in San Diego, each monitoring 10 frequencies from 30 to 900 MHz. The receiver sites were chosen so that one would be 20 km inland on an antenna farm peak 754 m above mean sea level (amsl), another was on the coast 200 m from the Pacific Ocean shore and 15 m amsl, and the third site was in an urban area 150 m amsl and 15 km inland from the shore. The sources are transmitters located in the Los Angeles area at distances of 150 to 300 km up the coast from the San Diego receiver sites.

The signals were monitored 24 hours each day with the raw data and hourly statistics recorded on magnetic tape for further processing. Results to date indicate that it is premature to define a model based on the Southern California data. A technical report is available which describes the measurement system, the transmitter characteristics, the propagation paths, and the data reduction. Figure 1-27 shows the received signal statistics at the inland peak site (Cowles Mountain) and the coastal site (Point Loma) from the channel 3 transmitter (KEYT) located in Santa Barbara 330 km from San Diego over land-sea paths. The solid line curves are the measured data statistics and the dashed curves are those predicted by the ITS irregular terrain model (ITM). Note that the KEYT-to-Cowles-Mountain path had measured signal levels that exceeded free-space levels for about 5 percent of the time. Using the measured data, we are exploring the correctness and pertinence of existing models such as those reported by the CCIR.

Figure 1-26. VF/LF noise measurement system.



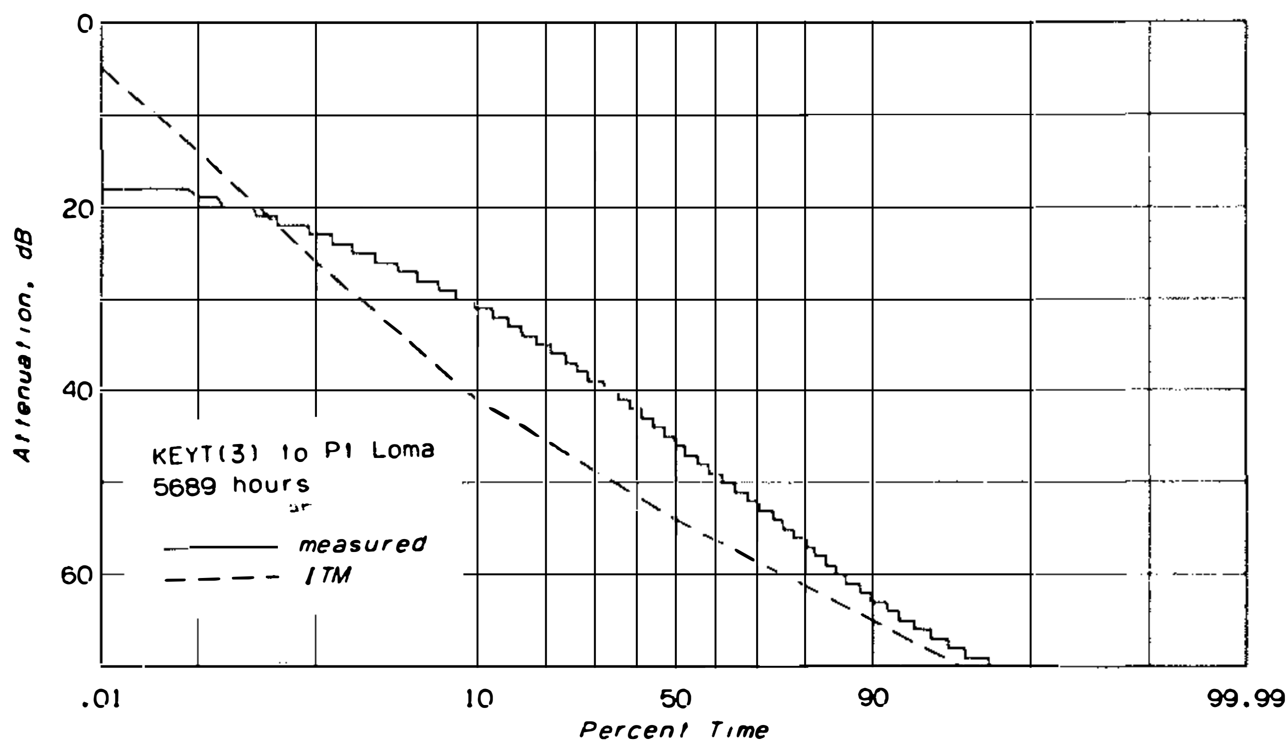


Figure 1-27. Example of received signal attenuation over a 330 km land-sea path with ducting apparently present for some of the time.

The Institute has developed extensive propagation models for determining communication boundaries for microwave communication systems. This work has been based on knowing the communication system transmitter locations, power levels, antenna types and orientations, detailed terrain parameters, receiver location, and receiver system performance. This detailed analysis requires large-scale computer usage, computation time, and manpower to determine the extent of coverage that can be obtained from fixed location reception. However, when the operational scenario of the signal reception is changed to a land mobile or maritime operation, the solution to the problem of determining the coverage becomes intractable given the analysis requirements. The purpose of the first phase of the Wide Area Propagation Model Development project has been to formulate a tractable approach to specify the area of coverage that a determined mobile receiver would be able to monitor. This new model changes from the previous approach of cumulative individual links analysis to a coverage mode represented by a generic individual link to reduce data complexity, computer, and manpower requirements.

This propagation model development is specifically tailored to determining the interceptor area coverage of the microwave band of 4 to 6 GHz. This model includes only the presumed most significant propagation effects so as to permit relatively facile assessment of relatively large areas that would be associated with land or sea interceptor operations. The model eliminates parameters that have very little impact on determining reception distances or where funding limitations force omission. This was necessary to minimize the quantity, complexity, and total computer time required for area coverage analysis. Parameters that will be eliminated in this model include the following:

- Rain attenuation. This is not a significant factor in this frequency band. Rain attenuation does not increase the path attenuation appreciably until the frequency exceeds 10 GHz. The frequency of occurrence of rains dense enough to cause significant increase in attenuation occurs less than 1 percent of the time.

- Over-the-horizon effects. In this model, the reception is considered essentially opaque to the effects of diffraction and forward scatter effects because of the infrequency of their reception occurrence. Our earlier studies indicated that special topographic profiles would have to occur to increase the expected reception distance significantly. This is coupled with the fact that an interceptor is most likely to select a high terrain point for intercepting radio communications. The previous studies at the Institute have indicated the frequency of occurrence of appreciable changes in reception distances are very infrequent.

- Seasonal and diurnal effects. Data reflecting seasonal or diurnal effects exhibit a significant degree of variability. This model will use annual values for determining reception. However, the model will accept changes in input parameters and would permit investigating the effects of variation from the annual term median values.

- Ducting and layering effects. These effects can have a very significant impact on radio horizon distance. Geographical location (latitude), land/sea interfaces, temperature, pressure, seasonal and diurnal effects could significantly alter presently modeled propagation parameters. These special atmospheric effects are scheduled for eventual further investigation. This work could then be an addendum to this model.

- Polarization. This factor likely has a very miniscule impact on determining reception distance and is not included.

Propagation effects that are included in the model are listed below:

- Line-of-sight (LOS). This is the principle mode of propagation for this model development.

- Multipath. Multipath is a fundamental limitation to the performance of microwave radio systems. This parameter directly influences the signal time availability.

- Terrain considerations. The radio horizon distance is assumed principally limited by Earth bulge, which is especially reasonable in the maritime instance. It is assumed that the interceptor will choose locations that will optimize coverage capability.

- Surface refractivity. The refractive index gradient is a key determining factor in predicting reception distances. The surface gradient by and large determines the amount the radio wave is refracted. Mathematically the effective Earth radius is changed so that the radio ray can be considered to be a straight line. This is a good approximation if the radio ray does not exceed 1 km in altitude. For the planned interceptor or heights under consideration this is an acceptable limitation.

All of the major objectives of formulating the signal availability and associated reception distributions have been completed for phase one. The model includes the statistical approach for multipath, surface refractivity, and antenna orientation impacts of the hypothetical or typical transmitter. Special emphasis has been placed on eliminating parameters that have minimal impact on determining reception distances. The approach taken for the Wide Area Propagation Model provides a relatively fast methodology for assessing coverage over large areas. Computational requirements have been greatly reduced by the approach. This model is expected to provide a very effective tool for a very diverse problem.

The objective of the EHF Telecommunication Performance Prediction Model project was the development of a computer model to predict the outage time, due to adverse propagation conditions, of analog and digital telecommunication systems operating in the frequency range of 10-100 GHz. The developed model is called the EHF Telecommunication System Engineering Model (ETSEM) and runs on a desk-top computer. ETSEM is composed of three basic groups of models.

The first group of models serves as aids in the selection and design of the propagation path. Antenna heights and Fresnel zone clearance as well as antenna azimuths and elevation angles can be determined. These modules of the computer program are similar to the corresponding modules of ADSEM, a computer model for lower frequencies developed previously by ITS.

The second group of modules combines the link equipment gain with the predicted cumulative distribution of propagation losses to produce a predicted cumulative distribution of the received signal level from which the system performance can be determined.

The third group of modules is composed of models that predict the signal-to-noise ratio for analog systems and the bit error rate for digital systems as a function of received signal level and equipment specifications. From the output of the second and third group of modules, the time that a desired performance level will be achieved is predicted.

Three types of propagation loss are modeled in the second group of modules. Monthly cumulative distributions of attenuation due to rain, multipath, and clear air absorption are combined into one distribution for the months selected.

The rain attenuation model uses the Rice-Holmberg model for the cumulative distribution of point rain rate. It was modified so that the thunderstorm ratio is computed from the ratio of the number of days with thunderstorms to the number of days with measurable precipitation. This alteration enables the computation of monthly distributions and has been used previously as seen in NTIA Report 84-148, "Microwave Terrestrial Link Rain Attenuation Prediction Parameter Analysis." The point-to-path conversion was done using the formula of the Crane global rain attenuation model. The Joss raindrop-size distribution is used because it was found to agree best with EHF attenuation measurements as shown in NTIA Report 84-149, "Atmospheric Channel Performance Measurements at 10 to 100 GHz." The raindrop-size distribution is critical to the attenuation predictions and more work is needed to ensure that the drop-size distribution is adequately modeled.

The Crombie multipath model was used to predict the cumulative distribution of attenuation due to multipath fading. Because it is a worst-month model, it presumably over predicts the amount of fading for the average month. Even so, rain dominates the predicted cumulative distribution of attenuation for most EHF paths so that multipath fading still only accounts for a fraction of the total amount of fading time predicted.

The cumulative distribution of clear air absorption is predicted by assuming that the oxygen absorption is nearly constant and that the amount of water vapor absorption varies. The pressure and temperature are assumed constant and equal to the mean for each month. The absolute humidity, ρ, in g/m^3 is modeled with a Gaussian distribution. The variance, σ, (good for probabilities of exceedance less than 50 percent) is determined by the mean absolute humidity, $\bar{\rho}$, for each month according to

$$\sigma = 0.0094\,\bar{\rho} + 2.05 .$$

The probability of exceedance for absolute humidity is then given by

$$P(\rho) = \frac{1}{2}\left[1 - \operatorname{erf}\left(\frac{\rho - \bar{\rho}}{\sigma\sqrt{2}}\right)\right] .$$

The specific oxygen absorption is found from

$$\alpha = a\,P^{\beta_1}\,\theta^{\beta_2}\,\exp\left(\beta_3\,\theta^2 + \beta_4\,P\theta^2\right)$$

where P is pressure and θ is the relative inverse temperature given by

$$\theta = 300/T$$

with T in Kelvin. The a, β_1, β_2, β_3, and β_4 are parameters interpolated from a table. These parameters were found by fitting the oxygen absorption predictions found in NTIA Report 83-137, "An Atmospheric Millimeter Wave Propagation Model," by H. J. Liebe for frequencies from 10 to 100 GHz. The resulting oxygen absorption predictions agree within 6.5 percent with those of Liebe. The specific water vapor absorption predictions are also based on Liebe's model and use his water vapor continuum and 22 GHz line.

Data bases of the meteorological parameters needed by the propagation loss models for the United States and Europe are included with the model. The necessary parameters may be interpolated from these data bases or hand entered.

An Atmospheric Millimeter Wave Propagation Model. Atmospheric propagation limitations dominate most considerations in the advancement of millimeter wave applications. Adverse weather causes radio signal degradations due to rain, wet snow, suspended particles, and water vapor. A practical atmospheric Millimeter Wave Propagation Model (MPM) has been developed to solve this complex problem in an efficient manner--complicated microphysical methodology is reduced to simple radio engineering terms. Such propagation modeling provides a cost-effective means of predicting the performance of a system for its intended use. A propagation model can take into account all performance-influencing factors of the atmosphere which in the actual operating environment would be difficult, if not impossible, to identify.

The neutral atmosphere was characterized for the frequency range from 1 to 300 GHz as a nonturbulent propagation medium [Liebe (1983), "An Atmospheric Millimeter Wave Propagation Model," NTIA Report 83-137]. This report presents a discussion of the MPM computer routine and gives representative results in numerical and graphical form. Attenuation and propagation delay effects are predicted from meteorological data sets including pressure, temperature, humidity, suspended particle concentration, and rain rate. Basically, the propagation model consists of four terms:

1. resonance information for 30 water vapor and 48 oxygen absorption lines in the form of intensity coefficients and center frequency for each line
2. continuum spectrum with water vapor, oxygen, and nitrogen terms
3. hydrosol attenuation term for haze, fog, and cloud conditions
4. two-coefficient rain attenuation model.

Oxygen lines extend into the mesosphere where they behave in a complicated manner due to the Zeeman effect. The geomagnetic field strength H is required as an additional input parameter. Each O_2 line splits proportionally with H into numerous sublines, which are juxtaposed to form a Zeeman pattern spread over a megahertz scale. More than 200 patterns for three main polarization cases were calculated. Detailed examples for model atmospheres provide basic millimeter wave propagation information over the height range 0 to 100 km of the neutral atmosphere.

Laboratory experiments and analytical efforts conducted at ITS have played a major role in developing the MPM routine that relates easily obtained meteorological data (pressure, temperature, humidity) to difficult-to-measure propagation factors (attenuation, delay, medium noise) in a most direct manner.

Model Applications

Since the introduction of the first MPM version in 1981, the model has proven useful for a variety of applications in millimeter wave communications, remote sensing, and radio astronomy. Tape copies of the model together with program listings have been requested by over 60 users from industry (27), Government (16), universities (10), and foreign countries (11). The Institute has worked with the MPM to lend support to the following applications:

- to generate examples about unique transfer characteristics of moist air in the 5 to 350 GHz frequency range (see example, Figure 1-28)
- to develop simple models for predicting transparency in the four atmospheric millimeter wave ranges and water vapor attenuation at the two H_2O line centers (Figure 1-29)
- to evaluate water vapor-dependent attenuation data from laboratory and field experiments conducted at 20.6, 31.6, 96.1 GHz (Figure 1-30), 110, and 337 GHz (Figure 1-31) with resulting good agreement between predictions and measured data
- to estimate location-dependent attenuation between 10 and 100 GHz for major U.S. population centers (NTIA Report 83-119)
- to plan the development of a system performance model for terrestrial millimeter wave communications [Liebe et al. (1983), NTIA Technical Memorandum 83-93, limited distribution]
- to provide numerical data on the effective height concept [that is, (zenith/horizontal) radio path behavior] up to 400 GHz using three model atmospheres (U.S. Standard, Arctic Winter, and Tropical Summer) for CCIR Study Group 5, International Working Party 3, 1983
- to compare the propagation characteristics over the range 30 to 150 GHz for two sites selected at h=1 km in Japan and at h=3 km in Spain for millimeter wave radio astronomy
- to interpret mesospheric temperature profiles from radiometric observations of the 25^- O_2 line performed over Europe from an aircraft flying at a height of 10 km.

The need for a Model of MM Wave Propagation in Rain stems from the frequency of rain and the severity of its effects. Millimeter wave propagation through rain is likely to encounter different amounts of attenuation depending upon the transmitted-received polarization. If dual orthogonal polarizations are used to increase channel capacity, loss of isolation at both polarizations can be caused by rain as well.

The forward scatter function, $f_{V,H}$, can be used to obtain corresponding propagation constants (wave numbers), as

$$K_{V,H} = \frac{2\pi}{k} \int_{r_{01}}^{r_{02}} f_{V,H}\, n(r_o)\, dr_o \quad , \qquad \text{(A)}$$

where k is the free-space wave number, and $n(r_o)$ is number of drops per unit volume of atmosphere between r_o and $r_o + dr_o$, with r_o the radius of a spherical raindrop equivalent in volume to a given oblate spheroidal raindrop (i.e., "equivolumetric" radius). The values r_{01} and r_{02} represent the minimum and maximum radii of drops in the unit volume of atmosphere. In turn, then, the attenuations $A_{I,II}$ (shorthand for A_I and A_{II}), in decibels per kilometer are given by

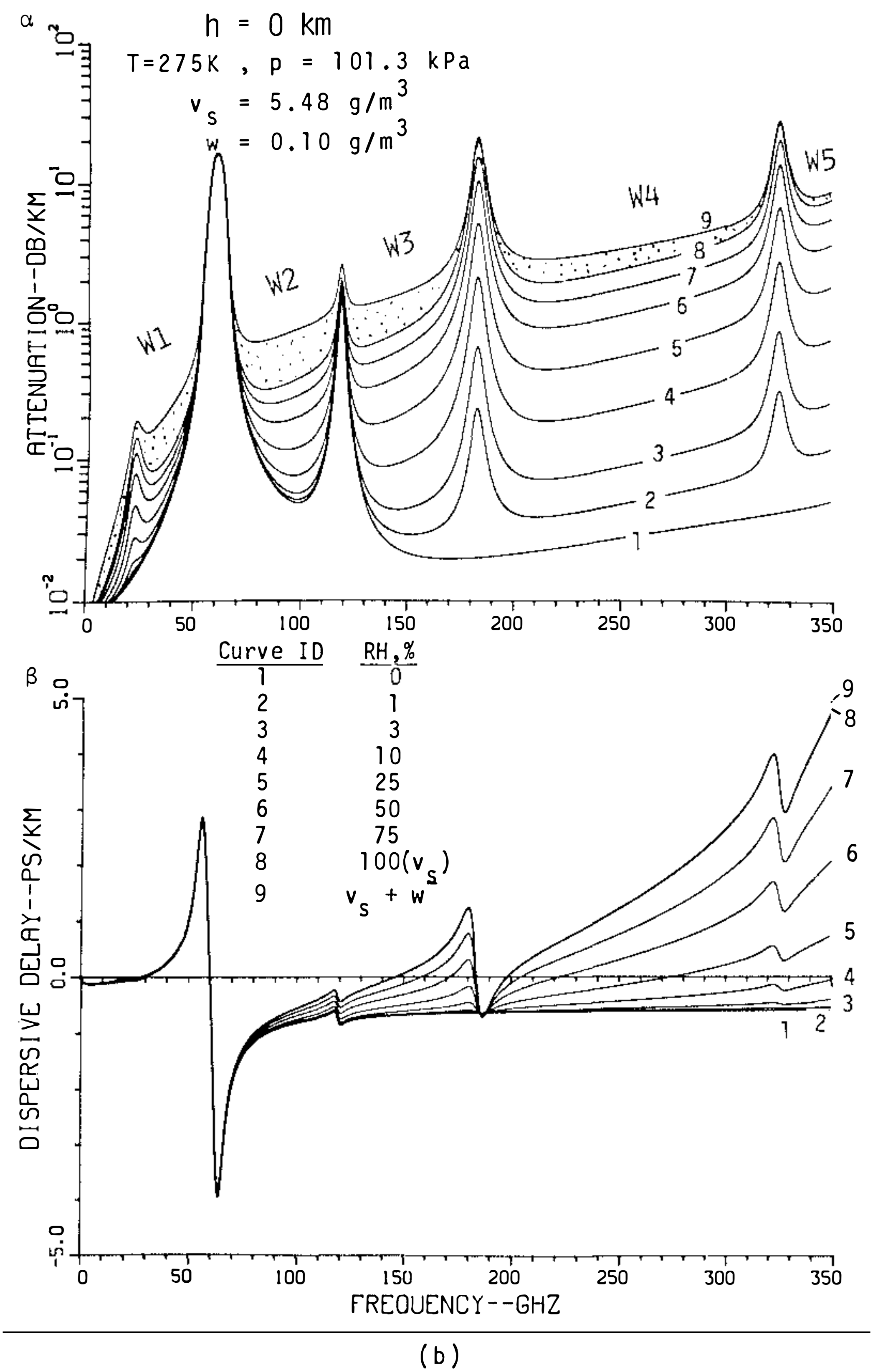


Figure 1-28. Predicted specific attenuation α and dispersive delay β for humid (RH=0 to 100%) sea level air over the frequency range from 5 to 350 GHz at 275°K. Window ranges are marked W1 to W5.

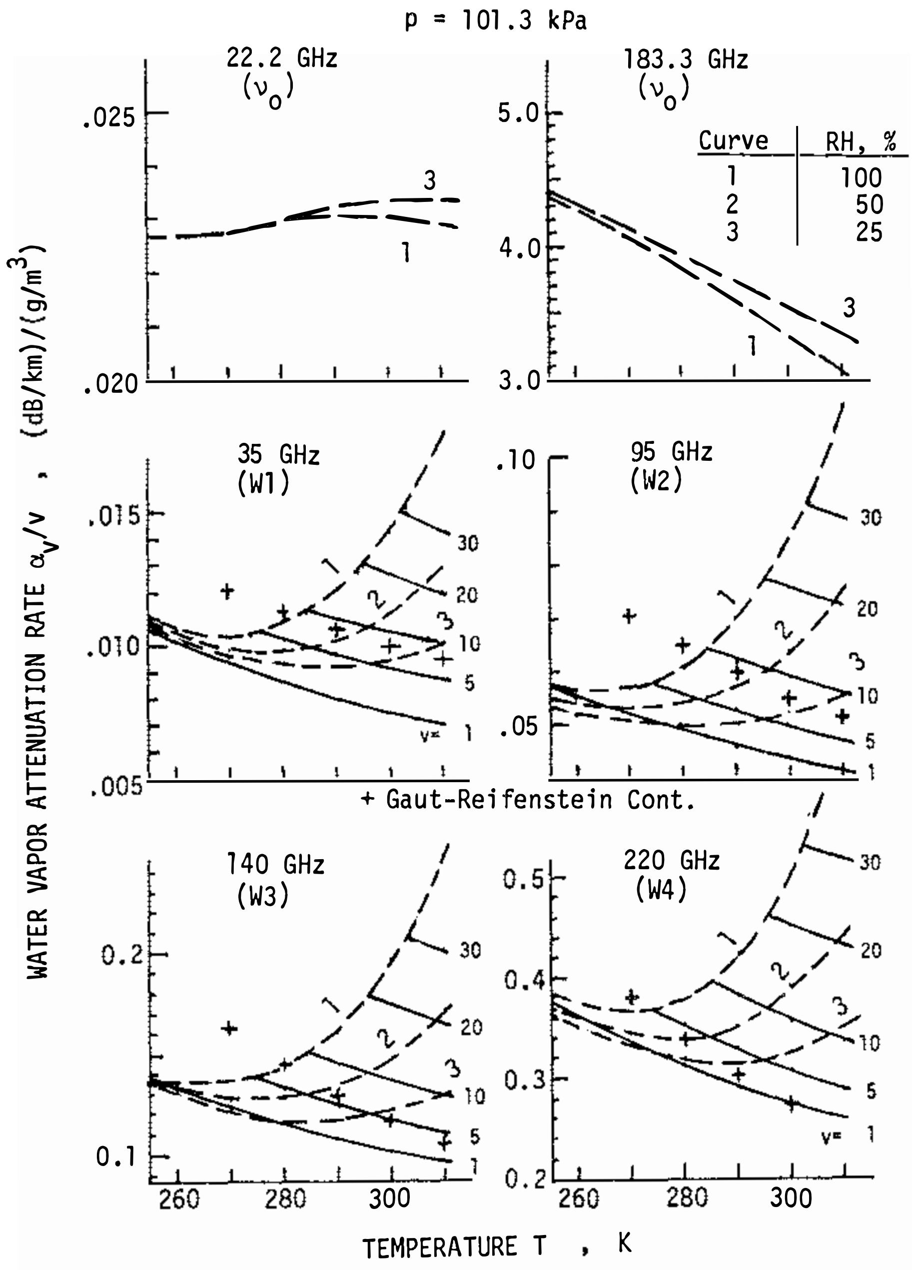


Figure 1-29. Specific water vapor attenuation α_v per unit concentration V(g/m^3) for different relative humidities at six millimeter-wave frequencies as a function of temperature from 260° to 310°K.

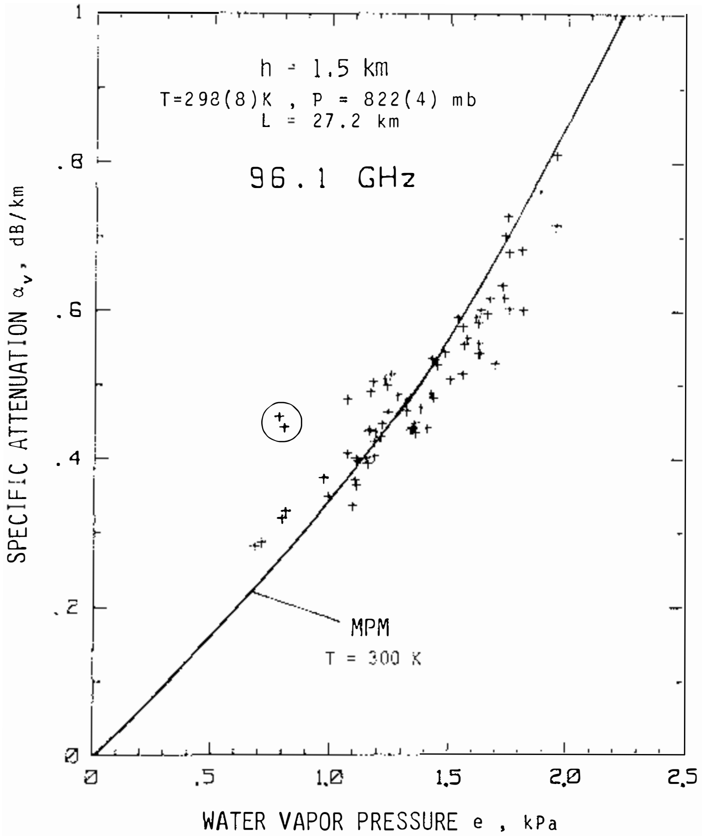


Figure 1-30. Predicted-versus-measured water vapor attenuation α_V from a horizontal path (L=27.2 km) operated by ITS at 96.1 GHz (see NTIA Report 84-149).

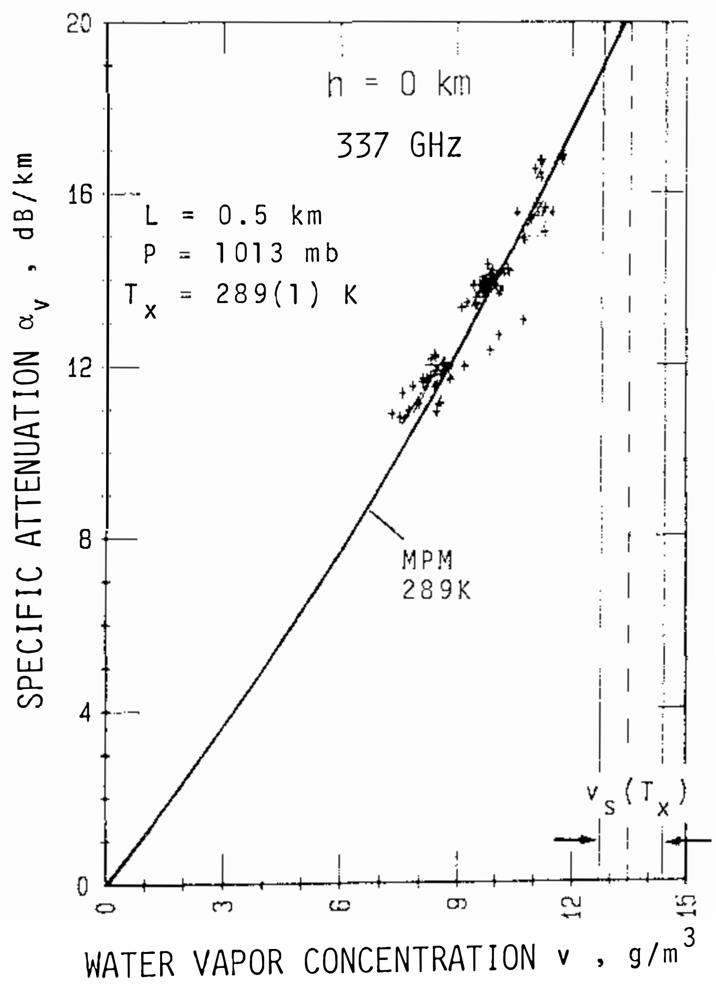


Figure 1-31. Predicted-versus-measured water vapor attenuation α_V from a horizontal path (L=0.5 km) operated by Case Western Reserve University (A. J. Gasiewski) at 337 GHz.

$$A_{I,II} = 10 \log_{10} \exp [2Im(k_{V,H}] \quad . \qquad (B)$$

At this point it should be noted that theory [Oguchi, T. (1983), Electromagnetic wave propagation and scattering in rain and other hydrometeors, Proc. IEEE 71, No. 9, pp. 1029-1078, September] obtains $f_{V,H}$, and thence $k_{V,H}$, for an ensemble of uncanted raindrops; thus, V and H coincide with the I and II axes, allowing the expression (B). The axes I and II are orthogonal axes parallel to the minor and major axes of an oblate spheroidal raindrop. The V and H stand for vertical and horizontal directions, respectively.

Much of our present attenuation prediction material uses spherical drop theory (Mie theory, Rayleigh approximations) as its basis. It would, therefore, be desirable to develop a direct connection with this theory, in a relatively simple, straightforward manner, so as not to have to reprogram extensively to incorporate the results of theoretical electromagnetic analysis, which is inherently rather cumbersome. Using this as our rationale, we can postulate a heuristic model of the form

$$Q_{I,II}(a,b,\lambda) = W_{I,II}(a,b,r_o) \; Q(r_o,\lambda) \qquad (C)$$

where

$$Q_{I,II}(a,b,\lambda) = 2\lambda Im(f_{V,H}) \qquad (D)$$

which separates the nonspherical variables from the spherical and electromagnetic variables. In other words, $Q_{I,II}(a,b,\lambda)$ in (C), which represents the droplet attenuation cross section as a function of the semiminor axis, a, semimajor axis, b, and the wavelength, λ, in both the I and II directions, is assumed expressible as the product of a weight, $W_{I,II}(a,b,r_o)$, which is a function of a, b, and the equivolumetric radius, r_o, and the spherical attenuation cross section $Q(r_o,\lambda)$. Since a sphere does not depolarize in the forward propagation direction, $Q(r_o,\lambda)$ is independent of the directions I or II.

Table 1-1 shows the comparison between modeled and specific attenuations desired, using (C), at 30 GHz ("FREQ") for various values of "RAIN RATE", with those results obtained from the Oguchi theory. The specific attenuations were computed for angles of incidence, "ALPHA", on a given composite of oblate spheroidal raindrops, of 90, 70, 50, and 30 deg. An exponential form of $n(r_o)$,

$$n(r_o) = Ae^{-Br_o} \qquad (E)$$

where $A = 16{,}000 \text{ mm}^{-1} \text{ m}^{-3}$ and $B = 8.2 \, R^{-0.21} \text{ mm}^{-1}$, with r_o in millimeters and R the surface rain rate in millimeters per hour, was used in (A) to obtain Table 1-1.

The occurrence of rain attenuation is often observed but difficult to predict. The purpose of the Rain Rate Model project is to examine existing rain data and consider the possibilities of treating rain attenuation probabilistically.

Ten models that predict rain attenuation distribution on point-to-point terrestrial microwave telecommunications links have been compared with one another. Such comparisons can take many forms, but the resultant comparison should be performed in a manner that has some physical meaning. An approach that has very little meaning is the comparison of a predicted median or average annual distribution of rain attenuation with a given yearly data distribution. Unless one knows where the observed annual distribution lies with respect to all other possible annual distributions in the historical sample space, one has no business comparing with the median, or any other such individual predicted distribution. This kind of comparison has been common in the past, but the conclusions to be drawn from such comparisons are generally nugatory.

Hence, another more meaningful comparison approach must be sought. This approach undoubtedly must use the concept of predicted year-to-year variability in rain attenuation distributions, since this variability is usually significantly large for percentages below 0.1 percent of a year. The approach that seems best for the moment, although it is not as quantitative as might be desirable, determines whether a given yearly data distribution lies inside or outside a desired confidence interval about the median predicted rain attenuation distribution. This confidence interval is determined from the predicted year-to-year variability of the distribution.

We now must consider an appropriate confidence interval to use in this test. At first glance, a 90 percent confidence interval might seem sufficient, but then there is still a prediction of 1 chance to 10 that the inside/outside comparison test has no significance. If we extend to a 99 percent confidence interval, there is now a prediction of 1 chance to 100 that the test has no significance, and we shall deem that an appropriate risk to run. Of the 10 models compared, 1 model was developed at ITS, while the remaining 9 models were developed in other telecommunications laboratories throughout the world.

Table 1-2 summarizes 56 individual attenuation comparisons made at the 0.01 percent exceedance level of an attenuation distribution. Each of the 10 prediction models are compared with at least 1 year's worth of data distribution at several worldwide locations. There are not nearly as many locations as comparisons because each distribution represents results from a specific link, having a given path length and operating frequency. There are often several links at one geographic location. Table 1-2 shows the average and maximum departures of the data above the 99.5 percent confidence limit at the 0.01 percent exceedance level for these 56 comparisons. In addition, Table 1-2 shows the "overall prediction efficiency," ε, in percent, where

Table 1-1. Modeled Versus Theoretical Specific Attenuations for Given Angles of Incidence and Rain Rates Calculated at 30 GHz

ALPHA = 90 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	30.0	.0348731	.0328800	.0380658	.0357100	.0369655
1.25	30.0	.2118814	.1922000	.2393396	.2158000	.2297595
2.50	30.0	.4505013	.4055000	.5177326	.4632000	.4941244
12.50	30.0	2.3768389	2.1660000	2.8616731	2.5780000	2.6884059
25.00	30.0	4.6420342	4.3160000	5.7156215	5.2200000	5.3286969
50.00	30.0	8.7912566	8.4290000	11.0875020	10.3400000	10.2523161
100.00	30.0	16.1374368	16.0600000	20.8919768	19.9300000	19.1448181
150.00	30.0	22.6904670	23.1900000	29.8667972	28.8700000	27.2119420

ALPHA = 70 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	30.0	.0351004	.0331100	.0379409	.0356100	.0369655
1.25	30.0	.2137703	.1944000	.2382635	.2153000	.2297595
2.50	30.0	.4550439	.4112000	.5150960	.4623000	.4941244
12.50	30.0	2.4080215	2.2130000	2.8426259	2.5770000	2.6884059
25.00	30.0	4.7094574	4.4230000	5.6734100	5.2240000	5.3286969
50.00	30.0	8.9317831	8.6690000	10.9971395	10.3600000	10.2523161
100.00	30.0	16.4201041	16.5700000	20.7047181	19.9900000	19.1448181
150.00	30.0	23.1091552	23.9600000	29.5839582	28.9900000	27.2119420

ALPHA = 50 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	30.0	.0356953	.0336800	.0376202	.0353400	.0369655
1.25	30.0	.2187741	.1999000	.2354885	.2139000	.2297595
2.50	30.0	.4671506	.4258000	.5082802	.4599000	.4941244
12.50	30.0	2.4924668	2.3320000	2.7930598	2.5760000	2.6884059
25.00	30.0	4.8934066	4.6990000	5.5632218	5.2350000	5.3286969
50.00	30.0	9.3181879	9.2810000	10.7604763	10.4100000	10.2523161
100.00	30.0	17.2039211	17.8700000	20.2124393	20.1600000	19.1448181
150.00	30.0	24.2762906	25.9100000	28.8387601	29.2800000	27.2119420

ALPHA = 30 DEGREES

RAIN RATE (MM/HR)	FREQ (GHZ)	MODEL VERTICAL ATTENUATION (DB/KM)	OGUCHI VERTICAL ATTENUATION (DB/KM)	MODEL HORIZONTAL ATTENUATION (DB/KM)	OGUCHI HORIZONTAL ATTENUATION (DB/KM)	SPHERICAL ATTENUATION (DB/KM)
.25	30.0	.0364085	.0343400	.0372477	.0350500	.0369655
1.25	30.0	.2248898	.2063000	.2322398	.2123000	.2297595
2.50	30.0	.4820974	.4426000	.5002679	.4571000	.4941244
12.50	30.0	2.5996177	2.4690000	2.7341323	2.5740000	2.6884059
25.00	30.0	5.1298847	5.0180000	5.4315104	5.2480000	5.3286969
50.00	30.0	9.8219501	9.9910000	10.4759161	10.4700000	10.2523161
100.00	30.0	18.2417399	19.3600000	19.6166098	20.3600000	19.1448181
150.00	30.0	25.8370685	28.1900000	27.9329172	29.6300000	27.2119420

Table 1-2. Summary of Departures of Yearly Microwave Attenuation Data Distributions Above the Modeled 99.5 Percent Confidence Limit at the 0.01 Percentile Exceedance Level for 10 Prediction Models

Table 1-2. Summary of Departures of Yearly Microwave Attenuation Data Distributions Above the Modeled 99.5 Percent Confidence Limit at the 0.01 Percentile Exceedance Level for 10 Prediction Models

	ITS Model	Other Models 1.	2.	3.	4.	5.	6.	7.	8.	9.
Overall Prediction Efficiency, ε (percent)	100.0	94.6	100.0	98.2	98.2	92.9	82.1	92.9	89.3	78.6
Average Outside Departure (dB)	0	0.247	0	0.131	0.16	0.118	0.674	0.128	0.597	0.639
Maximum Outside Departure (dB)	0	12.5	0	7.36	8.94	3.34	7.33	5.89	9.26	9.48
Prediction Efficiency in Köppen Zone										
A	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
C	100.0	94.0	100.0	98.0	98.0	92.0	80.0	92.0	88.0	76.0
D	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

$$\varepsilon = \frac{N - n_D}{N} \times 100 . \qquad (A)$$

In (A), n_D is the number of comparisons with departures and N(=56) is the total number of comparisons. An ε is also shown by climatic zone. The climatologist Köppen subdivided the world into five major climatic zones, specified as zones A, B, C, D, E. Without going into further detail, zone A is a wet, tropical zone; zone B is a dry, arid zone; zone C is a warm, temperate zone; zone D is a cold, temperate zone; and zone E is a polar-region zone. Most major industrial nations are located in zone C; hence, therein occurred most of the data (50 out of 56 distributions) used in Table 1-2. Zones A and D accounted for the three distributions apiece in Table 1-2, and zones B and E are not represented.

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

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

One task of this project was to develop and implement processors that generate tactical operation charts from the IONCAP program as a unique representation of maximum usable frequency (MUF) and frequency of optimum traffic (FOT) dependent on path length and the lowest usable frequency (LUF) dependent on path length, emission type, and transmitter power. These predictions will be generated every 2 hours. This task requires the development of a specialized input processor, output processor, and interface to the IONCAP program. The methodology developed in this task provides the ability to generate detailed tactical charts of propagation predictions for the U.S. Army 5th Signal Command.

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

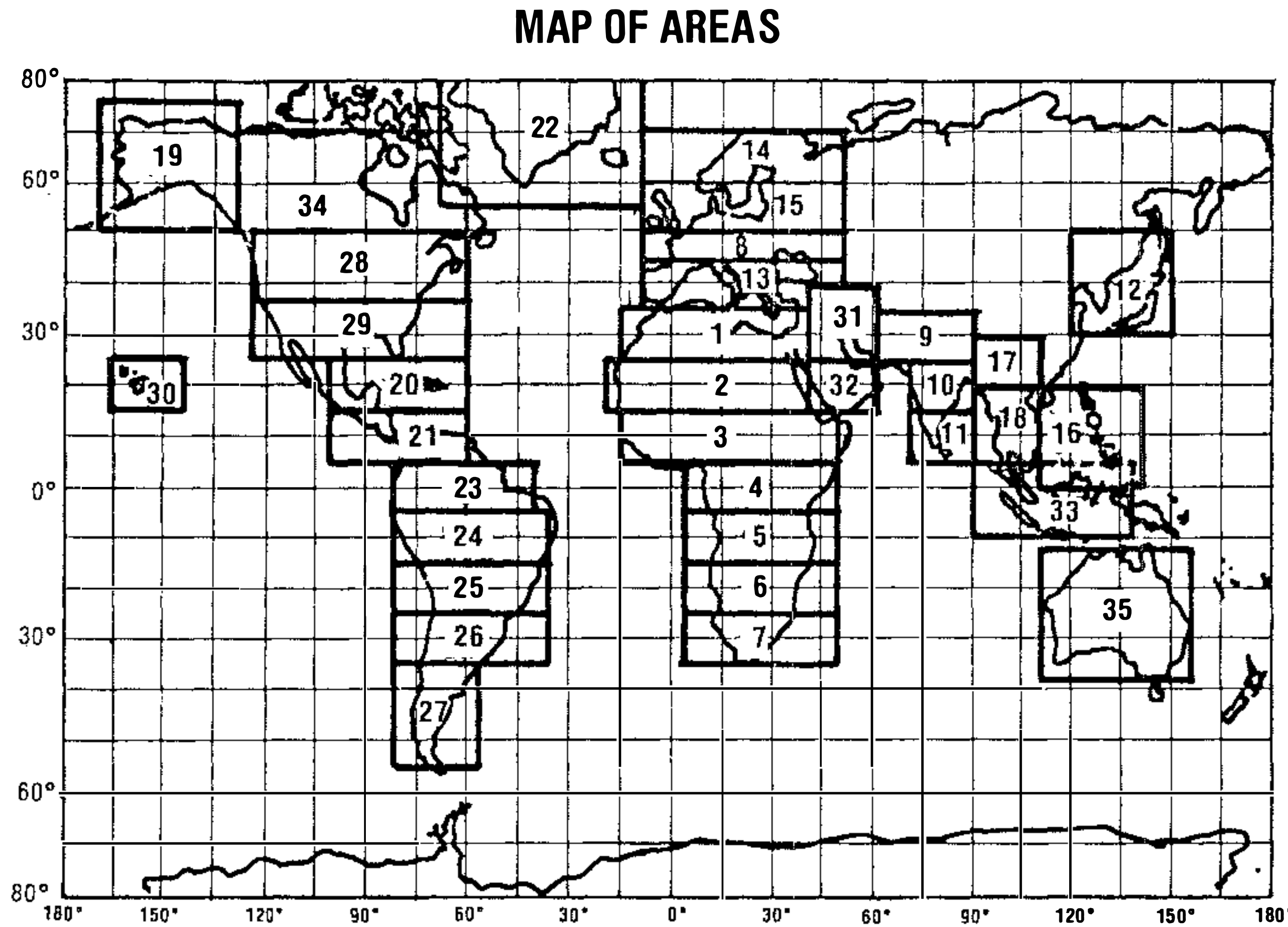
Army AG and ISD Books. The U.S. Army, in its tactical operations, makes extensive use of high-frequency communication. To assure this communication, it is desirable to be able to select the proper operating frequency at any time in many geographic locations for the specific equipment involved. This selection process has been assured by "Intermediate and Short Distance Sky-Wave Propagation Charts." Improvements in the performance of sky-wave systems as a result of recent operational experience with over-the-horizon radars permits a revision of these propagation charts to reflect these propagation prediction improvements. A revision of the "Intermediate and Short Distance Sky-Wave Propagation Charts" has been undertaken for the U.S. Army. The revised charts involve 35 different geographic areas covering most land masses. The predictions are provided in 35 volumes, 1 volume for each of the areas shown in Figure 1-32.

The Maximum Usable Frequency (MUF), the Optimum Traffic Frequency (FOT), and the Lowest Usable High Frequency (LUF) are presented for six seasonal intervals, for each hour of local time, six distance intervals, and for solar activity extremes of a normal solar cycle. Figures 1-33 and 1-34 are examples of the ISD sky-wave propagation charts.

In addition to the tactical operations, sky-wave propagation information is required to assure the proper frequency selection for communications between aircraft and the base stations. This sky-wave propagation information has been provided as "Air/Ground Sky-Wave Propagation Charts for Selected Worldwide Stations." These charts have been prepared for 58 air-base stations to essentially provide worldwide coverage.

The maximum frequency expected to be available for sky-wave propagation on at least 50 percent of the days (the MUF) is predicted for each ground station in a series of eight pages of charts. The charts are divided into tables that correspond to the 32 sectors as shown on the example map in Figure 1-35. Each table shows the MUF for various increments of distance at each even hour of Greenwich Mean Time (GMT) and at the solar activity extremes of a normal solar cycle, i.e., at solar activity indices of sunspot numbers 10 and 110. The seasonal variation of the MUF is shown in a series of charts, each for a 2-month interval. Figure 1-36 is an example of an A/G sky-wave propagation chart.

Another related project, the Army HF Propagation Study, was directed toward the development and implementation of an interactive processor to generate input to the IONCAP program. The project supports operational



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

Figure 1-32. ISD book geographical areas.

AFRICA I

MAXIMUM USABLE FREQUENCIES (MUF)

OPTIMUM TRAFFIC FREQUENCIES (FOT)

MARCH APRIL

	160 KM. (100 MI.)				400 KM. (250 MI.)				800 KM. (500 MI.)				1200 KM. (750 MI.)				1600 KM. (1000 MI.)				2400 KM. (1500 MI.)			
	SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110		SSN=10		SSN=110	
LT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT	MUF	FOT
01	4.7	3.7	10.0	8.1	5.1	4.0	10.7	8.7	6.6	5.1	13.2	10.7	8.3	6.4	16.3	13.2	9.9	7.7	19.4	15.7	12.6	9.8	24.7	20.0
02	4.5	3.6	9.0	7.4	5.0	4.0	9.7	7.9	6.5	5.2	11.9	9.8	8.2	6.5	14.8	12.1	9.8	7.8	17.5	14.4	12.4	9.9	22.3	18.3
03	4.0	3.2	8.1	6.6	4.5	3.6	8.6	7.1	5.8	4.6	10.6	8.7	7.3	5.9	13.1	10.8	8.8	7.0	15.6	12.8	11.2	9.0	19.9	16.3
04	3.4	2.7	7.1	5.8	3.8	3.0	7.5	6.2	5.0	4.0	9.4	7.7	6.3	5.0	11.6	9.5	7.6	6.1	13.8	11.3	9.7	7.7	17.6	14.4
05	3.4	2.7	6.5	5.3	3.8	3.0	7.0	5.8	5.0	4.0	8.8	7.2	6.4	5.1	11.0	9.0	7.7	6.2	13.2	10.8	9.9	7.9	16.8	13.8
06	4.2	3.5	7.1	6.2	4.8	3.9	7.7	6.7	6.5	5.3	9.9	8.6	8.3	6.8	12.5	10.8	10.1	8.3	14.9	13.0	12.9	10.5	19.1	16.6
07	5.4	4.4	8.6	7.5	6.1	5.0	9.4	8.1	8.4	6.9	12.1	10.5	10.8	8.9	15.3	13.3	13.1	10.7	18.4	16.0	16.7	13.7	23.5	20.5
08	6.2	5.1	9.9	8.6	6.9	5.7	10.8	9.4	9.4	7.7	13.8	12.0	12.1	9.9	17.5	15.2	14.6	12.0	21.0	18.2	18.7	15.3	26.9	23.4
09	6.6	5.4	10.8	9.4	7.4	6.0	11.5	10.0	9.8	8.1	14.5	12.7	12.6	10.3	18.2	15.8	15.2	12.5	21.8	19.0	19.5	16.0	28.0	24.3
10	7.2	5.6	11.5	10.0	7.8	6.1	12.2	10.6	10.1	8.6	15.1	13.1	13.2	11.5	18.7	16.3	15.6	13.6	22.3	19.4	19.8	15.5	28.7	25.0
11	8.1	6.3	12.4	10.8	8.8	6.8	13.0	11.3	11.2	9.1	15.9	13.9	14.1	12.3	19.7	17.1	16.8	14.5	23.5	20.4	21.6	16.9	30.2	26.2
12	9.0	7.1	13.3	11.6	9.8	7.6	14.0	12.2	12.4	9.7	17.1	14.9	15.7	12.6	21.0	18.3	18.8	14.9	25.0	21.8	24.2	18.9	32.0	27.9
13	9.8	7.6	13.8	12.0	10.6	8.3	14.6	12.7	13.6	10.6	17.8	15.5	17.2	13.4	21.9	19.1	20.7	16.1	26.1	22.7	26.6	20.7	33.4	29.1
14	10.2	8.2	14.0	12.2	11.1	9.0	14.8	12.9	14.4	11.7	18.1	15.8	18.2	14.8	22.3	19.4	21.9	17.8	26.6	23.1	28.2	22.8	34.0	29.6
15	10.3	8.4	14.0	12.2	11.3	9.2	14.8	12.9	14.8	12.0	18.1	15.7	18.7	15.2	22.3	19.4	22.6	18.3	26.5	23.0	28.9	23.4	33.8	29.4
16	10.2	8.2	13.7	11.9	11.2	9.1	14.5	12.6	14.6	11.8	17.8	15.5	18.6	15.0	21.9	19.1	22.3	18.1	26.0	22.6	28.6	23.1	33.3	29.0
17	9.8	7.9	13.2	11.5	10.8	8.8	14.1	12.2	14.2	11.5	17.3	15.1	18.1	14.7	21.4	18.6	21.8	17.7	25.5	22.2	27.9	22.6	32.6	28.4
18	9.1	6.7	12.8	11.0	10.1	7.5	13.6	11.7	13.4	9.9	16.9	14.5	17.1	12.7	20.9	18.0	20.7	15.3	24.9	21.4	26.4	19.5	31.9	27.4
19	8.0	5.9	12.2	10.5	8.9	6.6	13.1	11.3	11.9	8.8	16.3	14.0	15.1	11.2	20.1	17.3	18.2	13.5	24.0	20.6	23.2	17.2	30.7	26.4
20	6.7	4.9	11.7	10.1	7.4	5.5	12.5	10.8	9.7	7.2	15.5	13.3	12.3	9.1	19.1	16.4	14.8	10.9	22.7	19.5	18.8	13.9	28.9	24.9
21	5.5	4.1	11.5	9.9	6.0	4.5	12.2	10.5	7.8	5.7	14.9	12.8	9.8	7.2	18.3	15.7	11.7	8.7	21.7	18.6	14.9	11.0	27.6	23.7
22	4.9	3.8	11.5	9.3	5.3	4.1	12.2	9.9	6.7	5.2	14.8	12.0	8.4	6.5	18.1	14.7	10.0	7.8	21.5	17.4	12.8	9.9	27.3	22.1
23	4.7	3.7	11.5	9.3	5.1	4.0	12.2	9.9	6.4	5.0	14.8	12.0	8.0	6.2	18.2	14.7	9.5	7.4	21.6	17.5	12.1	9.4	27.4	22.2
24	4.7	3.6	10.9	8.9	5.1	4.0	11.7	9.4	6.5	5.0	14.3	11.6	8.1	6.3	17.6	14.3	9.6	7.5	20.9	17.0	12.3	9.6	26.6	21.6

Figure 1-33. ISD book propagation chart example of MUF/FOT.

AFRICA I

LOWEST USEFUL HIGH FREQUENCIES (LUF)

MARCH APRIL

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

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

	-1-		-2-		-3-		-4-		-5-		-6-		-7-	
	10	110	10	110	10	110	10	110	10	110	10	110	10	110
LT						160 KILOMETERS		(100 MILES)						
02	2.9	3.8	2.9	3.8	2.8	3.8	2.8	3.8	2.7	3.8	2.0	3.8	2.0	2.0
04	2.6	3.6	2.6	3.6	2.6	3.6	2.6	3.6	2.0	3.6	2.0	2.6	2.0	2.6
06	4.2 C	2.6	4.2 B	2.6	4.1	2.0	4.1	2.0	4.0	2.0	4.0	2.0	4.0	2.0
08	2.0	3.8	2.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10	4.0	4.9	2.8	4.9	2.3	4.9	2.0	4.9	2.0	3.1	2.0	3.0	2.0	2.8
12	4.7	7.3	4.7	7.3	3.7	7.3	2.8	7.3	2.6	7.3	2.0	4.6	2.0	3.3
14	5.8	9.1	5.8	9.1	2.9	9.1	2.3	9.1	2.0	3.4	2.0	3.3	2.0	3.2
16	6.2	8.8	6.2	8.8	2.0	8.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
18	5.2	7.2	5.2	7.2	5.2	7.2	5.2	2.0	5.1	2.0	5.0	2.0	4.8	2.0
20	3.7	5.4	3.6	5.4	3.4	5.4	2.0	5.4	2.0	5.4	2.0	3.0	2.0	3.0
22	2.6	3.2	2.5	3.1	2.3	3.0	2.0	2.8	2.0	2.1	2.0	2.0	2.0	2.0
24	2.9	4.7	2.9	4.7	2.9	4.7	2.9	4.7	2.0	4.7	2.0	2.0	2.0	2.0
LT						400 KILOMETERS		(250 MILES)						
02	5.0 D	9.7 C	5.0 C	6.5	2.0	3.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
04	3.5 C	7.0 C	2.0	4.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
06	4.0 B	7.7 C	2.0	4.2	2.0	2.5	2.0	2.2	2.0	2.0	2.0	2.0	2.0	2.0
08	3.4	4.9	3.3	4.1	3.1	4.0	2.7	3.7	2.3	3.1	2.0	3.0	2.0	2.8
10	4.7	7.6	4.3	5.8	4.2	5.7	4.2	5.6	3.9	5.6	3.5	5.4	3.4	4.9
12	5.8	14.0 E	5.1	7.8	5.0	6.5	4.9	6.4	4.9	6.3	4.6	6.3	4.0	6.2
14	5.4	14.8 E	4.4	6.9	4.3	5.2	4.3	5.1	4.2	5.1	4.0	5.0	3.5	5.0
16	5.9	14.5 E	3.8	5.0	3.2	4.8	3.1	4.6	2.9	4.1	2.7	3.5	2.1	3.4
18	10.1 D	13.6 E	6.4	9.2	3.7	4.5	2.3	3.3	2.0	2.9	2.0	2.2	2.0	2.0
20	7.4 C	12.5 D	3.9	5.5	2.6	3.1	2.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0
22	5.3 D	12.2 D	3.5	7.0	2.0	3.3	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
24	5.1 D	11.7 C	3.5	6.5	2.0	3.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
LT						800 KILOMETERS		(500 MILES)						
02	6.5 E	11.9 C	6.5 C	8.4	5.1	6.4	3.0	4.3	2.0	2.6	2.0	2.0	2.0	2.0
04	5.0 D	9.4 D	5.0 C	9.4 C	5.0 C	5.8	2.0	2.9	2.0	2.0	2.0	2.0	2.0	2.0
06	6.5 C	9.9 D	6.5 C	9.9 C	6.5 B	6.8	3.2	4.2	2.7	3.0	2.2	2.8	2.0	2.7
08	9.4 C	11.0	6.3	8.0	4.9	6.1	4.7	4.9	4.3	4.8	3.9	4.7	3.7	4.7
10	8.0	11.6	6.2	9.1	6.2	8.4	6.1	8.3	6.0	8.3	5.6	8.1	5.1	7.8
12	10.2	17.1 D	8.1	11.8	7.4	9.5	7.3	9.3	7.2	9.3	6.7	9.2	6.0	9.1
14	14.4 D	18.1 E	8.1	11.3	6.8	8.2	6.7	7.9	6.6	7.8	6.5	7.8	5.8	7.7
16	14.6 D	17.8 D	10.0	11.3	6.5	7.7	5.2	5.9	5.1	5.8	4.8	5.7	4.2	5.6
18	13.4 C	16.9 D	13.4 B	12.3	8.7	8.8	5.8	6.2	4.3	5.0	3.5	3.9	3.3	3.7
20	9.7 D	15.5 C	9.7 C	9.3	5.8	6.7	4.0	4.5	2.9	3.2	2.3	2.6	2.0	2.1
22	6.7 E	14.8 C	6.7 C	9.1	4.7	6.8	3.0	4.5	2.3	3.2	2.0	2.0	2.0	2.0
24	6.5 E	11.1	6.5 C	8.6	4.7	6.5	2.9	4.4	2.0	3.0	2.0	2.0	2.0	2.0

Figure 1-34 ISD book propagation chart example of LUF.

ADAK, ALASKA

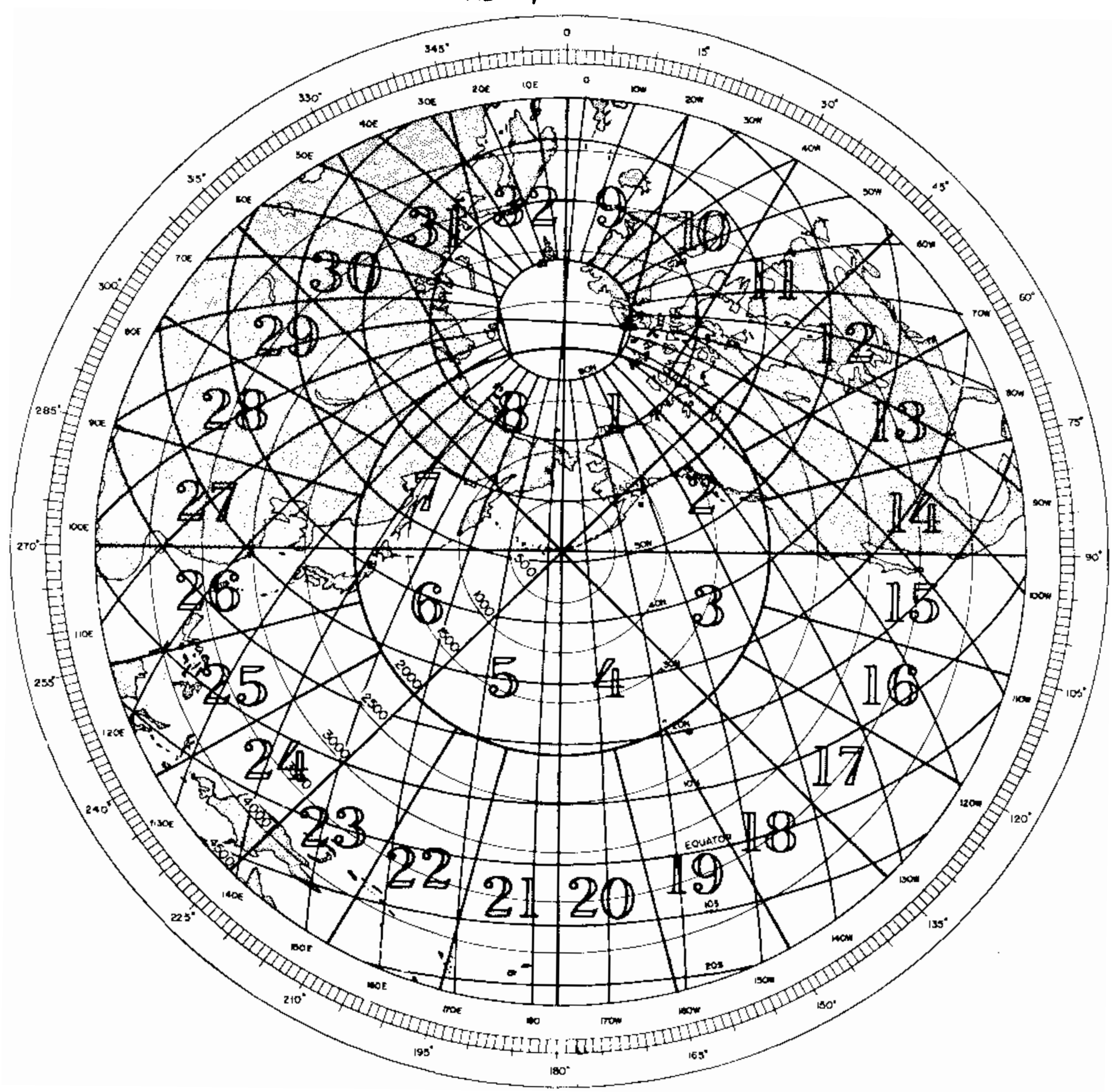


Figure 1-35. A/G book geographic sector example.

77 x 3490

STATION - ADAK, ALASKA | MAXIMUM USABLE FREQUENCIES (MUFS IN MHZ) | MARCH APRIL

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(270 - 285DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	19.9	30.1	16.4	23.7	17.7	26.3
04	19.2	30.8	15.6	24.4	17.2	27.1
06	19.5	30.2	16.0	24.2	17.6	26.7
08	19.1	27.3	15.8	22.0	17.3	24.3
10	17.7	22.1	14.6	17.8	16.0	19.6
12	15.0	18.0	12.3	18.9	13.5	15.9
14	12.3	17.6	10.1	18.5	11.1	15.6
16	11.1	17.0	9.1	17.8	10.0	15.0
18	12.2	16.6	10.0	17.5	11.0	14.7
20	14.6	[illegible]	11.5	[illegible]	12.6	17.1
22	19.0	[illegible]	15.6	[illegible]	17.2	24.6
24	19.8	[illegible]	16.2	[illegible]	17.8	26.6

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	19.0	[illegible]	19.9	[illegible]	17.7	31.2
04	18.4	[illegible]	19.2	[illegible]	17.2	31.9
06	18.8	28.8	19.5	30.2	17.6	31.1
08	18.4	26.1	19.1	27.3	17.3	28.1
10	17.0	21.0	17.7	22.1	16.0	22.7
12	14.4	17.1	15.0	18.0	15.3	18.6
14	11.8	16.7	12.3	17.6	12.5	18.2
16	10.6	16.1	11.1	17.0	11.3	17.5
18	11.7	15.8	12.2	16.6	12.5	17.2
20	12.9	19.2	13.4	20.2	13.6	20.9
22	17.7	26.8	18.3	28.0	16.6	28.7
24	19.1	28.7	19.8	30.3	17.8	31.4

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EAST SOUTHEAST (285 - 300 DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	18.8	27.5	15.7	21.7	16.7	24.1
04	18.3	28.5	14.9	22.6	16.5	25.0
06	18.4	28.7	15.1	23.0	16.6	25.4
08	18.5	26.4	15.4	21.3	16.8	23.5
10	16.9	22.1	14.0	17.8	15.4	19.6
12	14.7	17.9	12.1	18.7	13.3	15.8
14	11.9	16.8	9.7	17.7	10.7	14.9
16	10.6	16.1	8.7	16.9	9.5	14.2
18	11.2	15.5	9.5	16.4	10.4	13.7
20	13.2	17.3	[illegible]	13.7	[illegible]	15.1
22	17.0	24.9	[illegible]	[illegible]	[illegible]	21.6
24	18.9	27.4	[illegible]	[illegible]	[illegible]	24.0

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	17.9	26.0	[illegible]	[illegible]	[illegible]	28.5
04	17.6	27.0	[illegible]	28.5	[illegible]	29.5
06	17.7	27.3	18.4	28.7	16.6	29.5
08	17.9	25.2	18.5	26.4	16.8	27.2
10	16.3	21.1	16.9	22.1	15.4	22.7
12	14.1	17.0	14.7	17.9	15.0	18.4
14	11.4	16.0	11.9	16.8	12.1	17.4
16	10.2	15.3	10.6	16.1	10.8	16.6
18	11.1	14.8	11.6	15.5	11.9	16.1
20	12.5	16.7	13.0	17.6	13.3	18.2
22	14.9	22.1	15.5	23.2	14.0	23.8
24	18.2	25.9	18.9	27.4	17.0	28.4

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(300 - 315 DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	17.8	25.0	15.0	19.7	15.8	21.8
04	17.7	26.1	14.4	20.7	15.9	22.9
06	17.6	26.9	14.5	21.5	15.9	23.8
08	17.9	25.3	14.8	20.4	16.3	22.5
10	15.9	21.8	13.2	17.5	14.5	19.3
12	14.0	17.8	11.5	18.7	12.7	15.8
14	11.4	16.3	9.4	17.1	10.3	14.4
16	10.3	15.5	8.4	16.3	9.3	13.7
18	10.6	14.9	8.9	15.7	9.8	13.2
20	12.0	16.1	[illegible]	[illegible]	10.1	14.1
22	14.8	21.0	[illegible]	[illegible]	[illegible]	17.5
24	17.7	24.7	[illegible]	[illegible]	[illegible]	21.9

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	17.0	23.6	[illegible]	[illegible]	[illegible]	25.9
04	17.0	24.7	[illegible]	[illegible]	15.9	27.1
06	17.0	25.6	17.6	26.9	15.9	27.7
08	17.3	24.1	17.9	25.3	16.3	26.0
10	15.4	20.8	15.9	21.8	14.5	22.4
12	13.5	16.9	14.0	17.8	14.3	18.4
14	11.0	15.5	11.4	16.3	11.6	16.8
16	9.9	14.7	10.3	15.5	10.5	16.0
18	10.7	14.2	11.2	14.9	11.4	15.4
20	10.8	15.5	11.2	16.3	11.5	16.9
22	11.9	17.8	12.4	18.7	12.7	19.3
24	15.7	23.5	16.4	24.6	14.7	25.3

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(315 - 330DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	16.7	22.4	13.2	17.9	14.6	19.8
04	17.2	23.1	14.0	18.9	15.4	21.0
06	16.8	24.8	13.8	19.9	15.2	21.9
08	16.9	23.6	14.0	19.0	15.3	21.0
10	14.7	20.8	12.1	16.7	13.3	18.4
12	13.1	17.5	10.8	18.4	11.9	15.5
14	11.1	15.8	9.1	16.6	10.0	14.0
16	10.3	15.1	8.4	15.9	9.3	13.3
18	10.5	14.8	8.8	15.6	9.6	13.0
20	11.5	15.8	8.7	12.7	9.6	14.1
22	13.2	[illegible]	9.6	[illegible]	10.6	14.9
24	15.8	[illegible]	11.2	[illegible]	12.4	17.3

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	15.6	[illegible]	16.4	[illegible]	14.6	24.0
04	16.5	[illegible]	17.2	[illegible]	15.4	24.8
06	16.2	[illegible]	16.8	[illegible]	15.2	25.6
08	16.3	22.5	16.9	23.6	15.3	24.2
10	14.2	19.8	14.7	20.8	13.3	21.4
12	12.6	16.7	13.1	17.5	13.4	18.1
14	10.7	15.1	11.1	15.8	11.3	16.4
16	9.9	14.3	10.3	15.1	10.5	15.6
18	10.5	14.0	11.0	14.8	11.2	15.3
20	9.8	15.5	10.2	16.4	10.4	17.0
22	10.1	15.3	10.6	16.1	10.8	16.6
24	12.3	17.8	12.8	18.7	13.2	19.3

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SOUTH SOUTHEAST (330 - 345 DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	15.5	19.6	11.8	20.5	13.0	16.8
04	16.8	20.0	13.6	21.3	15.0	17.4
06	15.8	21.2	13.0	16.8	14.3	18.6
08	15.4	21.5	12.7	17.3	14.0	19.1
10	13.3	19.1	11.0	15.4	12.0	16.9
12	12.2	16.8	10.0	13.5	11.0	14.9
14	11.0	15.4	9.0	16.1	9.9	13.6
16	10.6	15.0	8.6	15.7	9.5	13.2
18	11.0	14.9	9.0	15.7	9.9	13.1
20	11.8	16.2	9.5	17.2	10.4	14.3
22	12.9	16.7	[illegible]	16.6	[illegible]	13.8
24	14.3	18.3	[illegible]	[illegible]	[illegible]	14.8

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	12.5	17.5	[illegible]	18.5	[illegible]	19.2
04	14.4	20.0	[illegible]	21.2	[illegible]	22.0
06	15.2	21.6	[illegible]	22.7	[illegible]	23.4
08	14.9	20.5	15.4	21.5	14.0	22.1
10	12.8	18.2	13.3	19.1	13.6	19.7
12	11.7	16.0	12.2	16.8	12.4	17.4
14	10.6	14.6	11.0	15.4	11.2	15.9
16	10.1	14.2	10.6	15.0	10.8	15.5
18	10.6	14.1	11.1	14.9	11.4	15.4
20	10.4	15.4	10.8	16.3	11.1	16.8
22	10.2	14.5	10.7	15.2	10.9	15.8
24	11.0	15.1	11.6	15.9	11.9	16.5

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(345 - 360 DEGREES)

UT	2000 NM 10-SSN-110		2500 NM 10-SSN-110		3000 NM 10-SSN-110	
02	14.8	17.9	11.4	18.4	12.6	15.0
04	15.5	18.1	11.7	18.6	12.9	15.2
06	14.2	18.2	12.2	18.3	13.4	15.1
08	13.4	18.4	11.4	14.1	12.5	15.6
10	12.0	17.3	9.8	13.8	10.8	15.3
12	11.3	15.9	9.3	12.8	10.2	14.1
14	11.0	14.9	9.0	15.7	9.9	13.2
16	11.0	14.9	9.0	15.7	9.9	13.1
18	11.4	15.2	9.1	16.0	10.1	13.3
20	12.4	16.4	10.5	17.4	11.1	14.4
22	13.1	16.6	[illegible]	[illegible]	[illegible]	14.0
24	13.7	17.2	[illegible]	[illegible]	[illegible]	14.3

UT	3500 NM 10-SSN-110		4000 NM 10-SSN-110		4500 NM 10-SSN-110	
02	11.8	15.4	[illegible]	[illegible]	12.7	16.9
04	12.5	16.9	[illegible]	[illegible]	13.6	18.5
06	13.8	17.7	[illegible]	[illegible]	[illegible]	19.5
08	13.4	18.5	13.9	19.4	12.5	20.0
10	11.5	16.4	12.0	17.3	12.2	17.8
12	10.9	15.1	11.3	15.9	11.5	16.4
14	10.6	14.2	11.0	14.9	11.2	15.4
16	10.5	14.2	11.0	14.9	11.3	15.4
18	10.8	14.4	11.4	15.2	11.7	15.7
20	12.0	15.4	12.5	16.2	12.8	16.8
22	11.6	14.6	12.1	15.4	12.4	16.0
24	11.6	14.5	12.1	15.3	12.4	15.9

Figure 1-36. A/G book propagation chart example of MUF.

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

The Institute has continued work on the development of a new MF sky-wave propagation model in FY 84 under the MF Propagation Studies project. The higher power AM stations south of the United States have caused interference in some United States AM broadcast service areas. Currently accepted sky-wave prediction models tend to underestimate field strengths in the Western Hemisphere. The Institute monitored signals from selected Central and South American stations. The data are being analyzed, and to date no modifications to the prediction models have been made.

Automated Performance Analysis of Ground Wave Circuits. There has recently been renewed interest by the U.S. military in communications at HF (3-30 MHz) and lower frequencies. Communications using UHF and microwave satellites are quite vulnerable during a military conflict. A satellite can be jammed or destroyed easily, and cannot singly be relied upon to provide uninterrupted communications. High frequencies and lower communications frequencies could provide a backup to UHF and microwave satellites. In the event of widespread nuclear explosions, communications via the ionosphere at HF and lower frequencies may not be possible. However, the ground wave at HF and lower frequencies will provide reliable communications capability under these conditions.

A need exists for an automated systems performance prediction technique to aid in the estimation of performance of communications circuits using the ground wave as the primary mode of propagation. A computer program is presently being developed at ITS for the U.S. Army Communications Command-Communications Electronics Engineering Installation Agency (USACC-CEEIA), Fort Huachuca, AZ, that will provide an automated systems performance technique to aid in the estimation of performance of communications circuits that use the ground wave as the primary mode of propagation.

The computer program Automated Performance Analysis of Ground Wave Circuits (GWAPA) will be a structured set of a number of computer programs that predict propagation loss, noise, system calculations, antenna factors and intermodulation distortion. The program contains three separate propagation models: a Smooth Earth model (SE), a Smooth Earth Mixed Path model (SEMP), and an irregular terrain model that includes forested and built-up terrain (WAGSLAB).

The computer program is being designed with a major emphasis on user friendliness and convenience. The program will first ask for the required input data to assess communication circuit performance and determine the run time and accuracy for all three models. The user will be presented with a table displaying this information. The user will then select the appropriate model based on run time and accuracy. In many cases where the terrain is relatively smooth, the two faster programs, SE and SEMP, will provide an answer of sufficient accuracy, but in the remaining cases the user may want the better accuracy of WAGSLAB. The WAGSLAB program is believed to be the most accurate loss prediction technique available over irregular terrain based on measured data, but this program requires a much longer computation time at high frequencies and rough terrain. Over relatively smooth paths and for most frequencies, the smooth earth models give similar accuracies with a much shorter run time.

The entire program GWAPA is expected to be delivered to the sponsor by January 85.

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

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

An effort is being made to effectively run the model on a smaller computer. This effort is still going on. Also, small reports are being made describing the input and output of each of the 15 programs that used the model.

Two further tasks are currently under way:

(1) production of computer-generated propagation and interference predictions as requested by the FAA

(2) ongoing comparisons of predictions with experimental data and with other models.

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

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

With the ultimate goal of developing an overall, comprehensive, usable noise model for application to telecommunication problems, the Institute has completed the necessary step of developing an updated and improved atmospheric radio noise model. The existing worldwide atmospheric-noise model (CCIR Report 322) was developed from approximately 4 years of measurements from a worldwide network of 16 measurement stations. Since the publication of CCIR Report 322 in 1963, much additional data have become available. The original network of measurement stations has made an additional 5 years (longer in a few cases) of measurements, and many years of data are available from other locations, primarily from 10 measurement locations within the USSR. All this additional data have been analyzed and an updated model has been prepared. The locations for the measurement data are:

<u>Worldwide Network Locations (CCIR 322)</u>

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

<u>New Locations</u>

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

Figure 1-37 shows the corrections (decibels) to the current CCIR Report 322 estimates (F_{am}, dB above KT_0b at 1 MHz) for the 3-month period December, January, and February and the 4-hour time block 0000-0004. Figure 1-38 gives the new atmospheric radio noise estimates for this 3-month, 4-hour time block. There are 24 (four 3-month periods and six 4-hour time blocks) sets of estimates as in the current CCIR Report 322. These maps of expected noise levels were obtained from numerical mapping techniques so numerical algorithms for obtaining the new noise estimates are also available.

1.4.3 Applications of Propagation Predictions

Many theoretical and experimental studies have been performed by NTIA/ITS in its endeavors to construct propagation models and prediction methods. The ultimate goal remains the application of these prediction methods or problems related to telecommunications issues.

An example of the application of predictions is the HF Broadcasting Conference Studies project. The Institute is playing a major role in developing the U.S. positions for the Second Session of the HF Broadcasting Conference (HFBC) that will be held in Geneva in January/February 1987. The Institute had developed a computer-based method to determine the impact on U.S. broadcasting objective of changes in technical criteria prior to the First Session of HFBC held in Geneva in January/February 1984. This computer-based method aided policy makers and frequency managers in determining the U.S. positions at the First Session.

The First Session of the HFBC decided the criteria that are to be used in planning the HF spectrum for broadcasting purposes. These criteria relate to the methods to be used to estimate sky-wave field strength, radio noise, and antennas, as well as the procedures to be used to begin to satisfy the requirements for broadcasting submitted by the various administrations of the International Telecommunication Union. The Institute is in the process of implementing the methods decided at the First Session of the HFBC onto the Boulder Laboratories Computer Facility. The program is constructed to perform the following functions in sequence:

1. accesses requirements for HF broadcasting submitted by administrations

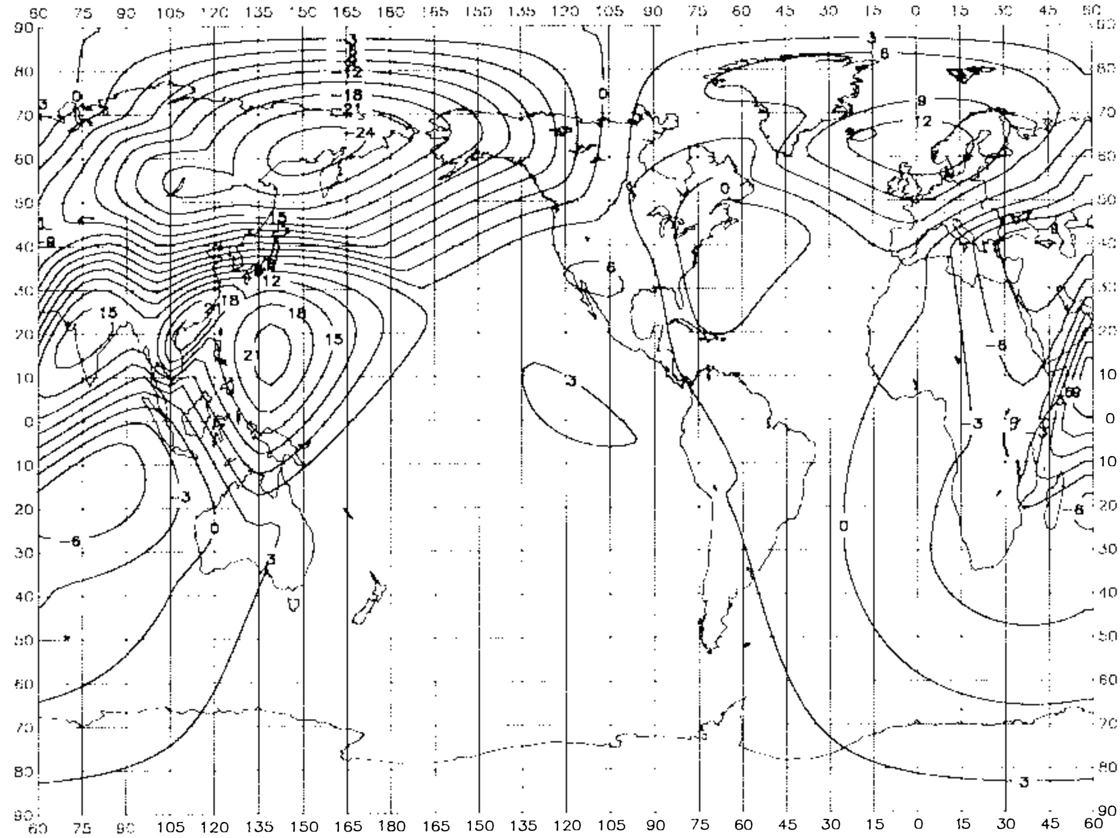

Figure 1-37. Corrections to expected values of atmospheric radio noise (F_{am}, dB above KT_ob at 1 MHz) given by the current CCIR Report 322 for December, January, February, 0000-0400 hours.

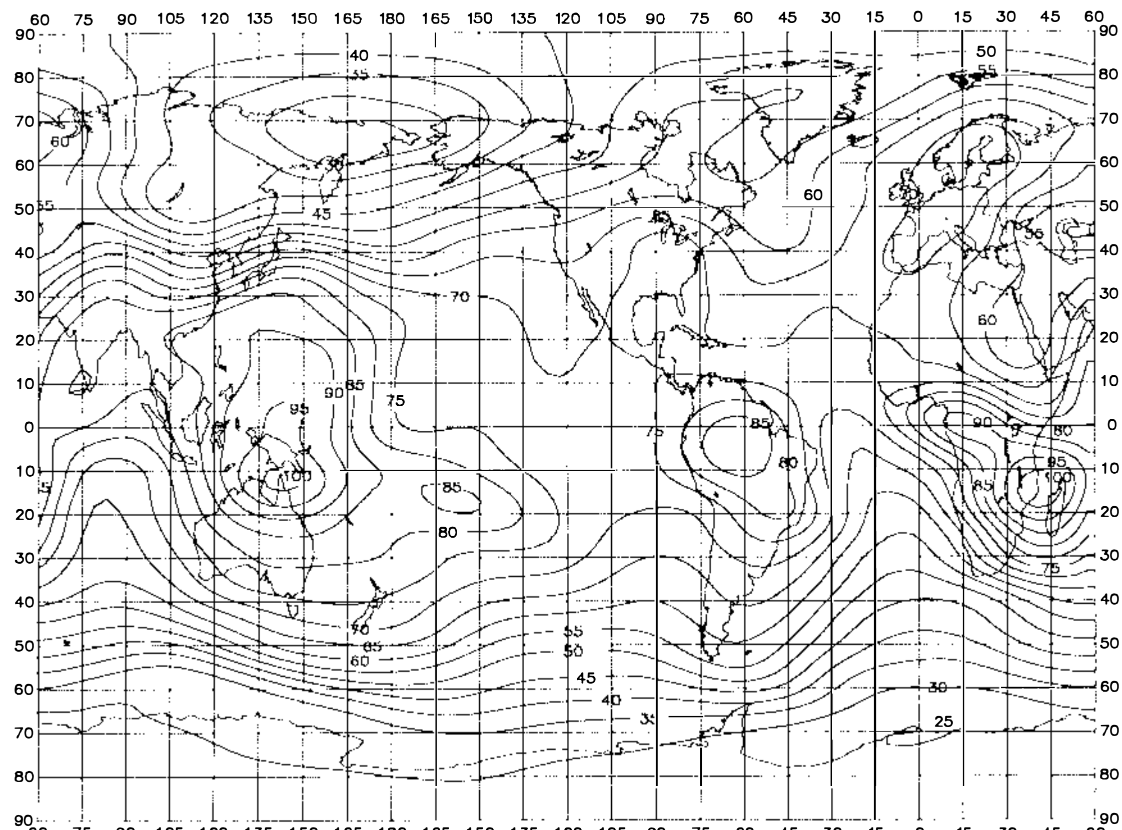

Figure 1-38. The "new" estimates of the values of atmospheric radio noise, (F_{am}, dB above KT_ob at 1 MHz) for December, January, February, 0000-0400 hours.

2. performs propagation analysis and determines appropriate bands to satisfy requirements

3. applies rules for requirements applicable for a specific season

4. selects technical characteristics in accord with requirements

5. calculates broadcast reliabilities in the presence of noise only to determine the level of protection given to service

6. assigns specific frequencies to requirements and assesses the capability of frequency assignments

7. performs broadcast reliabilities in the presence of noise and interference

8. determines if all requirements are met

9. produces plans for broadcasting on a seasonal basis.

Once completed, the program will be used by personnel in the United States to determine the form in which the United States will submit their broadcasting requirements and the positions that will be taken at the Second Session of the HFBC.

The Institute has undertaken a study to determine the link margin required for a direct broadcasting satellite service operating in the HF and VHF bands. The specific aspects of HF/VHF direct broadcast satellite service (DBS) considered were:

- determining the percentage of time that a given frequency assigned to the HF broadcasting service will penetrate the ionosphere to a given target area
- estimating the ground coverage provided by signals transmitted from a satellite
- estimating the ionospheric losses for those signals transmitted from a satellite that reach the ground
- determining the percentage of time that frequencies between f_1 and about 100 MHz will be impacted by sporadic E, ionospheric gradients, and other anomalous ionospheric structures
- identifying potential interference problems to the HF broadcasting service resulting from a DBS system
- determining the range of Faraday rotation expected for signals in the range from the lowest penetration frequency, f_1, to about 100 MHz that propagate through the ionosphere
- assessing the likelihood that fading or scintillation exceeding a given level will occur for the frequencies in the range f_1 to 26 MHz and 60 MHz to 100 MHz
- determining overall link margins.

Satellites in geostationary orbits with high and low elevation angles and in hovering type orbits were considered.

Procedures were developed to determine the percentage of time a signal penetrates the ionosphere, and the area on the surface of the Earth covered by the signal was described. Also, the methods used to determine the ionospheric losses associated with the penetration frequencies were studied. Interference and ducting effects were considered as was Faraday rotation of the plane of polarization of a transionospheric signal. The impact of ionospheric scintillation on HF/VHF transionospheric propagation was also studied.

The high frequency part of the electromagnetic spectrum can be used to provide broadcasting services from satellites with certain limitations. These limitations arise primarily from the impact of the ionosphere upon radio waves that are propagated through it.

The highest penetration frequencies needed to provide coverage to a particular area occur during solar maximum. This is exactly as expected on the basis of the known solar cycle variation of foF2, the F2 region critical frequency. The lowest penetration frequencies are needed during local winter evenings. The highest penetration frequencies are generally needed during the equinoctial periods. The location of the satellite used in DBS operations relative to the intended reception zone exerts a large influence upon the value of the penetration frequency. The lowest values of penetration frequency occur when the satellite is directly above the intended target area. For low-latitude broadcast zones, satellites in geostationary orbit require penetration frequencies that can be greater than those allocated to the HF broadcasting services. Use of orbiting satellites (such as an 8-hour orbit) or satellites that hover above a given region will lead to much smaller required penetration frequencies to cover an entire broadcast zone.

Table 1-3 gives typical 90 percent penetration frequencies needed to ensure DBS service over the entire year to low-latitude and middle-latitude locations for solar-minimum and solar-maximum conditions and for various orbital configurations. Also given in the table is the ionospheric loss associated with the 90-percent penetration frequency. It is safe to conclude that an upper limit of 3 dB will account for the ionospheric loss at all frequencies in the HF band that penetrate the ionosphere 90 percent of the time. An additional margin is required to overcome the problems associated with Faraday rotation of the plane of polarization of a linearly polarized signal that is transmitted through the ionosphere. The cost, in terms of decibels, needed to operate a DBS with circularly polarized signals is estimated to be 3 dB. This, too, is listed in Table 1-3.

If frequencies in the HF broadcasting service can be used in DBS operations, frequencies in the VHF broadcast bands could be used. The use of VHF signals will reduce the

Table 1-3. Summary of Results for DBS Satellite Calculations

Satellite Type, Orbit, Solar Condition, Reception Zone	90 Percent Penetration Frequency (MHz)	90 Percent Ionospheric Loss (dB)	Polarization Margin (dB)
HF/DBS; GSHE; SS Min; Low	16	3	3
HF/DBS; GSHE; SS Max; Low	26	3	3
HF/DBS; GSHE; SS Min; Mid	20	3	3
HF/DBS; GSHE; SS Max; Mid	32	3	3
HF/DBS; GSLE; SS Max; Low	40	2	3
HF/DBS; GSLE; SS Max; Mid	40	2	3
HF/DBS; MOL; SS Max; Mid	10	3	3
HF/DBS; 8Hr; SS Max; Low	18	2	3
VHF/DBS	Any >60	1	3

KEY:

HF/DBS:	HF Direct Broadcast Satellite
VHF/DBS:	VHF Direct Broadcast Satellite
GSHE:	Geostationary Orbit High Evevation Angle
GSLE:	Geostationary Orbit Low Elevation Angle
MOL:	Molniya orbit
8HR:	8-hour orbit
SS Min:	Solar Minimum Conditions
SS Max:	Solar Maximum Conditions
Low:	Low-Latitude Reception Zone
Mid:	Middle-Latitude Reception Zone

ionospheric loss to less than 1 dB, and the VHF signals will provide the required coverage to any reception zone assuming realistic orbital configurations. The need to transmit circularly polarized signals even at VHF, however, still requires the 3 dB polarization margin.

A major limitation to the operation of an effective direct broadcasting satellite service is the occurrence of ionospheric scintillation. The expected magnitude of the scintillation and its occurrence in time and space reveal that the operation of a DBS service during the evening broadcasting hours at low-latitude target areas is expected to be adversely impacted over much of the solar cycle. The use of multiple frequencies and multiple satellites will not ameliorate this situation totally. There exists little or no data that can be directly related to trans-ionospheric HF signals observed at low latitudes.

Ground Wave Measurements in the HF Band. The project supports a requirement by the Defense Nuclear Agency (DNA). It incorporates the results of HF ground-wave prediction work undertaken by ITS to form an important part of current DNA effort to improve and upgrade communication systems for the military in Europe.

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

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

A van-type truck with a receiver system has been instrumented to make mobile measurements. Data are collected, recorded, and evaluated as the vehicle is driven along radials emanating from a fixed transmitter. Measurements are made of received field strength versus geographic location of the receiver van. Since data analysis for model comparison requires assurance of homogeneity of measured/predicted differences that are stratified for selected comparisons, a substantial amount of data must be taken. In the receiver van, the use of computer control of instrumentation, data acquisition, and recording systems facilitates the collection of large amounts of data.

Measurements of radio propagation path loss have been made over four paths in the 3 to 30 MHz band. The paths are of lengths up to 45 km in the Boulder, CO, area. They range from smooth to mountainous terrain, from open areas with few or no man-made structures to suburban areas with building heights up to three stories, and from open spaces with little vegetation to heavily forested regions. On one path, measurements have been made with and without snow cover. The measurements are made in the daytime and because of the short paths, the primary mode of propagation was ground wave. Measurements of the ground constants at each of the four measurement frequencies are made at the transmitter site using the wave-tilt measurement technique.

Figure 1-39 shows the terrain profile for one of the measurement paths. The path is over relatively flat terrain with few man-made structures taller than two stories and with no forested areas. Figures 1-40 and 1-41 show a comparison of measured and predicted median losses along the path for two different frequencies. The rough curve in each figure is the measured loss. The dashed curve is the predicted smooth-earth prediction with the electrical ground constants given in the legend. The other solid-line curves on each plot are the WAGNER predictions. The top curve is Curve 1 and has the ground constants characteristics given in the legend. The second curve from the top is Curve 2, etc. Several sets of ground constants are used for each path in an attempt to bracket or bound the measured losses.

A complete description of the paths, measurement technique, and prediction procedure is provided in NTIA Report 84-151, "Measurements and Predictions of HF Ground Wave Radio Propagation over Irregular, Inhomogeneous Terrain."

VOA HF Propagation Studies. The Institute has continuously provided support to the Voice of America (VOA) Frequency Division for over 10 years. This support takes the form of providing VOA with HF predictions that are used to plan their seasonal broadcast schedules as well as providing a means for VOA engineering personnel to directly access the computer facility housed in the Boulder Laboratories. At times, the Institute has also undertaken specific tasks for the VOA to assist them in more effectively providing their broadcast service. In 1984, ITS provided to VOA HF predictions on a bimonthly basis for approximately 105 circuits. The predictions are used as guidelines in the selection of the final frequencies that are decided at Frequency Coordination meetings

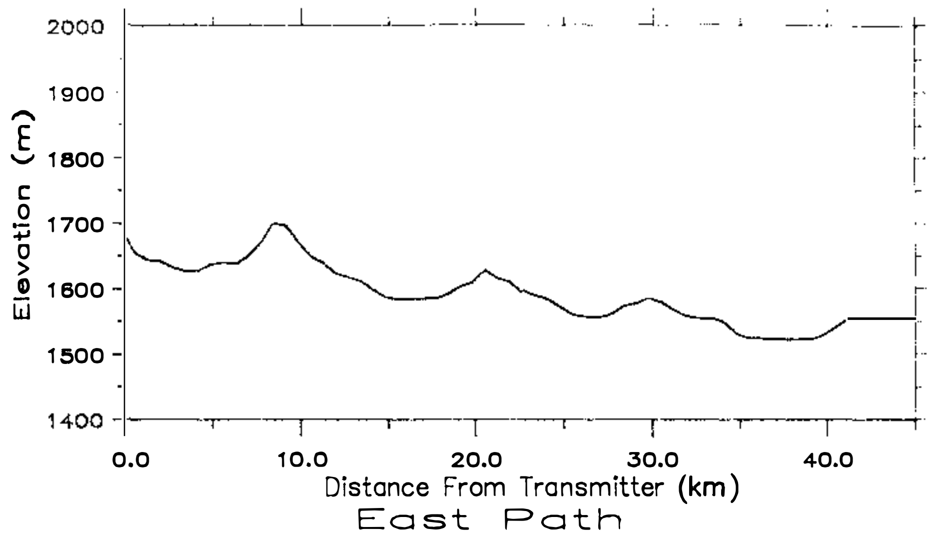

Figure 1-39. Terrain profile for HF ground-wave measurements.

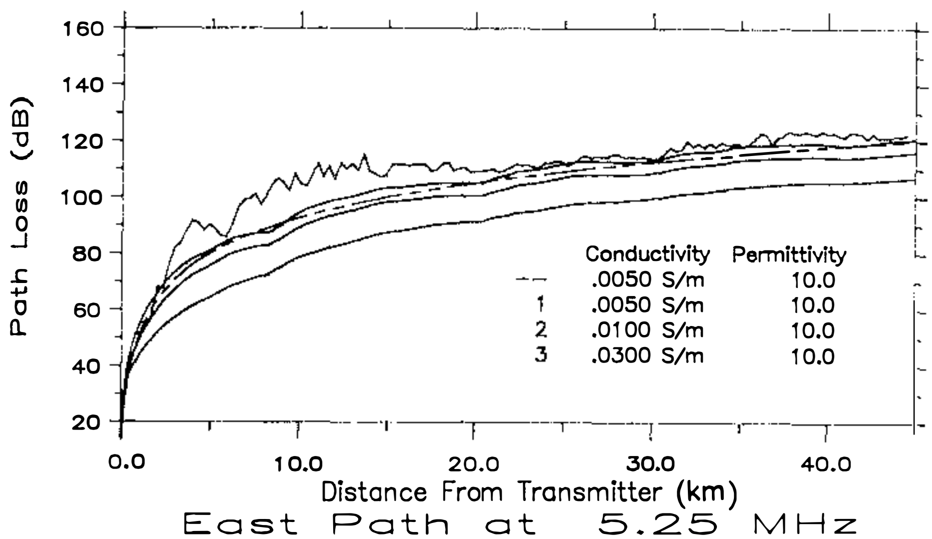

Figure 1-40. Predicted and measured median loss for the path at 5.25 MHz.

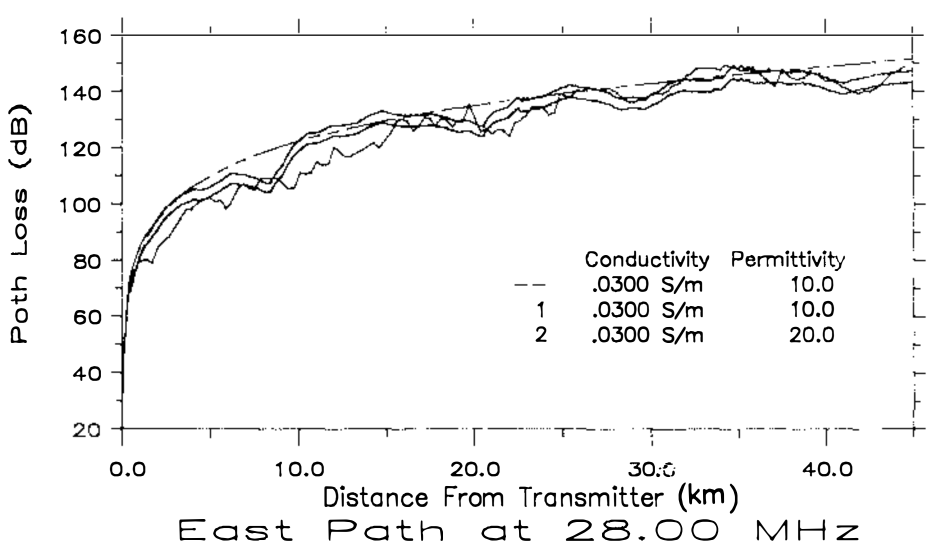

Figure 1-41. Predicted and measured median loss for the path at 28 MHz.

between the Voice of America, Radio Free Europe/Radio Liberty, the BBC, Deutsche Welle, Radio Nederland, and Radio Canada International.

U.S. Coast Guard Consultation. The U.S. Coast Guard is now participating with other countries in a Digital Selective Calling (DSC) network of shore stations monitoring four maritime frequencies. The DSC signal consists of a 7.5 s burst of Non-coherent Frequency Shift Keying (NCFSK) digital information.

The project purpose is to analyze the use of the DSC network for emergency distress messages. The study determines the probability of successful communications for circuits from ships in the North Atlantic ocean areas to the network of 26 shore stations.

The study has developed charts of the North Atlantic showing 10° sectors that represents a Simulated Ship Position (SSP), and then shows the probability of successful communication from SSP's to the network of 26 shore stations. It calculates reliabilities for four frequencies, four times of the day, three seasons of the year, and two sunspot numbers.

Each ship at a particular SSP is assumed to transmit 1 kW of power into a quarter-wave omnidirectional, vertical monopole antenna, and the shore station receives with a quarter-wave omnidirectional discone antenna. A signal-to-noise ratio (SNR) of 30 dB was required at each receiving site for a maximum bit error rate of 1 in 10^4. When the communication paths from each SSP to all shore stations can be considered to be statistically independent, the following algorithm calculates a combined communications probability for that SSP:

$$P_c = [1 - (1-R_1)(1-R_2) \times \dots \times (1-R_{26})]$$

where R_1 through R_{26} are the individual ship to shore circuit reliabilities.

In the cases where two shore stations are separated by less than 1500 km, the independent statistical assumption is not valid, and then the program uses the circuit of highest reliability, and ignores the other station.

Table 1-4 depicts the format of the output data, and Figure 1-42 shows an example of the area coverage charts that will be supplied. The output from this project will be used by the U.S. Coast Guard at the next International Maritime Organization Radiocommunication Sub-Committee meeting scheduled for September 12, 1984, in London, U.K., in order to estimate the usefulness of HF DSC for worldwide distress alerting.

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

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

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

This project was directed toward the development and/or implementation of simplified ground-wave considerations into a computer module that uses the same input as the IONCAP sky-wave model. This is intended to permit assessment of received signal strengths by ground-wave propagation compared to received signal strengths by sky-wave propagation.

Also included in this project is a study to extend the area coverage model QUILT to allow for azimuth-distance representation and to allow for user selection of the parameters to be presented.

A link performance analysis tool has been developed as a result of the Ground Network Communications Model (GNCM) project that allows a system designer or network analyzer to examine, in both a broad and detailed sense, the operation of a ground-based communication net. The model is valid over a 50 km by 50 km area, and with up to 300 nodes in the network. In the maximum size, the net would consist of 44,450 links. Using this tool, the overall parameters of the net are given in numbers of connected nodes and their connections. The designer is given the option of easily changing the network parameters (node location, antenna types, equipment types, etc.) 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

Table 1-4. Format of Reliability Data

SHORE STATIONS

SIMULATED SHIP POSITIONS

	BOSTON, USA	PORTSMOUTH, USA	PORTISHEAD, UK	LYNGBY, DENMARK	DAKAR, SENEGAL	CAPETOWN, RSA	RIO DE JANEIRO, BRAZIL	•	•	•	SAN FRANCISCO, USA	HONOLULU, USA	YOKOHAMA, JAPAN	CALLAO, PERU	REYKJAVIK, ICELAND	FROBISHER BAY, CANADA	CRI*
1	.85	.98	.88	.86	.72	.65	.42	•	•	•	.77	.43	.03	.11	.17	.20	.99
2	.83	.95	.82	.70	.44	.32	.30	•	•	•	.71	.03	.25	.55	.53	.33	.98
3	.42	.41	.11	.12	.22	.25	.36	•	•	•	.44	.55	.12	.60	.65	.71	.85
4	.03	.04	.00	.00	.61	.51	.35	•	•	•	.60	.62	.51	.31	.33	.38	.71
5	.00	.00	.12	.15	.16	.23	.00	•	•	•	.22	.17	.16	.23	.51	.46	.60
6	.11	.15	.16	.10	.12	.80	.05	•	•	•	.03	.00	.00	.07	.22	.25	.85
7	.01	.01	.16	.15	.13	.33	.31	•	•	•	.00	.01	.01	.05	.07	.09	.27
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
45	.80	.70	.61	.54	.50	.70	.65	•	•	•	.33	.40	.40	.44	.60	.12	.90
46	.55	.51	.55	.33	.66	.12	.00	•	•	•	.51	.51	.27	.33	.29	.52	.78
47	.23	.24	.36	.43	.11	.21	.26	•	•	•	.25	.33	.20	.00	.06	.11	.51
43	.00	.00	.00	.01	.02	.05	.11	•	•	•	.13	.15	.00	.11	.21	.27	.36
49	1.00	1.00	.99	.98	1.00	.99	.88	•	•	•	.66	.77	1.00	.92	.87	.88	1.00
50	.66	.33	.16	.63	.63	.57	.54	•	•	•	.19	.21	.38	.42	.51	.00	.78

RELIABILITY

FREQ. 8 MHz, SUNSPOT NO. 20

JANUARY, 1800 LMT

***Combined Reliability Index**

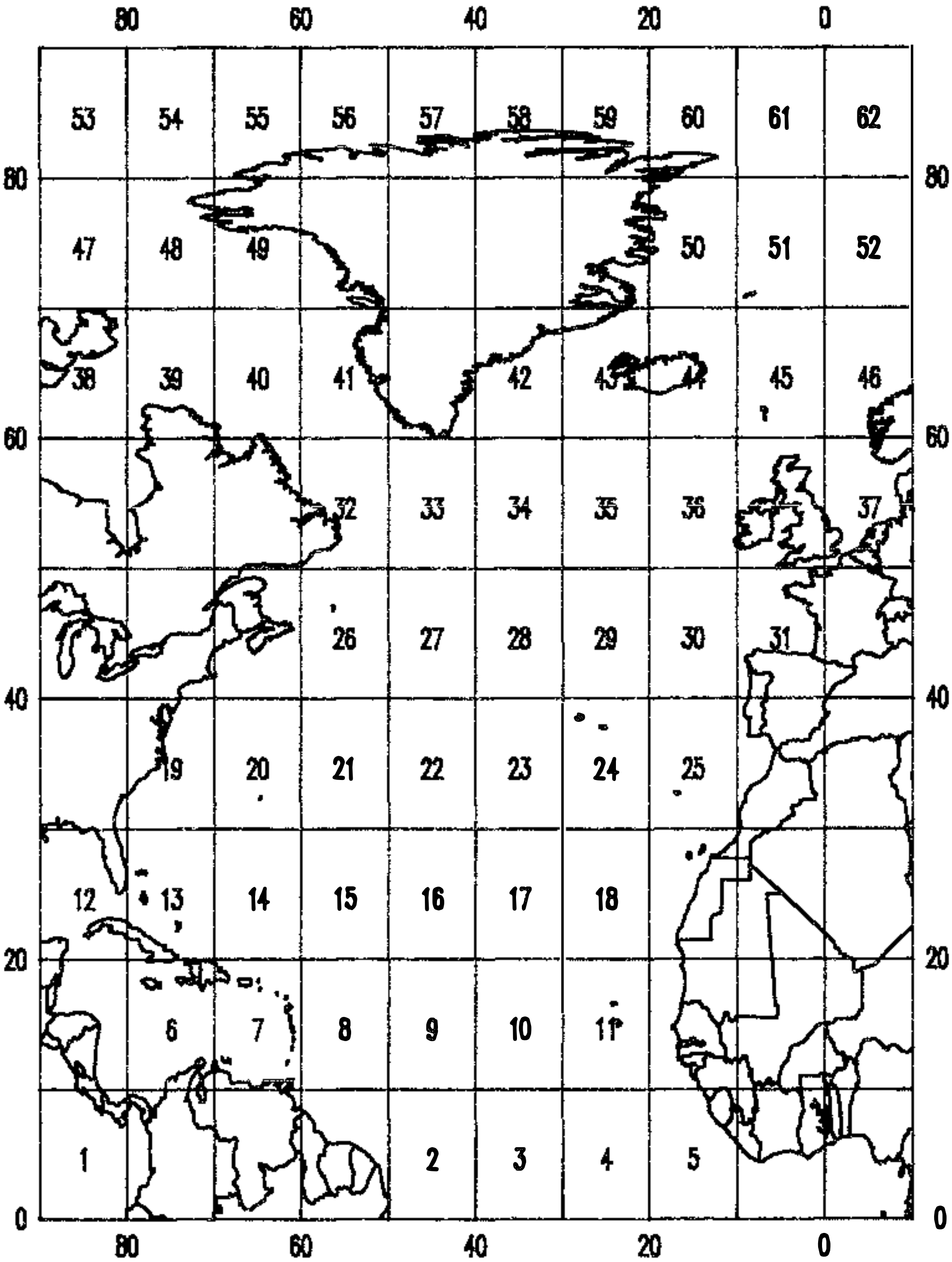

Figure 1-42. Format of area coverage.

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.

The GNCM has been enhanced with the capability to include contours of constant signal strength from one or more transmitters in the net. This is very useful for determining regions that are not in the coverage area of any node in the network. A simple foliage loss model and foliage data base completed the improvements to the model. An example of the coverage of a pair of transmitters in a Colorado area is shown in Figure 1-43.

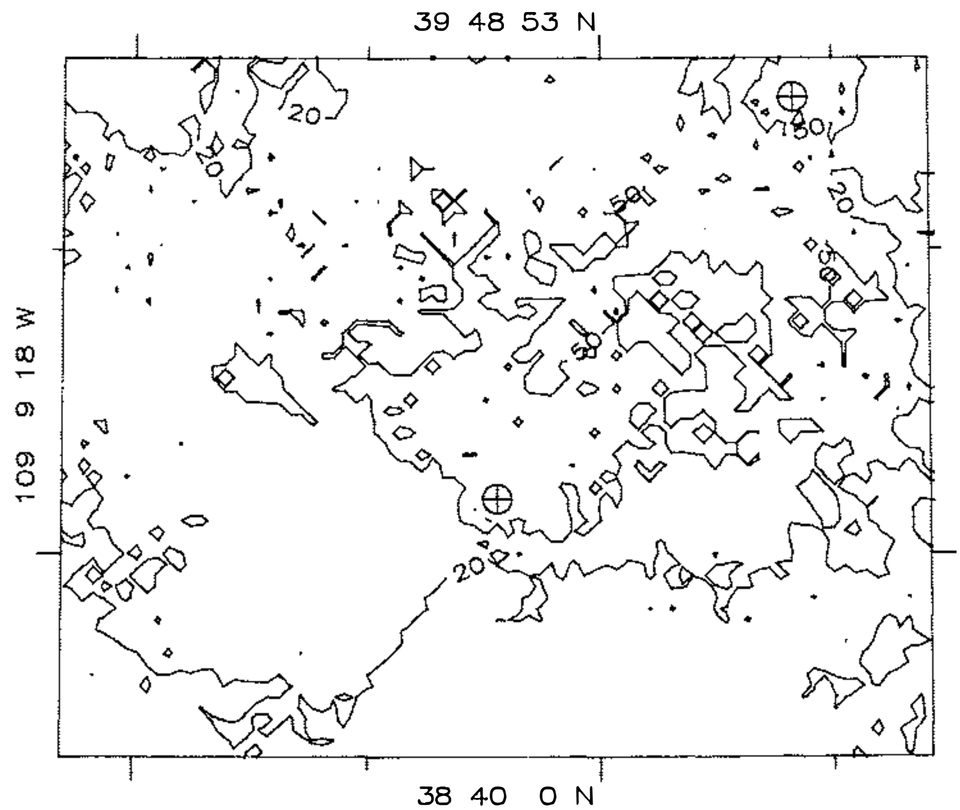

Figure 1-43. Coverage contours of 20 and 50 dBu in Colorado calculated from two identical transmitters located at the circled crosses.

CHAPTER 2. SYSTEMS AND NETWORKS

The Systems and Networks Division conducts research and analysis programs directed toward (1) developing domestic and international telecommunication standards, with a focus on system interconnection and quality of service; (2) assessing the performance and cost effectiveness of Government and public telecommunication networks; and (3) evaluating advanced telecommunication technologies for application to future needs. Activities of the Division are undertaken through a combination of Commerce-sponsored and other-agency-sponsored programs. The Commerce-sponsored programs provide technical support to the Administration and the Department in achieving Federal policy objectives such as enhancing domestic competition and international trade opportunities in the U.S. telecommunications industry. The other-agency-sponsored programs apply ITS expertise in solving specific telecommunication problems of other Federal agencies and, in some cases, state and local governments. The two categories of programs are complementary and often synergistic.

In typical recent projects, the Institute has contributed to Federal, American National, and international standards defining user-oriented data communication performance parameters and measurement methods; applied these standards in pilot measurements of competing U.S. public data networks; organized and headed U.S. participation in international standards negotiations of CCITT Study Groups VII (Public Data Networks), XVII (Data Transmission over Telephone Networks), and XVIII (ISDN); developed a minicomputer-based system to remotely monitor and control microwave radio sites in the Defense Communications Agency's Digital European Backbone (DEB); conducted field measurements and developed channel simulation facilities to assess microwave radio performance for the U.S. Army's Communications Systems Agency (CSA); developed user-oriented design tools for line-of-sight (LOS) microwave and troposcatter radio transmission systems; assisted the U.S. Forest Service and other civilian Federal agencies in developing cost effective telecommunications acquisition plans for the post-divesture environment; developed measurement plans and specified test equipment for an Experimental Integrated Switched Network being evaluated as a prototype future Defense Switched Network by the U.S. Army CSA; developed numbering, addressing and fiber optic interface concepts for future Integrated Services Digital Networks (ISDN's); and developed satellite mutual interference and performance prediction programs to assist U.S. negotiators at upcoming ITU World Administrative Radio Conferences for Space Services (Space WARCs). Division work is continuing in each of these areas.

The Systems and Networks Division comprises four groups: (1) Switched Networks Analysis, (2) Satellite Networks Analysis, (3) System Performance Standards and Definition, and (4) System Performance Engineering Analysis. Specific FY 84 programs and accomplishments of each group are summarized in the following paragraphs. More detailed information is provided in the referenced publications.

SECTION 2.1 SWITCHED NETWORKS ANALYSIS

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

Information Technology Policy. The objectives of the Information Technology Policy project are to identify technical and economic issues in information policy that require national attention, to clarify these issues through research, and to assist in preparing necessary action by the Department of Commerce. A summary of some current issues is contained in a recent report "Policy Implications of Information Technology" (NTIA 84-144). Two areas are being evaluated in more detail: the protection of intellectual property rights, and the impact of competitive common carrier policies. A profile of the telecommunications and information industries is also being developed.

The computer industry is one of the fastest growing sectors of the economy. Although the software required to operate the computers is generally protected under the Copyright Act, there is significant loss in revenue to this industry due to software piracy. The industry has thus pursued arrangements for license agreements to reduce this problem, but with little effect. An evaluation is continuing of what action Commerce can take to help resolve this issue.

There has been a concerted effort in the past 25 years to enhance the nation's communications capability consistent with new demands and emerging technology advances. The Institute began a study in FY 84 to assess the impact of the implementation of recent common carrier policies, for example by the FCC. An evaluation of residential telephone service has shown that the price of telephone service is decreasing an average of 5 percent per year relative to the average of all items in the economy (as measured by the Consumer Price Index).

The information industries, consisting of the communications and information processing sectors, now constitute 10 percent of the Gross National Product (GNP), with half contributed by the electronic communications industry and the other half by the hard copy communications and information equipment and services industries. The primary beneficiaries of the information industries are the knowledge industries which use information industry products to enhance the knowledge of the user. Examples of these industries are: education, consulting, brokerage, finance, real estate, research and development, government services, and advertising. They contribute about half of the GNP. The characteristics of these industries will be aggregated as required to identify and evaluate information industry issues.

Concept Validation Facility for the Defense Switched Network. The Institute continued to furnish engineering support services to the U.S. Army's Communications Systems Agency at Ft. Monmouth, NJ during FY 84. The primary task under this project involved the development of experiment plans for a concept validation facility for the Defense Switched Network. A major part of this facility consisted of the Experimental Integrated Switched Network (EISN). The EISN integrates packetized voice and data for transmission over satellite links via a burst modem. The wide-band satellite portion is being used by the Massachusetts Institute of Technology (MIT) to evaluate advanced communications concepts for the future Defense Switched Network (DSN) in CONUS. When coupled with other terrestrial links, the EISN nodes can be used as a scaled-down version of the private line portion of a DSN.

Five sites have been selected for EISN experiments, and equipment was installed for operation in FY 84. The sites are at MIT Lincoln Laboratory in Massachusetts; RADC near Rome, NY; CSA at Ft. Monmouth, NJ; DCEC in Reston, VA; and ACC at Ft. Huachuca, AZ. All sites have wide-band satellite network (WB SATENET) earth station facilities that provide Demand Assignment Multiple access (DAMA) for connectivity.

The five sites will ultimately have full connectivity via terrestrial land lines and broadcast connectivity via the satellite. This configuration serves as the scaled DSN test facility. Figure 2-1 shows a block diagram of the major components at each site. The interim set of components includes the DAMA equipment known as Pluribus Satellite Message Processor (PSAT), the Earth Station Interface (ESI), and the antenna system. Also included is a Telephone Office Emulator (TOE) and a Packet/Circuit Interface (PCI). The TOE provides a T1 carrier for the PCI and also serves as the central office for four telephones. The PCI interfaces via the PSAT and the ESI with the Earth Station Antenna. The TOE and PCI are also used to dial-and-hold terrestrial lines to serve as trunks in certain routing and control experiments. Additional components will be added to expand the capability of the test facility. These include a digital circuit switch (which would serve as an access area switching hub); a military function processor or controller

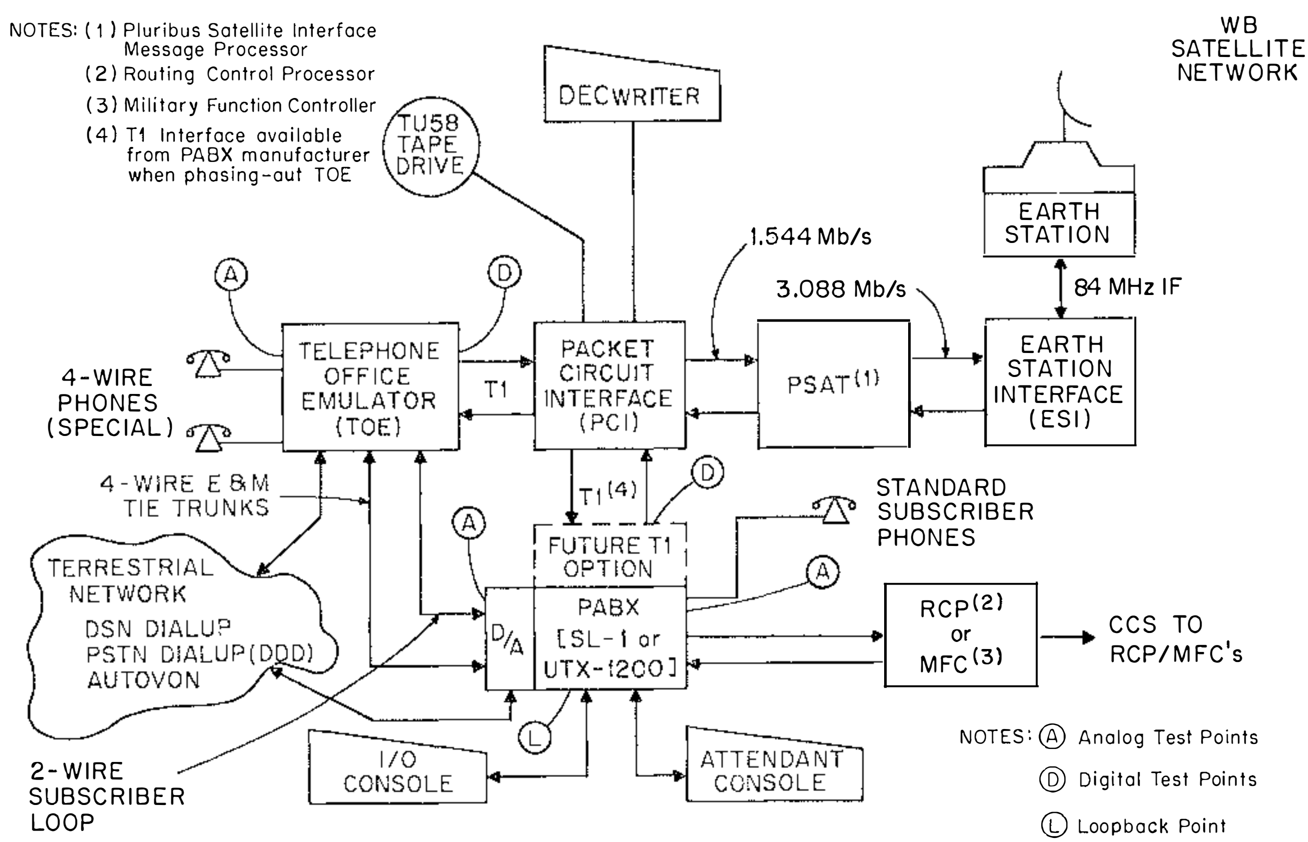

Figure 2-1. Experiment configuration at each node.

(MFC), which in conjunction with the switch provides certain military unique functions such as multilevel precedence and pre-emption (MLPP); a common channel signaling (CCS) system for remotely controlling the switches or the MFC; and a simulated terrestrial network to generate realistic traffic loads on the network. (One "off-the-shelf" digital switch was installed at Ft. Monmouth during 1983 and another was installed at Ft. Huachuca during 1984 for the Army's portion of the network. Other sites have, or will have, similar switches.)

The Institute has prepared a series of informal reports to the CSA leading toward the design of specific expriments. These reports are:

- o Defense Switched Network Access Area Concept Validation Facility Test Objectives
- o Aspects of Network Control for the DSN
- o Recommendations for CVF Implementation and Testing
- o Experiment Guide for the EISN Concept Validation Facility.

A major subtask under this program has been to evaluate and recommend test equipment for use on the experiments. Various measurements can be used to characterize the network and to monitor performance. Some are standardized and some are not. The recommended measurements are based on current standards or accepted practices whenever possible. These equipments were procured for use on the test bed in FY 84. The structure of the kinds of measurements considered is shown in Figure 2-2. The Institute has designed a number of specific experiments following this structure. In most cases we have recommended that measurements of user-oriented parameters and of the engineering parameters be made concurrently so they may be correlated.

High-Speed Modem Federal Standards. The rapid growth of distributed processing has resulted in data terminal operation at increasingly higher digital bit rates. Until recently, full-duplex interfacility transmission over the telphone network at rates higher than 1,200 b/s has typically required use of conditioned, 4-wire dedicated circuits. Recent advances in modem technology now permit full-duplex transmission at rates to 9,600 b/s using dial-up 2-wire circuits over the switched public telephone network.

The CCITT has moved rapidly in preparing Recommendations to ensure compatibility among modems that will utilize this new technology. The latest of these Recommendations is V.32, expected to be adopted in the forthcoming Plenary in the fall of 1984. The National Communications System (NCS), with technical support by ITS, has moved equally rapidly in tracking evolution of the CCITT documents and drafting proposed Federal Standards consistent with requirements of the Recommendation.

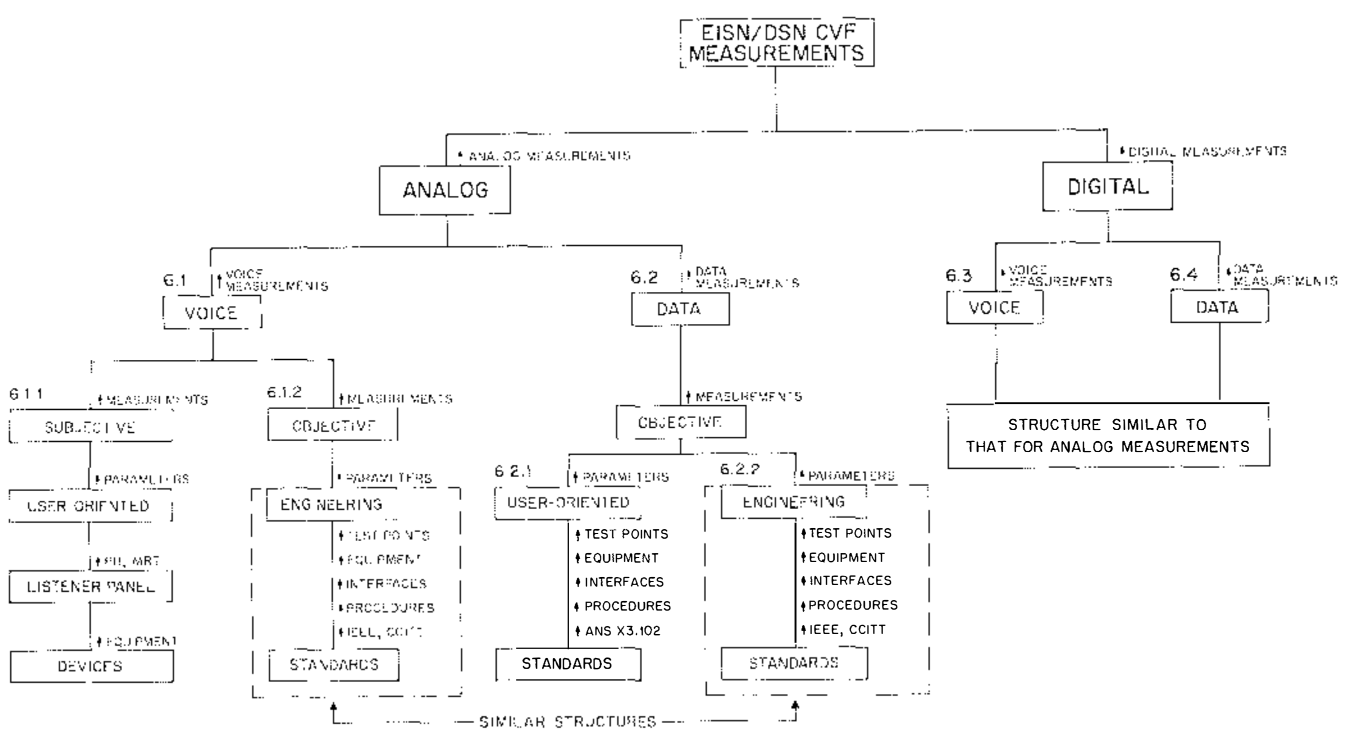

Figure 2-2. Structure of measurements development.

The NCS asked ITS to draft proposed Federal Standards, for submission to the Federal Telecommunications Standards Committee, covering the new-technology applications for full-duplex modems operating at 2,400 b/s and 4,800 b/s over 2-wire dial-up circuits. (Continuation of this work is expected in early FY 85 to address 9,600 b/s transmission.) Preparation of these proposed Federal Standards has required the integration of the requirements of existing Federal Standards (which will be superceded) for 4-wire full-duplex and 2-wire half-duplex operation. In doing this, consideration has been given to the sometimes subtle technical differences between the U.S. and European switched telephone networks (e.g., echo suppressor disabling, auto call/auto answer sequences, and guard tone frequencies for frequency-division techniques.)

Work on this project has produced two proposed Federal Standards (pFS). The first, pFS-1005A, "Coding and Modulation Requirements for 2,400 Bit/Second Modems," to supercede FS-1005, is based on techniques described in CCITT Recommendations V.22 bis, V.26, and V.26 bis. The standard describes two alternative modem types: (1) a "conventional" 4-wire full-duplex and/or 2-wire half-duplex modem for 2,400 b/s operation, with operational fallback to 1,200 b/s and (2) a 2-wire full-duplex modem for 2,400 b/s operation, with operational fallback to 1,200 b/s. The latter design utilizes an enhancement of the well-established frequency-division technique for 2-wire full-duplex operation.

The second of the proposed Federal Standards is pFS-1006A, "Coding and Modulation Requirements for 4,800 Bit/Second Modems," which will supercede FS 1006. Like pFS-1005A, this draft presents requirements for all three transmission modes. The 2-wire full-duplex mode is based on techniques described in CCITT Recommendation V.32. Unlike previous modem techniques that use frequency division of the 2-wire circuit to derive two distinct channels for full-duplex operation, V.32 recommends employment of echo cancellation techniques. The Recommendation further calls for the use of adaptive equalization and, for 4,800 bit/second modems, a modulation technique known as Differential Quadrant encoding.

Anticipated FY 85 follow-on to this project will result in drafting proposed Federal Standard 1007A, which will incorporate the V.32 techniques for establishing requirements for 2-wire full-duplex operation at 9,600 b/s.

Evaluation of Tactical Army Switches. As part of the TRI-TAC program, the project manager of the Multi-Service Communications Systems (PM, MSCS) at Ft. Monmouth, NJ, is evaluating adaptive searching, signaling, and routing alternatives for the AN/TCC-39 tactical circuit switches. At the same time, major design changes are being planned for the same switch, resulting in what is called the AN/TTC-39A.

Intermittently, during FY 84, ITS performed the following two tasks:

Provided reviews, critiques, and (as needed) analysis of the adaptive signaling and routing alternatives submitted by the engineering contractor, GTE. Previous emphasis has been on unresolved traffic issues, and this is likely to continue in the future.

When the specifications became available, ITS addressed and assessed the technical capabilities of the AN/TTC-39A design. Emphasis again was on traffic analysis, adaptive routing, network management, and control functions.

The project was completed in September 1984.

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

The Institute is providing technical support and expertise to NCS in the development of three proposed Federal standards. These are: pFS-1015, entitled "Telecommunications: Analog to Digital Conversion of Voice by 2,400 Bit/Second Linear Predictive Coding;" pFS-1029 entitled "Telecommunications: Interoperability and Security Requirements for Encryption of Narrowband Digitized Voice Using the Data Encryption Standard;" and pFS-1028 entitled "Telecommunications: Interoperability and Security Requirements for Use of the Data Encryption Standard with CCITT Group 3 Facsimile Equipment."

The last two standards mentioned above relate to the encryption of voice traffic. Proposed FS-1015 specifies a standard method of digitizing the speech waveform using Linear Predictive Coding (LPC) techniques. This standard will ensure compatibility among Government-owned narrow-band speech coders. Proposed FS-1029 specifies the method to be used to encrypt the output of such speech coders. This standard has been approved by the Federal Telecommunications Standards Committee (FTSC). The third standard listed (pFS-1028) specifies the method of encryption to be employed when using CCITT Group 3 compatible facsimile equipment.

The ITS technical role in developing these standards typically involves either writing an initial draft of significant portions of the standard or providing recommendations on the initial technical content of the standard. The Institute also examines industry and Government comments on the proposed standards and recommends revisions based on these comments. The Institute has also assisted the FTSC in assessing the technical and economic impact of each standard.

Access Area Charcterization and LAN Assessment. This project continues the ITS engineering services for the U.S. Army Communications Systems Agency. In addition to developing experiments for the EISN, it includes a study to characterize military access areas for connecting to long-haul facilities with emphasis on administration, operation, maintenance (AO&M), and automated network management and control facilities. In addition, ITS is assessing the impact of certain standards development activities such as the Integrated Services Digital Network (ISDN) standards under development by the CCITT and evaluating Local Area Networks (LAN's) that have applications on military bases.

The Access Area Characterization Study is the major effort that began in April 1984. The Institute was requested to reevaluate the Access Area concept in the light of the following recent legislative and regulatory decisions and technology advances:

- the Modified Final Judgment approved by Judge Green, which resulted in the divestiture of AT&T from the Bell Operating Companies on January 1, 1984
- the Final Decision of the Computer II Inquiry, resulting in the deregulation of enhanced services and customer premises equipment
- recent decisions by the FCC placing channel termination equipment on the customer's premises side of the network (FCC Docket 80-216)
- development of advanced large-scale integrated circuitry leading toward digitization of networks, including computer controlled switches, digital transmission links, and common channel signaling
- development of high-capacity digital transmission facilities using fiber optics, microwave radio, and satellites
- integration of voice, data, and imagery into development of digital networks
- development of automated network management and control systems.

These examples illustrate the changing environment faced by users, of telecommunications. As one of the largest users the military departments are faced with a dilemma--how to meet mission requirements cost effectively in this new competitive environment.

The Institute's Access Area Characterization Study has two objectives: (1) to develop methodology for characterizing an access area by defining its main parameters, and (2) to develop a management plan for the access area (or combinations of access areas) that includes administration, operation, maintenance, and control of major telecommunication facilities.

In the past, access areas have been assumed to be a collection of military posts, camps, and stations that share local switching and transmission facilities. These facilities may also connect at a common hub with long-haul networks to provide access to other areas or to serve as tandem interconnection facilities.

In the future, it may be advantageous to view the access area from an entirely different perspective, reflecting the changing environment in which military communications systems must operate. For example, beginning in 1984, long-haul facilities will terminate in Local Access Transport Area (LATA) Points of Presence (POP's) and may be provided by competing commercial carriers.

The original concept of an access area is changing in other ways as well. The DSN in CONUS, in the near term, is expected to evolve from an AUTOVON/AUTODIN structure into a stored program controlled network that incorporates the military unique features of the public switched telephone network (PSTN). At the same time a private line network (PLN) would be developed to provide additional survivability, connectivity, and special services. This PSTN/PLN hybrid network may subsequently develop into the Worldwide Digital System Architecture (WWDSA) and ultimately, at least in part, into an Integrated Services Digital Network (ISDN). Figure 2-3 depicts

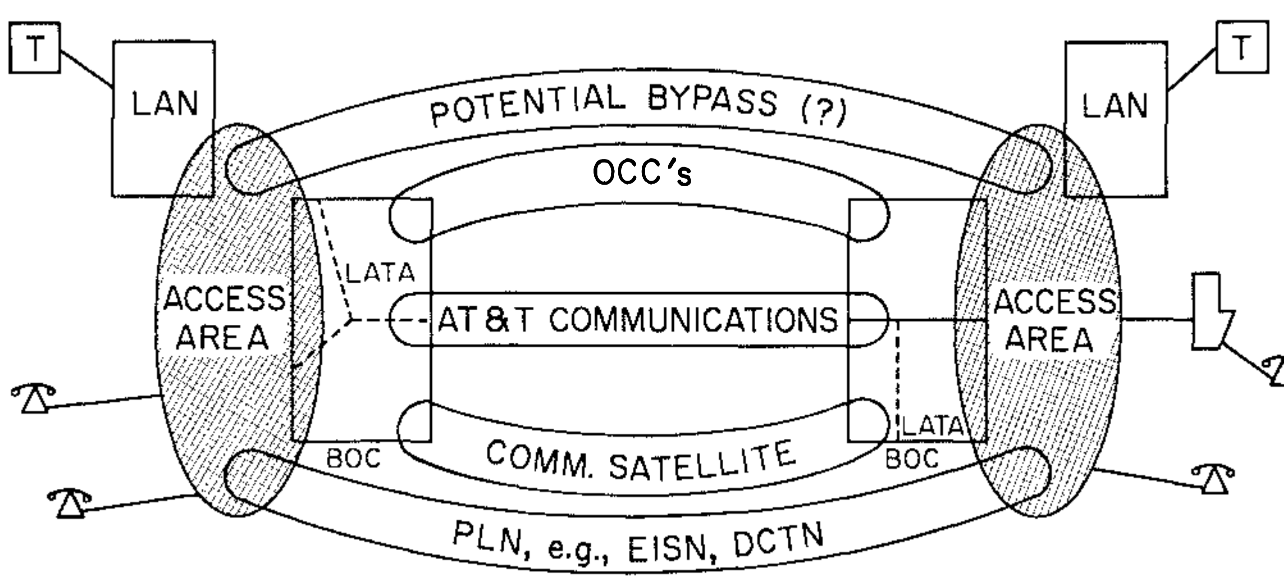

Figure 2-3. Possible access area interconnections.

this hybrid concept in the current environment.

These dynamic changes, both real and contemplated, raise a number of questions about the access area concept. Do we need access areas? How many? How are they configured? How are they managed? What impacts their size? What are the staffing requirements? The ITS study is currently addressing these and other questions in a two-phase program.

Phase A of the study is designed to take a new look at how access areas should be defined. Some of the parameters being considered include subscriber locations, number of subscribers, subscriber density, coverage area, LATA and DMATS structures, communities of interest, traffic flows, service types, modernization programs, other network interfaces, OCONUS gateways, and finally, the impact of these parameters on cost.

The ITS approach to access area characterization is illustrated in Figure 2-4. We started with certain basic assumptions. For example, it was assumed that the DSN will consist of a hybrid network as discussed above. A number of "givens" can also be specified, such as the number and location of subscribers, their service needs, traffic profiles, leased line costs, and five levels of stress scenarios.

Some work has already been accomplished in characterizing access areas. Military department contracts with industry were directed toward various aspects of defining access areas and their administration, operation, and maintenance. The results obtained from these past studies will be important inputs to the ITS study.

An important "given" that must be obtained and used extensively is the traffic flow between subscribers, both currently and as predicted for the future. This includes all forms of traffic (voice, data, video), internal and external to a base. Ultimately this kind of traffic flow engineering must extend to the entire access area. The requirements for each component of traffic depend on a number of factors including number of subscribers, their offered load, mission needs, service category (i.e., voice, data, etc.), communities of interest, and desired grade or service. Thus, not only must the traffic density be considered in characterizing the area but other essential factors must be considered as well.

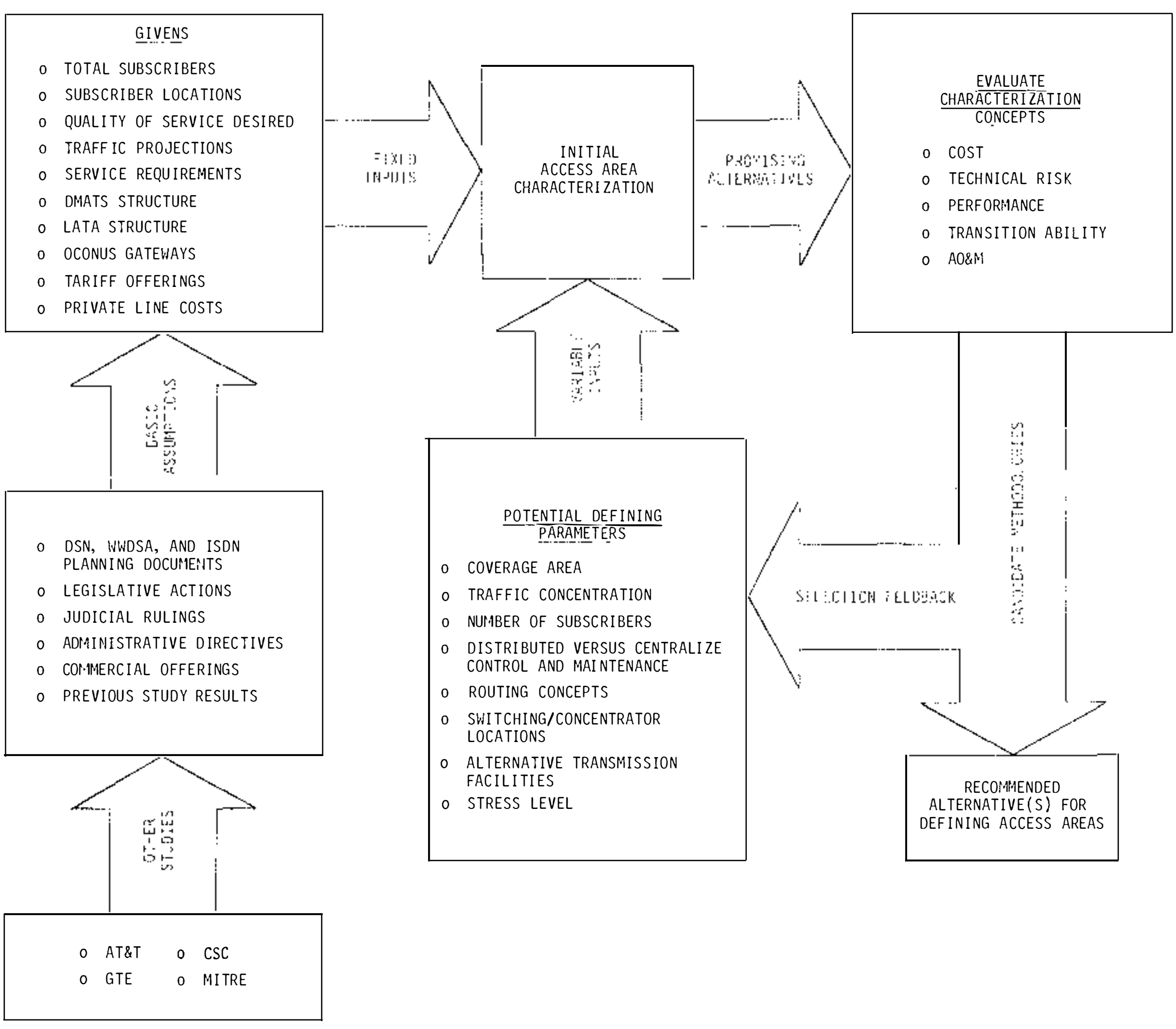

Figure 2-4. ITS approach for developing a method for characterizing access areas.

The basic assumptions and quantitative "givens" form a set of fixed inputs upon which any access area characterization must be based. At the same time, another set of variable inputs can be developed. Their optimum values are the defining parameters. Examples are shown in Figure 2-4. The variable parameters must be adjusted to optimize the access area. There are a number of criteria that must be used to judge this optimization process. These evaluation criteria include cost, performance, transition ability, maintainability, and possibly others.

As each alternative is evaluated, every variable can be adjusted (with others held fixed) to determine its sensitivity to the evaluation criteria. Although the process is a simple iterative one, there are too many variables and evaluation criteria to make it completely objective. Some subjective analysis and decisions, based on experience in the switched network area, must also enter the process to make the approach practical.

Phase B of this study, which is currently underway, is a Local Area Network Assessment.

Local Area Networks, or LAN's, are efficient arrangements for high volume and many low volume users in concentrated areas such as industrial parks, office complexes, and other clusters having common interests for information interchange. In such clusters the majority of the data communication traffic is between terminals separated by short distances of no more than a few kilometers.

LAN's may or may not be connected to each other. Sometimes interconnections exist between LAN's in a given access area via a central office. Other times the community of interest may be between LAN's in separated access areas.

LAN's permit independent devices to communicate with each other, such as host computers, data terminals, word processors and printers, as well as telephones and video display devices. For economic reasons, coverage is confined to fairly limited geographic areas (10 km separations of terminals). Simultaneous transmissions of voice, video, and data are possible on some systems. Signal speeds range from a moderate 100 kb/s to a high rate of 10 Mb/s. Transmission media includes coaxial cable, CATV cable, twisted wire pairs, and optical fiber.

The objective of this LAN assessment task is to detemine how LAN's may be interconnected and interoperated. This includes both intra- and inter-access area connections. In order to assess the LAN interoperability, ITS is conducting a study of the major systems currently available and will classify them according to their basic architectures. This classification includes such alternatives as topologies (bus, star, ring), transmission (baseband or broadband), control protocol (contention, token passing, polling). station linking (broadcast or point-to-point), transmission media (coax, fiber optic, wire pair), transmission rate, capacity, and format (time or frequency division).

Given the LAN architectures, ITS is assessing the levels of interoperability. Obviously, two LAN's with identical architectures may interoperate as long as capacity limitations are not exceeded. At the other extreme are LAN's whose architectures are different in nearly every respect. In between are similar LAN's where relatively simple gateways can provide interoperation.

The Institute is also assessing the current status of LAN standards. Committee 802 of the IEEE was formed in 1980 to standardize LAN's. This committee is working primarily on the two lowest layers of the seven-layer International Standards Organization (ISO) Open Systems Interconnection (OSI) reference model, i.e., the physical layer (level 1) and the data link layer (level 2). The LAN study will indicate where standards are available, what their status is, and how various LAN's relate to the OSI reference model. In this way it should be easier to assess where new interfaces are needed and where further development of standards is required.

The end result of this task will be a Type A Specification for LAN gateways. The specification should suffice for major systems. The basic gateway concept will be so structured to permit detailed LAN gateway specification in the future. Both the Access Area Characterization (Phase A) and the LAN assessment are scheduled for completion by the middle of fiscal year 1985.

DES Applications Study for White Sands Missile Range. This study was performed for the U.S. Army Communications Command (USACC) at White Sands Missile Range (WSMR).

The USACC-WSMR is responsible for much of the planning, and the installation and operation, of a large and varied communications system. The system is used to support all phases of range operations. WSMR utilizes almost every form of electronic communications in existence--telephone, netted voice intercoms, mobile radio, telemetry, teletype, digital data networks including computer networks, and missile tracking data networks. Transmission media include wire line, analog and digital microwave radio, VHF, UHF, and other radios, and fiber optics. Voice and data communications use both point-to-point and various netted types of operation. Also, there are a number of networks that employ a broadcast type of operation.

In addition to intrarange communications at WSMR, communications circuits between WSMR and other ranges and locations exist. The USACC-WSMR has determined that much of the communications in support of range operations at White Sands is of a sensitive but unclassified nature. It is also recognized that these communications are vulnerable to possible exploitation, particularly through interception.

For these security reasons, WSMR has embarked upon a major program to convert certain nonsecure communications circuits and networks to protected or secure operation. This multiyear communications security improvement program (CSIP) represents the leadership role characteristics of WSMR in advancing range telemetry and communications. The WSMR CSIP begins with requirements definition and extends through hardware development, installation, test, and operations. The DES application study conducted by ITS was an initial attempt to examine the major types of communications at WSMR for which DES protection is applicable. The focus of the study was to develop concepts, plans, and preliminary design alternatives for use of the DES in these WSMR communications networks. The attendant problem of cryptovariable management was also addressed.

The provision of complete protection in all WSMR networks will require advances in several related technical areas as well as in the state-of-the-art of security technology. Multiyear hardware developments will be required in some cases to attain full protection. The study defines those technical risk areas where further technical developments are required or where evaluation by WSMR of relevant competing technologies is required prior to hardware implementation. Specific recommendations regarding the DES mode of operation, DES equipment, and key management philosophy were given for the various WSMR communications networks, where possible.

Emergency Data Network. The National Communications System requested that ITS examine the following questions: Could the thousands of television stations located throughout the United States provide the nucleus for an emergency order-wire network using Teletext data transmission? With limited alteration to existing commercial facilities, and with minimal disruption to present television practices, could the Government capitalize on the prospective Teletext market and effect an inherent reconstitution capability? And if not TV, what are the other public broadcast resources presently being employed that could be used in a similar type data network (e.g., FM radio)?

These questions arose because of two requirements: that the coverage be nationwide and that the emergency use of facilities not interfere with normal broadcast functions. A report, "Feasibility of Using Teletext and FM SCA Channels in an Emergency Data Network," by W.J. Hartman and V.J. Pietrasiewicz was submitted to the sponsor. This report discusses the concept of Teletext, outlines the salient characteristics of Teletext transmission looks at the status of domestic Teletext implementation, and offers a forecast of future Teletext use. National TV coverage is examined to determine whether coast-to-coast connectivity is even a possibility using computer-derived maps to illustrate TV transmitter locations and respective areas of coverage. The report concludes that the current connectivity is insufficient to justify such a system.

Although the conclusion is reached that the FM radio exhibits essentially the same regions of non-coverage as TV, the use of the SCA channel is much more extensive and is growing rapidly. Therefore, the FM-SCA channels offer a better prospective technology for the emergency network.

A further examination of the methods for utilizing the SCA channels for an emergency order-wire network is in progress.

Systems Engineering Support to the Naval Ocean Systems Center in Meteor-Burst Communications. The Naval Ocean Systems Center (NOSC) is the focal point for the development of a number of Navy, DCA, and other DoD meteor-burst communications systems. The details of these systems are classified. The Institute has been providing technical expertise and assistance to NOSC in the analysis, design, and development of these systems. We have been providing systems engineering support in several areas related to meteor-burst communications. This support includes the development of functional requirements for the systems, assistance in overall systems design including hardware definition, software design, interfaces to other systems, establishment of link protocols, and networking. Another major ITS effort under this project is the development of cryptographic approaches to meeting the security requirements of these systems. The project also requires the development of test methodology to evaluate system and component performance. The Institute has been participating in technical and administrative working groups in the meteor-burst communications area. These groups include both Government and industry personnel who are engaged in the development of the systems, or who are the eventual users of these systems.

Backup Network Concepts for HFIP Applications. At their own laboratories and with the aid of industrial contractors, the U.S. Navy has been engaged in the High Frequency Improvement Program (HFIP). In the last decade a number of advanced systems components have been developed, such as the HF Power Amplifier (by Westinghouse), the HFIP Receiver/Exciter (by Rockwell/Collins), the Wide-band Modem (first by General Atronics, later by GTE), and others. Little attention, however, appears to have been given to systems integration and systems architecture as they would pertain to tactical backup networks.

In May of 1984, ITS was tasked to start a review of the current status of HFIP equipment specifications and to consult with key HFIP personnel involved in network development and applications. Another goal was to determine tactical telecommunication requirements for Over-the-Horizon Targeting (OTH-T) HF backup in case of satellite unavailability. The links in question emphasize information exchanges ship-to-ship within a battle group as well as between battle groups. Finally, ITS also outlined a plan for development of concepts and architecture to fulfill the HF/OTH-T network requirements incorporating to the extent possible existing and planned HFIP assets.

The project was completed in September 1984.

DTE/DCE Standards. A figure of merit for metallic transmission media (e.g., twisted wire pairs, coaxial cable, or twin-axial cable) was described in the FY 83 annual report. This figure of merit, $Fm_{\alpha} = 10^9 f/\alpha^2(\omega)$, may be calculated from manufacturer's measured attenuation coefficient, $\alpha(\omega)$, at a known frequency, f. The constant 10^9 is based on the assumption that f is in megahertz and $\alpha(\omega)$ is expressed in dB/unit length. The significance of this figure of merit is that the Fm_{α} is also equal to the product of maximum bit rate (P), and length squared (ℓ^2). The P is in Megabits/second and ℓ is in the same units as that of the attenuation coefficient length (e.g., kilometer, mile, 100 ft, etc.).

Thus, for a given implementation, the required $P\ell^2$ product must be less than the figure of merit for the transmission media to be used. This first-order approximation may be used to select an appropriate transmission cable from a catalog of offered products when baseband NRZ signaling is to be used. Also, a simple attenuation measurement on installed transmission media (for example, in a building or in an underground duct) may be sufficient to determine its maximum digital rate performance.

Similarly, fiber optic transmission media can be characterized by a figure of merit, $Fm_o = P\ell = 1/4\sigma$, where σ is the rms impulse response width, per unit length, of the multimode optical fiber. This performance measure of optical fibers is not always published by the manufacturer. The most often published characteristic is the 3-dB bandwidth, which is defined as the lowest frequency at which the magnitude of the fiber transfer function decreases to one-half of its value at zero frequency. For any given impulse response shape, there is a relationship between this f-3 dB bandwidth and the impulse response width. Using the relationship obtained empirically from measurements on several graded-index, multimode fibers, the above figure of merit, Fm_o = 1.5 f-3 dB.

A brief derivation of the above figure-of-merit relationship was published in an article entitled, "Characterization of Transmission Media" by Joseph A. Hull in Telecommunications magazine, February 1984.

Institute staff reviewed MIL-STD-188-111, "Subsystem Design and Engineering Standards for Common Long Haul and Tactical Fiber Optic Communications." A staff member participated in the final standard coordination meeting. The standard was approved and submitted for publication on January 24, 1984. This is the first Government standard in fiber optic systems. This standard was used as a model in the development of NTIA Report 84-154, "Optical Fiber Communications Link Design in Compliance with Systems Performance Standards." This report develops an engineering approach to the design of optical fiber communication links to meet mandated specifications for performance and interoperability. It follows and expands on technical guidance originally developed for the above MIL-STD. This engineering approach should be useful in the implementation of other Government and voluntary standards under development.

The design approach is intended to guide the selection of subsystem components from commercially available products to assure compliance with a standard. A graphical representation was developed to assist in the preparation of the optical power loss budget. The figure-of-merit for optical fibers, described above, was recommended for the selection of an appropriate bandwidth characteristic for the fiber. Sample calculations are presented to demonstrate the overall approach.

Optical Fiber Guidelines. The Federal Government is the largest single user of telecommunications equipment and services in the United States. A growing element in these equipments and services is that of Automated Data Processing (ADP). Figure 2-5 shows an estimated total Federal ADP budget progression for fiscal years 1982 through 1984. The $12.2 billion FY 84 budget is broken down in Figure 2-6. These figures illustrate the investment in capital equipment, equipment rental, and commercial sevices by the Federal Government in a portion of the overall telecommunicaions arena that is undergoing a dramatic change in technology. The rapid move from central processing to distributed processing of data creates strong interest in both the intra-facility and long-distance transmission of data. Some 80 percent or more of the data transactions take place within the corporate facilities of most organizations. This should also apply to Federal facilities.

There is a strong national and international interest in developing appropriate interface standards for an Integrated Services Digital network (ISDN). The Institute is actively participating in the development of these standards. Optimistically, ISDN services will become available in metropolitan areas like Washington, DC, within the next 5 years. It is therefore urgent that Federal communications and information systems planners consider not only new technologies but also the new opportunities afforded by an ISDN offering.

Intrafacility communications will be upgraded, as a minimum, by the introduction of advanced digital Private Automatic Branch Exchanges (PABX) for voice and data. Local Area Networks (LAN's) will be used where higher data rates are required. The Federal Telecommunications Standards Committee, chaired by the National Communications System, has established a Fiber Optics Task Group (FTSC/FOTG) to:

1. exchange information on emerging fiber optic technologies, including cost vs performance capabilities;
2. collect and discuss requirements from Federal offices on systems that might use fiber optics;
3. develop guidelines for use by Federal agencies that wish to consider fiber optic intrafacility systems, keeping in mind cost trade-offs and the ISDN implementation; and
4. create a mechanism by which the Government requirements can be conveyed to vendors and to voluntary standards developing organizations.

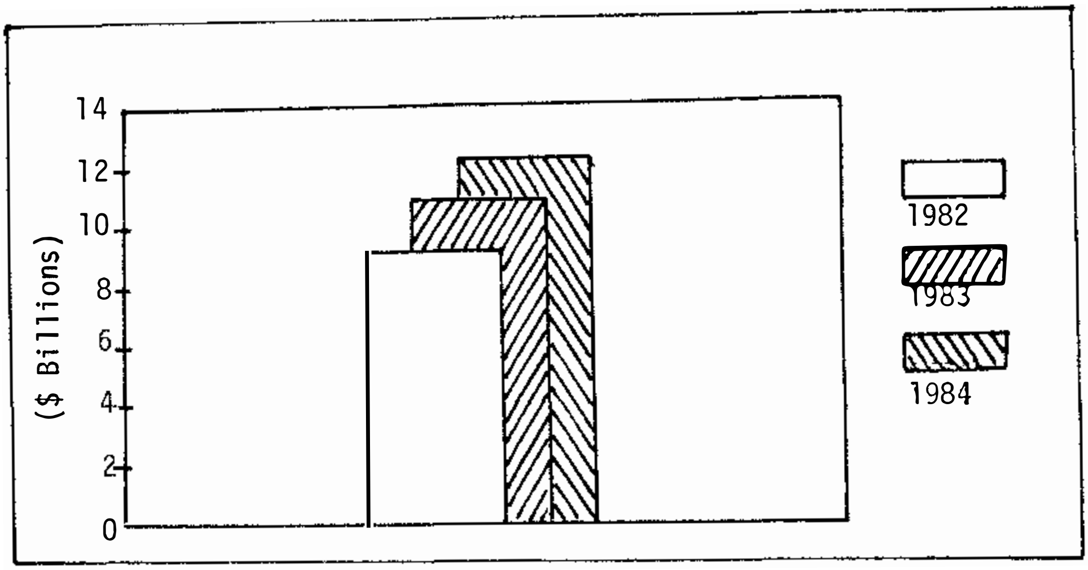

Figure 2-5. Total Federal ADP budget 1982-1984.

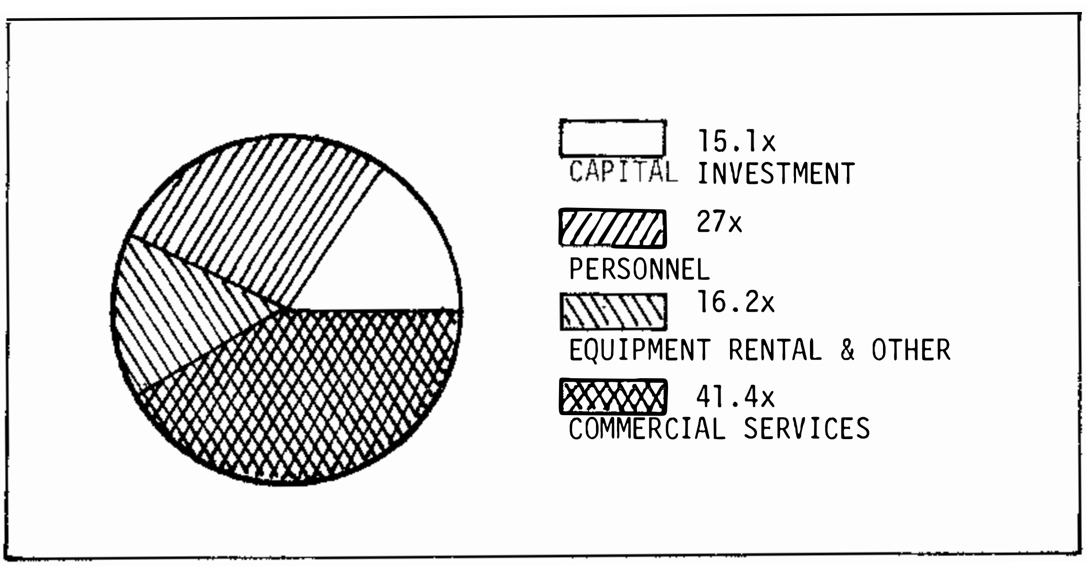

Figure 2-6. Breakdown of Federal ADP expenditures (FY 84).

A paper entitled "High Data Rate Optical Fiber Local Area Networks," by Joseph A. Hull, was written to provide an introduction to fiber optic LAN's for the above FOTG. It appears in the Proceedings of FOC/LAN-84, the Eighth International Fiber Optic Communications and Local Area Networks Exposition, September 1984.

An ITS staff member proposed and now leads the FTSC/FOTG. He also represents the Task Group in several related voluntary standards committees, including EIA TR 30.1 (Signal Quality), EIA TR 44.5 (Industry-Government Liaison for Fiber Optic System Standard), ANSI X3T9.5 (High Bandwidth Computer Communications), and IEEE 802 (Local Area Network Standard).

Institute staff members are working with senior staff in other Federal departments and agencies where current intrafacility communication systems upgrade is in progress. The guidelines to be developed by the FOTG will reflect experience gained in these current activities.

Integrated Services Digital Network (ISDN) Numbering Plan Design Considerations. In recent decades, communication networks have evolved at a tremendous pace. Around the globe, users have seen new technologies develop in several arenas, have used the services that were spawned from them, and have demanded more services.

There was a time when analog telephone systems were adequate to serve most user communities. Those "plain old telephone systems" (POTS) used both analog transmission and switching to move a message from one point to another. Since voice was the primary mode of communication for the vast majority of public users, public switched telephone netwoks (PSTN's) were built on a large scale. At the same time private networks were constructed to meet special business and military needs.

Included in the design of each of the PSTN's and private networks were the same basic architectural components necessary for the networks to operate. User terminals (telephones, etc.), access loops, local (end office) switches, tandem switches, transmission facilities, and transmission media (plant) are examples of these components. Architectural functions were applied to each of the configured networks to allow the networks to peform in a certain way. Signaling, routing, technical control, connectivity (including homing), performance criteria (e.g., grade of service), etc., were established to permit end-to-end requirements to be met.

Even though one network (public or private) contained the same fundamental elements as another, the specialized features of a particular network (supplied through its equipment and control functions) made it unique when compared to other "similar" networks. If a user desired the service features provided by one network, he subscribed to that service (network). If he also needed a second service feature package, he might acquire the use of a second network.

In recent years, the extraordinary advances achieved in semiconductor technology have completely revolutionized several industries, particularly those associated with computers and telecommunications. Large-scale integration (LSI) provided the mechanism for creating microcomputers and more powerful large computers. The intelligence (processing) and storage (memory) attributes of LSI chips allowed a communications switch technology to form switches with a digital format and stored program control. More importantly, however, integrated circuitry brought the computer and telecommunications industries together. For several years data processing had been developing almost completely independent from communications technology. Large-scale integration prompted the development of computer (data processing) equipment with communications features and communications hardware containing computer-processing assistance. Users clamored for both types of equipment.

New technology was (and is) expensive, however. Development costs are passed on to the user. As in the earlier analog (voice) era, user communities desiring digital data services used public data networks which had been established, but had to develop, or subscribe to, private data networks to satisfy abnormal data needs. Huge computers were available, but were very costly to own and operate. In all cases, users paid for using, or owning, data-service networks and computers.

For several years then, communications planning and subsequent implementation of networks had been, for the most part, individually oriented around specific user requirements. Major voice and data networks were developed for general categories of users, while smaller, specialized networks were created for those with more personalized requirements. There were many networks to satisfy the many different service requests. The networks were independent. They were costly to run.

The changeover to digital transmission by many (network) service-providers in the last 10 years set the stage for a dramatic change in concept relative to the manner in which customer services should be provided. With the increased user demand for more and more services, and the escalating costs associated with sole-purpose networks, international planning bodies and standards organizations determined that the all-digital (switching and transmission) networks forming all over the world presented an ideal opportunity to reduce cost and accommodate market demand--if they were united. If many small, specialized networks were combined to yield a relatively few, all-service-encompassing larger networks, more users could be served and costs could be reduced. An "Integrated Services Digital Network (ISDN)" philosophy was proposed.

But how is the ISDN philosophy accomplished? How can the many relatively small subnetworks (PSTN's, PDN's, private networks, etc.) operate together? How do users "talk" <u>into</u> and <u>through</u> subnetworks, and access total-country ISDN's? How does one ISDN user with one type of terminal reach another user with a similar terminal? With the numerous access and numbering requirements for the various existing networks, (i.e., each network requires a different set of digits to be dialed [transferred] in some sequence to initiate communication), how can all users be offered equal access to all networks? ISDN numbering strategies provide several answers.

A numbering plan is the essential ingredient in the effort to connect users, and networks, together. The numbering (addressing) scheme is used to accomplish two tasks. First, the numbering plan allows a user to (ideally) choose and use a number of services over various networks easily. Terminals, transmission carriers, special features (e.g., privacy), etc., can be selected, as required, to meet desired performance and economic goals. This general task of the numbering plan could be referred to as "user interfacing."

The other purpose of a numbering plan is "network interfacing." The numbering plan determines how the networks and subnetworks interface. That is, based on user requirements, the quantity and structure of networks, geographical and political constraints, and hardware limitations, what has to happen to make "user interfacing" possible? Network management functions such as signaling, routing, switching, and billing are correlated to parts of the numbering scheme.

An NTIA Report entitled, "Integrated Services Digital Network (ISDN) Numbering Plan Design Considerations," has been written by Val J. Pietrasiewicz and J. Jay Austin, to illuminate the many facets of the ISDN numbering plan design, and to focus on those technical areas that require further attention to successfully achieve a comprehensive worldwide ISDN implementation. This report discusses desirable numbering plan attributes, describes the various CCITT (International Telegraph and Telephone Consultative Committee) Recommendations that apply to ISDN numbering (e.g., E.164, E.163, X.121, I.330, etc.), summarizes ISDN numbering plan studies being pursued by the CCITT, presents descriptions of numbering plans for several major networks (e.g., the North American numbering plan), compares these against the attributes and standards, and outlines areas for additional study.

ISDN Quality of Service (QOS) Standards Support. During fiscal year 1984, Institute personnel continued to provide leadership in several national and international standards bodies. Two prominent examples are Dr. William Utlaut, Director of ITS, who is Chairman of the Exchange Carriers Standards Association/American National Standards Institute T1D1 Committee, and Thijs de Haas who is Chairman of CCITT Study Group XVIII. Study Group XVIII provides coordination for all ISDN matters within CCITT, and develops ISDN Recommendations. The T1D1 committee develops inputs to support U.S. positions in international ISDN standards activities.

While a number of ITS people directly supported ISDN standards work through committee participation, others provided support by studying ISDN (its concepts, its implementation, strategies, etc.), and by proposing technical areas for further committee research, e.g, providing "contributions" to the committees.

In the area of ISDN Quality of Service (QOS), three support efforts were performed by ITS people. James Hoffmeyer wrote an NTIA Report entitled, "Voiceband Quality of Service Issues in the Post Divestiture Environment," which addressed the technical problems associated with the interconnection of telephone networks and the equipment provided by the many vendors. Although progress has been made by both national and international telepone QOS standards groups in telephone quality standardization, unsolved issues remain. These issues are identified in the report along with recommendations for new programs to resolve them.

Two CCITT Contributions were drafted to support QOS Committee work. One Contribution addressed voice quality to an "expanded" Open Systems Interconnection (OSI) Reference Model. Another Contribution discussed objective QOS parameters.

SECTION 2.2 SATELLITE NETWORK ANALYSIS

The development and growth of a vigorous commerical satellite industry is clearly evident today. There are well-established services for domestic, regional, and international, large volume, geographically centralized services in the Fixed-Satellite Service (FSS). Broadcasting-Satellite Service (BSS), often referred to as Direct Broadcast Satellite (DBS) Service, soon will be introduced in the United States. The National Telecommunications and Information Administration (NTIA) has had primary responsibilities for assuring that adequate frequency spectrum and geosynchronous orbit resources are available to support the growth of the industry--and that responsibility continues.

A resolution passed at the 1979 World Administrative Radio Conference (WARC) calls for another WARC to be convened in two sessions--1985 and 1988. The first session will consider the need for planning (i.e., achieving international agreement on the assignment of frequencies and orbit locations and future space services--the second session will undertake the planning as determined necessary during the first session.

The Fixed-Satellite Service is the principal focus of preparation for the 1985 Space WARC. Throughout this year, ITS has provided technical support to United States preparation for the conference through the development of an interference analysis model, given the name of Geostationary Satellite Orbit Analysis Program (GSOAP), and through participation in the IRAC Ad Hoc 178 Working Group (Ad Hoc 178-1C) on Manual and Automated Techniques for the Evaluation of Planning Methods.

Earlier discussion mentioned a well-developed commercial satellite industry (in the FSS) for large volume, geographically centralized services (large trunk applications). However, utilization of satellite technology by dispersed, low-volume users (this-route applications in rural areas) has not been nearly so successful. Such utilization does not offer the economic incentives of large trunk applications and will occur only when lower-cost ground terminals are available. This is true in spite of the fact that there is clear need, particularly in less-developed parts of the world, for basic communications capabilities, and satellite communications technology seems to offer the best solution to that need.

A jointly supported effort with the Department of State (DoS), Agency for International Development (AID) was initiated in 1980 to define a low-cost earth terminal design and to build an initial terminal following that design. That terminal would be used in engineering and performance tests to establish the design feasibility and thereby encourage industry development and production. The original earth station design and service requirements study followed a parametric approach by establishing a matrix of options for technical characteristics of components of the earth station, such as the antenna size, the low noise amplifier noise temperature, and the high power amplifier output capabilities. Technologies that could be used for telephony, such as single channel per carrier frequency modulation (SCPC-FM), digital voice encoding such as adaptive delta modulation with quadrature phase-shift-keying (QPSK), or voice synthesis such as linear predictive coding (LPC) with QPSK, also are used as parameters of the study. This study guided the development of technical specifications for the earth station. The purchase of major components that meet those specifications was completed this year.

The ITS Satellite Network Analyis Group work has included five NTIA-sponsored efforts plus two complementary projects sponsored by AID. In addition, there have been two study efforts directed to modeling radio propagation effects--studies of diffraction by a rounded obstacle (rather than a knife edge) and an analytical modeling of changes in pulse shape for pulses reflected from the ionosphere. These nine projects (programmatic efforts), established for management tractability, are:

1. Technical Support to Planning and Preparation for the 85/88 Space WARC
2. Development of the Geostationary Satellite Orbit Analysis Program (GSOAP)
3. Studies of Earth Station Antenna Sidelobe Characteristics
4. Advanced Satellite Communications Technology Studies
5. Study of Impact of Reduced Satellite Separation on Earth Station Antenna Design
6. Technical Support to the AID Rural Satellite Program
7. Technical Support to AID in the Development of a Low Cost Television System for Educational Applications
8. Rounded-Obstacle Diffraction Studies
9. Pulse Distortion Studies (Phase II).

Technical Support To Planning and Preparation for the 85/88 Space WARC. As noted earlier, the 1979 WARC of the International Telecommunication Union (ITU) resolved that a World Administrative Radio Conference be convened in two sessions to consider the need for planning all space services to assure equitable use of frequency and geosynchronous orbit resources and to accomplish planning as determined necessary. The word "planning" as used in this discussion means detailed, a priori assignments of frequency spectrum and geosynchronous orbit positions for use by specified space services. The first session is scheduled for August 1985; the second session is scheduled for 1988.

In the ITU Table of Frequency Allocations, 13 space services are provided frequency resources. These services are listed below:

1. Aeronautical Mobile-Satellite
2. Amateur Satellite
3. Broadcasting-Satellite
4. Earth Exploration-Satellite
5. Fixed-Satellite
6. Maritime Mobile-Satellite
7. Inter-Satellite
8. Meteorological-Satellite
9. Mobile-Satellite
10. Radionavigation-Satellite
11. Space Operation
12. Space Research
13. Standard Frequency and Time Signal-Satellite.

The Fixed-Satellite Service, with more than 100 existing space systems, is the service that uses most space resources. For this reason, a view is developing that Space WARC planning should consider only the Fixed-Satellite Service and only certain frequency bands allocated to that service.

Institute support to U.S. preparation for the 85 Space WARC includes continued development of the GSOAP model (discussed below), participation in Ad Hoc 178 activities (Ad Hoc 178 is coordinating U.S. preparation for the Space WARC), performance analysis of earth station antenna side-lobe characteristics (discussed below), and the provision of several stand-alone computer models to the Ad Hoc 178-1C Software Working Group. These and other stand-alone models are being collected as a library of relatively simple models, available on the NTIA HP-1000 computer in Annapolis, to support preparations for the 85 Space WARC. A brief description of each of the models provided by ITS is given below.

Minimum Ellipse Model

The Minimum Ellipse Model determines the minimum elliptical beam of a geostationary satellite antenna, given the orbital position of the satellite and the locations of the Earth points that define the polygon boundary of the service area. The method is based on a straightforward and exhaustive search for a minimum elliptical beam over all possible ranges of all necessary parameters that specify the elliptical beam.

Geosynchronous Satellite Geometry Model

The Geosynchronous Satellite Geometry Model calculates the distance, azimuth, and elevation angle to a geosynchronous satellite as seen from any point on the surface of the Earth.

Usable Service Arc Model

The Usable Service Arc Model determines the usable service arc for a service area on the surface of the Earth based on the elevation angles of the geosynchronous satellite orbital position as seen from points determining the service area.

Automated ITU Appendix 29 Computer Model

The Automated ITU Appendix 29 Computer Model calculates the interference potential between geostationary satellite networks sharing the same frequency bands. Its purpose is to provide a preliminary analysis of the electromagnetic interactions between a proposed space radio-communications system, using certain specified characteristics and parameters. The program is based directly on procedures set out in Appendix 29 to the ITU Radio Regulations, Geneva 1971.

Footprints Projection Model

The Footprints Projection Model automatically computes and plots Earth footprints and service area polygons on a map projection of the Earth's surface. The map projections available in the program are:

Mercator
Cylindrical Equidistant
Mollweide
Alber's Equal Area Conic
Bi-Parallel Conformal Conic
Stereographic
Orthographic
Lambert Equal Area
Azimuthal Equidistant
Gnomonic.

The program can be used as a design tool to maximize geostationary satellite antenna coverage over a particular portion of the Earth's surface and to limit potential interference in adjacent areas.

Propagation Loss Model

The Propagation Loss Model calculates the basic transmission loss, under clear sky and rainy sky conditions, between a point on the geosynchronous orbit and a point on the surface of the Earth. The program assumes the 1 percent worst month for the rain attenuation calculations, i.e., a propagation loss that is not exceeded for 99 percent of the time during the worst month.

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

The ITS effort in developing GSOAP has been coordinated closely with the NTIA Office of Spectrum Management (OSM). The OSM plans to use GSOAP in preparing for the forthcoming 1985 and 1988 Space WARC's (World Administrative Radio Conference for the planning of Space services), both before and at the site of the conferences. It is expected that GSOAP will interface with a data base developed by NTIA/OSM and a scenario synthesis program that is being developed under a contract from OSM to private industry.

Improvements made to GSOAP in this fiscal year include:

- modeling of a general shaped-beam antenna gain pattern
- refinement in implementing the CCIR propagation model
- implementing the 1983 RARC-BS-R2 (Regional Administrative Radio Conference for the planning of the Broadcasting-Satellite Service in Region 2) propagation model
- inclusion of the calculation of gas absorption by oxygen and water vapor
- implementing various calculation options requested by OSM
- inclusion of the C/I calculation in the multiple-transponder case on the assumption of rectangular spectrum and passband shapes.

A subroutine package for calculating the baseband signal performance is under development by OSM, and inclusion of the package in GSOAP is also under way in ITS.

We began the development work on a large-scale computer at the U.S. Department of Commerce Boulder Laboratories, concentrating our effort in developing GSOAP as portable software. In the middle of this year, we transferred GSOAP from the large-scale computer to an ITS minicomputer, which is the same type as the OSM computer. Several problems stemming from the small core memory size have been solved since, and GSOAP now can analyze a scenario consisting of 50 satellites and 200 Earth points.

Two draft reports, one on the technical bases of GSOAP (excluding the calculation of baseband signal performance) and the other on the calculation of polarization angles, have been written and are under review. A preliminary version of the GSOAP user manual is also under review.

Remaining modeling/programming efforts include:

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

Efforts in completing this model will require continuing close coordination with OSM. Efforts for completing development of GSOAP will continue into next year.

Studies of Earth Station Antenna Side-lobe Characteristics. In conjunction with the upcoming (85/88) World Administrative Radio Conference, one question that is being asked has to do with mandatory use of reference patterns in calculating interference. Related to this question is the fact that relatively little data have been submitted to the CCIR to describe the performance characteristics of earth station antennas used for fixed-satellite service (FSS). This lack of data is particularly acute for small antennas, i.e., when $D/\lambda < 100$, where D equals the diameter of the antenna and λ equals the wavelength of the radio energy being received or transmitted by the antenna.

In response to these needs for technical information, and as support to preparation for the 85/88 Space WARC, ITS has collected off-axis gain performance patterns of antennas produced by U.S. manufacturers. Measured sidelobe performance data for over 80 percent of the antennas listed in applications for licensing by the FCC in the 4/6 GHz band for common carrier services in 1982 have been obtained and analyzed with results available to space services planners including CCIR study/working groups. The Institute is concerned with the effects on system performance of interference levels to and from adjacent satellites in light of the FCC's new Report and Order, Docket No. 81-704, which will eventually reduce satellite orbit separations from the present 4° to 2°.

This study considers the immediate side-lobe angle area (1° to 7°) and also greater angles to the extent that data are available from manufacturers. Actual antenna patterns from different manufacturers were obtained and digitized producing a data base consisting of 168 separate patterns for 22 antennas in the 4 GHz (space-to-Earth) frequency range and 71 patterns in the 6 GHz range (Earth-to-space) for the same 22 antennas. The antennas studied range from 2.8 to 13 m in diameter with diameter-to-wavelength ratios (D/λ) from 35 to 267.

All antennas in this study were designed to meet the rules and regulations of the FCC as published in 1974 and updated in 1982, as given by:

$$G(\theta) = \begin{cases} 32 - 25 \log\theta \text{ dBi}, & \text{for } 1° \leq \theta < 48° \\ -10 \text{ dBi}, & \text{for } 48° \leq \theta < 180° \end{cases}$$

where θ is the angle in degrees from the antenna boresite.

Figure 2-7 shows statistical results of our analysis for all antennas studied in the downlink (4 GHz) frequency range and Figure 2-8 shows results for all antennas studied in the 6 GHz range. The CCIR, in Recommendation 465-1, utilizes a similar reference pattern. However, they recommend that the envelope only be used for antennas with a D/λ greater than 100. Statistical results, with antennas of D/λ greater than 100, are shown for the 4 and 6 GHz ranges in Figures 2-9 and 2-10, respectively.

The region between 1° and 4° away from the boresite is an extremely sensitive interval with respect to interference to/from the Earth terminal. With the FCC's decision to move U.S. satellites from a 4° separation to 2°, they have reduced the level for the reference envelope to avoid unacceptable interference. The proposed new U.S. reference envelope is given by:

$$G(\theta) \begin{cases} 29 - 25 \log\theta \text{ dBi}, & \text{for } 1° \leq \theta \leq 7° \\ +8 \text{ dBi}, & \text{for } 7° < \theta \leq 9.2° \\ 32 - 25 \log\theta \text{ dBi}, & \text{for } 9.2° < \theta \leq 48° \\ -10 \text{ dBi}, & \text{for } 48° < \theta \leq 180° \end{cases}$$

for copolar signals for all antennas transmitting in the Fixed-Satellite Service. In addition, the FCC has stated that this curve may not be exceeded between 1° and 7°. The FCC also is proposing a crosspolar reference curve which shall be 10 dB below the copolar signal in the region between 1° and 9.2° from the boresite.

The CCIR, in Recommendation 580, has adopted a similar design objective for antennas with $D/\lambda > 150$. That design objective is that at least 90 percent of the side-lobe peak amplitudes not exceed

$$G(\phi) = 29 - 25 \log\phi \text{ dBi for } 1° \leq \phi \leq 20°.$$

The recommendation further states that this requirement should be met for any off-axis direction within 3° of the geostationary-satellite orbit. Recommendation 580 makes no mention of recommended side-lobe gain at angles $\phi > 20°$, nor does the recommendation include antennas with $D/\lambda < 150$. However, a recent modification proposed for Recommendation 465-1 is that no more than 10 percent of the side-lobe peak amplitudes exceed the envelope defined by

$$G(\phi) = \begin{cases} 52 - 10 \log (D/\lambda) - 25 \log\phi \text{ dBi}, \\ \quad \text{for } 100 (\lambda/D) \leq \phi < 48° \\ 10 - 10 \log (D/\lambda) \text{ dBi, for} \\ \quad 48° \leq \phi \leq 180°. \end{cases}$$

Several conclusions may be drawn from the discussion above and the study results summarized in Figures 2-7 through 2-10.

- o The performance of some existing antennas does not conform with the current FCC requirements. For example, see the analysis results shown in Figure 2-8 for the angular region 1° - 4°.
- o The performance of existing antennas will be poorer still when compared to the side-lobe requirements that the FCC has adopted in conjunction with their decision to reduce spacing (in orbit) between satellites.
- o In view of the preceding conclusion, reduced spacing between satellites will require redesigned earth station antennas.
- o Side-lobe performance data for redesigned antennas, then, should be analyzed in a manner analogous to the

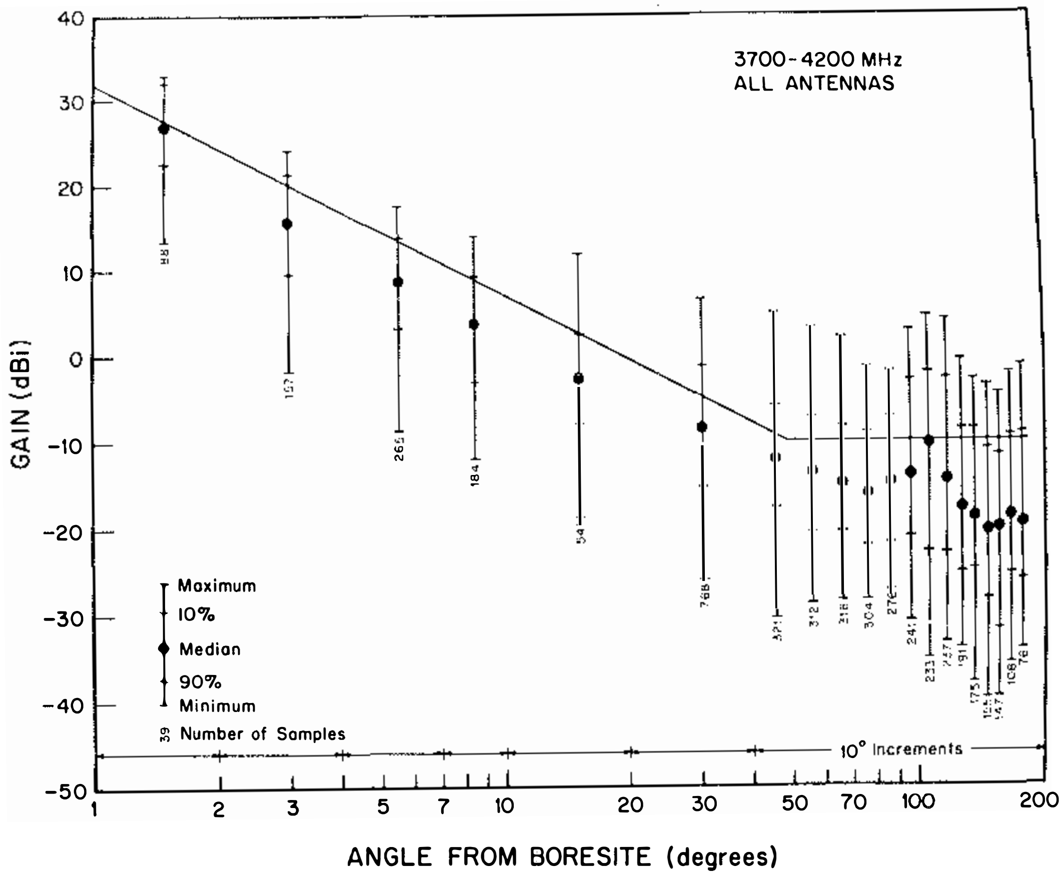

Figure 2-7. Statistical plot of sidelobe peak values for all antennas in the 3700-4200 MHz frequency range.

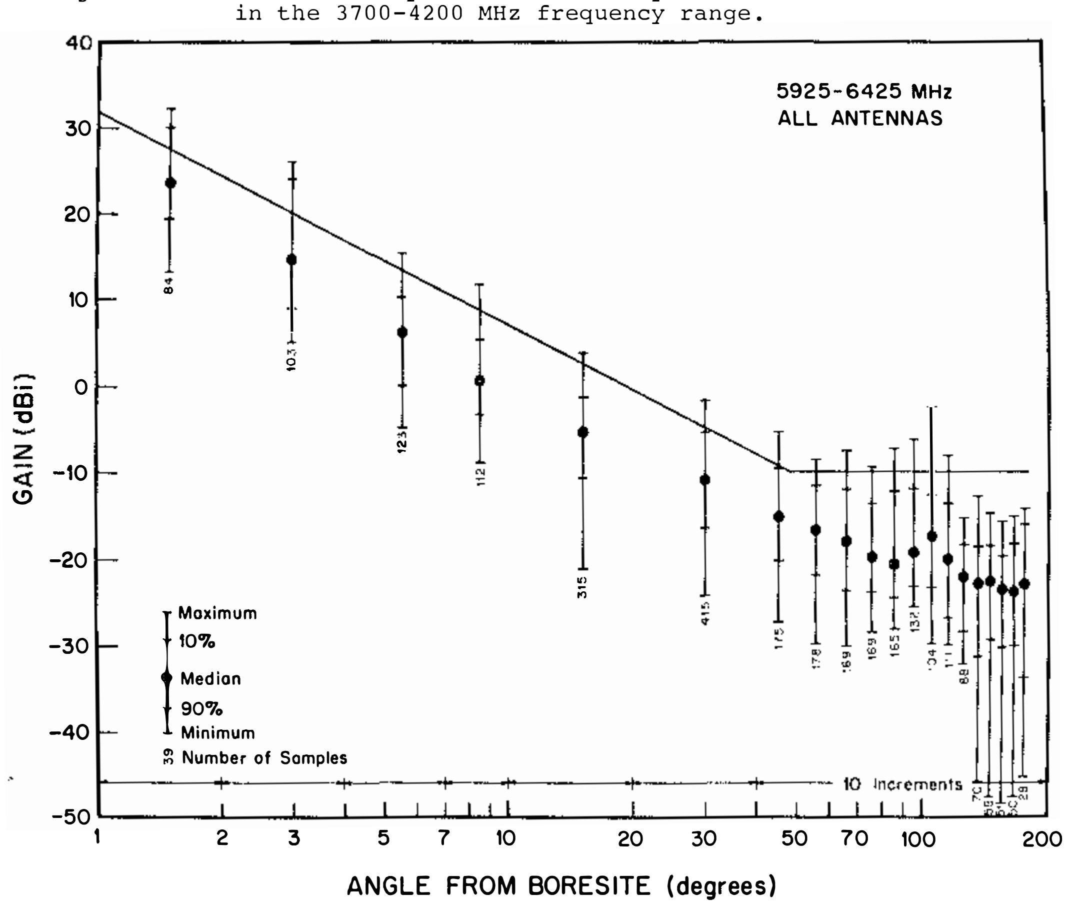

Figure 2-8. Statistical plot of sidelobe peak values for all antennas in the 5925-6425 MHz frequency range.

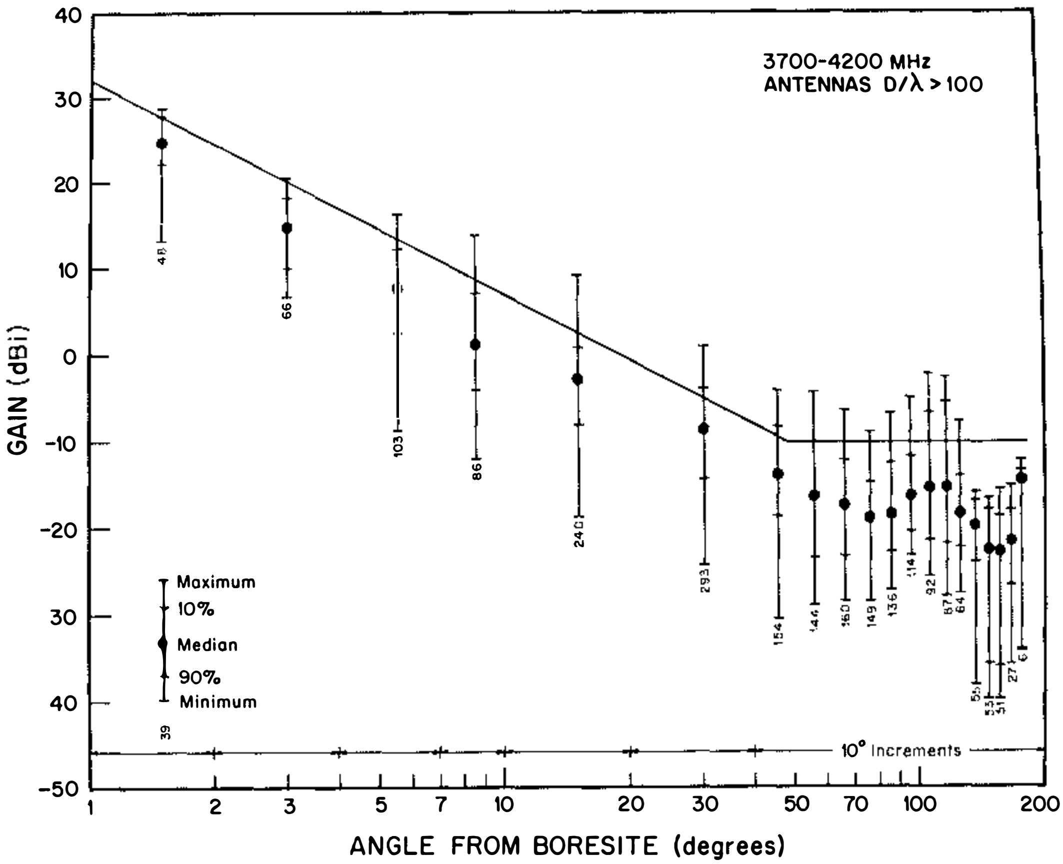

Figure 2-9. Statistical plot of sidelobe peak values for all antennas with D/λ > 100 in the 3700-4200 MHz frequency range.

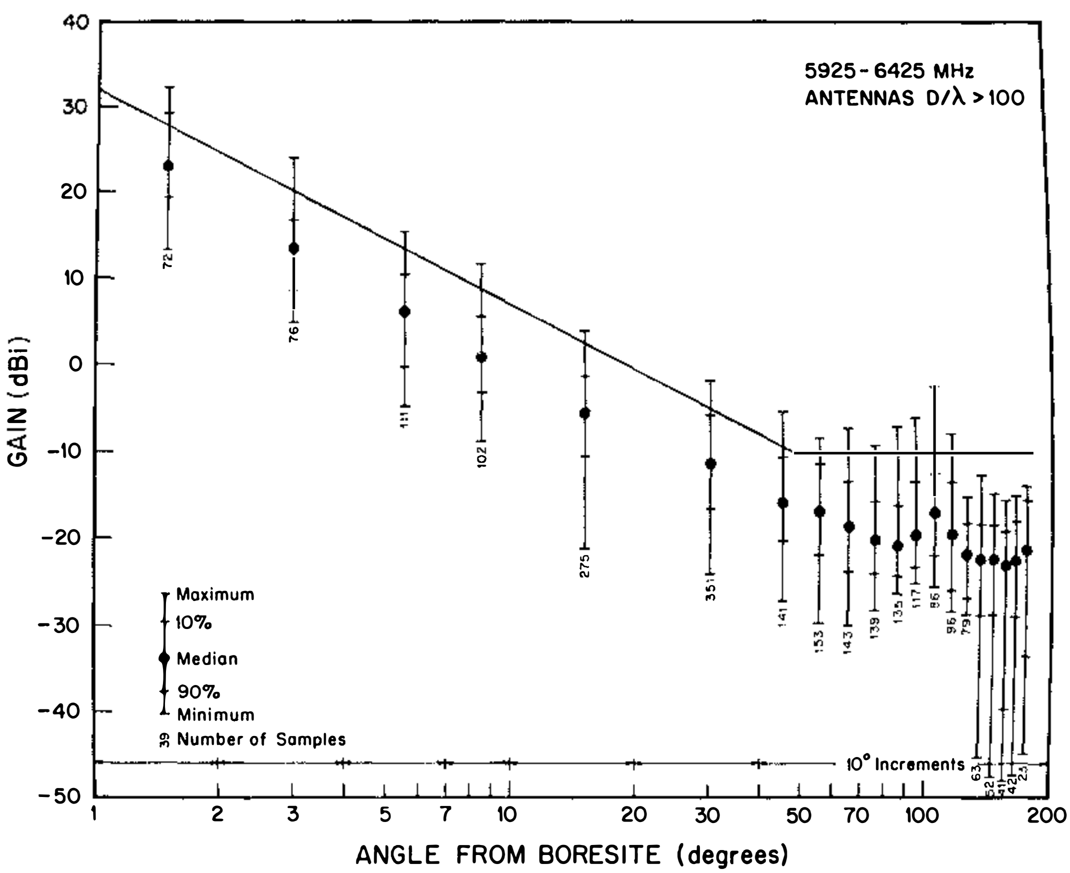

Figure 2-10. Statistical plot of sidelobe peak values for all antennas with D/λ > 100 in the 5925-6425 MHz frequency range.

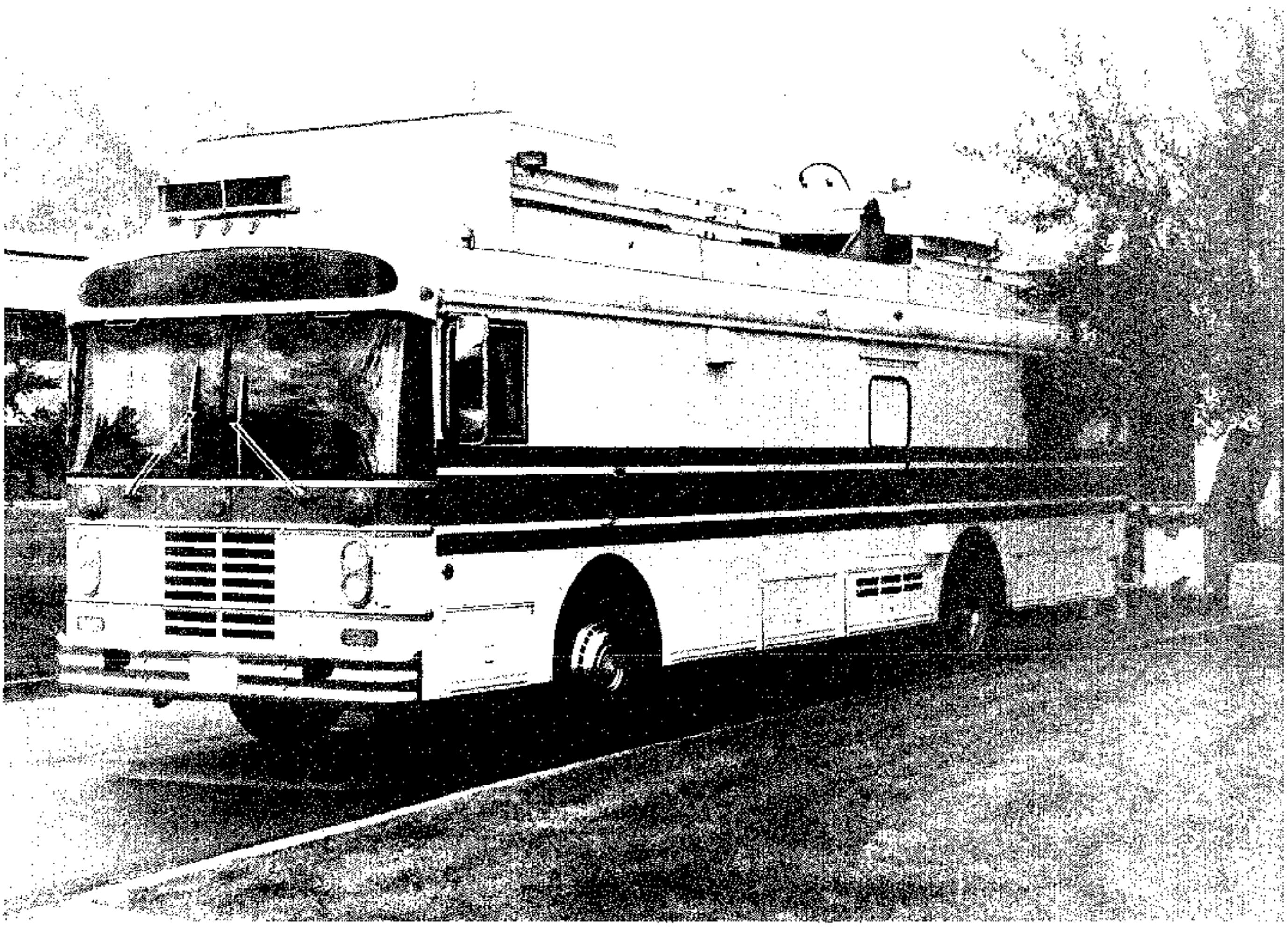

Figure 2-11. Portable Earth Terminal built by NASA.

studies ITS has conducted on existing antenna data.

Advanced Satellite Communications Technology Studies. Late in 1982, NASA solicited suggestions for experiments to be performed with the Advanced Communications Technology Satellite (ACTS). The Institute for Telecommunication Sciences responded and was included on the list of experimenters. Subsequently the funding of ACTS became uncertain and launch was delayed until 1989. In light of the uncertainties surrounding ACTS, the focus of the ITS work was broadened to accommodate experimentation using available communication satellites, and significant beginnings on establishing an experimental satellite communications facility were made.

A study was made of alternative satellite communications experiments of interest to ITS, and of the criteria for experiment evaluation. A list of questions posed by CCIR and others was formulated. Studies of path diversity, absolute path delay, frequency reuse, and other topics were considered. The benefits of experiments as a function of cost were considered.

A search was made to locate equipment critical to a satellite measurements program, and negotiations were begun to acquire the equipment. A key resource, obtained at the cost of transportation only is a Portable Earth Terminal that was custom built by NASA for use in satellite communications studies (see Figure 2-11). The vehicle is equipped with a roof-mounted antenna, a full complement of equipment racks, and two 12-kW motor generators. The Portable Earth Terminal is intended for mobile applications and for use in path diversity experiments.

A second key resource, committed for transfer to ITS, is a millimeter wave antenna system (see Figure 2-12). This instrumentation grade azimuth-over-elevation pedestal supports a 4.6 m (15-ft) aluminum honeycomb dish with fiberglass skin. Gain at 30 GHz is 59 dB.

The earth terminal equipment and experiments will be controlled via microcomputers using an IEEE-488 interface bus. Consideration was given to equipment requirements for both the primary earth terminal and the portable earth terminal, and preliminary cost estimates were assembled.

Figure 2-12. NASA millimeter wave antenna system.

During the coming year, work will be continued on the design of experiments, the design and improvement of earth terminal facilities, and design of software for experiment and equipment control.

Study of Impact of Reduced Satellite Separation on Earth Station Antenna Design. In order to maintain an open entry policy for the development of domestic satellite systems, the FCC issued a Notice of Inquiry and Proposed Rulemaking on November 18, 1981, as Docket No. 81-704, regarding the separation (in orbit) between space stations in the Fixed-Satellite Service (FSS) and characteristics of antennas for associated earth stations. The FCC proposed to reduce the spacing of satellites operating at 6/4 GHz from 4° to 2° and the spacing of satellites operating at 14/12 GHz from 3° to 2°. In conjunction with this reduction in satellite spacing the permissible side-lobe performance of earth station antennas also was reduced by 3 dB from $G(\theta)=32-25\log(\theta)$ to $G(\theta)=29-25\log(\theta)$ for angles, (θ), out to 7° with respect to the mainbeam axis. A 10 dB cross-polarization isolation standard was also introduced.

Following receipt of comments from 47 respondents, the FCC issued its Report and Order on August 16, 1983, an action initiating a phased implementation of the antenna side-lobe performance standards described above. The FCC noted that uniform orbital separations at 2° for systems operating at 6/4 GHz need be accomplished only as actually required by traffic demands. In progressing toward that goal, orbital separations as great as 3° and as small as 2° between individual satellites could be allowed to provide average spacing of 2.5°. Orbital separations of 2° for systems that operate at 14/12 are feasible now. In the Report and Order, the FCC noted that some increase in interference to existing systems could occur and that these existing systems would have to be upgraded or replaced over the next several years. The FCC, therefore, ordered that, to achieve the reduced orbit separations of satellites, the new standards for earth station antenna side-lobe and cross-polarization performance would apply to all new antennas installed after July 1, 1984, and to all antennas after January 1, 1987.

That order, however, has been deferred until further notice by an FCC Order released January 27, 1984, as a result of Petitions for Reconsideration filed by four parties who questioned certain technical details of the improved antenna performance specifications and contended that FCC policy objectives could be achieved with less cost and disruption to their operations and services.

Late in the year (4th quarter), ITS initiated this study of impact on earth-station antenna design resulting from reduced satellite separation. The study involves the collection and review of documents, such as the Docket 81-704 materials that describe (FSS) applications with particular interest given to applications using small earth-station antennas. An earth-station antenna is considered "small" when the diameter-to-wavelength ratio, D/λ, is less than 100 or 150 depending on several details of the application.

The collected information on possible interference and independent technical analyses is being used to develop engineering guidelines for proper selection of small earth-station antennas, considering the intended service application and quality of service objectives. These materials are being used to prepare a Guidelines document that will be circulated to appropriate organizations for comments, then revised and published early next year.

Technical Support to the AID Rural Satellite Program. The Agency for International Development established the Rural Satellite program as a cooperative effort between the United States and a number of developing nations to demonstrate the benefits of communication satellites and other communications technologies to the advancement of developing nations. The existence of ubiquitous communications systems in less-developed rural areas of the world would be expected to enhance food production and distribution, to improve health and family planning services, to improve productivity, and to facilitate access to education systems. Satellite communications are likely to be used in developing countries, however, only if the cost of earth stations to provide thin-route service can be reduced substantially.

As part of the technical support provided to AID, during previous years, a parametric analysis of (thin-route) earth-station design and service capabilities has been performed. Parameters of this analysis included:

- o Earth station antenna gain-to-system noise temperature ratio, G/T, ranging from 17.5 to 30.0 dB/K
- o Earth-station antenna diameter ranging from 3.0 to 10.0 m
- o Low-noise amplifier (LNA) noise temperatures ranging from 55 to 200 K
- o High-power amplifier (HPA) output power ranging from 1 to 400 W
- o INTELSAT (IV and IV-A) and domestic satellite resources
- o Frequency modulation (FM) and digital encoding with phase shift keying (i.e., CVSD with QPSK) of voice services.

The results of this analysis were used to develop technical specifications for the major components of a small earth station to be used in performance verification and demonstration tests. Procurement actions were initiated last year for buying a 5-m antenna with circular polarization to accommodate operation with INTELSAT satellites, a low-noise amplifier with noise temperature of 85 K, a TWT high-power amplifier with maximum output power not less than 15 W, frequency converters for operation at 6/4 GHz, and CODEC and MODEM units to allow digital voice and data communications using continuously-variable slope delta modulation (CVSD) and quadrature phase-shift keying (QPSK) rf modulation with forward error correction (FEC).

During the present year, the parametric analyses were extended to consider INTELSAT V and V-A satellites. A paper on this work was presented at the 10th AIAA (American Institute for Aeronautics and Astronautics) Communication Satellite Systems Conference in Orlando, FL, March 18-22.

Procurement of the major components of the small earth station also was completed this year. Coordination meetings were held with the sponsors and INTELSAT representatives to develop a performance verification and demonstration test schedule. Details of that coordination are pending as this year ends.

Technical Support to AID in the Development of a Low Cost Television System for Educational Applications. As part of a larger program directed toward facilitating educational programs in less-developed countries, the Agency for International Development funded a study by the Battelle Pacific Northwest Laboratories (Battelle) to determine the feasibility of a single channel TV receiver that would be low in cost and would have modest power requirements. The Institute provided technical monitoring services to AID in connection with Battelle's work, which was completed during the year.

Targeted objectives of the study were recommendations for a simplified television system responsive to the needs of rural villages and urban poor that would include a 90 percent reduction in the cost of receivers, receiver power requirements of 5-15 W, and a design adapted to indigenous manufacture and local assembly.

Battelle's main conclusions may be summarized as follows: 1) Costs of electronics may be minimized by fully using newest developments in very large-scale integrated circuits (VLSI), and by limiting receivers to a single channel. 2) Since picture tubes and cases comprise about half the cost of television receivers, manufacture of these parts in less developed countries along with assembly of receiver electronics is needed to fully realize possible savings.

Battelle believes that an electronics industry in a less-developed country can build gradually, beginning with assembly of imported components and gradually replacing these with indigenously made parts as infrastructure develops. Assuming a mixture of some locally made electronics and hardware with imported integrated circuits and some picture tube parts to begin with, projected manufacturing costs for such simplified television receivers would lie in the following range:

COMPONENT	COST
Electronics	\$ 6 to \$ 7
Picture Tube	\$ 4 to \$ 5
Case	\$ 0.8 to \$ 1
Total	\$10.8 to \$13

Battelle concluded that power consumption could be held to 4 or 5 W by choosing a 5 to 7 in. (diagonal) picture tube using either a large length-to-diameter ratio with magnetic deflection or an electrostatically deflected design.

Rounded Obstacle Diffraction Studies. The prediction of ground-wave propagation loss over irregular terrain often requires evaluation of the diffraction effects caused by rounded obstacles along the propagation path. However, current methods of calculating these effects are somewhat restricted in their application and can lead to significant errors in the predicted attenuation for some situations. For instance, in some cases it can be shown that errors of over 17 dB can occur for practical propagation paths (100 MHz, 15 km path distance) if proper account is not given to polarization and electromagnetic ground constants. Therefore, a study was undertaken to extend and correct previous results on the subject of diffraction by a smooth, convex surface. Equations and curves have been developed that are suitable for both horizontal and vertical polarization and a full range of electromagnetic ground constants. The curves provide attenuation predictions in the transition region between knife-edge and smooth-earth diffraction theory. The results of this work will be presented in a paper to be published early next year.

Pulse Distortion Studies (Phase II). This work is a continuation of an analytical study to determine the change in pulse shape for a pulse reflected from the ionosphere. The impulse response for reflection from an ionospheric layer with a sech^2 electron density profile has been investigated. A constant electron collision frequency and a vertical component (only) of the Earth's magnetic field were assumed, and both vertical and oblique incidence reflection were considered. Because of assumptions that were necessary for the solution of the field components, only approximate results were obtained for reflection at oblique incidence under the influence of the vertical magnetic field.

Numerical evaluations of the impulse response were accomplished by a computer program using Fast Fourier Transform (FFT) techniques. The FFT program is satisfactory for smaller values of penetration frequency and layer thickness typical of E-layers, but becomes impractical for the larger values that characterize the F-layer. For the latter case, an expression for the envelope of the impulse response was derived, from which distortion effects can be estimated.

Results of the study are contained in a paper to be published in Radio Science. The paper contains numerical examples of the impulse response for various input values of penetration frequency, gyro-frequency, collision frequency, and layer thickness.

SECTION 2.3 SYSTEM PERFORMANCE STANDARDS AND DEFINITION

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

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

Two related data communication performance standards have been developed. The first defines the user-oriented performance parameters. That standard was approved as Interim Federal Standard 1033 in 1979, and was subsequently adapted and approved as American National Standard (ANS) X3.102, "Data Communication Systems and Services--User Oriented Performance Parameters." The X3.102 standard is unique in providing a set of performance measures that may be used to describe the quality of any data communication service, irrespective of network technology, architecture, topology, or user access protocol.

Twenty-one user-oriented performance parameters are defined in American National Standard X3.102. The parameters express performance relative to three primary communication functions: access, user information transfer, and disengagement. Each function is considered with respect to three possible results, or outcomes, an individual performance trial may encounter: successful performance, incorrect performance, and nonperformance. One or more "primary" parameters are defined to express performance relative to each function/criterion pair. The X3.102 parameters also include a small set of "ancillary" parameters, which express the average proportion of primary function performance time that is attributable to user delays. American National Standard X3.102 is currently being implemented in several industry and Government telecommunications organizations, and has been proposed for adoption as a mandatory Federal Telecommunication Standard.

The second standard defines uniform methods of measuring the ANS X3.102 parameters. That standard was published as proposed Federal Standard 1043 in 1981. It has since been adapted for proposal as an American National Standard, designated X3S35/135, "Data Communication Systems and Services--Measurement Methods for User-Oriented Performance Evaluation." The measurement standard is expected to be submitted for formal balloting as an American National Standard in the fall of 1984.

Figure 2-13 illustrates the process of data communication performance measurement as described in the proposed measurement standard. Inputs to the measurement process consist of (1) measurement objectives defined by the experiment context, and (2) digital signals observed at the monitored user/system interfaces. Results of the measurement process consist of (1) estimated (mean) values for ANS X3.102 performance parameters characterizing the monitored system, and (2) associated precision and variability statistics (e.g., confidence levels and limits, histograms, and regression coefficients). The measurement process is accomplished in four primary phases:

1. Experiment Design. General measurement objectives are developed into a detailed experiment plan that defines the specific performance information to be collected and the focus and conditions of individual tests.

2. Data Extraction. Signals transferred across selected pairs of digital user/system interfaces are monitored in real time. At each monitored interface, the nature and time of occurrence of performance-significant interface signals are recorded in a chronological reference event history.

3. Data Reduction. The recorded reference event histories are merged and processed to produce estimated mean values for selected ANS X3.102 performance parameters.

4. Data Analysis. The reduced data are examined statistically to determine the precision of individual parameter estimates and any associated conclusions.

Figure 2-13 also illustrates the organization of the proposed measurement standard. Section 2 defines a general procedure for the design of data communication performance measurement experiments. Sections 3 and 4 specify functional requirements for ANS X3.102 data extraction and data reduction systems, respectively. Section 5 outlines methods of analyzing measured performance data and defines statistical information that should be reported with the estimated means. Section 6 provides standard forms that may be used in summarizing such results. Appendices provide definitions for specialized measurement terms as well as application examples.

The Institute's FY 84 Data Communications project had two overall goals:

1. To facilitate approval and initial use of the proposed measurement standard by developing and documenting

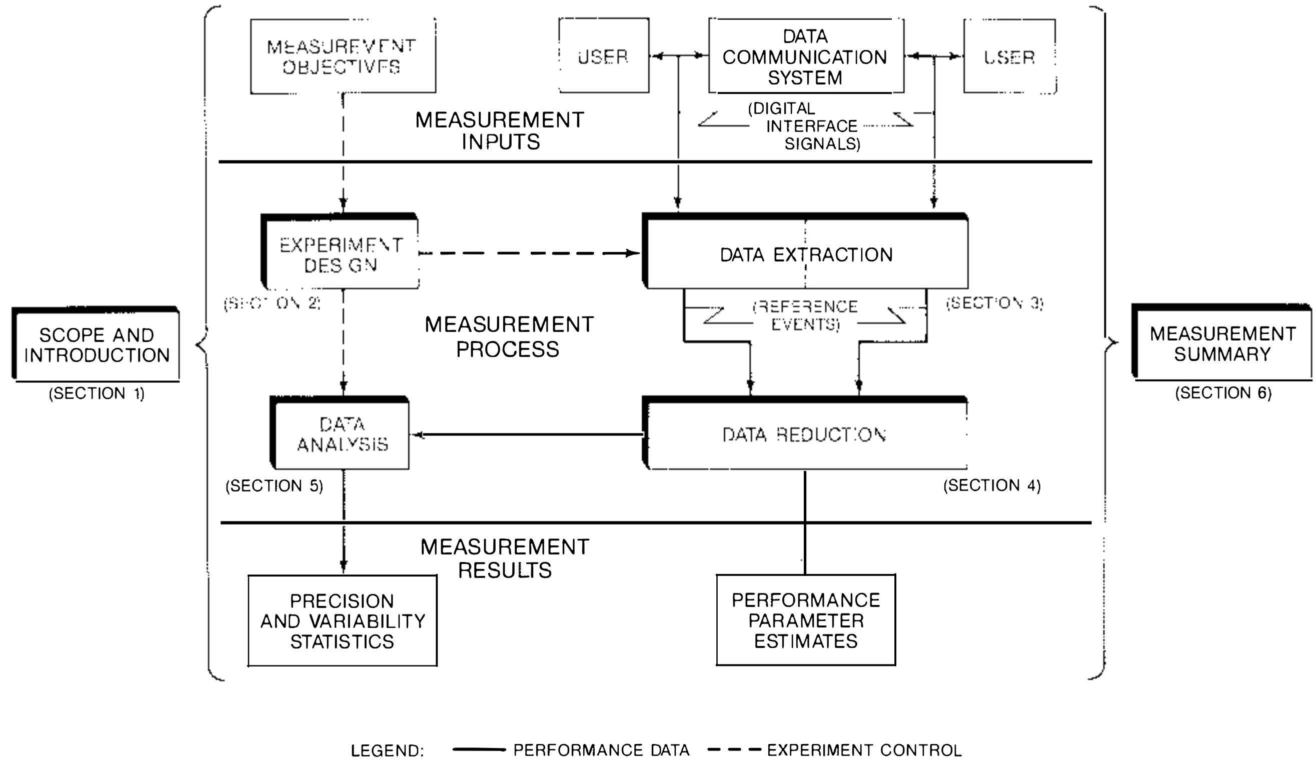

Figure 2-13. Overview of the standard.

key performance measurement software systems and techniques.

2. To complete and document pilot measurements of three U.S. public data networks (PDN's) using ITS-developed, microprocessor-based test sets conforming to the ANSI standards.

The Institute completed, documented, and demonstrated two transportable FORTRAN performance measurement computer programs during FY 84. The first, the ITS Data Reduction program, automates the test data reduction function as specified in Section 4 of the measurement standard. The second, the ITS Statistical Design and Analysis program, automates key steps in measurement experiment design and data analysis as specified in Sections 2 and 5 of the measurement standard. Both programs are written in machine-independent ANSI (1977) Standard FORTRAN and are available from ITS at duplication cost. The ITS Statistical Design and Analysis program has been documented in an NTIA Report (84-153) and summarized in a companion technical paper (published in the proceedings of the 1984 International Conference on Communications) by Martin J. Miles. An NTIA Report documenting the ITS Data Reduction program will be published in FY 85.

Both programs were used extensively in FY 84 in reducing and analyzing test data extracted in Public Data Network (PDN) performance measurements conducted at ITS during FY 83 and early FY 84. Figure 2-14 shows the output of the ITS Data Reduction program for a typical PDN test. The output consists of four parts: the test descriptors, access assessment summary, and disengagement assessment summary shown in Figure 2-14a, and the user information transfer assessment summary, shown in Figure 2-14b.

The test descriptors identify the particular data extraction run and summarize the conditions under which the test was conducted. The access assessment summary lists the operator - defined specifications used in processing the performance data, the number of access performance trials encountering each of the four possible outcomes defined in the X3.102 standard and the calculated estimates for each of the five ANS X3.102 access performance parameters. The disengagement assessment summary lists the corresponding information for the disengagement function. In the example shown, disengagement results are presented for only one of the two users (the data source). In an actual ouput listing, disengagement results are summarized for both users, and may either be consolidated or reported separately as selected by the program operator.

The user information transfer assessment summary lists operator-defined specifications, outcome counts, and calculated parameter estimates for the user information transfer function. Calculation of parameter estimates is

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PERFORMANCE ASSESSMENT SUMMARY

PERFORMANCE MEASUREMENT

ITS PON ACCESS/DISENGAGEMENT PERFORMANCE MEASUREMENT    0936.001

REDUCTION RUN . . . . . . . . . . . . . . . . . . . . . . 1

PERFORMANCE DATA BATCH

NTIA - PON test from Washington,                           0936

SOURCE USER . . . . . . . . . . . . . NTIA - Term2 (NBS-Gaithers
DESTINATION USER . . . . . . . . . . . NTIA - Host1 (Boulder)
ORIGINATING USER . . . . . . . . . . . . . . . . . . . . . SOURCE

SESSION TYPE . . . . . . . . . . . . . . . . . CONNECTION ORIENTED
INITIAL DISENGAGEMENT TYPE . . . . . . . . . . . . . . NEGOTIATED

MEASUREMENT START TIME . . . . . . . .  12/13/83  14:05:26.275 UT
MEASUREMENT END TIME . . . . . . . . .  12/13/83  14:45:57.436 UT

ACCESS ASSESSMENT SUMMARY
FOR CURRENT PERFORMANCE DATA BATCH

ACCESS SPECIFICATIONS

SPECIFIED ACCESS TIME . . . . . . . . . . . . . . . .  45.000 SECONDS
SPECIFIED USER FRACTION OF ACCESS TIME . . . . . . .   0.0090

ACCESS PERFORMANCE STATISTICS

NUMBER OF ACCESS ATTEMPTS . . . . . . . . . . . . . . .  20 (+)
NUMBER OF 'SUCCESSFUL ACCESS' OUTCOMES . . . . . . . .  19
NUMBER OF 'INCORRECT ACCESS' OUTCOMES . . . . . . . . .   0
NUMBER OF 'ACCESS DENIAL' OUTCOMES . . . . . . . . . .   1
NUMBER OF 'ACCESS OUTAGE' OUTCOMES . . . . . . . . . .   0

(+) THIS NUMBER EXCLUDES ACCESS ATTEMPTS
    THAT FAIL DUE TO USER BLOCKING

MEASURED VALUES OF ACCESS PERFORMANCE PARAMETERS

ACCESS TIME . . . . . . . . . . . . . . . . . . . . .  44.537 SECONDS
USER FRACTION OF ACCESS TIME . . . . . . . . . . . .   0.0090

INCORRECT ACCESS PROBABILITY . . . . . . . . . . . . . . 0
ACCESS DENIAL PROBABILITY . . . . . . . . . . . 5.0 X 10(-02)
ACCESS OUTAGE PROBABILITY . . . . . . . . . . . . . . . 0

DISENGAGEMENT ASSESSMENT SUMMARY
FOR CURRENT PERFORMANCE DATA BATCH

(SOURCE DISENGAGEMENT ATTEMPTS)

DISENGAGEMENT SPECIFICATIONS

SPECIFIED DISENGAGEMENT TIME . . . . . . . . . . . .  14.000 SECONDS
SPECIFIED USER FRACTION OF DISENGAGEMENT TIME . . . .  0.0250

DISENGAGEMENT PERFORMANCE STATISTICS

NUMBER OF DISENGAGEMENT ATTEMPTS . . . . . . . . . . .  19 (+)
NUMBER OF 'SUCCESSFUL DISENGAGEMENT' OUTCOMES . . . . .  17
NUMBER OF 'DISENGAGEMENT DENIAL' OUTCOMES . . . . . . .   2

(+) THIS NUMBER EXCLUDES DISENGAGEMENT ATTEMPTS
    THAT FAIL DUE TO USER DISENGAGEMENT BLOCKING

MEASURED VALUES OF DISENGAGEMENT PERFORMANCE PARAMETERS

DISENGAGEMENT TIME . . . . . . . . . . . . . . . . .  13.772 SECONDS
USER FRACTION OF DISENGAGEMENT TIME . . . . . . . . .  0.0290

DISENGAGEMENT DENIAL PROBABILITY . . . . . . . . 1.1 X 10(-01)
```

a. Test descriptors, assess assessment summary, and disengagement assessment summary.

```
TRANSFER SPECIFICATIONS

SPECIFIED BLOCK TRANSFER TIME . . . . . . . . . . . .    6.000 SECONDS
SPECIFIED USER FRACTION OF BLOCK TRANSFER TIME . . .       0

SPECIFIED USER FRACTION OF INPUT/OUTPUT TIME . . . .  0.0250

SPECIFIED USER INFORMATION BIT TRANSFER RATE . . . .     1000 BITS/SEC

SPECIFIED BIT ERROR PROBABILITY . . . . . . . .  1.0 X 10(-08)
SPECIFIED BIT LOSS PROBABILITY . . . . . . . .   1.0 X 10(-08)
SPECIFIED EXTRA BIT PROBABILITY . . . . . . . .  1.0 X 10(-08)

MINIMUM SIZE OF TRANSFER SAMPLE . . . . . . . . . . .     1800 BITS

TRANSFER PERFORMANCE STATISTICS

NUMBER OF BIT TRANSFER ATTEMPTS . . . . . . . . . . . .  77824 (+)
NUMBER OF 'SUCCESSFUL BIT TRANSFER' OUTCOMES . . . . .   76926
NUMBER OF 'INCORRECT BIT' OUTCOMES . . . . . . . . . .       0
NUMBER OF 'LOST BIT' OUTCOMES . . . . . . . . . . . . .    896
NUMBER OF 'EXTRA BIT' OUTCOMES . . . . . . . . . . . .       0

NUMBER OF BLOCK TRANSFER ATTEMPTS . . . . . . . . . . .     19 (++)
NUMBER OF 'SUCCESSFUL BLOCK TRANSFER' OUTCOMES . . . .      18
NUMBER OF 'INCORRECT BLOCK' OUTCOMES . . . . . . . . .       1
NUMBER OF 'LOST BLOCK' OUTCOMES . . . . . . . . . . . .      0
NUMBER OF 'EXTRA BLOCK' OUTCOMES . . . . . . . . . . .       0

NUMBER OF TRANSFER SAMPLES . . . . . . . . . . . . . . .     3 (+++)
NUMBER OF 'TRANSFER DENIAL' OUTCOMES . . . . . . . . .       0

NUMBER OF 'SUCCESSFUL BIT TRANSFER' OUTCOMES
  IN 'SUCCESSFUL TRANSFER' SAMPLES . . . . . . . . . . .     0

(+)   THIS NUMBER EXCLUDES BIT TRANSFER ATTEMPTS
      THAT RESULT IN 'REFUSED BIT' OUTCOMES

(++)  THIS NUMBER EXCLUDES BLOCK TRANSFER ATTEMPTS
      THAT RESULT IN 'REFUSED BLOCK' OUTCOMES

(+++) THIS NUMBER EXCLUDES TRANSFER SAMPLES
      THAT RESULT IN 'REJECTED SAMPLE' OUTCOMES

MEASURED VALUES OF TRANSFER PERFORMANCE PARAMETERS

BIT ERROR PROBABILITY . . . . . . . . . . . . . . . . . . 0
BIT LOSS PROBABILITY . . . . . . . . . . . . . 1.2 X 10(-02)
EXTRA BIT PROBABILITY . . . . . . . . . . . . . . . . . . 0

BLOCK TRANSFER TIME . . . . . . . . . . . . . . . .   6.098 SECONDS
USER FRACTION OF BLOCK TRANSFER TIME . . . . . . . . . .  0

BLOCK ERROR PROBABILITY . . . . . . . . . . . . 5.3 X 10(-02)
BLOCK LOSS PROBABILITY . . . . . . . . . . . . . . . . . 0
EXTRA BLOCK PROBABILITY . . . . . . . . . . . . . . . . 0

USER INFORMATION BIT TRANSFER RATE . . (VALUE NOT CALCULATED)
USER FRACTION OF INPUT/OUTPUT TIME . . (VALUE NOT CALCULATED)

TRANSFER DENIAL PROBABILITY . . . . . . (VALUE NOT CALCULATED)

USER INFORMATION TRANSFER ASSESSMENT SUMMARY
FOR CURRENT PERFORMANCE DATA BATCH

CORRELATOR SPECIFICATIONS

USER INFORMATION WINDOW SIZE . . . . . . . . . . . . . . .   16 BITS
CORRESPONDENCE THRESHOLD . . . . . . . . . . . . . . . . .   16 BITS

MAXIMUM DATA SHIFT IN ERROR CLUSTER SEARCH . . . . . . . .   64 BITS
MAXIMUM DATA SHIFT IN UNDELIVERED BIT SEARCH . . . . . . . 4096 BITS
MAXIMUM DATA SHIFT IN EXTRA BIT SEARCH . . . . . . . . . . 4096 BITS

BIT-ORIENTED CORRELATION --- SUMMARY OF RESULTS

NUMBER OF CORRELATOR OUTPUT BLOCKS . . . . . . . . . . .    19

NUMBER OF BIT CORRELATION OUTCOMES . . . . . . . . . . . 77824
NUMBER OF 'CORRECT BIT' OUTCOMES . . . . . . . . . . . . 76928
NUMBER OF 'INCORRECT BIT' OUTCOMES . . . . . . . . . . .     0
NUMBER OF 'UNDELIVERED BIT' OUTCOMES . . . . . . . . . .   896
NUMBER OF 'EXTRA BIT' OUTCOMES . . . . . . . . . . . . .     0

NUMBER OF SOURCE USER INFORMATION BLOCKS TRANSMITTED . . .  19
NUMBER OF SOURCE USER INFORMATION BLOCKS CORRELATED . . .   19

NUMBER OF SOURCE USER INFORMATION BITS TRANSMITTED . . . . 77824
NUMBER OF SOURCE USER INFORMATION BITS CORRELATED . . . .  77824

NUMBER OF DESTINATION USER INFORMATION BLOCKS RECEIVED . .  19
NUMBER OF DESTINATION USER INFORMATION BLOCKS CORRELATED .  19

NUMBER OF DESTINATION USER INFORMATION BITS RECEIVED . . . 76928
NUMBER OF DESTINATION USER INFORMATION BITS CORRELATED . . 76828
```

b. User information transfer assessment summary.

Figure 2-14. Performance assessment summary produced by the ITS Data Reduction program.

suppressed where the extracted data is insufficient, as is the case for three parameters in the example shown. The user information transfer summary also lists the operator-defined specifications used in correlating the transmitted and received data and the correlator output results.

Figure 2-15 lists results obtained from the ITS Statistical Design and Analysis program for the same test summarized in Figure 2-14. The output consists of two parts. The first, Figure 2-15a, lists the calculated parameter estimates and associated 90 percent and 95 percent confidence limits for the time (e.g., delay) parameters defined in ANS X3.102. The second, Figure 2-15b, lists the corresponding information for the failure probability parameters. The Data Reduction and Statistical Design and Analysis programs are executed from a command file so that both output listings are produced in response to a single operator request.

During FY 84, the Institute also began work on a comprehensive monograph describing the mathematical foundations of the ITS Statistical Design and Analysis program. Figures 2-16 and 2-17 are illustrations from that monograph. They are distribution functions for communication failure probabilities (e.g., Block Error Probability, Access Denial Probability) based on a mathematical model first applied to communications in research conducted at the Institute. The model is an exension of the classical Bernoulli model (independent trials, constant failure probability) in which one additional parameter (the conditional probability of failure given a failure on the immediately preceding trial) is introduced. The result is a stationary Markov model with two states. Introducing the conditional probability parameter enables the model to more realistically represent communication failures, such as bit errors, which commonly occur in clusters or "bursts." The Markov model provides a basis for determining sample size requirements and estimating precision in the measurement of communication failure probabilities, as described by Miles in NTIA Report 84-153.

Figure 2-16 shows, from two perspectives, a distribution of failure probabilities calculated from the Markov model for the special case of a sample size (n) of 100; an overall failure probability (p) of 0.3; and a conditional failure probability (λ) of 0.5. In each

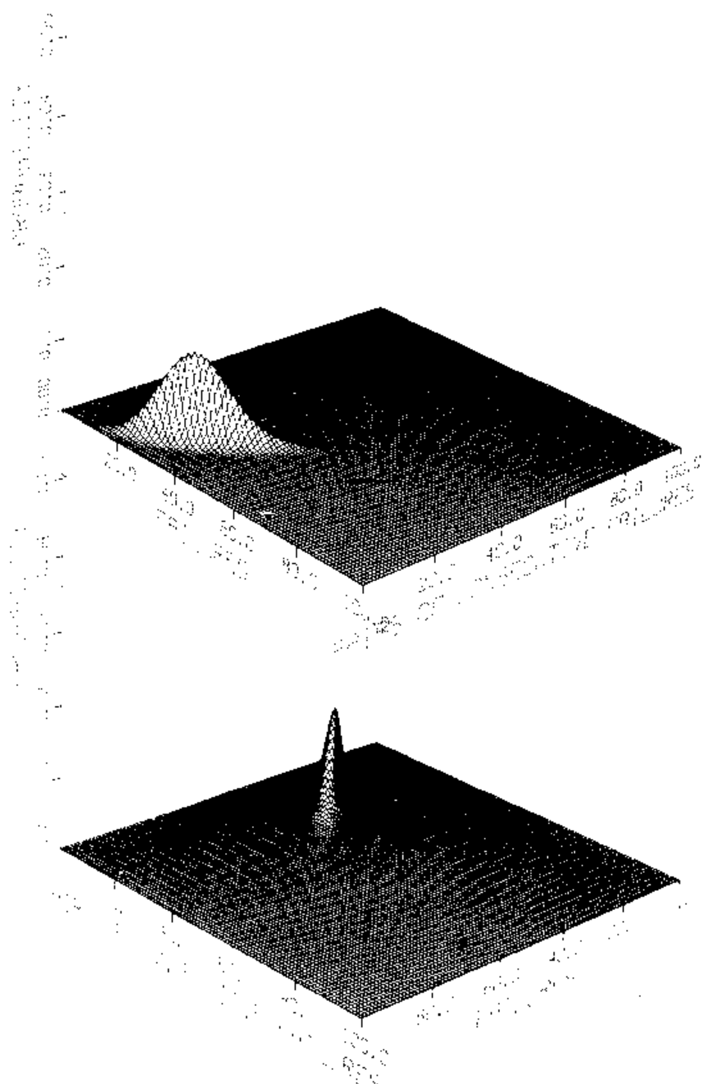


Figure 2-16. Failure probability distribution for the 2-state Markov model with p=0.3, λ=0.5, and n=100 (shown from two perspectives).

MEASUREMENT RESULTS SUMMARY

RUN: ITS PDN ACCESS/DISENGAGEMENT PERFORMANCE MEASUREMENT 0936.001
BATCH: NTIA - PDN test from Weshington, 0936

PERFORMANCE PARAMETER	SAMPLE SIZE	ESTIMATED VALUE	CONFIDENCE LEVEL (PERCENT)	LOWER CONFIDENCE LIMIT	UPPER CONFIDENCE LIMIT
ACCESS TIME	19	.44537e+02	90	.43637e+02	.45437e+02
			95	.43446e+02	.45627e+02
USER FRACTION OF ACCESS TIME	19	.89580e-02	90	.87864e-02	.91297e-02
			95	.87535e-02	.91626e-02
BLOCK TRANSFER TIME	18	.60978e+01	90	.60106e+01	.61851e+01
			95	.59920e+01	.62037e+01
USER FRACTION OF BLOCK TRANSFER TIME	18	.00000e+00	90	.00000e+00	.00000e+00
			95	.00000e+00	.00000e+00
DISENGAGEMENT TIME (SOURCE)	17	.13772e+02	90	.13435e+02	.14108e+02
			95	.13363e+02	.14180e+02
USER FRACTION OF DISENGAGEMENT TIME (SOURCE)	17	.28967e-01	90	.28301e-01	.29633e-01
			95	.28174e-01	.29760e-01
DISENGAGEMENT TIME (DESTINATION)	19	.36752e+01	90	.36056e+01	.37448e+01
			95	.35908e+01	.37595e+01
USER FRACTION OF DISENGAGEMENT TIME (DESTINATION)	19	.18304e+00	90	.16765e+00	.19842e+00
			95	.16471e+00	.20136e+00

ESTIMATED PERFORMANCE TIMES ARE EXPRESSED IN SECONDS

a. Time parameter estimates and confidence limits.

MEASUREMENT RESULTS SUMMARY

RUN: ITS PDN ACCESS/DISENGAGEMENT PERFORMANCE MEASUREMENT 0936.001
BATCH: NTIA - PDN test from Weshington, 0936

PERFORMANCE PARAMETER	SAMPLE SIZE	ESTIMATED VALUE	CONFIDENCE LEVEL (PERCENT)	LOWER CONFIDENCE LIMIT	UPPER CONFIDENCE LIMIT
INCORRECT ACCESS PROBABILITY	20	.00000e+00	90	.00000e+00	.10785e+00
			95	.00000e+00	.13409e+00
ACCESS DENIAL PROBABILITY	20	.50000e-01	90	.00000e+00	.19817e+00
			95	.00000e+00	.23110e+00
ACCESS OUTAGE PROBABILITY	20	.00000e+00	90	.00000e+00	.10785e+00
			95	.00000e+00	.13409e+00
BIT ERROR PROBABILITY	77824	.00000e+00	90	.00000e+00	.32848e-04
			95	.00000e+00	.42781e-04
BIT LOSS PROBABILITY	77824	.11513e-01	90	.79880e-03	.65790e-01
			95	.60687e-03	.81987e-01
EXTRA BIT PROBABILITY	77824	.00000e+00	90	.00000e+00	.14480e-01
			95	.00000e+00	.18774e-01
BLOCK ERROR PROBABILITY	19	.52632e-01	90	.00000e+00	.17846e+00
			95	.00000e+00	.20670e+00
BLOCK LOSS PROBABILITY	19	.00000e+00	90	.00000e+00	.11262e+00
			95	.00000e+00	.13975e+00
EXTRA BLOCK PROBABILITY	19	.00000e+00	90	.00000e+00	.11262e+00
			95	.00000e+00	.13975e+00
DISENGAGEMENT DENIAL PROBABILITY (SOURCE)	19	.10526e+00	90	.27004e-01	.28035e+00
			95	.21949e-01	.31367e+00
DISENGAGEMENT DENIAL PROBABILITY (DESTINATION)	19	.00000e+00	90	.00000e+00	.11262e+00
			95	.00000e+00	.13975e+00

WHEN THE OBSERVED NUMBER OF FAILURES IS 0 OR 1, THE CONDITIONAL PROBABILITY OF FAILURE USED TO ESTIMATE CONFIDENCE LIMITS IS 0.9998 FOR BIT LOSS AND EXTRA BIT PROBABILITIES, 0.3 FOR ACCESS DENIAL PROBABILITY, AND 0.1 FOR ALL OTHER PERFORMANCE PARAMETERS

b. Probability parameter estimates and confidence limits.

Figure 2-15. Measurement results summary obtained from the ITS Statistical Design and Analysis program.

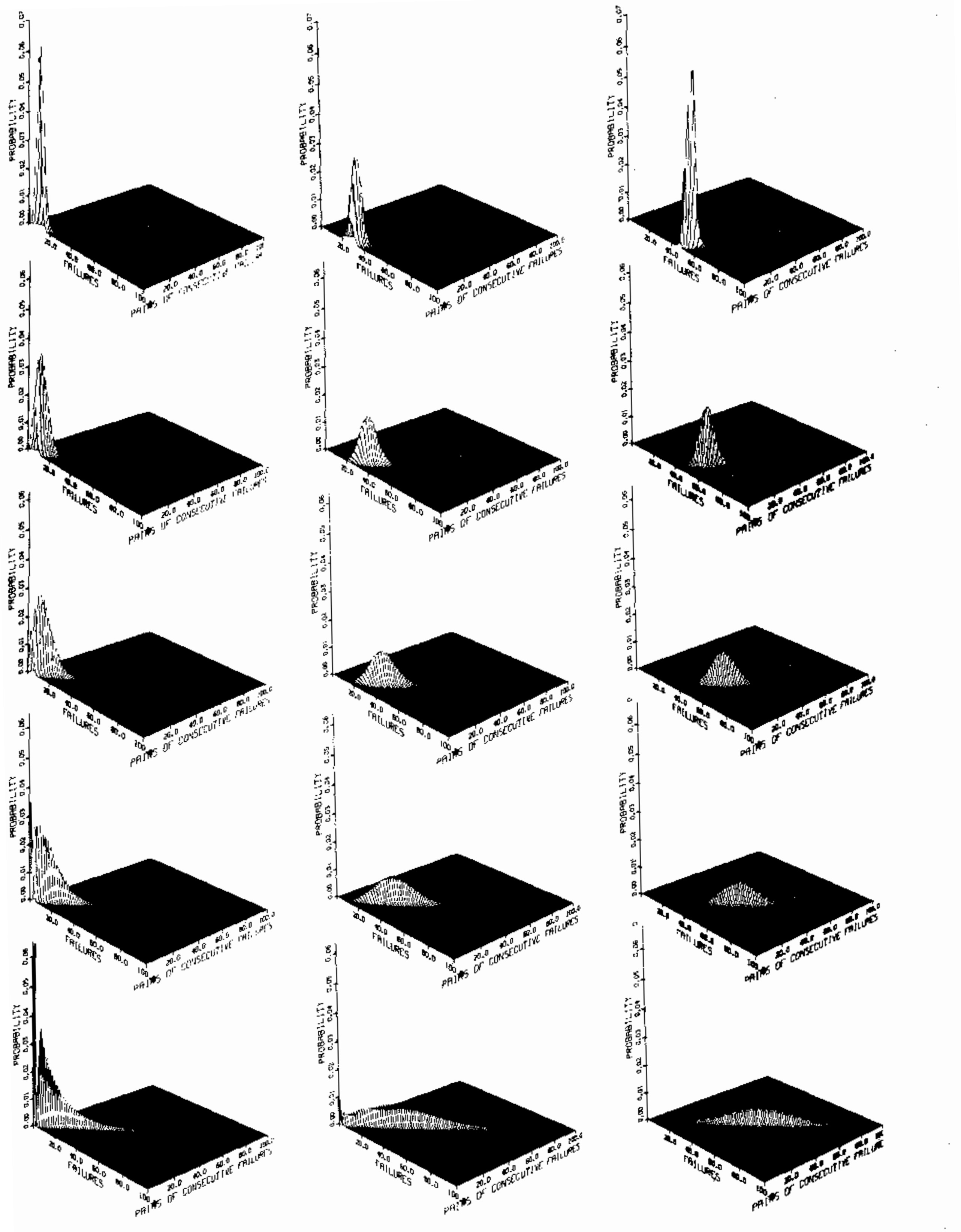


Figure 2-17. Effect of variations in p and λ on the Markov failure probability distribution.

graph, the axes defining the horizontal plane express the number of failures, s, and the number of pairs of consecutive failures, r, which may be observed in a sample of size 100. The vertical axis expresses the probability of each possible (s,r) combination. For the assumed population, the probability of observing s=30 failures and r=15 pairs of consecutive failures is greater than is the probability of observing any other combination of s and r (because s/n=0.30 and r/s=0.50). In contrast, the probability of observing s=75 failures and r=5 pairs of consecutive failures is very small (because $\frac{s}{n}$=0.75 and r/s=0.15, and these values are very different from p=0.3 and λ=0.50, respectively).

Graphs such as these are useful in illustrating the concept of a confidence interval or region. A parameter estimate derived from measurement of a finite sample will not normally correspond exactly with the "true" (population) value of the parameter because of sampling error. The extent to which the true value may deviate from the measured estimate is normally expressed by a confidence interval--(i.e., a range of values about the estimate within which the "true" value can, with a stated probability, be expected to lie). The stated probability is called the confidence level. The one-dimensional confidence interval for a failure probability becomes a multi-dimensional "confidence region" when the probability is a function of two or more variables as is the case when failures are grouped or clustered in time.

In Figure 2-16, any intersection of a horizontal plane with the graphed probability surface creates a two-dimensional confidence region defined by the intersection contour. The percentage of the (unit) volume under the surface that is above the intersection contour is the confidence level (i.e., the likelihood that the region contains the true values of both p and λ). For example, a contour that delimits 95 percent of the volume is a 95 percent confidence region, and we may be 95 percent confident that the true values of both p and λ are in that region.

Figure 2-17 is a matrix of probability functions for the two-state Markov model, showing the effect of variations in p and λ on the graph's location and shape (and the associated confidence region). As one would expect, increasing p translates the graph's peak (or mode) in the direction of more failures, while increasing λ broadens the curve in the direction of more consecutive failures. The confidence region is oval for small values of p and λ and becomes much more eccentric for larger values, particularly as λ approaches 1.

The complete monograph summarizing ITS work in statistical test design and data analysis will be published in FY 85. It is expected to assist test engineers and mathematicians in understanding the ITS Statistical Design and Analysis program and applying it in practical communication performance measurements.

The second major goal of NTIA's FY 84 Data Communications project was to complete and document pilot measurements of three U.S. PDN's. These measurements had two specific objectives. The primary objective was to demonstrate the use of ITS-developed, microprocessor-based test sets implementing ANS X3.102 and the proposed measurement standard in assessing widely used public data communication services. A secondary objective was to obtain some preliminary data on the performance of the various network alternatives. The FY 84 measurements were a continuation and extension of earlier measurements summarized in the Institute's FY 83 Annual Report.

Figure 2-18 illustrates the overall plan of the ITS PDN measurements. Two microcomputer-based test sets were developed: one emulating a network-accessible host computer and one emulating a remote data terminal (and its operator). The host emulator was located at ITS in Boulder and was connected to the local offices of each of three public data networks via 9.6 kbps leased telephone lines. The terminal emulator was placed in several remote test cities, where it obtained access to the PDN's via the local exchange telephone network. The terminal emulator was also able to communicate with the host emulator via the direct distance dial (DDD) telephone network, bypassing the PDN's. The switched local telephone links operated at 1200 bps.

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

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

Figures 2-19 through 2-23 present selected results of public data network measurements conducted by the Institute in early FY 84. Figure 2-19 shows the effect of time of day on measured values for the ANS X3.102 performance parameter Block Transfer Time--in this application--the total elapsed time between issuance of a WRITE system call in the remote terminal emulator (data source) and completion of the corresponding READ system call in the host computer emulator (data destination). Both histograms are based on 80 successfully transferred blocks, each 128 characters in length. The source city is Washington, DC, and the destination city is Boulder, CO, in each test. The system utilization factor (service

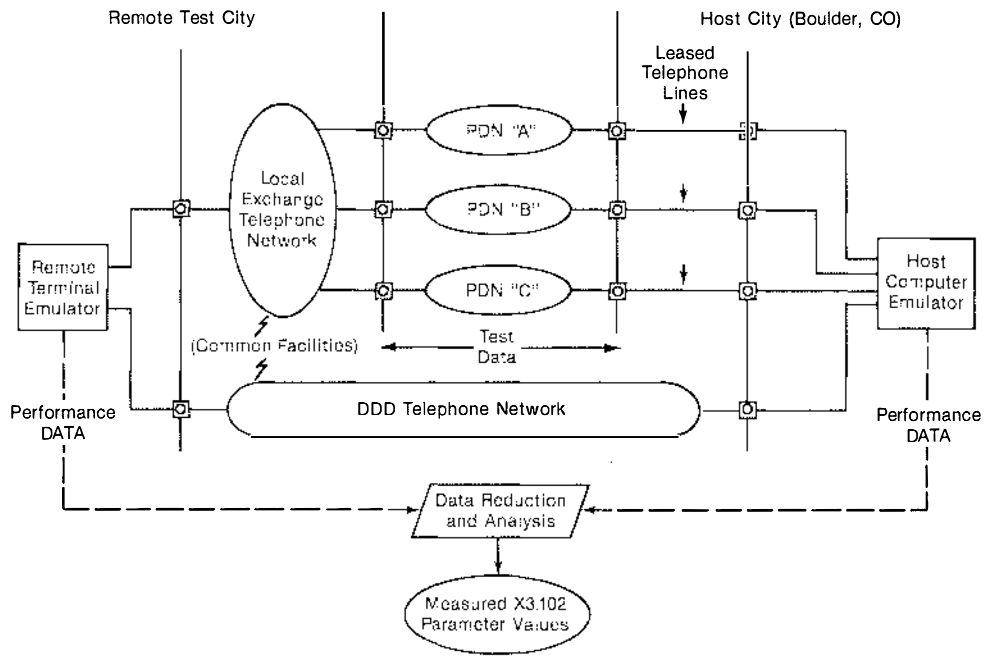


Figure 2-18. Overall plan of ITS Public Data Network measurements.

time divided by interarrival time measured at the source user interface) is 71 percent in each case. The data summarized in Figure 2-19a were collected at approximately 2:00 a.m., and thus reflect "off-peak" usage conditions; the data summarized in Figure 2-19b were collected at approximately 9:30 a.m., and thus reflect "normal business day" usage.

The difference between the two histograms is noticeable but not dramatic. The "off-peak" block transfer times range from 2.8 to 5.32 s, with a mean of 3.94 s and a standard deviation of 507 ms; the "normal business day" times range from 3.11 to 7.18 s, with a mean of 4.55 s, and a standard deviation of 1.164 s. The longer and more variable delays observed in the latter test are no doubt attributable to heavier traffic in the network during the business hours.

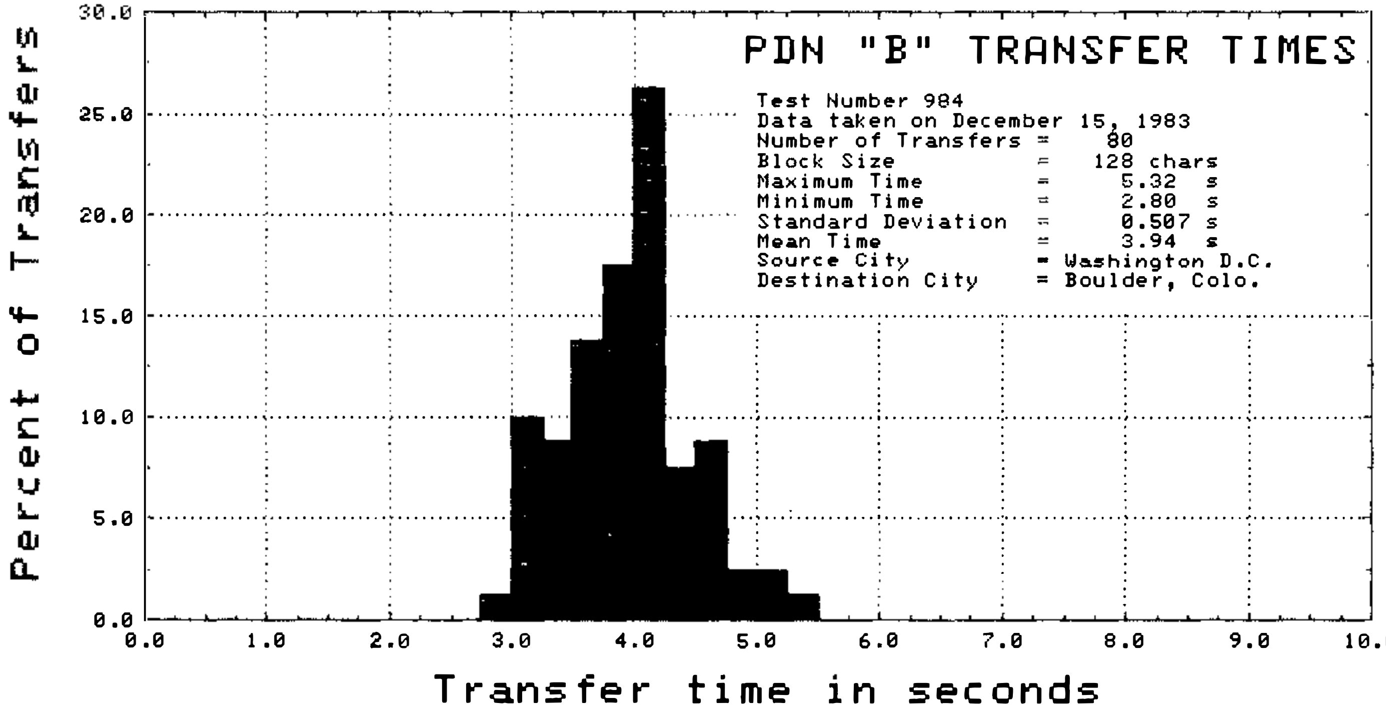
Figure 2-20 compares 128-character block transfer times for tests conducted over two different network transmission paths: Washington, DC, to Boulder, CO, (Figure 2-20a), and Seattle, WA to Boulder, CO (Figure 2-20b). With the exception of the source city, the conditions of the two tests are nominally identical. Perhaps surprisingly, the difference between the two histograms is very slight--less than 4 percent in a comparison to the sample means.

A much more substantial difference in both mean Block Transfer Time and variability is evident in comparing the test data summarized in Figure 2-19b with that summarized in Figure 2-20a. The conditions of these two tests are nominally identical with the exception of the utilization factor: 71 percent in the former test and 40 percent in the latter. The mean Block Transfer Time in the low-utilization test is 1.67 s (36 percent) lower than in the high-utilization test; the standard deviations are 86 ms and 1164 s, respectively. The longest block transfer time recorded in the low-utilization test is 3.13 s; the corresponding maximum in the high-utilization test is 7.18 s. The differences are clearly attributable to queueing delays in the network.

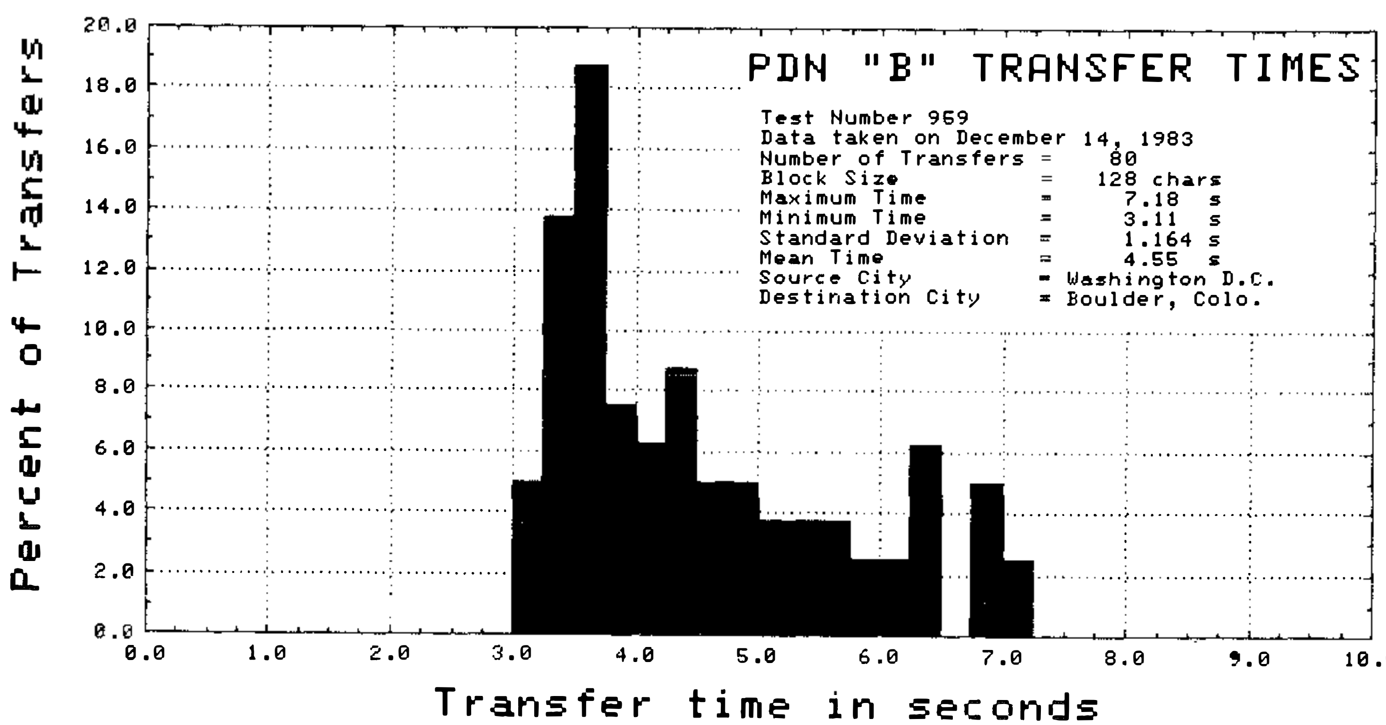
Figure 2-21 compares 512-character block transfer times measured on a Direct-Distance-Dial (DDD) connection with corresponding times measured on connections established via two public data networks. Each test was conducted between Washington, DC, and Boulder, CO, during normal business hours. With the exception of the network selected, the tests were nominally identical. The utilization factor in each test was 93 percent. Each test resulted in 20 successful block transfer attempts.

The DDD block transfer times are clearly shorter, and much less variable, than the PDN times. The difference between the PDN "B" and PDN "C" times is insignificant at the 95 percent confidence level. The DDD block transfer times averaged 4.48 s, with a standard deviation of 36 ms; taken together, the PDN times averaged 7.49 s, with a standard deviation of 812 ms. All 20 percent of the DDD block transfer times were between 4.25 and 4.5 s; the grouped PDN times range from a low of 6.02 s to a high of 8.99 s.

These results clearly illustrate the effect of network resource sharing on user-to-user Block Transfer Time. A terrestrial DDD connection is essentially a dedicated "pipe" with a very low (and constant) delay. The Block Transfer Time in such a connection is dominated by the character modulation time, which can be calculated (for 512 data characters plus a terminating Carriage Return transmitted at 120 characters per second) to be about 4.28 s. In contrast, the PDN's transfer user data in a

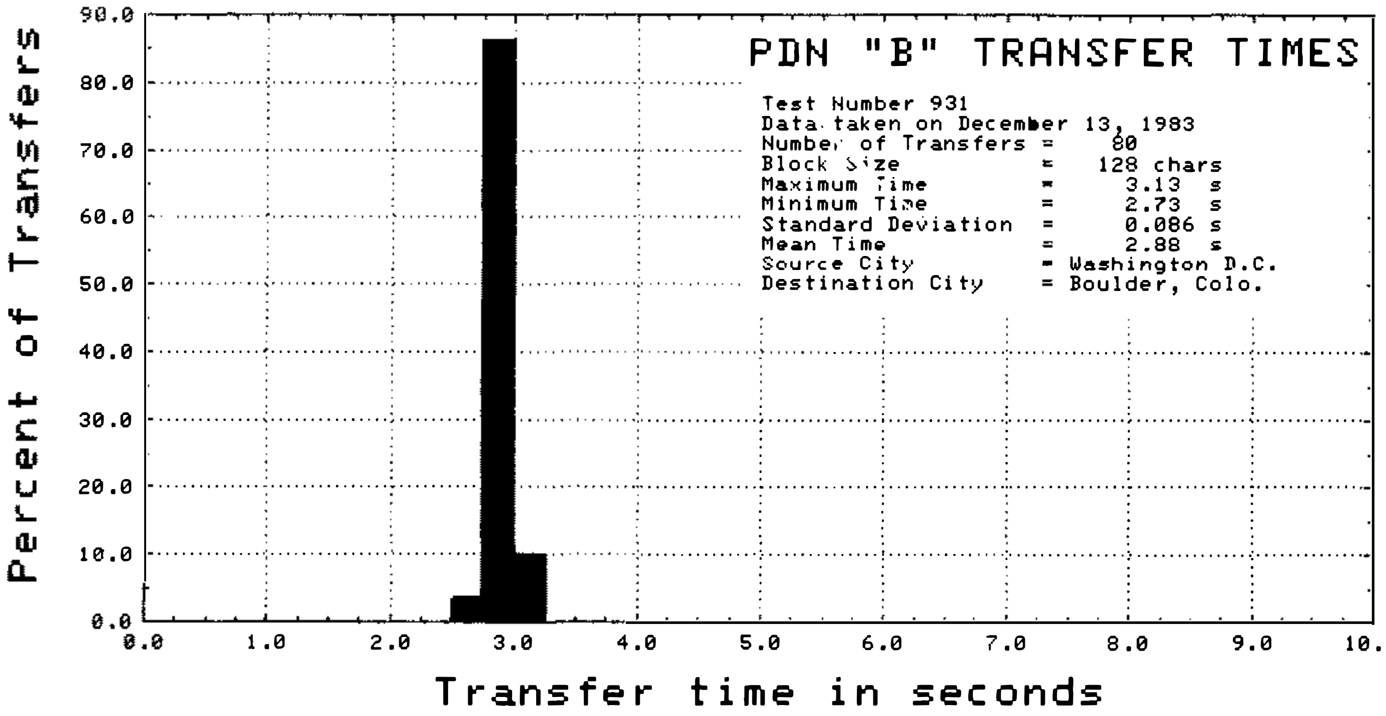


a. "Off-peak" usage period (2 a.m. local time at the source).

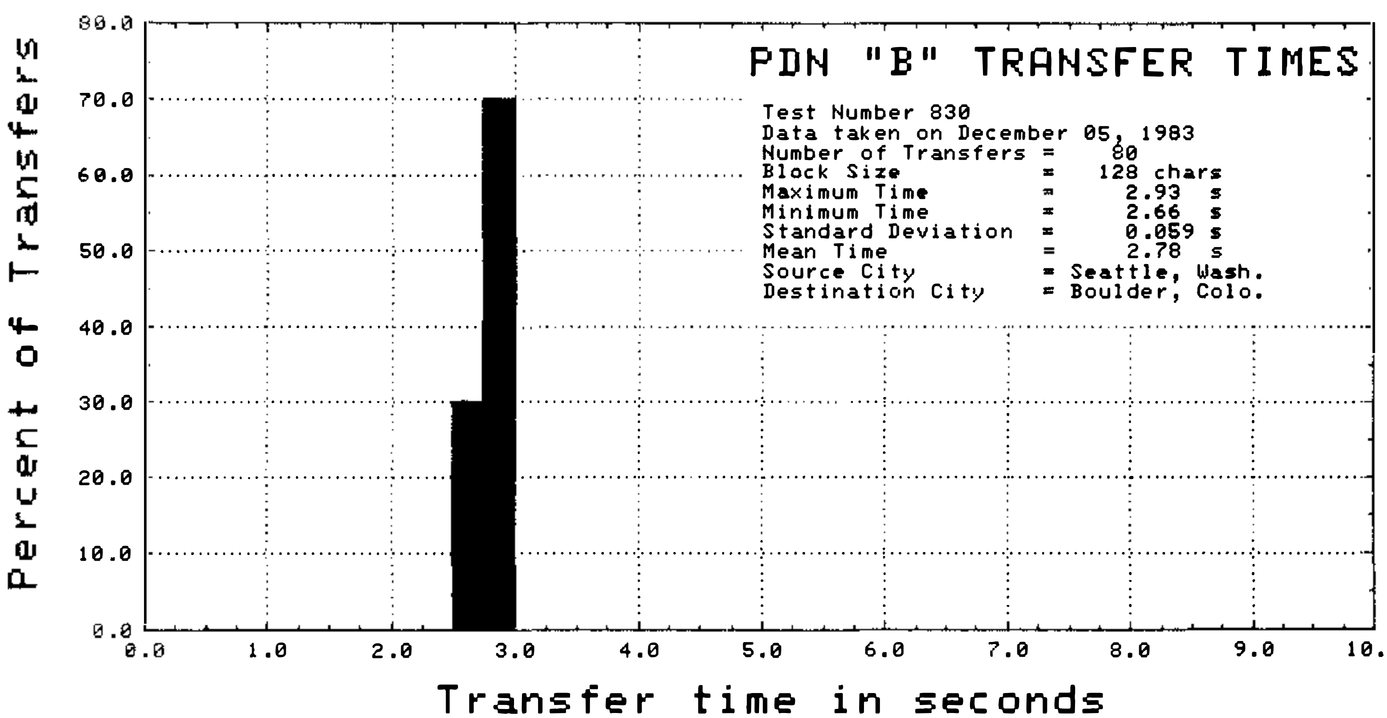


b. "Normal business day" usage period (9:30 a.m. local time at the source).

Figure 2-19. Block transfer time distributions for two usage periods.

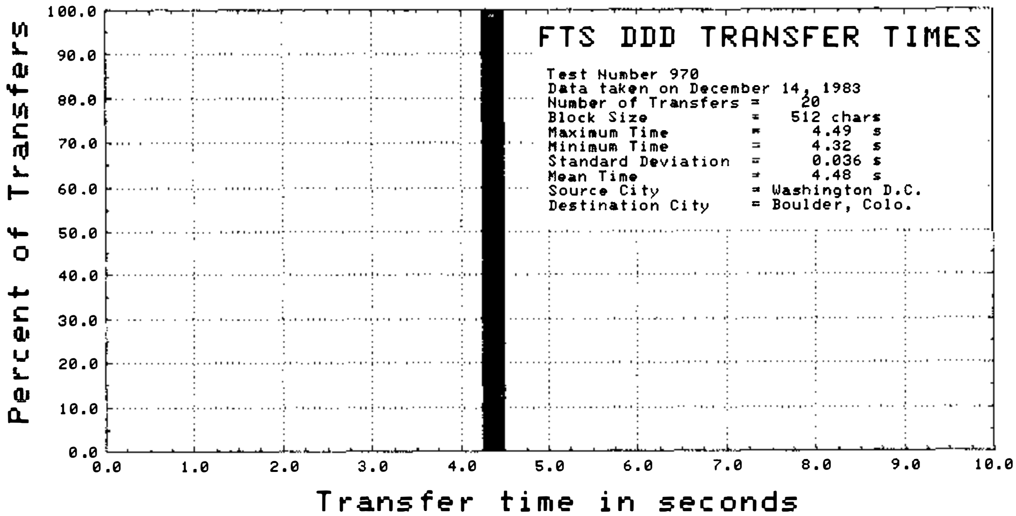


a. Source terminal located in Washington, DC.

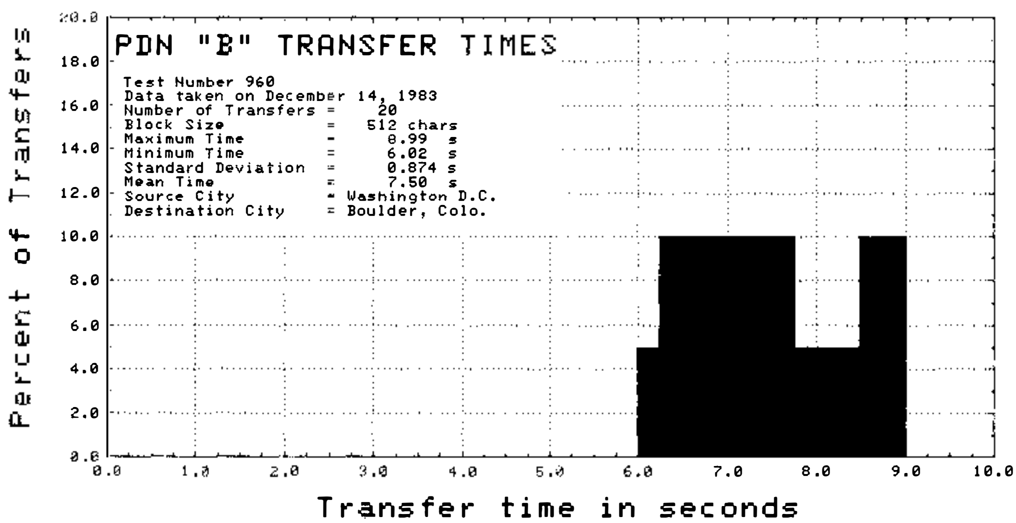


b. Source terminal located in Seattle, WA.

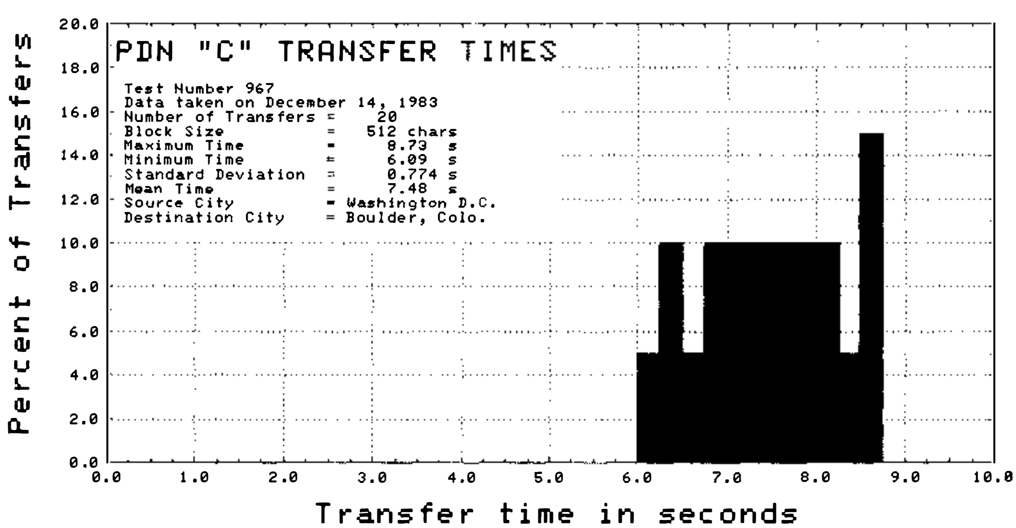
Figure 2-20. Block transfer time distributions for two source terminal locations.



a. Direct-Distance-Dial connection.



b. Connection via PDN "B".



c. Connection via PDN "C".

Figure 2-21. Block transfer time distributions for Direct-Distance-Dial and public data network connections.

store-and-forward fashion, and may introduce queueing delays at network nodes to improve transmission capacity utilization. Public data network users accept the longer and more variable delays such networks introduce in exchange for other benefits--notably, the cost savings resource sharing provides.

Figure 2-22 is a joint distribution of source user and destination user disengagement times for communications between Washington, DC, and Boulder, CO. The two populations are clearly distinct: the source user terminal application program disengagement times range from 12.74 s to 16.61 s, with a mean of 13.77 s and a standard deviation of 790 ms; the destination user (host application program) disengagement times range from 3.41 s to 4.08 s, with a mean of 3.68 s and a standard deviation of 160 ms. The source distribution is separated from the destination distribution by a gap of more than 10 source standard deviations.

The difference between the source user and destination user disengagement times is a result of differences in the nature of the disengagement function at the two interfaces. Source user disengagement includes log-out from the host computer and disconnection from the PDN, and requires four distinct transfers of control information through the network; destination user disengagement is completed prior to log-out and disconnection, and requires only one end-to-end control information transfer. Such asymmetry is typical of modern data communication systems.

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

The project involves three major functions. The first is to lead and coordinate U.S. participation in key standardization efforts of the CCITT and CCIR. This work is conducted under the auspices of the U.S. Department of State. Institute personnel currently chair two of the five U.S. CCITT Study Groups: Study Group D and the Joint Working Party on Integrated Services Digital Networks (ISDN's). Study Group D prepares U.S. inputs to international meetings of CCITT Study Groups VII (Public Data Networks) and XVII (Data Transmission over Public Telephone Networks). The ISDN Working Party prepares U.S. inputs to international meetings of CCITT Study Group XVIII, which has overall responsibility for ISDN standardization within the CCITT. In FY 84, ITS also contributed to the

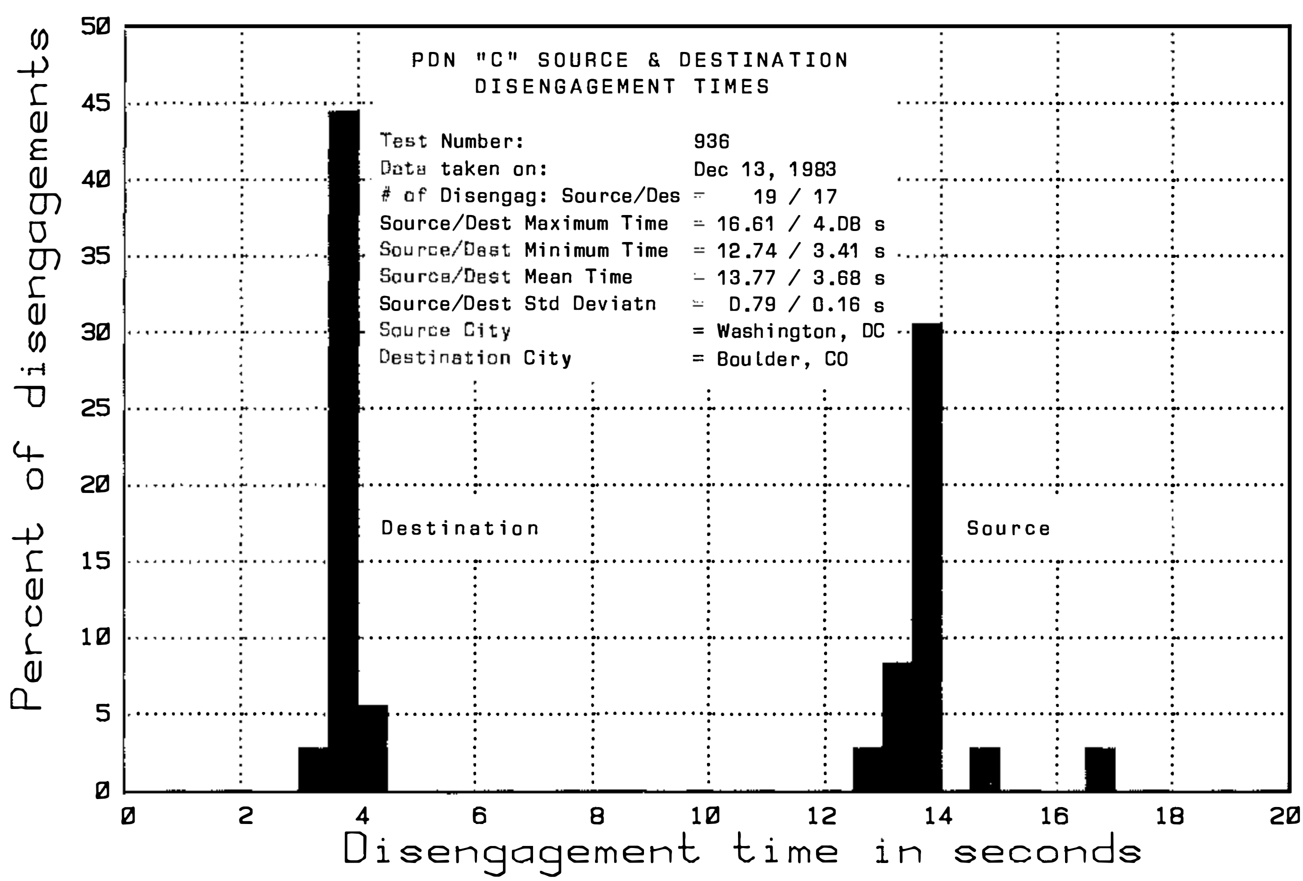


Figure 2-22. Source user and destination user disengagement times.

planning and organization of work on two U.S. CCITT preparatory groups (the Modem Working Party and the Message Handling Working Party); chaired a Technical Working Group under the U.S. ISDN Joint Working Party; headed the U.S. Delegations to international meetings of CCITT Working Party XI/6 (ISDN Subscriber Line Signaling); and provided international chairmanship of CCIR Interim Working Party 8/11 (Direct Printing Equipment in the Maritime Mobile Service).

The responsibilities of a U.S. CCITT Study Group Chairman include the review, coordination, and approval of proposed U.S. contributions to CCITT; coordination of U.S. concensus positions on international standards issues; and leadership of the U.S. Delegations to international CCITT meetings. CCITT Working Party and Technical Working Group Chairmen are responsible for coodinating the development of proposed U.S. contributions to CCITT under the guidance of their parent U.S. Study Groups. CCIR Working Party chairmen are responsible for the direction and coordination of international efforts leading to CCIR Recommendations, which govern spectrum use and the design of radiating communications equipment.

During the 1981-1984 Study Period, Study Group (SG) VII was extremely active and productive, generating 34 new X-series Recommendations and agreeing to revisions in 27 others. Actions of significant impact and interest included:

- revisions to X.25
  - addition of new facilities and capabilities to support provision of the Open Systems Interconnection (OSI) Network Service (extended addressing, extended interrupt packet, etc.)
  - extension of Recognized Private Operating Agency (RPOA) selection facility
  - deletion of datagrams
- joint work with SG XVIII to develop Recommendations for ISDN support of circuit-switching and packet-switching terminal equipment
- functional definition of Public Switched Telephone Network (PSTN) access to Packet Switched Public Data Networks (PSPDNs)
- Recommendations on Open Systems Interconnection including the Basic Reference Model, Service Conventions, the Network, Transport, and Session Service Definitions, and the Transport and Session Protocol Specifications (developed in close cooperation and liaison with International Organization for Standardization (ISO) TC97/SC16 and SC6)
- development of a new Recommendation on formal description techniques
- agreement on eight new Recommendations dealing with Message Handling Systems
- generation of a Recommendation on general principles of interworking, based on principles of OSI
- further development of quality of service Recommendations outlining principles and objectives for public networks.

The major emphasis in the work of Study Group XVII in the 1981-1984 Study Period was on full duplex modems for use over the public switched telephone network. Under the combined leadership of the United States and United Kingdom, a Special Rapporteur's Group drafted a new Recommendation for a family of modems using echo-cancellation techniques at speeds of 4800 and 9600 b/s. This Recommendation was subsequently adopted by the Study Group as V.32. Noteworthy is the use of Trellis coding for use at 9600 bps, where specific connections might otherwise not give satisfactory results. Another important subject considered by Study Group XVII was a Common Physical Interface. U.S. proposals were based on the structure of the ISDN basic interface, which provides serial bit-stream control of the modem functions and is intended to replace the present common method of parallel control lines and (for example) 25 pin connectors. The Study Group also considered support of V-series modems in a mixed ISDN/analog network environment, resulting in Recommendation V.110/I.463.

The 1981-1984 CCITT Study Period saw a major effort toward drafting new Recommendations dealing with Integrated Services Digital Networks (ISDN's). Some 27 new I-series Recommendations were drafted in Study Group XVIII and submitted to the CCITT Plenary Assembly (October 1984). The I-series Recommendations are divided in several groups. The I.100 series Recommendations describe ISDN's in general, characterize ISDN services and capabilities, define relevant terms, and outline the scope and organization of the other ISDN Recommendations. The I.200 series Recommendations provide specific descriptions of so-called bearer and teleservices. The I.300 series Recommendations deal with network functional principles, reference models, connection types, and numbering, addressing, and routing principles. Finally, the I.400 series Recommendations provide detailed physical layer specifications for basic and primary rate user-network interfaces.

CCITT Working Party XI/6 developed four Recommendations that describe layer 2 protocols (I.440/Q.920 and I.441/Q.921) and layer 3 protocols (I.450/Q.940 and I.451/Q.951) for the ISDN subscriber line.

The Modem Working Party contributed strongly to both Recommendation V.32 (4800/9600 bps echo cancelling modems) and Recommendation V.22 bis (2400 bps Frequency Division Multiplexing modems). The Message Handling Working Party participated in developing eight new Recommendations that will facilitate the international communication of electronic mail messages. The ISDN Technical Working Group developed contributions to CCITT Study Group XVIII on technical topics including ISDN architectural reference models, services and capabilities, user-network interfaces, multiplexing and rate adaption, and support of existing data services.

In conjunction with its international standards activities, the Institute participated in organizing a major new U.S. standardization body during FY 84: The American National Standards Institute (ANSI) Accredited Standards Committee (ASC) Tl, "Telecommunications." Committee Tl was formed by the Exchange Carriers Standards Association (ECSA) to provide a public forum for the development of voluntary U.S. telecommunication standards in the post-divestiture environment. It is expected that Committee Tl will also develop technical positions on telecommunication issues under consideration in international standards bodies, including the CCITT. At the request of industry representatives, staff members of the Institute assumed several leadership positions in the new Tl organization, including the chairmanship of Subcommittee TlDl (ISDN); interim chairmanship of the Subcommittee TlQl Joint Working Group on Digital Performance (pending the formation of separate Digital Circuit and Digital Packet Working Groups); and membership in the Tl Advisory Committee, which oversees and directs all Tl standardization work. The TlDl Committee is an outgrowth of the U.S. CCITT ISDN Technical Working Group, which the Institute organized and chaired under the auspices of the U.S. Department of State prior to the formation of Tl.

A second major function of NTIA's International Standards project is to inform interested nonparticipants of significant developments in the various international standards committees for which NTIA has leadership responsibility. Over a period of time, this function broadens and strengthens U.S. input to the CCI's (and other international standards organizations) by adding new contributors and expanding the "knowledge base" from which U.S. contributions may be drawn. This function is accomplished by several means, including NTIA and open literature publications, tutorial workshops, and presentations at professional society and industry conferences. Specific FY 84 results included an NTIA Report describing the process of U.S. and international standardization, with a focus on ISDN and the OSI Reference model; several open literature publications and conference presentations on ISDN, OSI, and related CCITT and ISO standardization activities; and the maintenance and enlargement 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 1981-1984 Study Period. The Institute also planned a 3-day conference on the CCITT's newly-completed X.400 series Recommendations in cooperation with the industry-sponsored Electronic Mail Association, and will host the conference in Boulder on November 13-15, 1984. Invited speakers include Rep. Timothy E. Wirth (D-CO), Chairman of the House Subcommittee on Telecommunications, Consumer Protection, and Finance, and the Honorable Clarence J. Brown, Deputy Secretary of Commerce, as well as many U.S. and international experts on Electronic Mail Systems.

The third major function of NTIA's International Standards project is to develop U.S. contributions to international standards organizations. Such contributions are undertaken on a selective basis, in situations where the Institute has special expertise or resources not readily available to other U.S. participants. A total of eight such contributions were prepared in FY 84, each addressing the completion and alignment of CCITT Recommendations and ISO Standards for the Network and Transport Layers of the Open Systems Interconnection Reference Model. Specific topics addressed included the definition of Quality of Service parameters and their negotiation between OSI end systems, the internal organization of the network Layer, Network Layer addressing, and the applicability of the OSI Reference Model to ISDN's. Institute personnel served as editors (or "rapporteurs") for several draft OSI standards at the request of ISO and CCITT groups. The ISO/CCITT standards for Open Systems Interconnection will facilitate information exchange among dissimilar computers on a worldwide basis by encouraging the development of compatible data communication protocols.

SECTION 2.4 SYSTEM PERFORMANCE ENGINEERING ANALYSIS

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

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

NOAA Telecommunication Study Methodology. The Institute was requested by the National Oceanic and Atmospheric Administration (NOAA) to provide a methodology to allow them to study the entire range of their telecommunication systems. The methodology was to describe in broad detail the steps necessary to first, analyze their current system, to see how well it is meeting the NOAA mission requirements and second, to design a rationalized system that would make full use of current technology to provide full mission support for NOAA at less cost than the present system.

The methodology developed was based in part on methodologies recommended by other researchers for conducting a telecommunications systems analysis. The methodology was adapted and interpreted to match the requirements of NOAA. The NOAA telecommunication plant is widespread and complex; it uses everything from technologies of 40 years ago to the latest high-speed satellite communication links. The many types of systems and services employed by NOAA make the problem of fully understanding and documenting the current scheme complex and costly. The one certainty in the situation is that it would be more expensive to retain the current system and practices than to devise and install a rationalized system.

The methodology was completed and submitted to the sponsor as a letter report.

Update of FED-STD-1037 (Glossary of Telecommunications Terms). As technology changes and new telecommunications services and products are added to the marketplace, it becomes important to standardize the language used in Federal procurement of the new goods and services. The importance of a standardized vocabulary is seen in the case of optical communications--a technology whose vocabulary contributes a large portion of the additions to FED-STD-1037. In fiber optics, a glossary of common terms was needed to bridge the gap between the disciplines of geometric optics, physical optics, and communications engineering, since workers in these different disciplines often used different terms and units of measure to describe the same phenomena.

The absence of a precise, common language among researchers, manufacturers, systems designers, users, and merchants was a hindrance to effective technology development and applications. A set of internationally agreed upon terms was also needed in the procurement process to specify fiber optics products and systems; buyers and sellers of fiber optics product and systems needed a common language to conduct trade. It was the marketplace, then, that initiated the push to write a glossary of fiber optics terms, and it is procurement that has encouraged the incorporation of the new fiber optics terms and other new-technology terms into the FED-STD-1037 dictionary.

The original Federal Standard 1037 contained approximately 2000 terms and definitions. Approximately 1300 new terms and definitions have been proposed for inclusion in the revised FED STD 1037A. One of the major revisions to 1037 is the proposed addition of 450 terms from the NBS Handbook 140, "Optical Waveguide Communications Glossary," coauthored by NTIA.

In addition to fiber optics terms, many new terms from data communications, from the post-divestiture arena, and from Integrated Services Digital Network ISDN technology have also been proposed.

New terms and definitions have been proposed by a score of Federal (DoD and civil-sector) agencies, and have been put into a data base for electronic editing. This data base, with some of the definitions in FED-STD-1037, will be reviewed by a working group and a resolution committee composed of FTSC (Federal Telecommunications Standards Committee) members.

The committee will evaluate each definition, for 1037A inclusion or rejection, according to specific criteria, and then, in later meetings, use an interactive process to refine and polish the definitions to be put into the revised glossary.

The Institute gathers and collates term names and definitions to be included in the new glossary. Later ITS will review material for the drafts of the glossary, including working group drafts and coordination drafts. Further support is provided by ITS in participating in the resolution of review comments that result from the committee meetings.

The widest possible participation by many Government agencies is encouraged in this standards effort. About a dozen Government agencies attend the resolution committee meetings, and 75 member agencies of the FTSC will review the draft standard.

The Institute has a 10-year history of successes in developing and publishing dictionaries that are standards. Work began in 1973 for the Military Standard 188-120 (published in 1975), "Military Communication Systems Standards: Terms and Definitions."

In 1979, NTIA published NTIA Special Publication 79-4, the "Optical Waveguide Communications Glossary."

In 1980, The General Services Administration published Federal Standard 1037, "Glossary of Telecommunication Terms," in which ITS was the lead agency for editing, reviewing, and cross-referencing.

In 1982, the National Bureau of Standards published jointly with NTIA the NBS Handbook 140, "Optical Waveguide Communications Glossary," which was the revision of NTIA-SP-79-4. This revised fiber-optics dictionary was adopted by IEEE and published as a stand-alone volume in their dictionary series. It was also submitted to the International Electrotechnical Commission as a U.S. contribution to an international standards effort. And it is, of course, being incorporated into FED-STD-1037A.

Revision of Military Standards for Communications Systems. The Defense Communications Engineering Center (DCEC) has tasked the Institute for Telecommunication Sciences to prepare a revision of the military standard covering long-haul and tactical communication systems. The current standard, MIL-STD-188-100, was developed in 1972 and has received only minor updates since. Our task is to provide a revision that reflects the capability of state-of-the-art equipment and practices and will allow the specification of end-to-end performance of communication channels which are carried by interconnected strategic and tactical subsystems.

The project involves preparing of draft versions of parts of the revised standard and coordinating these with DCEC and the various military departments involved. The final product will be a complete draft version of the standard.

Automated Passive Repeater Link Engineering. The need exists for an automated prediction technique to estimate the performance of passive repeater links. This need can be filled efficiently using a desk-top computer with a set of interactive programs that provide the design engineer with fast turn-around predictions presented in a report-ready format. The Institute began developing such a set of programs in FY 84 under a project sponsored by the USACEEIA. These programs perform two principal functions: (1) To calculate the optimum orientation values for passive repeaters from the Earth geometry, parameter values of the terminal and repeater sites, and (2) to calculate the performance of the link based on the passive repeater size, antenna gains, other equipment parameters, and atmospheric and terrain parameters.

Three passive repeater types are being considered:

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

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

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

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

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

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

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

- o atmospheric attenuation
- o atmospheric multipath
- o rain attenuation.

The project is expected to be completed early in FY 85.

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

The first deployment demonstrated that TRAMCON would afford many benefits to DEB system operation and availability. In mid-1981, the TRAMCON system was established as an integral part of the digital European upgrade. A series of development and deployment steps were established by the management and technical committees for TRAMCON. These steps include development and refinement of software for the master terminal, the addition of an intelligent remote unit, and the establishment of an intra-TRAMCON master network.

The TRAMCON system was established to monitor, collect, and display data that reflects the operational status of a digital communication system. These data typically are status and alarm indications that are designed into the transmission system hardware and analog and pulse parameters that describe the transmission quality. Examples of information provided by these alarms and parameters are: which receiver and transmitter are on line, which multiplexer is carrying the mission traffic, the absence of data stream activity, the received signal level, and the number of reframe attempts by the multiplexer.

The general functional capability of the master terminal is illustrated in Figure 2-23. The present master consists of a mini-computer system with the peripherals shown. The responsibility of the master is to collect status and parameter information from all remotes within its control, to assemble these responses into usable displays for the system manager using English text, and to maintain a near-term history of system status and performance. The general functional capability of the remote unit is shown in Figure 2-24. The general objective of the remote unit is to sense electrical parameter changes that indicate the operating parameters of a digital microwave system at a location, formulate those changes into a response, and transmit this change information to the master upon request. The master and remote relationship is shown in Figure 2-25. A segment may consist of more than one master--one with polling, switch, and monitor responsibility, the others with monitor responsibility. A segment may consist of up to 24 remote terminals.

During FY 1984, a version of the TRAMCON master that allowed field configuration of site and DEB segment specific information was developed, installed, and tested at Donnersberg and Reese-Augsburg communication facilities in support of the DEB-IIA segment. Initial familiarization and training on the operation of the early version of this system were provided to Air Force and Army pesonnel who have been assigned various test and evaluation efforts. The system is currently undergoing a full year of operational test and evaluation to assess the usability and effectiveness of the system in operating and maintaining the communication system.

Also during the year, work has begun on software expansion to allow each master system to monitor and control multiple segments of transmission systems to provide redundancy for other masters operating on other segments. Development has begun on outlining, in the software, the ability to accommodate remote units with programmed intelligence. This developed capability will greatly improve the efficiency of data acquisition from the remote sites and will also allow for shorter refresh time.

LOS Microwave Channel Simulator. The U.S. Army Communications Systems Agency (CSA) has funded the Institute to develop a line-of-sight (LOS) microwave channel simulator. The device being built by ITS does not dynamically vary parameters to simulate the random fluctuations of a real-world LOS microwave channel. Rather, it uses static device parameters to obtain equipment signatures. These signatures can then be used for the comparative evaluation of digital radios.

One of the key differences between the LOS channel simulator being built by ITS and those discussed in the literature is that in the ITS device, the simulation is implemented at rf rather than at IF. Simulation at IF has the disadvantage that some of the critical components of the signal path are left out. These components include the phase locked loop (PLL) and automatic gain control (AGC) systems as well as circuitry that limits the rf bandwidth.

The model on which the simulator is to be based is a two-path model and may be classified as a signal model rather than as a filter model. Although simulators have been built using a tap-delay line implementation of a filter model, there are some disadvantages in doing so. Two disadvantages are:

1) The tap-gain functions are complex. They generally are not Gaussian in nature, yet most of the tap-delay-line applications treat them as such.

2) The tap-gain functions are not independent of each other, thus making it very difficult to establish proper control for simulating a variety of channels.

The difficulty of synthetically generating the tap-gain controls can be overcome through the use of the playback approach, but this approach also has disadvantages.

For the reasons given above, we have elected to develop a simulator based on the signal

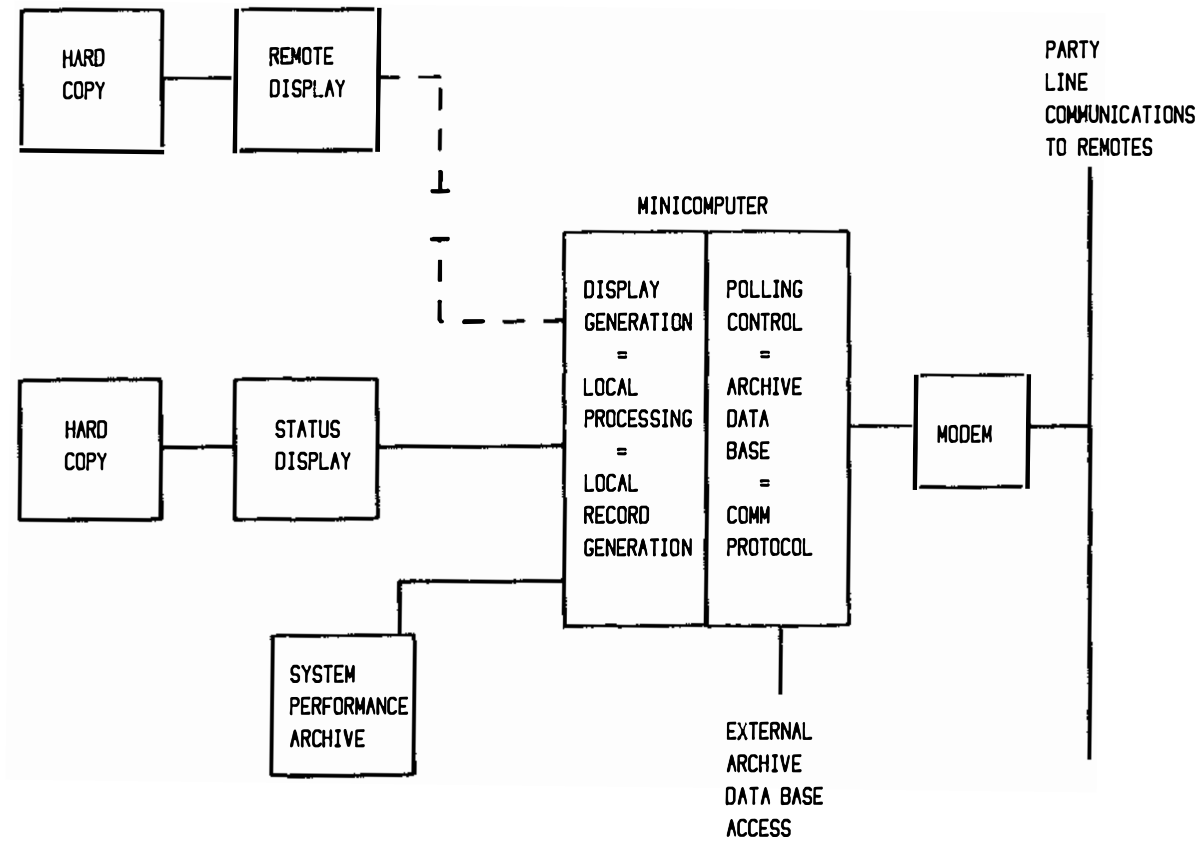


Figure 2-23. The general functional relationship of the master terminal.

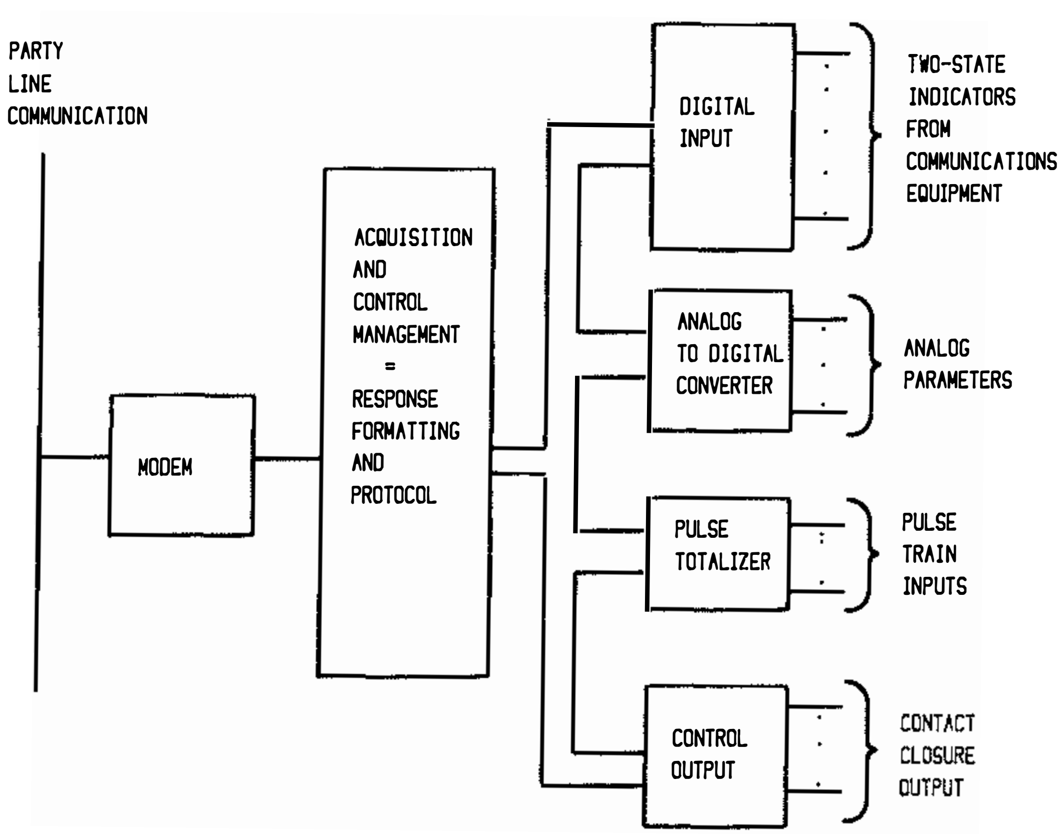


Figure 2-24. The general functional capability of the remote unit.

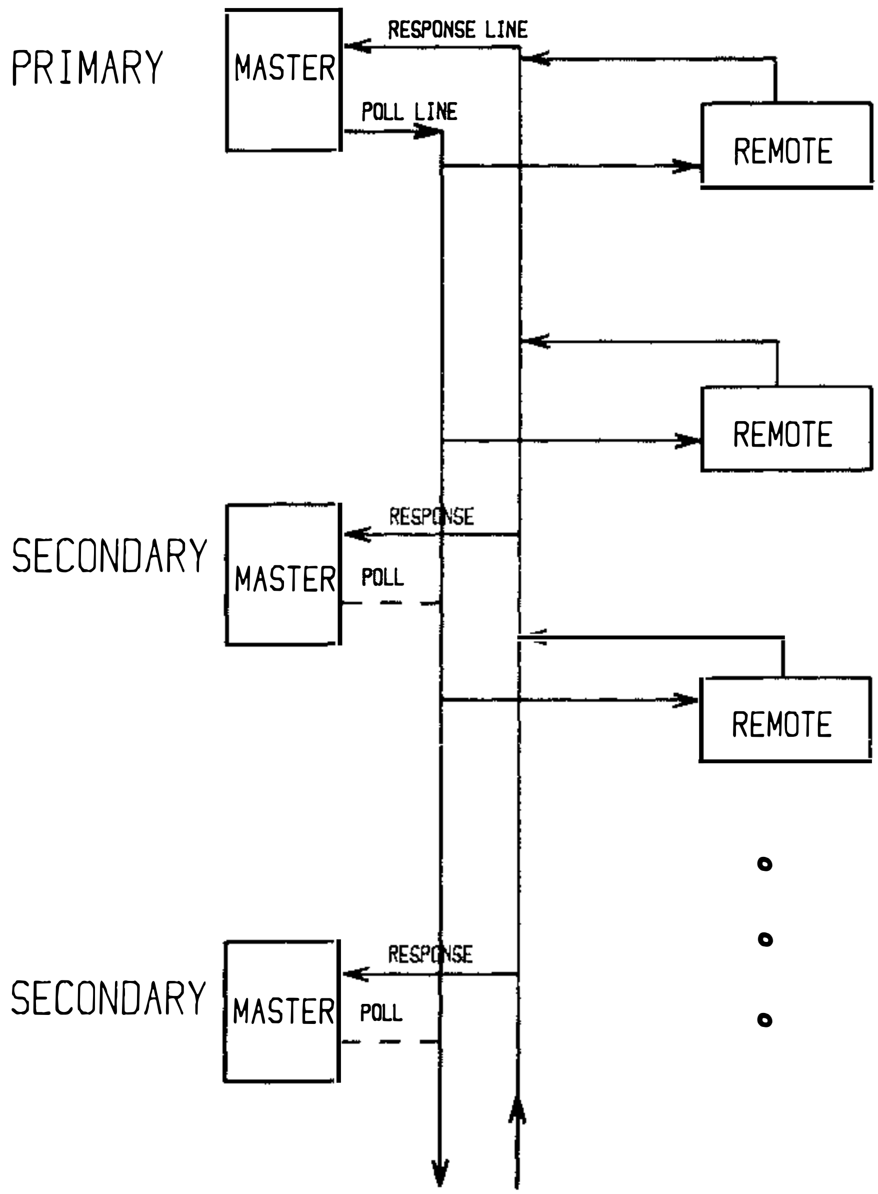


Figure 2-25. The master/remote relationship.

model concept, and to implement this concept at rf.

The block diagram of the proposed rf simulator is shown in Figure 2-26. It is based on the simple two-path mathematical model. The most important component is the switch section. This is the delay element for the multipath signal, which follows the upper portion of the diagram. The lower path is the route for the direct path signal.

At first glance, Figure 2-26 implies that the control of the parameters (time delay and phase) will require critical adjustments in order to precisely set the position of frequency-selective notches at desired positions (particularly difficult at rf). This is not the case, however, because the control function follows a different basic approach. The objective is not to precisely adjust the system for notch position, but to provide a control method that places a great many notches in positions that are both measurable and predictable. This method should alleviate implementation problems that others have experienced, even at IF.

The signal leveler in Figure 2-26 serves the purpose of maintaining a nearly constant signal level for the delayed signal path regardless of the amount of delay switched into the path; i.e., it compensates for the insertion loss of the delay elements. The line stretcher provides very small relative delays between the direct path and the delay path.

Before presenting the proposed control method, we shall briefly describe the function of the switch section in Figure 2-26--the basic delay line for the multipath signal. It is not a tap delay line, but one that is composed of a number of elemental delays in a sequence arrangement, each one associated with a switch

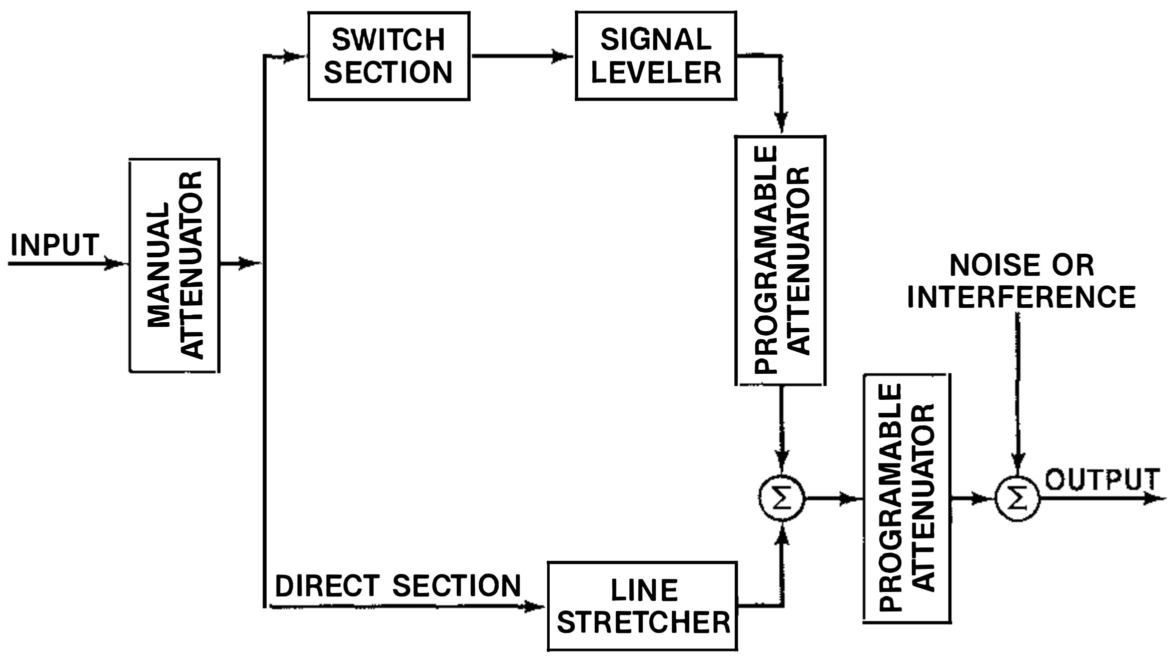


Figure 2-26. Block diagram of the proposed rf simulator.

network. The configuration for each element of the line is shown in Figure 2-27. In this figure, F is a fixed-delay value common to all switch sections, and d_i is an incremental value of delay. Both sections of the switch operate together, so that in the position shown, the delay of the output signal with respect to the input is given by F. When the switch changes state, this relative delay is incremented by the small amount d_i, and becomes $F + d_i$. The amount of incremental delay increases by powers of 2 for each successive switch section. Thus the delay for the i_{th} section is given by:

$$d_i = 2^i d',$$

where d' is the smallest incremental delay when both switches in Figure 2-27 are activated. The total delay is the sum of the delays from the individual switch sections. As an illustrative example, let the switch be composed of eight sections where i = 0, 1, 2, ..., 7. Also assume a value for d' = 0.1 ns. For this arrangement the number (N) of independent incremental delays is given by

$$N = (2^8 - 1) = 255,$$

and we see that the switched-control delay line functions in a binary manner. The range of possible delays thus becomes 0.1 to 25.5 ns when d' = 0.1 ns, in steps of 0.1 ns. These values are for illustration only. The actual incremental values used in the design will depend on a more detailed mathematical development of the binary chain, with respect to other parameter values that will have an effect. Some of these will have to be derived experimentally, and cannot be quantified As an example, in Figure 2-27 we have included a delay value attributed to the switch itself, which is labeled S. This must be minimized by testing and selection of the switch, and also compensated for by adjustments in the value of i and/or the selection of d'.

It is anticipated that the realization of the simulator will permit operation over a frequency range on the order of 1 to 10 GHz. The design will be optimized at one frequency (probably 8 GHz) and calibration procedures will be developed for other operating frequencies. The elemental delay lines will be fabricated from miniature semirigid coaxial lines useful at these frequencies. When, during the development, a precise measure of the incremental delay is established and the tolerances due to parameters such as S are determined, then a calculation can be performed that will describe the multipath structure in the frequency domain for each of the (say) 255 switch

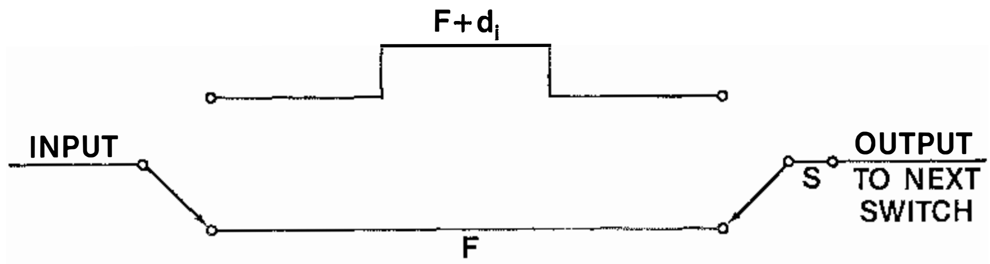


Figure 2-27. An illustration of a single delay element of the switch section in Figure 2-26.

settings. From this analysis, a number of subset conditions can be determined that will describe the position of a certain notch within a subrange of the signal spectrum, and also provide a predictable count of the number of times during a test run (for any given number of settings) that the notch fell within any particular subrange. It is this process that permits us to elude the problem of trying initially to place a given notch at any particular position within the spectrum. In a sense, the performance evaluation technique becomes a statistical process, but with predictable features that will permit static performance data to be derived.

Since the switched delay line functions as a binary chain, the possibilities of both manual operation and external control are easily seen. A BER measurement made over an interval of 1 s should be adequate for a test of a system having a digital bit rate of the order of 10 Mb/s since our interest is in outages due to BER of the order of 10^{-6}. By placing the switched line under control of a simple clock (1 s intervals) a complete set of 255 measurements (the full range of an 8-section line) can be performed automatically in as many seconds (less than 5 min). Each of these sets would be developed for a fixed ratio between the direct path and multipath magnitudes. This ratio is controlled by the programmable attenuator in the multipath signal line of Figure 2-26. The overall signal level at the output (input to system under test) is controlled by a similar attenuator following the two-signal summing junction. These attenuators are also binary switched units, and can be controlled in the same or similar fashion as that applied to the delay-line unit.

The development of this simulator is planned in phases. The first task is to prove the basic concept of an rf, two-path, LOS simulator. Detailed design of the simulator depicted in Figure 2-26 will be accomplished. All necessary hardware for the basic simulator will be procured and assembled. The simulator control will be accomplished through the use of a simple clock. Testing and calibration of the simulator will be performed to verify that the simulator output is representative of LOS fading.

The objective of the next task is to refine the capabilities of the simulator by using a microcomputer to control the setting of the switches and attenuators. The microcomputer will also be utilized to collect and analyze bit-error-rate (BER) or synchronous-error-second (SES) data. Figure 2-28 depicts the test configuration. A data bit stream generator will be fed into the transmitter portion of the radio under test. The input signal to the simulator will come from the rf section of the transmitter preceding the TWT, and the output will go to the rf input of the receiver. The output from the receiver will be fed into an error analyzer. Information on the BER or SES will be recorded on magnetic tape or other mass storage under control of the microcomputer. The software for performing the control recording and data analysis functions will be developed under this task. A microcomputer, a magnetic tape drive (or other storage device), and the equipment to provide data bit stream generator and error analysis will be procured under this task. A second channel will be added to the simulator in order to provide the capability for evaluation of space diversity radios.

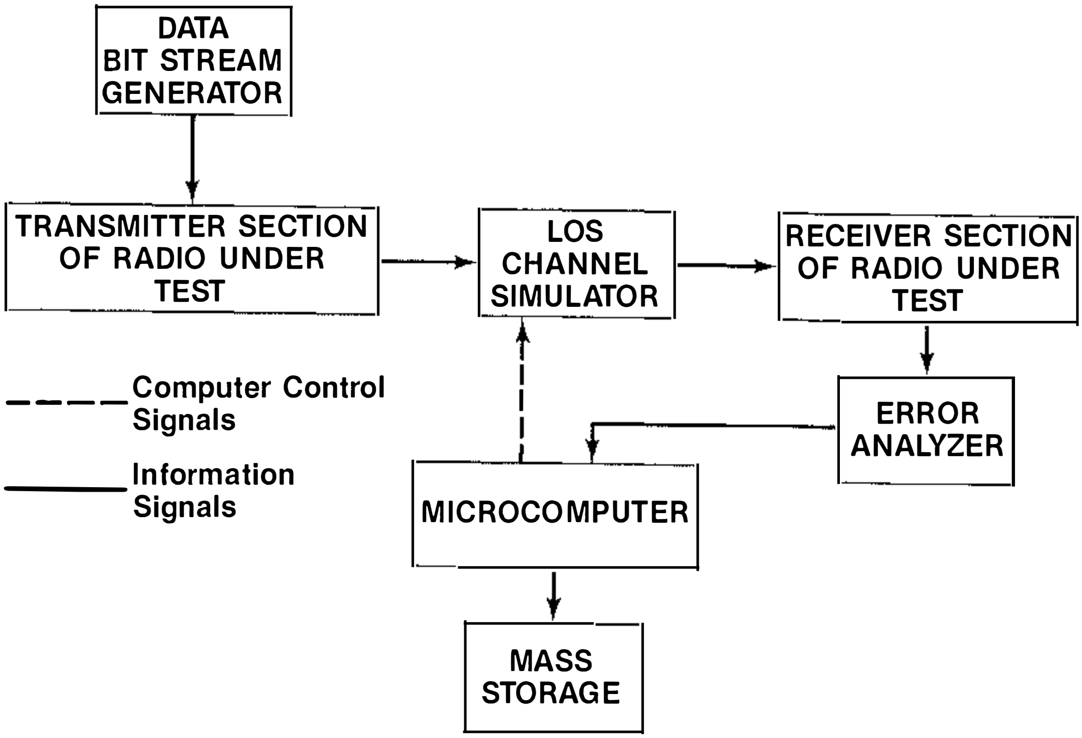


Figure 2-28. Radio test configuration.

The simulator will be utilized to analyze the performance of a DRAMA radio. The DRAMA radio is currently undergoing testing at Pt. Mugu, CA, on a 65-mile (104 km), over-water path. The radio is being tested using various configurations of adaptive equalization and space diversity combining. The simulator will be used to evaluate the DRAMA radio in a configuration identical to that used in the Pt. Mugu tests. Compatibility between the laboratory and field test results will lend credibility to the use of the simulator for radio performance evaluation.

A typical set of measurements for a given radio configuration will consist of stepping through each of the possible delays (say 255) for a given attenuation setting. This is then repeated for additional attenuation settings, i.e., differences in amplitude between the direct path and the delay path. For each delay switch and attenuator setting, the BER and/or SES data will be recorded on the floppy disk. This will permit the generation of plots similar to "m-curves" for different radio configurations. Here the plots will be attenuation vs. delay for fixed BER or percent SES. The use of these curves for comparing the performance of different radios tends to be somewhat subjective if the curves cross each other at some point. A quantitative comparison can be obtained by using the numerical integration of the area under the curves. The output of the simulator will be monitored on a spectrum analyzer to verify that the notch is being correctly placed within the spectrum.

A jamming signal simulator will be added at a later date to the hardware depicted previously in Figure 2-28. The capability to simulate the jamming threat as well as the multipath fading phenomenon is particularly needed for the development and testing of electronic counter-counter measure techniques that are expected to be employed in the next-generation digital microwave radios to be used in the Defense Communications System.

During FY 84, the Institute began development of a "proof-of-concept" model. It is anticipated that this model will be completed by the end of CY 1984. The Institute expects additional funding during FY 85 to automate the control of the simulator and to exercise the simulator in conjunction with DRAMA radio testing in the laboratory.

Initial results have shown that simulation at rf microwave frequencies is feasible. If the remaining tasks in the simulator devlopment are funded and are found equally successful, the simulator will be made available on a cost-reimbursable basis to industry and other Govenment agencies for use in digital radio testing.

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

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

The tests are being conducted over a microwave link at the Pacific Missile Test Center (PMTC), Point Mugu, CA, through the cooperation of the U.S. Navy. The test link is one that is frequently subject to atmospheric multipath, created by strong ducting gradients in the refractive profile.

The performance of two digital microwave systems, operating at 44.7 and 12.9 Mb/s, were compared over brief intervals of time in NTIA Report 83-126 [Hubbard, R.W. (1983), Digital microwave transmission tests at the Pacific Missile Test Center, Pt. Mugu, CA]. The performance data were augmented with propagation data and meteorological data. The multipath was measured and described through the use of the ITS PN Channel Probe [Linfield, R.F., R.W. Hubbard, and L.E. Pratt (1976), Transmission channel characterization by impulse response measurements, OT Report 79-76, August]. This instrument and the test radios were all multiplexed over the same space-diversity path, so that a direct correlation between the multipath structure and the performance data was possible. The same configuration is being used for the current DRAMA radio tests. A standard "base-line" radio is operated as a reference for the performance data, and a second radio is used as the test radio in which the variations of the switching algorithms and equalization circuits are implemented. The DRAMA radio tests will be concluded during the fall of 1984. A report describing the results of this testing will be available in January 1985.

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

The angle diversity tests consist of two phases. During Phase I, which is now complete, the Signatron antenna was coupled to the recording receiver built at the Institute. During Phase II, which is being conducted during the fall of 1984, the angle-diversity antenna is coupled to the DRAMA radio receiver. The initial results obtained during Phase I led to the conclusion that the particular form of angle diversity used in these tests has potential for use in LOS microwave links. The technical basis for this conclusion is drawn from short but significant samples of the recorded data that indicate an improvement in overall fade margins for the angle-diversity signals. However, the full potential of the angle-diversity technique can only be evaluated when it is coupled with the signal processing method to be used. This can be accomplished by evaluating the technique using the DRAMA radio. It is expected that the results from this Phase II testing will be available in early CY 1985.

The basic data acquisition system being used in these tests is described in the NTIA Report by Hubbard.

Digital Radio Perfomance Data. Following some digital propagation measurements performed by ITS in 1979 [Hubbard, R.W. (1979), Investigation of digital microwave communications in a strong meteorological ducting environment, NTIA Report 79-24, August], the Range Communications Department of the Pacific Missile Test Center (PMTC), Point Mugu, CA, procured a commercial digital microwave (7350 MHz) radio. The system was multiplexed over an existing link in the PMTC network and placed under test for an extended period. The Institute was tasked by PMTC to develop the test procedures and instrumentation required to evaluate the performance of the radio under severe multipath conditions. The radio, supplied by a commercial vendor, was designated as the MDR-8. It was configured for space-diversity reception, using a vertical antenna spacing of approximately 29 m (95 ft), and each diversity receiver used a form of adaptive slope and notch equalization in the IF to compensate for multipath (frequency selective) fading. The objective of these tests was to determine if the radio would meet a high level of performance availability without the use of frequency diversity (as was originally recommended by ITS). The tests were conducted during 1980-1981. The radio transmission rate was 44.7 Mb/s (T3), and a pseudo random bit stream at this rate was used to measure the error rate and burst-error statistics over the test link. Cursory results of the tests showed that in a severe multipath channel (which is dominant during summer and early fall months) the radio would fall short of desired performance specifications. Thus, the PMTC devoted resources toward a configuration using both space and frequency diversity and improvements in the adaptive equalization circuitry. As a consequence, the detailed error-performance data were not completely analyzed by PMTC. The Institute retained the original data tapes collected during this program and analyzed only a limited amount of the data.

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

A complete analysis of the recorded data has not been made at this writing. A detailed report is anticipated in the fall of 1984. The report will include a statistical analysis of the error data including the following distributions:

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

The above list is not exhaustive, but it includes the major distributions that can be readily obtained with the proper search program of the data tapes. Since these data are essentially synchronous with the propagation-oriented data, the potential for meaningful studies of the correspondence between these data is quite high.

The analysis, then, is a unique study of the correlation of radio performance data (e.g., BER distributions), channel impulse response data from the channel probe, and meteorological data.

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

In previous years, ITS developed a pseudo-random noise (PN) probe for application to troposcatter circuits. The probe uses a digital bit stream, clocked at rates up to 20 MHz, and develops an impulse response of a transmission channel from which the delay-spread characteristics over a tropo channel may be measured. The instrument operates at 70 MHz and interfaces with the tropo radio at that IF level. The instrument was used initially to measure the delay-spread parameter for several candidate test links for the AN/TRC-170 system. In these measurements. an AN/TRC-97 system was used as the host radio. The objective was to determine that the delay-spread over the selected links did not exceed the design criteria for the AN/TRC-170 systems. The results of the measurements were presented in NTIA Technical Memorandum 83-84 [Hubbard, R.W. (1983), Delay-spread measurements over troposcatter links, March]. Subsequent to these measurements, the AFTCTO has continued to use the ITS probe instrument to obtain additional data from other test links in Arizona and Florida.

The most recent ITS activity in this program has been the design and construction of a new PN probe system for the AFTCTO. The instrument was designed for use as a permanent and integral part of the test instrumentation assembled for the AN/TRC-170 test program. The new instrument has many advanced features and operational improvements. A complete list of these characteristics and specifications is given in Table 2-1.

During FY 84, improvements to the probe have been made. The Institute has also supported the U.S. Air Force and the Mitre Corporation in the use of the probe on several troposcatter links.

U.S. Forest Service Telephone System Requirements Analysis. The Institute has performed a number of studies for the U.S. Forest Service over the past several years. The initial studies were in support of Forest Service Regions 2 and 4, and were focused on (1) the assessment of near-term telecommunication requirements, and (2) the development of long-range planning tools. These efforts have been expanded by the Forest Service Washington Office as will be discussed in the following paragraphs.

The objective of the current project is to provide assistance to Forest Service Regional, Supervisor, and District Offices, stations, and laboratories in assessing telecommunication needs, identifying problem areas, developing cost-effective solutions, and obtaining General Service Administration (GSA) approval, as necessary, for new equipment and services required. This study takes the telecommunication problem areas identified in earlier studies and develops guidelines for use by Forest Service personnel in addressing them. It is envisioned that the reports produced in this study will provide a foundation for a telecommunications handbook to be used by personnel responsible for voice telecommunications, administration, operation and maintenance at all levels in the Forest Service.

Table 2-1. Troposcatter Probe Characteristics

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

FY 84 work conducted for the Forest Service Washington Office had the following goals:

1. develop telephone system installation and maintenance guidelines
2. develop guidelines for evaluating telephone system management features and options
3. develop guidelines for requesting GSA approval for telephone equipment or services
4. update draft reports submitted during FY 83
5. develop a computer program to allocate FTS costs to the various organizational levels of the Forest Service.

The problems addressed in these studies are not unique to the Forest Service. Most, if not all, Government agencies are facing similar telecommunications problems in this era of deregulation, divestiture, and rapidly changing telecommunications technology. In the past, the telephone system manager had little choice but to go to the local telephone company representative for all of his telephone needs, including the end instrument, the Private Branch Exchange (PBX), and both local and long-distance service. Deregulation and divestiture have created an atmosphere that is conducive to increased competition. This makes it imperative that the telephone system manager shop around for the best buy in both telephone equipment and services.

One problem faced not only by the Forest service, but other Government agencies and industry as well, is that more expertise is now required for the cost-effective management of telephone systems. With the increased availability and sophistication of telecommunication equipment and services, trained personnel are needed to identify requirements, develop system specifications, evaluate alternatives, and install and effectively manage new systems. The ITS studies described here are intended to provide a first step towards the development of a handbook approach to Federal telephone systems acquisition and management.

ANNEX I
ITS PROJECTS FOR FISCAL YEAR 1984
ORGANIZED BY DEPARTMENT AND AGENCY

AGRICULTURE, DEPARTMENT OF

U.S. Forest Service

Project	Title	Leader
9104559	Forest Service Voice Communication Analysis, Phase II	Hoffmeyer

COMMERCE, DEPARTMENT OF

National Telecommunications and Information Administration (NTIA)

Project	Title	Leader
9102101	Information Technology Policy	Salaman
9102103	ISDN Technical	Linfield
9102104	ISDN Technical	Pietrasiewicz
9104120	Data Communications	Seitz
9104123	International Standards	Seitz
9104142	85/88 Space WARC Support	Jennings
9104143	Reference Antenna Pattern Studies	Jennings
9104144	Advanced Satellite Communications Technology Studies	Gatterer
9107100	Technical Subcommittee Support	Berry
9107120	Spectrum Engineering Models	Berry
9107122	RSMS Operations	Matheson
9107123	RSMS Upgrade	Matheson
9107124	Spectrum Resource Assessments	Grant
9107126	HF Broadcasting-WARC	Washburn
9107127	Geostationary Satellite Orbit Analysis Program Development	Jennings
9107128	Spectrum Efficiency Studies	Berry
9108101	MF Propagation Studies	Washburn
9108102	VHF/UHF Propagation Studies	Haakinson
9108108	Millimeter-Wave Modeling & Experimental Data Acquisition	Rush
9109103	Two-Degree Spacing	Jennings

DEFENSE, DEPARTMENT OF

Project	Title	Leader
9104491	PFS 1026 Standard Authentication	Pietrasiewicz
9104519	Boundary Studies	Thompson
9104531	BATTLETOAD Support	Rush
9104545	Pulse Distortion Studies Phase II	Vogler
9104550	DOD HF/VHF Propagation Studies	Teters
9104561	MF Signal & Noise Measurements	Layton

Air Force Systems Command (ESD)

Project	Title	Leader
9104468	TRAMCON '84	Skerjanec
9104538	TRAMCON Manual & Training	Skerjanec

Air Force Miscellaneous

Project	Title	Leader
9104431	AN/MSR-T4 Receiver System	Barghausen

Army Communication Command (USA/CC)

Project	Title	Leader
9104496	Army HF Propagation Study	Teters
9104503	Rain Rate Model	Dutton
9104511	DOD Noise Model	Spaulding
9104518	DRAMA Radio Tests	Hubbard
9104533	Army HF Propagation Study	Teters
9104535	MDR-8 Performance Analysis	Hubbard
9104541	Automated Passive Repeater Link Engineering	Hause
9104544	Air-to-Ground & Intermediate and Short Distances--Books	Teters
9104548	USACEEIA Millimeter-Wave Model	Allen
9104549	DES Security Improvement Program	Pomper
9104556	HF Ground-Wave Model	Adams
9104560	Review of Federal Standard 1037	Hoffmeyer

Army Communications-Electronics Command (CENCOMS)

Project	Title	Leader
9104423	Millimeter Wave Vegetation	Violette
9104467	Ground Network Communication Model	Adams
9104514	Wide-Band Consultation	Adams
9104553	Evaluation of Tactical Army Switches	Nesenbergs

Army Communications Systems Agency (CSA)

Project	Title	Leader
9104497	Defense Switched Network Access Area Program	Linfield
9104527	TRAMCON Master Integration	Skerjanec
9104530	Angle Diversity Measurements	Hubbard

Army Research Office (ARO)

Project	Title	Leader
9104405	Millimeter Wave Attenuation	Liebe

Defense Communications Systems (Army)

Project	Title	Leader
9104557	Line-of-Sight Channel Simulator Development	Hoffmeyer
9104562	Access Area Engineering Services	Linfield

Defense Communications Agency (DCA)

Project	Title	Leader
9104498	DTE/DCE Standards	Hull
9104536	Data Encryption Standard--Related Standards	Pomper
9104551	PD-53 Teletext (Phase I)	Pietrasiewicz
9104558	Optical Fiber Guidelines	Hull
9104564	NCS Test Set Demonstration	Seitz
9104566	Revise MIL-STD-188-100	Farrow

Defense Nuclear Agency (DNA)

Project	Title	Leader
9104526	HF Ground Wave Measurements, Part II	Adams

Naval Ocean Systems Center (NOSC)

Project	Title	Leader
9104552	Meteor-Burst Cryptography Study	Pomper
9104563	Network Concepts for HF Improvement Program	Nesenbergs

INTERNATIONAL COMMUNICATION AGENCY (ICA)

Project	Title	Leader
9104473	Voice of America HF Propagation Studies	Rush

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Project	Title	Leader
9104543	HF Satellite Broadcasting Study	Rush

STATE, DEPARTMENT OF

Project	Title	Leader
9104411	AID Assistance	Jennings
9104521	AID Concept Program	Jennings

TRANSPORTATION, DEPARTMENT OF (DoT)

Federal Aviation Administration (FAA)

Project	Title	Leader
9104515	Air Navigation Aids	Johnson
9104554	Radar Frequency Assignments	Haakinson

U.S. Coast Guard (USCG)

Project	Title	Leader
9101532	Consulting USCG	Adams

ANNEX II
PROJECT INDEX

ANNEX III
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AVAILABILITY OF PUBLICATIONS

NTIA Reports, Special Publications, and Contractor Reports are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Order by accession number shown in publications listing. Requests for copies of journal articles should be addressed to the journal.

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, 1984) a full-time permanent staff of 87 and other staff of 18. In FY 1984, its support consisted of $3.3 million of direct funding from Commerce and $5.5 million in work sponsored by other Federal agencies.

The Boulder Laboratories include research and engineering components of the National Bureau of Standards, the National Oceanic and Atmospheric Administration, and the National Telecommunications and Information Administration. Common administrative services are the rule in the Boulder Laboratories. The Radio Building, which houses ITS, is on the U.S. Department of Commerce campus at 325 Broadway.

The following brief history shows the Institute's beginnings. The Radio Section of the National Bureau of Standards was founded prior to World War I and played a major role in the evolution of our understanding of radio propagation. Dr. J. H. Dellinger, its director for most of the period up until World War II, was strongly convinced of the importance of research and gave it practical application as first chairman of the Study Group on Ionosphere Propagation in the CCIR.

During World War II, the Interservice Radio Propagation Laboratory (IRPL) was organized at the National Bureau of Standards, under the direction of Dr. Dellinger. His group provided a common focus for military needs in propagation during the war. In 1946, the Central Radio Propagation Laboratory (CRPL) was established, and in its early years had direct ties with the Defense Department; for example, senior officials of DoD would appear before Congress to defend the CRPL budget. In 1949, Congressional concern for the vulnerability of Government laboratories located in Washington, DC, and the crowding of the NBS Connecticut Avenue campus made it advisable for the radio research work to be taken elsewhere.

Three sites, one in California, one in Colorado, and one in Illinois, were considered, and Boulder, Colorado, was selected. The first group from CRPL, which at that time included radio standards work, moved to Colorado in 1951, and the move was completed in 1954, during which year President Eisenhower dedicated the NBS Radio Building. The Radio Standards program left CRPL at the time of the move to Boulder, and has pursued a parallel existence at Boulder in NBS since that time.

In 1954, CRPL consisted of two research divisions: Radio Propagation Physics and Radio Propagation Engineering. The Radio Systems Division was formed in 1959. In 1960, the Upper Atmosphere and Space Physics Division and the Ionosphere Research and Propagation Division were formed from the Radio Propagation Physics Division. In 1962, CRPL received a full-time director, Dr. C. Gordon Little. In 1965, Dr. H. Herbert Holloman, first Assistant Secretary for Science and Technology in Commerce, implemented a decision to unify geophysics in Commerce with the creation of the Environmental Science Services Administration (ESSA), made up of the Weather Bureau, the Coast and Geodetic Survey, and the Central Radio Propagation Laboratory. At that time, the CRPL was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the Institute for Telecommunication Sciences came into being. It contained the telecommunications-oriented activities of ITSA. Dr. E. K. Smith served as an interim director for one year and was followed by R. C. Kirby who was director for the ensuing three years.

Meanwhile, in Washington, major attention was being given to the organization of telecommunications in the Federal establishment, and the Department of Commerce established an Office of Telecommunications in 1967. Reorganization Plan No. 1 of 1970 and Executive Order 11556 established the Office of Telecommunications Policy (OTP) in the Executive Office of the President, and assigned additional responsibilities to the Secretary of Commerce in support of OTP. To meet these responsibilities, the Office of Telecommunications (OT) was given expanded responsibilities on September 20, 1970, and ITS, along with its programs, property, personnel, and fiscal resources, was transferred to OT.

In 1971, Douglass D. Crombie became director of ITS. ITS has shifted from its strong emphasis on radio wave propagation and antennas since 1970 in the direction of applications in spectrum management and in telecommunication systems.

In March 1978, President Carter signed Executive Order 12046 which established the National Telecommunications and Information Administration and merged some of the functions of the Office of Telecommunications Policy with those of the Office of Telecommunications in the new agency. ITS was assigned the responsibility of managing the telecommunications technology research programs of NTIA and providing research support to other elements of NTIA as well as other agencies on a reimbursable basis. Among other assigned tasks, the Institute was to remain "...the central Federal Government laboratories for research on transmission of radio waves."

In January 1981, Dr. William F. Utlaut assumed responsibility for the direction of the Institute. A major reevaluation of programmatic and organization structure was carried out under his direction to redefine and aline the efforts of ITS to meet changing requirements and responsibilities.

The Institute and its predecessor organizations have always played a strong role in pertinent scientific (URSI), professional (IEEE), national (IRAC), and international (CCIR, CCITT) telecommunications activities. The director of CCIR from 1966 to 1974 was Jack W. Herbstreit, a former deputy director of CRPL and ITSA, and the current CCIR Director is Richard C. Kirby, formerly director of ITS. At the present time, the U.S. preparatory work for 2 of the 11 Study Groups of CCIR is chaired by members of ITS (U.S. Study Groups 1 and 6), and staff members of ITS lead U.S. delegations to 3 CCITT Study Groups (VII, XVII, and XVIII) and actively participate in the International Organization for Standardization (ISO). The Institute also actively supports the Interdepartment Radio Advisory Committee (IRAC).

The work ITS does for other agencies in the Government derives its legal authorities from 15 U.S.C. 272(3) "Advisory Services to Government Agencies on Scientific and Technical Problems" and 15 U.S.C. 272(f) "Invention and Development of Devices to Serve Special Needs of Government." As a matter of Federal policy, NTIA does not accept work more appropriately done by other nongovernment or government organizations. It is also a matter of policy that all sponsored work reinforce NTIA's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

Within these policy guides, ITS aspires to being <u>the</u> Federal laboratory for research in telecommunications. It is clear that the Government has a responsibility to pursue long-range studies in telecommunications that are not economically profitable for industry. It is also clear that the Government must have its own, independent laboratories to assess the significance of research conducted elsewhere. Toward these ends, ITS strives to maintain a knowledgeable staff that is working on the frontiers of technology and is in touch with the telecommunications problems of the Federal Government. The Department of Defense has long been the primary source of advanced technology. At the present time, the largest part of the other agency sponsorship of ITS comes from needs of the Department of Defense. The Institute maintains, however, a significant portion of its other agency work in support of civilian Federal agencies, where there is also clear need for Government expertise in high technology areas.

ANNEX V
ORGANIZATIONAL DIRECTORY

INSTITUTE FOR TELECOMMUNICATION SCIENCES
NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
325 Broadway, Boulder, Colorado 80303
(303) 497 + Extension (FTS 320 + Extension)

Name	Mail Code	Ext.	Room
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GEISSINGER, Marcia L. - Secretary	ITS.D	5216	3020
O'DAY, Val M. - Executive Officer	ITS.D1	3484	3023
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SALAMAN, Roger K. - Special Technology Liaison	ITS.D6	5397	3015
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System Performance Engineering Analysis HOFFMEYER, James A. - Chief	ITS.N4	3140	2213B

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