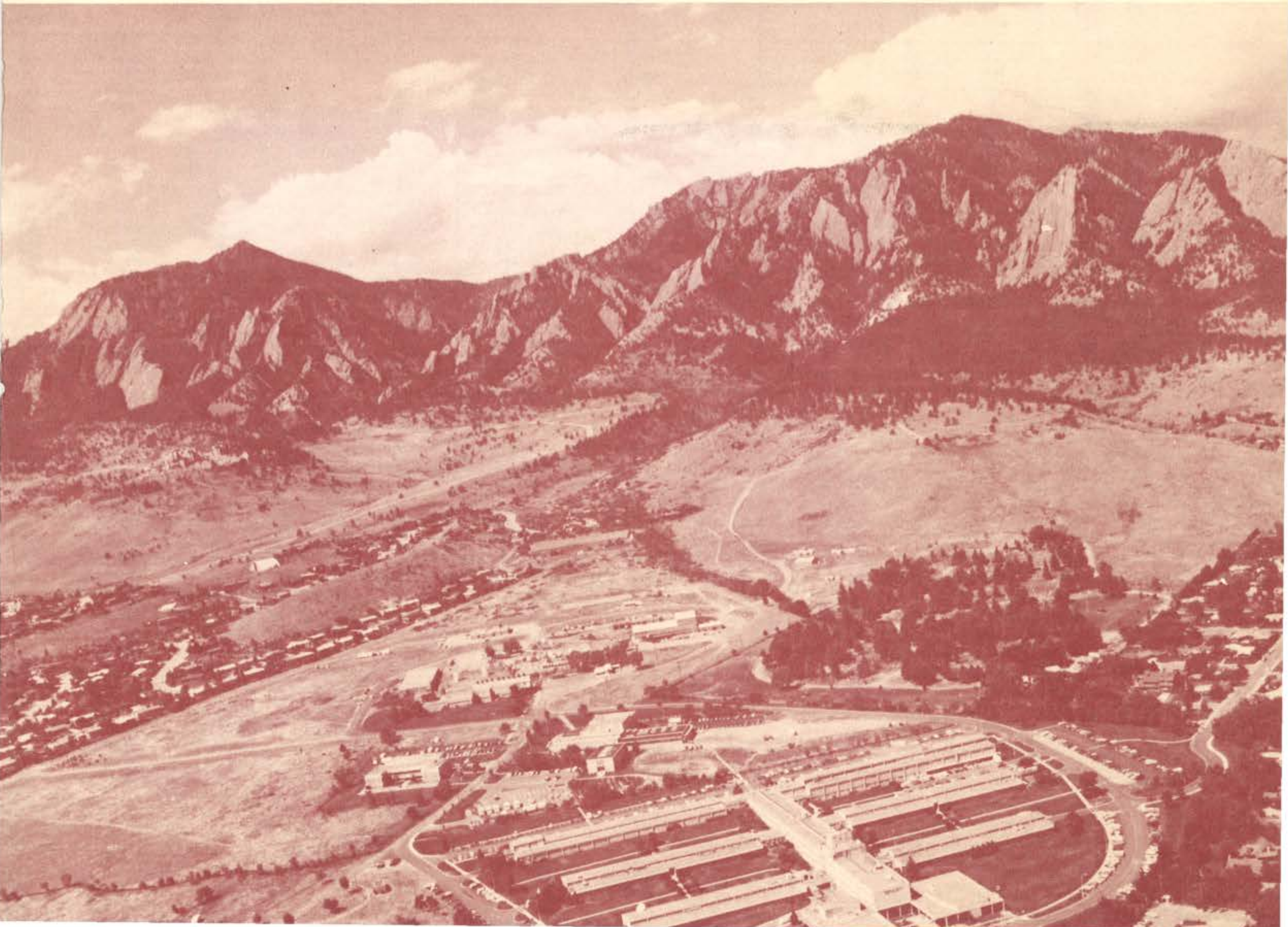
INSTITUTE FOR TELECOMMUNICATION SCIENCES
OF THE
NATIONAL TELECOMMUNICATIONS AND
INFORMATION ADMINISTRATION

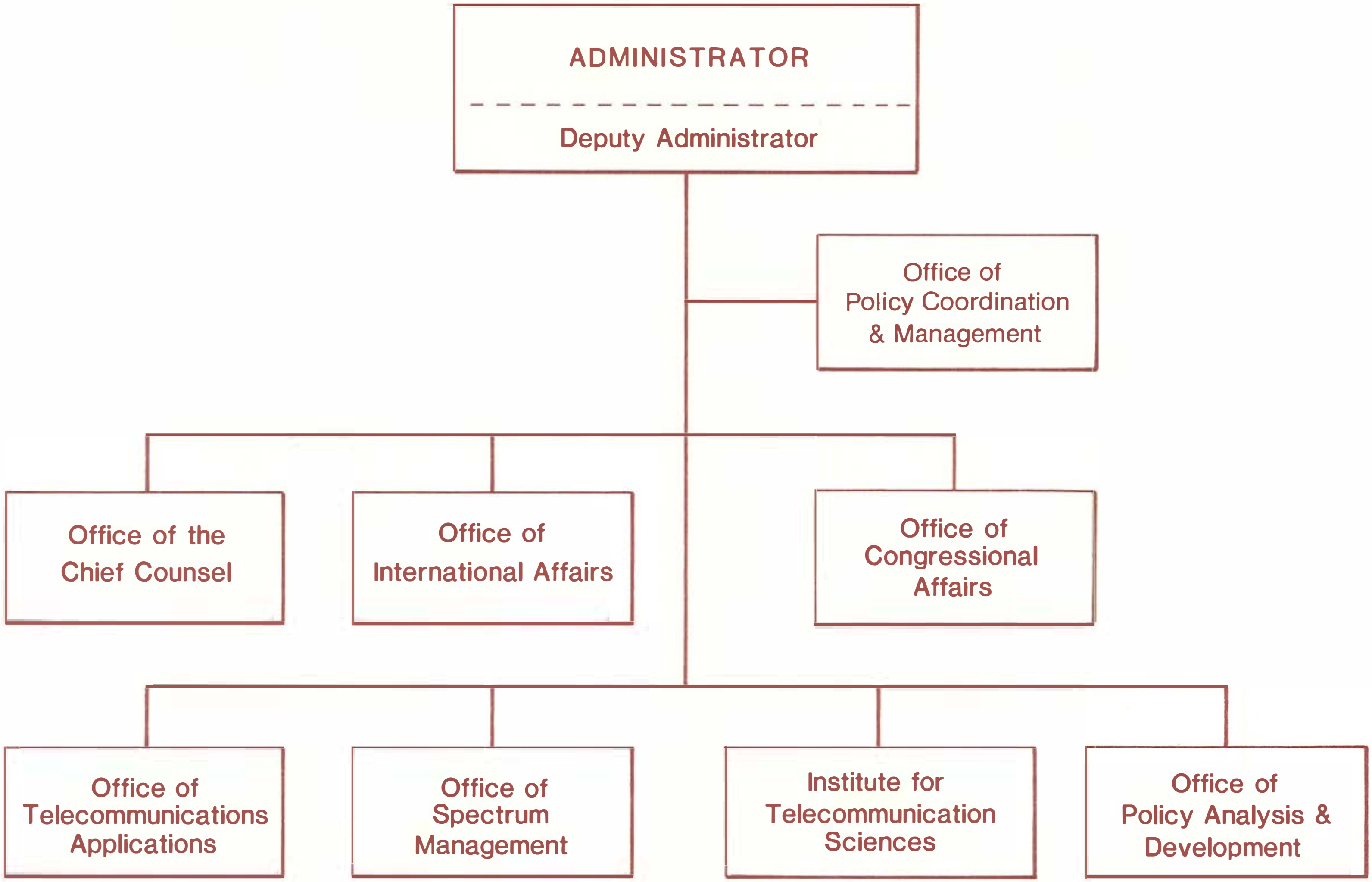
ANNUAL TECHNICAL PROGRESS REPORT 1985

For the period Oct. 1, 1984, through Sept. 30, 1985



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

Rodney L. Joyce, Acting Assistant Secretary
for Communications and Information

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INTRODUCTION

The $200 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) 1985 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 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 telecommunications 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 five 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. In Section 1.4, the projects directed toward EM Wave Transmission studies are described. The section is divided into projects dealing with radio propagation effects associated with the lower atmosphere, propagation effects associated with the ionosphere, and effects related to ground-wave propagation. In Section 1.5, projects dealing with the application of the propagation studies to specific telecommunication systems concerns are discussed.

SECTION 1.1 SPECTRUM EFFICIENCY STUDIES

In 1983, the Interdepartment Radio Advisory Committee (IRAC) directed its Technical Subcommittee (TSC) to quantify terms relating to efficient use of the spectrum. Working Group 13 (WG 13) was formed by TSC to develop the definitions and to test them by applying them to specific bands in the fixed service and the mobile service. Three ITS projects support the TSC WG-13 effort: TSC Support, Spectrum Efficiency Studies, and Spectrum Engineering Development.

Working Group 13's definition of the Technical Spectrum Efficiency Factor (TSEF) was noted by IRAC in February 1984, and WG 13 then specified a computer model to evaluate the TSEF in the fixed service. During FY 85, the model for the fixed service has been implemented by ITS and NTIA's Office of Spectrum Management (OSM). The fixed-service model has been applied to three bands, and a model for computing the TSEF in the land mobile service has been developed. These activities are reported here.

The TSEF is the ratio of the time-bandwidth-area product (TBA) denied to other users by a reference system to the TBA that is denied to others by the system being evaluated. The reference system is a practical, state-of-the-art system that accomplishes the same mission as the evaluated system while using the minimum TBA.

To compute the TSEF for the station being evaluated, one must be able to compute the time, bandwidth, and area that a station denies to other potential users, using information on the station's characteristics, its environment and transmission path, and a propagation model. To specify the reference system, the mission, and in particular, the communications requirement of the system, must be known.

Given fixed resources and time, there is a trade-off between the accuracy and completeness of the TSEF calculation for each station and the number of stations evaluated. Working Group 13 decided that a statistical distribution of the TSEF in a band would show how efficiently the band was being used. Only a completely computerized model could evaluate all the stations in the fixed service (for example, there are over 7000 assignments to the fixed service in the 7124 to 8000 MHz band alone), so the model was developed to use computer-readable data files. The only such data base available is the Government Master File (GMF).

Unfortunately, the GMF does not contain the communications requirement for the assignment. It does contain the assigned bandwidth and an operation time code. It was assumed that these two parameters were an accurate reflection of the time and bandwidth needed for the station mission. This means that the TSEF calculated depends only on the ratio of the areas denied by the stations.

The boundary of the denied area was defined by a specified power level that would be received by a hypothetical victim receiver with an isotropic, lossless antenna at a specified height. This area was computed using the transmitting antenna height, the site elevation, a model for the directional gain of the antenna, the transmitter power, and a propagation model.

There are digital data bases that contain terrain elevations for a grid of points in the United States. However, the resolution of the data grid is too coarse for accurate engineering of line-of-sight (LOS) links at frequencies above 900 MHz. It is unlikely that any grid point will correspond to the highest point in a locality, or that the path profile will include all the detail of the local terrain. But node locations and antenna heights for LOS links are carefully chosen by on-site surveys to take full advantage of local high points and terrain characteristics. Furthermore, the errors in digital terrain elevation data are large compared with the first Fresnel zone radius at these frequencies. Therefore, these digital terrain data bases and propagation models that use terrain elevation data were not used in calculation of the TSEF in the fixed service.

Instead, WG 13 used free-space transmission loss out to the distance at which the first

Fresnel zone was no longer clear of terrain obstacles. At greater distances, the larger of the free-space loss and the loss for a smooth spherical Earth was used. Making the smooth Earth path simulate the actual link depended on the fact that transmission loss at frequencies above 900 MHz is most sensitive to Fresnel zone clearance. Antenna heights for the evaluated link were assumed to be engineered so that the highest intervening terrain feature was just cleared by the first Fresnel zone. This is a reasonable assumption because higher antenna towers are unnecessarily expensive, and lower antenna heights result in unacceptable link outages.

Using site elevations and antenna heights from the GMF, equivalent antenna heights were computed that would provide Fresnel zone clearance over a smooth, spherical Earth for a path of the same length while maintaining the actual antenna height difference. These equivalent antenna heights were used in the smooth Earth propagation loss calculation.

To find the distance to the denial boundary in a specific boundary in a specific direction, the power radiated in that direction must be known. The GMF does not include antenna patterns--it contains only the antenna type and the main beam gain. For the Fixed-Service-TSEF model, the antenna pattern was approximated by a three-sector pattern. One sector of the pattern represents the antenna main beam; a second sector represents the side lobes; and the third sector represents the back lobes. Within each sector, the directional gain of the antenna is assumed to be constant as a function of angle. The sector angles and gains were modeled using manufacturer's antenna pattern envelope data.

Several items of information necessary for a complete and accurate calculation of the TSEF were not included in the GMF. These include the communications requirement of the system, the emission spectrum of the transmitter, and the selectivity of the receiver. So the number calculated using the Fixed-Service model differs from the true TSEF by an unknown factor U.

Sample output from the model is shown in Figure 1-1. Note that the most common value of U*TSEF in this example calculation is about 0.5, and that some systems have TSEF's in excess of 1. This is because of the conservative definition of the reference system and the unknown parameters mentioned earlier.

The TSEF concept is defined only for stations or, at best, systems. It is, therefore, not useful for the regulatory task of determining whether a frequency band (or larger portion) of the spectrum is being fully and efficiently used. It cannot be used to determine how much bandwidth should be allocated to provide a proposed service. Since it includes only the technical efficiency, it cannot be used to determine whether the communications mission is being accomplished economically.

The TSEF concept can be used to evaluate the technical spectrum efficiency of current or

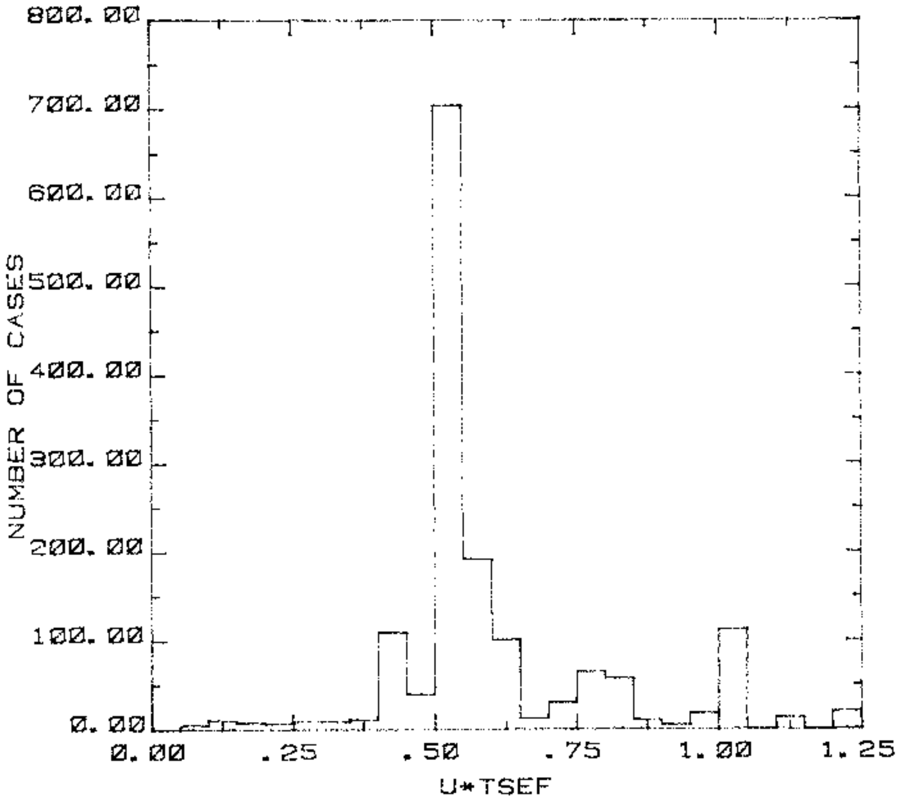


Figure 1-1. Histogram of TSEF values in the 8025 to 8500 MHz band.

planned systems. The evaluation of current systems might show that a significant increase in technical spectrum efficiency is possible with new technology, and thereby might justify phasing out currently deployed systems. When new systems are being planned, the TSEF can be used as a figure-of-merit for rating the technical spectrum efficiency of various candidate systems or components. It can be used in parametric trade-off studies, finding the combination of controllable parameters that lead to the design that uses the fewest spectrum resources. The benefits (increase in TSEF) of a particular design could then be compared with the costs of the designs to make final procurement decisions.

The TSEF of proposed system upgrades could be compared with the TSEF of current systems to determine the degree of improvement in technical spectrum efficiency. Because factors such as bandwidth required and area denied often trade off with each other, counter-intuitive results may be discovered. A saving in bandwidth caused by a change of modulation may actually increase the area denied by increasing the susceptibility to interference.

Because it is normalized, the TSEF can be used to compare the relative efficiencies of equipment providing diverse services. These relative efficiencies can be used by frequency managers and regulators to indicate which services offer the greatest opportunity for increased spectrum efficiency through tightened equipment standards or changes in system configurations.

The particular implementation of the TSEF concept for the fixed service suffers from the constraint that it uses only computer-readable data. In particular, the communications requirement of the station was unavailable, so that the reference system could not be accurately specified. To test the applicability of the concept without these constraints, WG 13 developed a model for the land mobile services that uses all available information about the system. It will be applied to only a limited sample of land mobile systems, because collection of all available data takes considerable effort, and because that data must be entered by hand. This interactive computer model is described in WG-13 documents, and has been implemented at ITS. It will be applied to land mobile systems in three bands in FY 86.

The optimum reception of signals in non-Gaussian interference has been studied in the NSG Detection and DoD Consulting projects. The real-world interference environment is almost never Gaussian in nature, yet receiving systems in general use are those that are optimum for white Gaussian noise (e.g., linear matched filter or correlation detectors for digital signals). Gaussian noise is also the worst kind of interference in terms of minimizing channel capacity or in its information-destroying ability. Therefore, large improvement (processing gains) can be achieved if the actual statistical characteristics of the noise and interference are properly taken into account.

The development of totally optimum systems for non-Gaussian interference is not generally feasible, and the standard approach has been to develop systems that approach true optimality as the signal level becomes "sufficiently" small and the number of waveform (desired signal plus interference) samples, N, increase without limit. The detectors derived by such techniques are termed locally optimum Bayes detectors (LOBD), and rather strict conditions must be met so that these detectors also are asymptotically optimum (AO) detectors. The structure of the LOBD generally takes the form of the ordinary "Gaussian" receiver preceded by one or more particular nonlinearities based on the various probability distributions of the interference process. Performance of these LOBD detectors is usually specified by the asymptotic relative efficiency (ARE), which gives a comparison of two detectors (the LOBD and linear detector, for example) as the desired signal $S \to o$ and $N \to \infty$. This limiting performance measure, naturally, can be quite misleading for detectors in actual use where the desired signal is not "sufficiently" small and N is relatively small. Actual performance characteristics have been obtained, partially, by various analytic techniques but primarily by Monte Carlo simulation of actual (software) LOB (and various suboptimum nonlinearities) detectors.

In order to design the locally optimum detectors, tractable physical-statistical models of the real-world interference environments needed to be developed. Extensive work over the last few years has led to such models. These models are of two general types: Class A, which characterizes collections of "narrowband" interfering signals and various coherent pulse structures; and Class B, which characterizes "broadband" interference such as atmospheric radio noise and various forms of man-made noise. The Class A models have the parameters A_A and Γ'_A and the Class B models have two parameters (ignoring scaling), A_α and α. The parameters are intimately involved in the physical processes giving rise to the interference.

Figure 1-2 shows the ARE of the LOBD compared to the hard limiter (a suboptimum, nonparametric nonlinearity) for Class B noise. Note that the bandpass-limiter performs "almost" as well as the much more complex adaptive LOBD, at least in the limit (ARE). Simulation of the bandpass-limiter and LOBD detectors shows these results hold in actual physical situations (realistic signal levels and size of N); in fact, there are situations where the bandpass-limiter outperforms the "optimum" LOBD.

Figure 1-3 shows the same results (ARE) for bandpass-limiter compared to the LOBD for Class A interference. This shows that the LOBD can have significant improvement over the suboptimum bandpass-limiter in Class A noise, but these are only results that are valid in the limit. Figure 1-4 shows actual simulation results for one example of Class A noise for the binary coherent phase-shift keying-system (CPSK) for N = 10 and 100. Note that for N = 100, the improvement of the LOBD over the linear receiver is

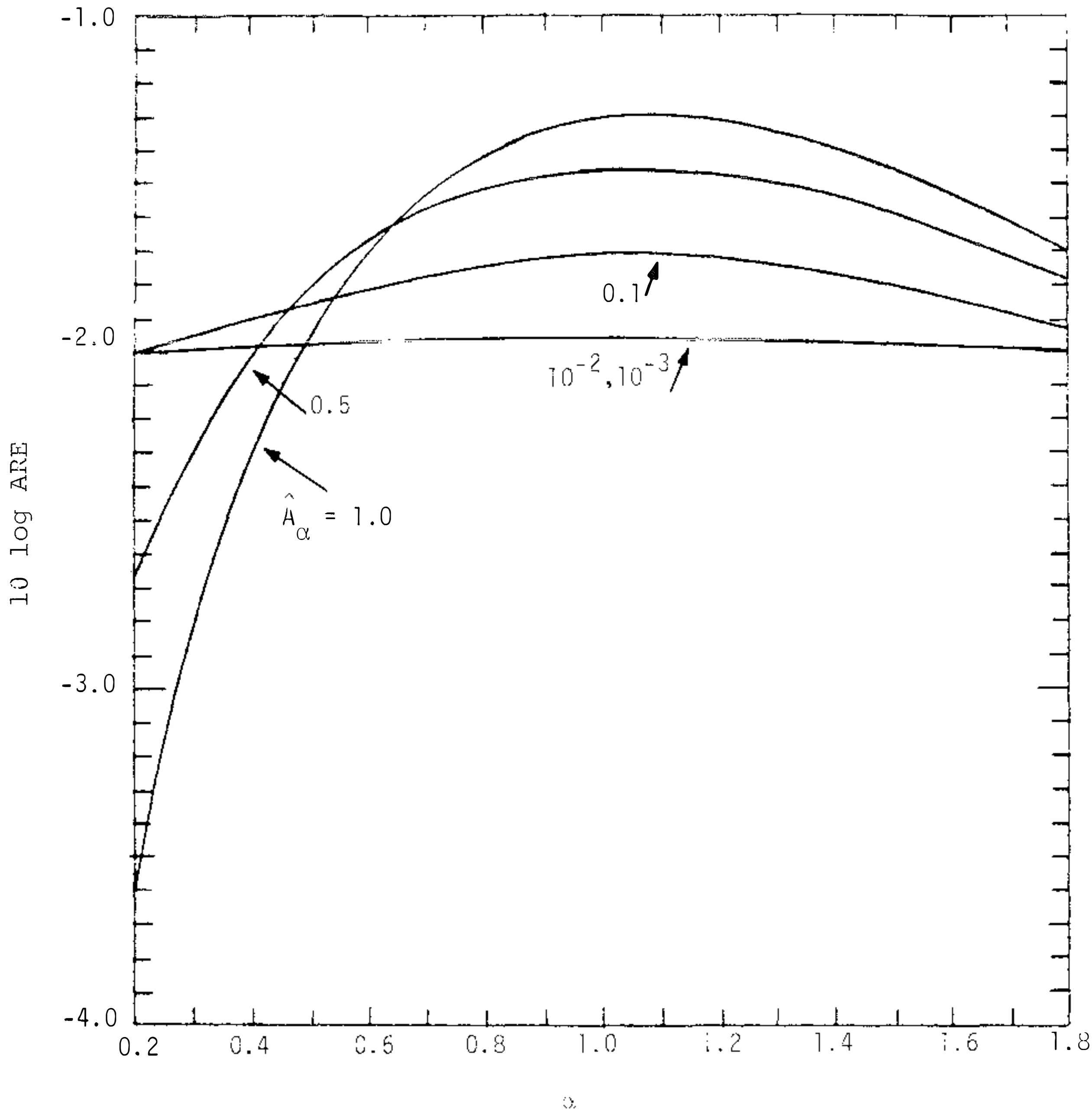


Figure 1-2. The asymptotic relative efficiency, ARE, of the bandpass-limiter versus the locally optimum detector for coherent reception for Class B noise.

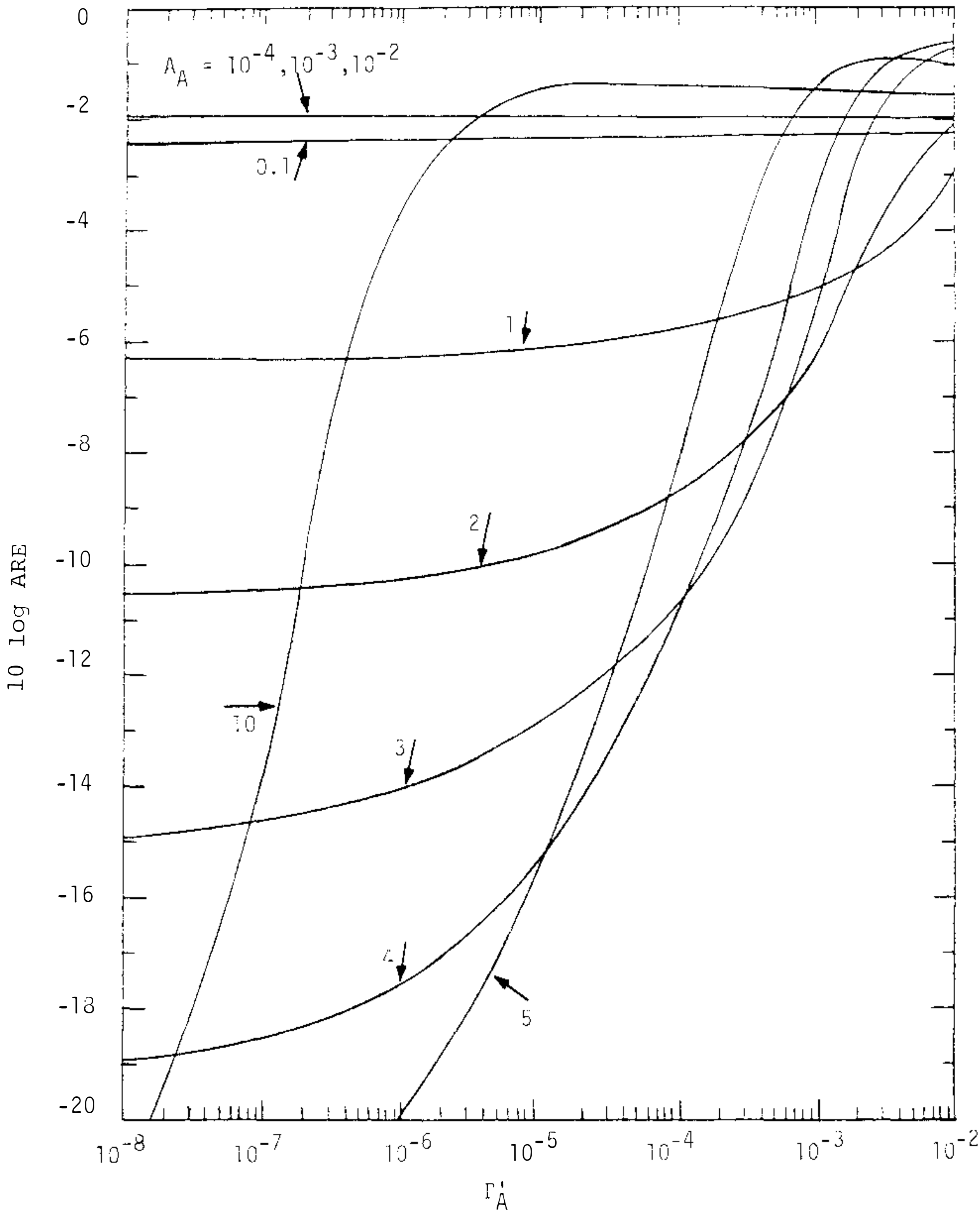


Figure 1-3. The asymptotic relative efficiency, ARE, of the band-pass limiter versus the locally optimum detector for coherent reception for Class A noise.

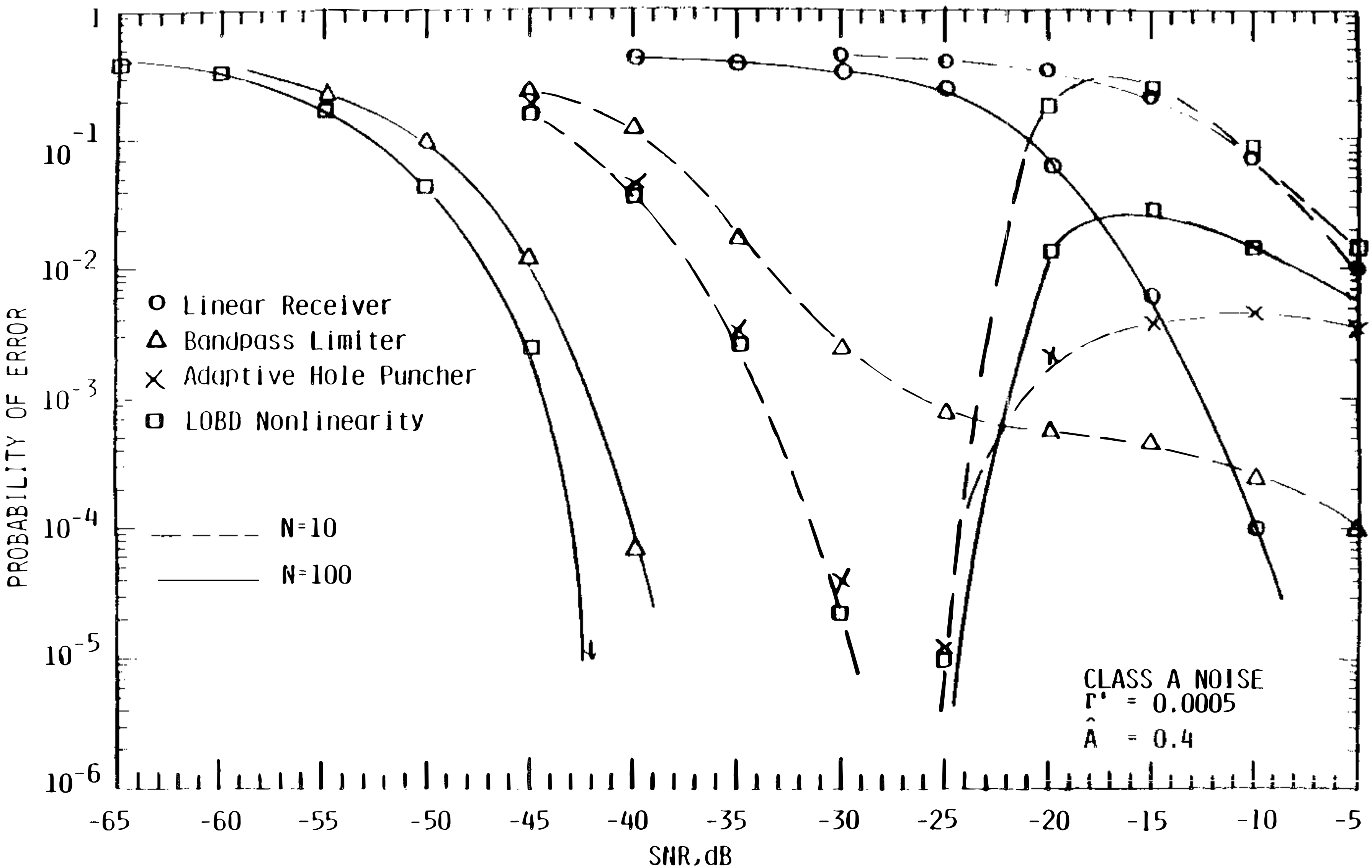


Figure 1-4. Simulation results for Class A noise, CPSK, and constant signal.

approximately 34 dB. Theoretical (ARE) calculations also indicate the LOBD should perform 34 dB "better" than the linear receiver for this example of Class A noise. Also note that for N = 100, the bandpass-limiter is approximately only 4 dB inferior to the LOBD nonlinearity, but for N = 10, the bandpass-limiter becomes quite inferior to the LOBD. An important result shown on Figure 1-4 is that as the signal level increases (past a signal-to-noise ratio of about -26 dB in this case) performance rapidly deteriorates for the LOBD. This is because the LOBD nonlinearity for Class A noise looks quite a lot like the hole-puncher nonlinearity. These results demonstrate quite graphically that the "small enough" signal requirement in LOBD receivers must receive attention.

SECTION 1.2 SPECTRUM RESOURCE ASSESSMENT

The NTIA is responsible for managing the radio spectrum allocated to the Federal Government. 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, the guidance provided by NTIA with the assistance of the Interdepartment Radio Advisory Committee (IRAC) encompasses the areas of utilizing spectrum, identifying existing and/or potential electromagnetic compatibility (EMC) problems between systems of various departments and agencies, providing recommendations for resolving any compatibility conflicts, and recommending changes that result in more efficient and effective use of the spectrum and improved spectrum management procedures. Spectrum Resource Assessments are studies of these areas for specific services or bands. This year, ITS assessed the Travelers' Information Stations (TIS).

In 1977, the Federal Communications Commission (FCC) revised Part 90 of its Rules and Regulations. In Subsection 90.242, provisions were made for the TIS at 530 and 1610 kHz. The TIS was also authorized to operate on a secondary basis to stations operating on a primary basis in the 510 to 525 kHz and 1615 to 1715 kHz bands. The TIS is designed to transmit only noncommercial voice information for automobile travelers regarding traffic and road conditions, availability of lodging, location of rest stops and service stations, and descriptions of local points of interest. These stations are restricted to use in the immediate vicinity of air, train, and bus transportation terminals, bridges, tunnels, and any intersections of a Federal interstate highway with any other interstate, Federal, state, or local highway.

As a result of WARC-79 agreements, the band from 1605 to 2000 kHz has experienced changes in frequency allocation. The AM broadcasting service was expanded from the present 1605 to 1705 kHz. The FCC released a first Notice of Inquiry (NOI) in General Docket No. 84-467, May 16, 1984, inviting comments to assist them in developing recommendations for the United States proposals for the Administrative Radio Conference for Planning of Broadcasting in the 1605 to 1705 kHz Band scheduled for 1986. In early January 1984, IRAC formed an ad hoc committee (Ad Hoc 193) to help develop the position and proposal documents of the Executive Branch for the Region 2 Administrative Radio Conference.

Some of the comments that have been received by the FCC suggest possible changes in the allocation of frequencies to TIS and the use of high-power AM broadcasting stations in the 1605 to 1705 kHz band. In a spectrum resource assessment (SRA) published in April 1985, the frequency band from 1605 to 1705 kHz was analyzed to determine the effects of cochannel and adjacent-channel AM broadcasting stations on existing systems operating in the band. Preliminary results for TIS showed a requirement for large separation distances between TIS and AM radio stations, particularly at night when sky-wave propagation is possible. Other problems with TIS operations in a shared environment with AM broadcasting have been discussed in meetings of Ad Hoc 193. These discussions resulted in a request to NTIA for a thorough investigation of the alternatives that would address the technical, economic, and administrative aspects of TIS and broadcasting operations. The Federal Highway Administration (FHWA), although not having any TIS assignments itself, has the Federal Interstate Highway Systems represented by the various state departments of transportation as its constituency. The FHWA sponsored a conference on motorists' information services (September 18-20, 1984) where the Highway Advisory Radio (HAR--their name for TIS) played a major roll in the presentations and discussions. Officials from various state highway departments indicated increasing requirements for TIS on both 530 and 1610 kHz.

The National Weather Service is also contemplating the use of TIS along the Nation's interstate highway system in the various rest stop areas to disseminate weather information--particularly severe weather watches. This could easily mean over a thousand new assignments depending on feasibility and number of states covered. The largest Government user of TIS is the Department of Interior (DoI) with 153 assignments. This department projects its use of TIS will more than triple in the next 5 years to over 500 assignments.

The current use, proposed uses, changes in allocations in the 1605 to 1705 kHz band, which could affect TIS, and assistance to IRAC in developing a national position for the upcoming Regional Administrative Radio Conference was the basis for this study, which considered the uses of TIS, present frequency assignments, future spectrum needs, and compatibility analysis.

This study of TIS has raised the following spectrum management issues.

- o Should TIS allocations at 530 and 1610 kHz remain exclusive?

- o Should the upper TIS frequency move to 1700 kHz or 1710 kHz when AM broadcasting phases into the 1605 to 1705 kHz band?
- o Are power and antenna height limits now imposed on TIS reasonable?
- o Can TIS operate effectively on FCC Rules and Regulations, Part 15, limitations?
- o Can TIS operate successfully in the 540 to 1600 kHz band on a secondary basis?
- o Can TIS operate compatibly in the 88 to 108 MHz FM band?
- o Should TIS be upgraded to Travelers Information Service in light of its expanding role?

Information from documents generated by IRAC Ad Hoc 193 dealing with the future of TIS is incorporated in the following discussion.

TIS Allocations

The TIS are presently allocated two frequency bands for their exclusive use. They are 530 ± 5 kHz and 1610 ± 5 kHz, at the bottom and top of the present AM broadcasting band, respectively. In light of the expanding use of the TIS in the near future by both Government and non-Government users, these frequencies should continue to be exclusive. However, there may be good reason to consider moving the upper frequency 1610 kHz to 1700 kHz (1690 kHz also desired) when the expansion of the broadcasting service to 1705 kHz is implemented. The 1610 kHz frequency will have adjacent AM broadcasting assignments at 1600 and 1620 kHz. Since the allowed station classes for the expanded broadcasting band are yet to be determined, the potential interference impact on TIS cannot be totally assessed at this time, but at best would limit the use of the 1610 kHz frequency in many areas. This, of course, assumes that TIS would remain exclusive at 1610 kHz. If AM broadcast stations are allowed to be cochannel at this frequency, the use of TIS would be even more restrictive.

After discussing this situation with users of TIS, it was determined that it may be beneficial for TIS to move to 1700 kHz when automobile receivers can tune the expanded band. There was a definite preference by the TIS community for 1700 kHz rather than 1710 kHz, mainly due to experience at 1610 kHz. At present, the 1610 kHz TIS frequency is just above the AM broadcasting band, which ends at 1600 kHz. There are still many automobile radios that cannot tune the 1610 kHz TIS frequency or cannot tune it close enough to discriminate against stations at 1600 kHz. There are presently few assignments at 1710 kHz, but this will change rapidly as displaced users of the 1605 to 1705 kHz band move into this frequency area. As 1710 kHz is used more, most likely by the radiolocation service, compatibility problems with TIS will also grow. It is felt, then, that TIS should have an exclusive channel at 1700 kHz. Both Government and non-Government users of TIS would also like an additional channel at 1690 kHz for future expansion.

In light of the expanding use of TIS, it is still desirable to have both the 530 kHz and 1610 kHz exclusive frequency allocations while phasing out 1610 kHz and phasing in the 1700 kHz exclusive frequency. As long as automobile radio manufacturers are going to be expanding the tuning range of the AM receivers, it would be desirable to ask them to cover the range from 530 to 1705 kHz. There are still some receivers that cannot tune the 530 kHz frequency.

TIS Rules and Regulations

At present, the rules and regulations governing the TIS antenna heights, transmitted power, and field intensity at a given distance are not always adequate for needed coverage. The problem is not with the TIS designated 2 mV/m at 1.5 km field intensity, but with achieving that value at lower ground conductivity levels with the allowed antenna heights (restricted to 15 m or less) and the transmitter power (10 W or less for monopole antennas and 50 W for leaky-cable antennas).

It is suggested that the adoption of a constant coverage approach be considered. With a constant coverage philosophy, the controlling factor is the allowed field intensity at a given distance from the antenna as the main criterion. For example, if the presently allowed field intensity of 2 mV/m at 1.5 km is adequate (it seems to be for most cases), then allow either antenna height adjustment or power output adjustment, or a combination of both, to achieve the desired field strength at the constant coverage distance. The systems now are too dependent on antenna installation procedures and local ground conductivity. The antenna ground planes, particularly at 530 kHz, are critical to proper coverage. These ground planes must be well designed and installed and maintained properly to obtain desired coverage. Experience shows that ground planes are not always installed and maintained properly. This is due in part to existing landscaping where proper ground radials are difficult, if not impossible, to install. One installation that was checked showed a measured field intensity at 1.5 km of 30 μV/m which was not adequate for the desired coverage. The antenna system was mounted on a building for convenience and had no ground radials (building ground was used).

The constant coverage approach would only designate the maximum field intensity at a given distance, and the installing agency would be responsible for the measurements required to show compliance. It should be noted that field intensity requirements for proper reception at a given distance from the antenna are greater at 530 kHz than at 1610 kHz according to a DoI study. Perhaps the field intensity would be given as 500 μV/m at 8 km, which would meet the needs of most Government TIS stations.

The preferred boundary where good reception is desired (5 and 8 km were the two most often quoted coverage distance needs by agencies using TIS) and using the DoI required field intensity for good reception (330 μV/m at 530 kHz and 250 μV/m at

1610 kHz), the required distance separation between TIS stations as given in the FCC Rules and Regulations may not be adequate for interference-free reception at the boundaries and should be reviewed for possible change.

TIS in the AM Broadcasting Band and Under FCC Rules and Regulations, Part 15

The separation distances and nighttime interference potential in the AM broadcasting band from 540 to 1605 kHz between broadcasting stations and TIS would be of such magnitude that little use could be made of TIS in this band.

Under FCC Rules and Regulations, Part 15, Subpart D, Low Power Communications Devices, the provisions for operation are such that use by TIS would not be practical. For example, the field strength at 30 m cannot exceed approximately 45 μV/m at 530 kHz and 15 μV/m at 1600 kHz. Most automobile radios would have trouble receiving a signal at this level. There are few uses for TIS where the listener would have to be stopped and within a few meters of the transmitter.

TIS in the 88 to 108 MHz FM Band

Perhaps the most promising band for future TIS operations would be the 88 to 108 MHz FM broadcasting band. Of particular interest are the 20 channels from 88.1 to 91.9 MHz set aside for noncommercial educational stations. The majority of station assignments in this subband at present are low power (under 1 kW). There are few of these stations in remote areas where Government TIS tend to be located. The antenna installations and overall system would be somewhat simpler and less expensive than current AM systems for the desired coverage. The 10 W maximum power restriction for existing Class D FM stations would be adequate for TIS. A computerized frequency assignment plan for the continental United States should be fairly simple to set up and, in fact, may be only an expansion of an existing program for assigning noncommercial educational FM stations now in use by the FCC.

TIS as a Type of Service

The expanding role of TIS both within the Government and the private sector would seem to dictate a more important status to these stations. The expansion from the few hundred assignments now in use to a few thousand assignments that are possible by the year 2000 would seem to justify this as a class of service to the public. It is suggested as an outcome of this study and findings of IRAC Ad Hoc 193 that the TIS acronym stand for Travelers' Information Service rather than Travelers' Information Stations.

Recommendations

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

- The frequencies at 530 and 1610 kHz should remain exclusively for TIS use in the United States with a phase-out of 1610 kHz and phase-in of 1700 kHz when appropriate.
- The United States should adopt a position for the Region 2 MF Conference supporting a limit on power for broadcasting stations operating on the U.S. frequencies used by TIS.
- The frequency at 1700 kHz should be considered for TIS use at some future date when automobile receivers can tune there.
- The FM broadcasting band from 88 to 108 MHz should be considered for TIS operation and be interstitially located throughout the band on a noninterference basis.
- A "constant coverage" scheme should be developed for TIS, which provides adequate field strength for good reception at 5 km and 8 km that would allow antenna height and/or transmitter power to be adjusted to whatever level is necessary to produce that field.
- An addition to the Manual of Regulations and Procedures for Federal Radio Frequency Management should be made providing rules, regulations, and recommendations for Government use of TIS.
- The TIS separation distance requirements should be reviewed and appropriate tables of distance separation given in the Manual.
- Distance and/or frequency separation guidelines for nondirectional beacon stations and TIS should be given in the Manual.

SECTION 1.3 ADVANCED INSTRUMENTATION AND SPECTRUM MEASUREMENTS

In its role as frequency manager to the Federal Government, NTIA is required to operate and maintain an instrumentation capability for performing measurements of spectrum usage and emission spectra radiated by specific equipment. The Radio Spectrum Measurement System (RSMS), Figure 1-5, has performed this measurement function since 1973.

After many years of very satisfactory performance, the RSMS has been updated. The RSMS Engineering Enhancements project developed new measurement and analysis capabilities as needed to support the RSMS operations work. Extensive measurement programs were undertaken in the Government Land Mobile Radio (LMR) and radar bands, comprehensive site surveys were made, and many special electromagnetic compatibility problems were studied. In more recent years, maintenance problems with the electronic systems in the RSMS were becoming serious. In addition, more complex measurement programs became more desirable, but the computer system associated with the RSMS was already at its limits and was not capable of being expanded further.

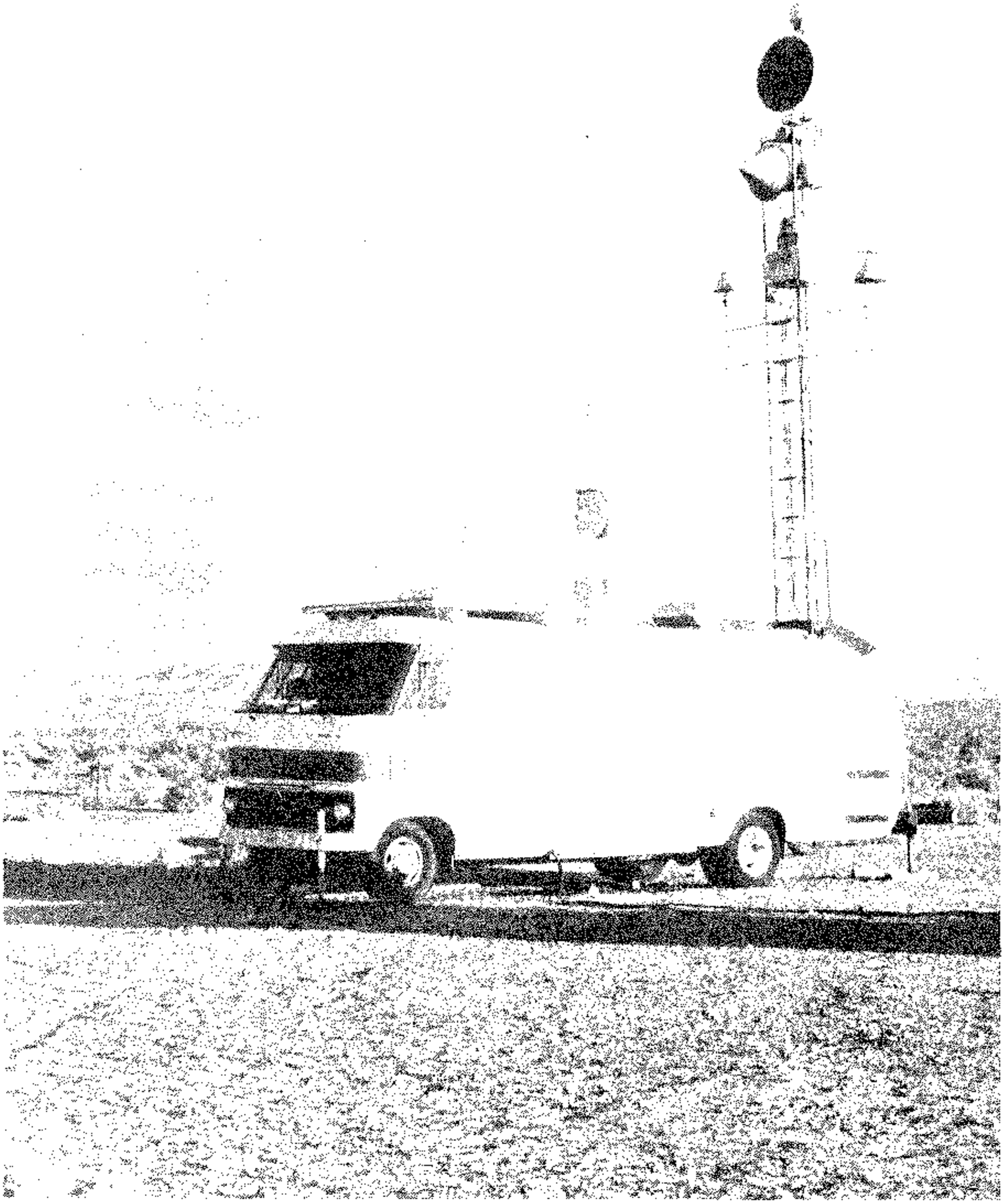


Figure 1-5. Exterior view of Radio Spectrum Measurement System.

In 1982, a decision was made to upgrade and refurbish the RSMS. Substantial efforts in 1982-1985 have almost finished the production of an improved RSMS. A partially equipped RSMS has already completed a set of Maritime Mobile and LMR measurements in the New York area. The RSMS will be complete when the "radar" measurement system is installed in early FY 86, providing a complete set of measurement capabilities in the RSMS for frequencies up to 18 GHz.

Major RSMS work completed in FY 85 included the repair and modification of the old RSMS vehicle, the rebuilding of the antenna tower to provide high sensitivity up to 18 GHz, the installation of the LMR measurement system in the modified vehicle, and completion of major parts of the LMR and radar system measurement and analysis software.

Three major systems make up the RSMS, with a computer forming the core of each of the systems. Two measurement systems are located in the RSMS vehicle, and a general-purpose, data-processing system is located in the Boulder Laboratories. One RSMS measurement system is optimized for measurements of channelized voice communications such as LMR. The other measurement system is optimized for measurements of wide-band signals like radars and microwave systems, but it is very flexible and can be used to measure other types of signals also. Since the LMR and radar systems are controlled by separate computers, they can be operated simultaneously to measure two frequency bands at a time.

The LMR system has been designed to make measurements on narrow-band channelized communication services. This system operates up to 1000 MHz with very high dynamic range (130 dB instantaneous range) and high rejection of signals on adjacent channels. Rectangular bandpass IF filters of 3 kHz, 7.5 kHz, 15 kHz, and 30 kHz (Figure 1-6) permit measurements to be made on various types of signals. Although the high dynamic range minimizes the false responses from intermodulation products, a wide-band overload system gives positive indications whenever too-large signals are present.

The radar system (Figure 1-7) is a more general-purpose measurement system, operating at frequencies in the 10 to 18,000 MHz range with measurement bandwidths between 10 Hz and 30 MHz. Special-purpose peak detectors and pulse train separators allow this system to make reliable measurements on low-duty-cycle radars as well as a wide range of other types of signals.

The computer system in the Boulder Laboratories is used extensively for many functions. These functions include analysis and retrieval of measured data, development of measurement and analysis software for the RSMS, digital communications with computers in the RSMS and Annapolis, on-line documentation of RSMS software, and text processing. A dozen terminals on the lab computer provide these functional capabilities at the desk of everyone in the group.

The measurement software developed for the radar system in FY 85 includes two families of measurement capabilities: WBScan and Superscan. WBScan was designed especially for radar measurements and includes the use of peak detectors for low-duty-cycle radar signals, as well as a several-second "dwell" time at each frequency to allow a typical radar antenna to rotate and point at the RSMS site. An example of a typical WBScan output

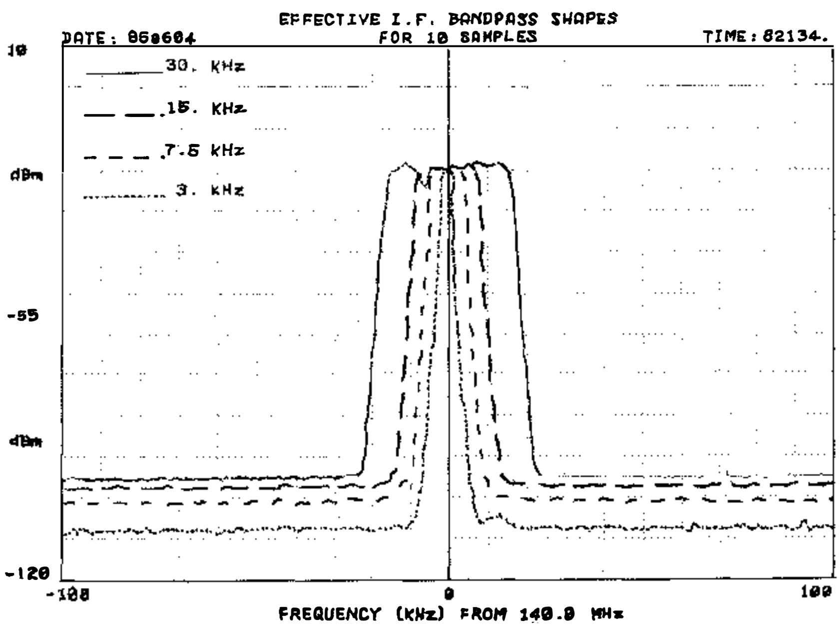


Figure 1-6. LMR receiver bandpass characteristics.

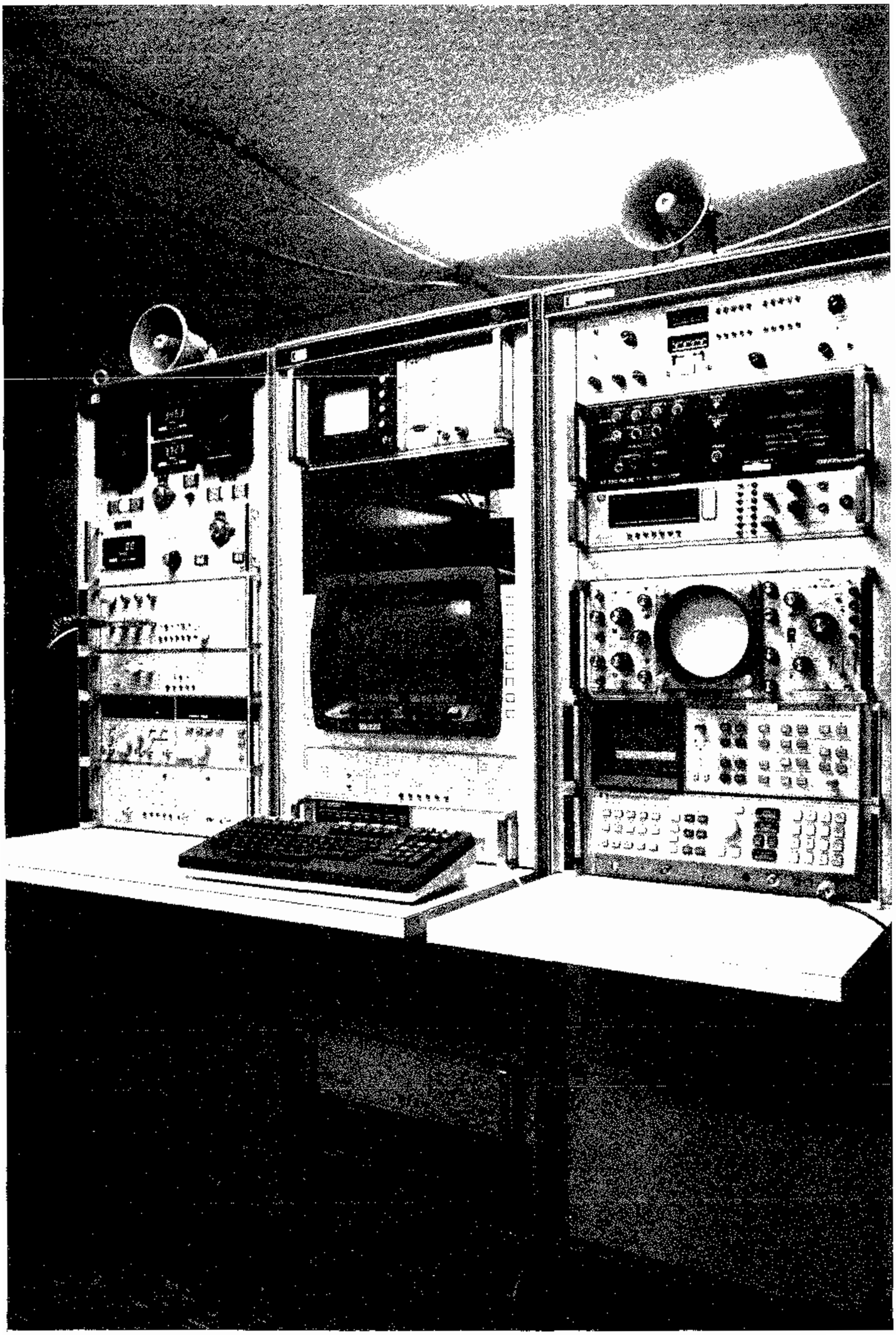


Figure 1-7. Upgraded RSMS radar measurement system (configured as three racks).

is shown in Figure 1-8. The vertical labels on the graph near the radar signals can be added by the operator as the measurements are being made. In addition, special comments--up to 500 characters in length--can be added by the operator during the measurements.

Superscan (Figure 1-9) is the other measurement family used on the radar system. Superscan rapidly makes simultaneous measurements with a peak and an average detector at 500 frequencies within a frequency band. Superscan uses a spectrum analyzer to measure at 500 frequencies across the IF signal bandwidth, while the rf tuning is held fixed. Since the maximum IF bandwidth is 30 MHz, the maximum Superscan sweep width cannot exceed 30 MHz. In practice, 10 MHz is a more realistic maximum sweep width. The advantage of this technique is measurement speed--as much as 20 times faster than by stepping the rf tuning.

The Superscan measurement techniques are particularly useful when unknown or mixed types of signals are expected in the measurement band. Since peak and average detectors are used, Superscan gives useful measurements for both low-duty-cycle and high-duty-cycle signals. Indeed, a comparison of the responses given by each detector provides an important criterion for identification of signals. In addition, Superscan establishes thresholds for the peak and average detectors. If a peak or average measurement exceeds the corresponding threshold, the presence of a signal is noted, and--depending on program options--the scans containing signals can be saved on disk or magnetic tape.

An important objective in all of the new software is to make operation of the system as automatic as possible, not requiring an operator for most measurements and doing as much of the operator's job as possible when there is an operator present. Three specific functions have been incorporated into these programs to enhance automatic operation, including:

- measurement sequencer with 100 steps
- "autolog" features
- telecommunications.

The measurement sequencer is a set of software routines that allows selecting a sequence of up to 100 measurement events. (An "event" is a calibration or measurement program, plus the control parameters needed to run the program.) Since each individual event can be scheduled to run many times before the program goes to the next event, an almost infinite measurement period can be scheduled to run. To further facilitate the selection of particular events, there is a library that contains up to 50 standard measurement events. This library will tend to standardize measurement and analysis procedures and assure direct comparability of data measured at many different sites.

The "autolog" routines assist automatic operation by generating an operations log during measurements. Any significant event generates a single line of text describing the event. (A typical significant event might be the recording of a data record on magnetic tape, for example.) This single line of text is appended to a log file kept on the disc, so it will be available afterwards for operator review even if the system goes down. Using standard text-editing commands, the operator can review the autolog file and add whatever text comments seem needed. Note that these text comments can be added anywhere in the text file.

Figure 1-10 shows a representative, but fictitious, example of an autolog file. The "@" and " " at the beginning and end of most of the lines show that these lines were written by the autolog program. Since all automatic autolog lines were written according to a particular formula, these autolog lines can be automatically sorted for various data or compared against other information.

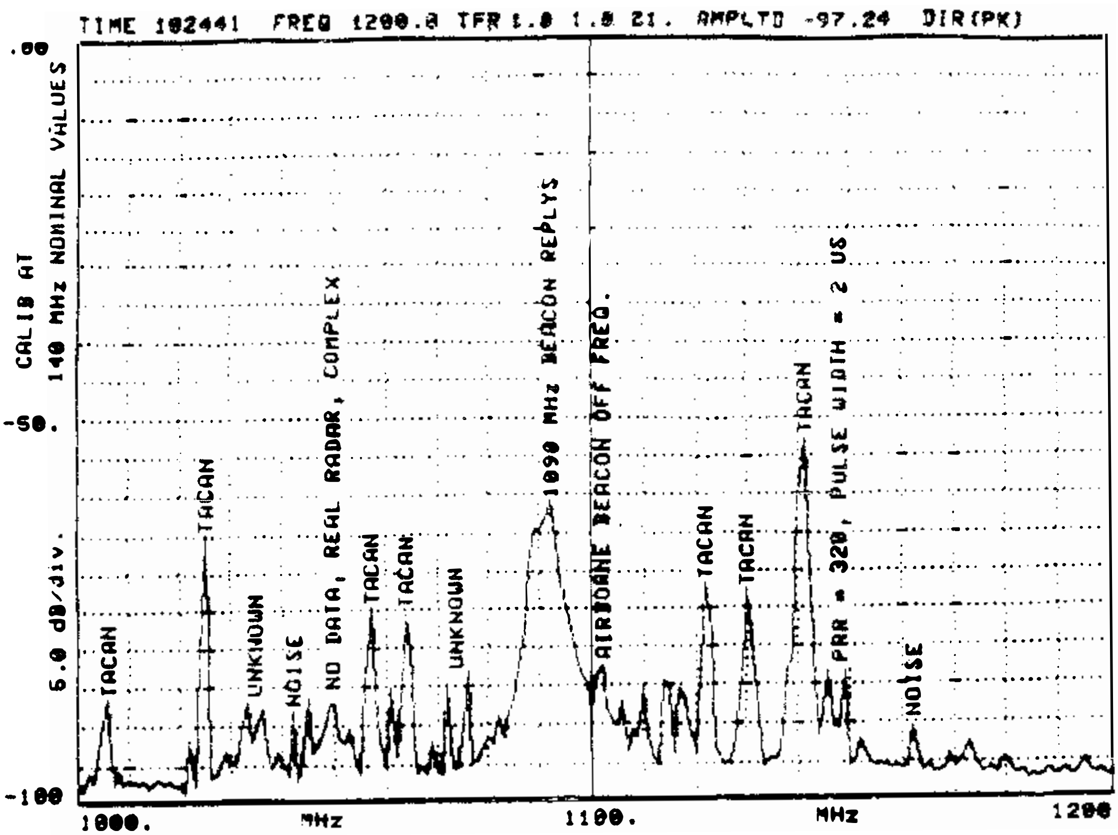
Finally, telecommunications will allow us to monitor the operation of the RSMS at a distance and even change the schedule of measurement or calibration events. Under the best of conditions, we may be able to collect large amounts of data without continually maintaining crew members in the field. Under less ideal conditions, we will be able to sense when the RSMS computers quit operating and are in need of restarting. Although the procedures are not completely implemented yet, we expect to be able to call into the lab computer from a terminal on our desk, or even from a home computer terminal. This call will be relayed to one of the RSMS measurement system computers, which will react in the proper manner by downloading a file, restarting a measurement program, etc.

The radar system will be installed in the RSMS early in FY 86, with initial work scheduled for radar and satellite studies on the East Coast.

Although the RSMS was not operational for most of FY 85, the availability of the LMR measurement system in the RSMS allowed the first of the RSMS Operations to be accomplished in August 1985 in the New York City-Long Island area. Two separate sets of measurements were made at each of two sites. A special set of Maritime Mobile measurements was made to determine the usage patterns (message length and usage statistics) on a few critical channels, as well as usage statistics for the whole Maritime Mobile band.

In addition, usage measurements were made in the 151 to 162 MHz, 162 to 174 MHz, 406 to 420 MHz, and 450 to 470 MHz LMR bands as a "target of opportunity" and an opportunity to test the new RSMS capabilities in additional LMR bands. The LMR measurements were routine, following the pattern of earlier LMR measurements and measuring about 125 channels each second, except that statistics were simultaneously collected based on three different thresholds. The three thresholds will be used in continuing studies of how much measured occupancy is affected by a different choice of thresholds.

Message length statistics and usage patterns in the Maritime Mobile band were measured at the request of the U.S. Coast Guard. This



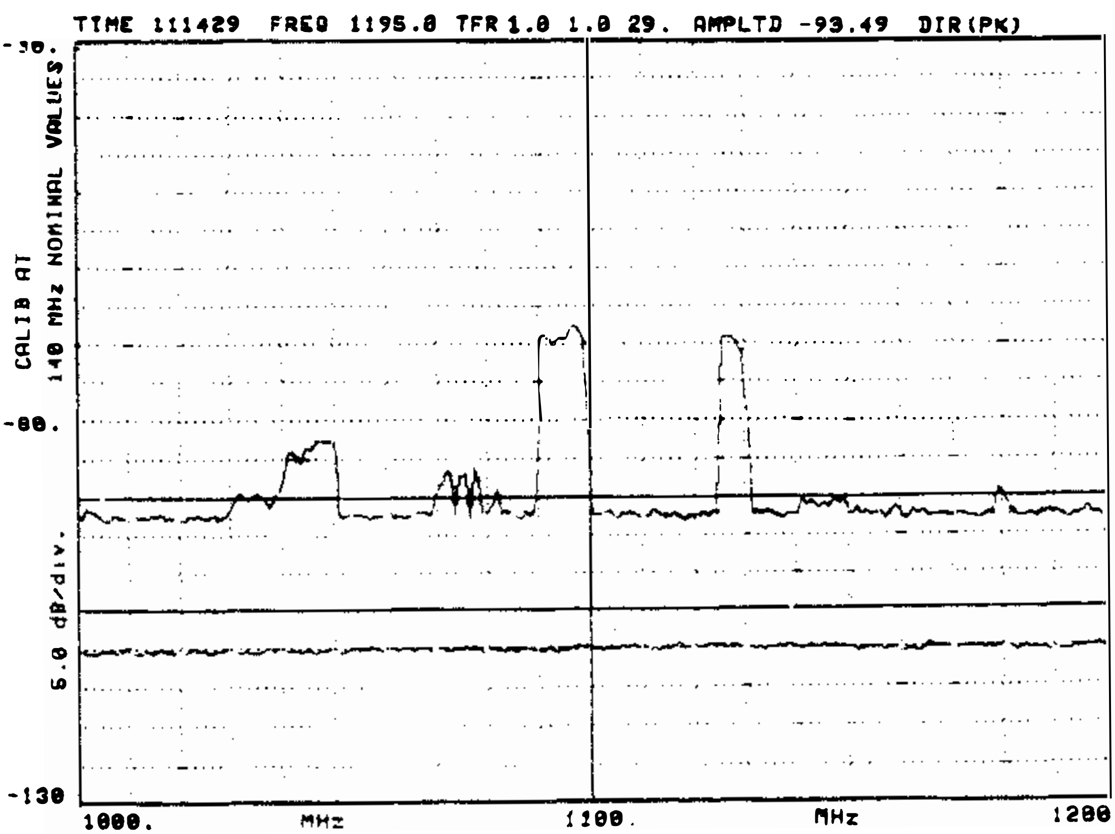


Figure 1-9. Example of SUPERSCAN measurements.

```
@SUPSCN 100.100.004 850904.1550       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.005 850904.1550       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.006 850904.1554       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.007 850904.1603       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.008 850904.1612       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.009 850904.1612       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.010 850904.1613       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.011 850904.1613       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.012 850904.1614       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.013 850904.1614       1/18000 1111111111 1010001 01          0000}
@SUPSCN 100.100.014 850904.1615       1/18000 1111111111 1010001 01          0000}
@ANTPAT   1.001.015  2735         ASR-8 STAPLETON       ANT PAT                  }
@ANTPAT   1.001.016  1331         ARSR-1E DENVER        ANT PAT                  }
@WBSCAN   1.001.017 850905.1536  2700/ 2900 1111111111 1010001 05          0000}
@ANTPAT   1.001.018  2735         ASR-8 STAPLETON (B)   ANT PAT                  }
@ANTPAT   1.001.019  1330         ARSR-1E DENVER        ANT PAT                  }
@ANTPAT   1.001.020  2735         ASR-8 STAPLETON (B)   ANT PAT                  }
@ANTPAT   1.001.021  1331         ARSR-1E DENVER        ANT PAT                  }
@COMENT   1.001.022             38 THIS IS JUST A PRACTICE COMMENT RECORD        }
@COMENT   1.001.024             14 THIS IS A TEST                                }
@WBSCAN   1.001.025 850905.1707  2700/ 2900 1111111111 1010001 05          0000}
@ANTPAT   1.001.026  1331         OFFD                  ADGFGF                   }
@SUPSCN 100.100.028 850906.1338  2100/ 3100 1111111111 1010001 01          0000}
@COMENT 100.100.029             20 THIS IS ANOTHER TEST                          }
@WBSCAN 100.100.030 850906.1350  1000/ 1200 1111111111 1010001 02          0000}
@COMENT 100.100.031             46 WE WILL DO ANOTHER SCAN IN THE 10-12 GHz BAND.}
@WBSCAN 100.100.032 850906.1406  1000/ 1200 1111111111 1010001 02          0000}
@COMENT 100.100.033            104 THIS HAS ONLY BEEN A TEST.  IF THIS HAD BEEN A}
@WBSCAN 100.100.034 850906.1444  1000/ 1200 1111111111 1010001 02          0000}
@ANTPAT 100.100.035  1090         1090 MHz 200 msec     ANT PAT                  }
@WBSCAN 100.100.036 850906.1502  1000/ 1200 1111111111 1010001 02          0000}
}
   Note:  It has been raining outside, and the antenna tower has been burned o
ff by a lightning stroke.  The following data was measured without recalibrati
ng the system and may be incorrect due to the burned-off antenna stubs.  If tim
e permit the measurements will be done over.}
}
@WBSCAN 100.100.037 850906.1515  1000/ 1200 1111111111 1010001 02          0000}
@SUPSCN 100.100.038 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.039 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.040 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.041 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.042 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.043 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.044 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.045 850906.1515  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.047 850906.1531  2100/ 3100 1111111111 1010001 01          0000}
@WBSCAN 100.100.049 850906.1633  1000/ 1200 1111111111 1010001 02          0000}
@SUPSCN 100.100.050 850906.1633  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.051 850906.1633  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.052 850906.1633  2100/ 3100 1111111111 1010001 01          0000}
@SUPSCN 100.100.053 850906.1633  2100/ 3100 1111111111 1010001 01          0000}
@WBSCAN 100.100.054 850906.1653  2700/ 2900 1111111111 1010001 05          0000}
```

Figure 1-10. An example of an "AUTOLOG" file band is under study now because the CCIR and the International Maritime Organization (IMO) are designing a new digital selective calling (DSC) system for this band that would eventually replace the manual watchkeeping on ships and shore stations currently required for the safety and distress channels. Accurate statistics on the current usage patterns (message length statistics, total number of calls during peak hours, etc.) need to be incorporated into traffic models to determine the proper sizing of the proposed DSC system.

The RSMS made band usage measurements in the New York harbor area and on the coast of Long Island Sound in July and August of 1985. Usage measurements were made on all channels in the Maritime band, sampling each channel every 5 s. In addition, five channels were selected to be measured every 0.1 s, so that reliable message length statistics could be obtained--even for short messages. Included in the five channels were global and local safety and distress and calling channels. Several days of measurements were made at each site in this band on a 24-h/day basis. A limited number of audio recordings were also made so that usage could be correlated with the actual type of message being transmitted.

A typical 2-min sample of channel usage is shown in Figure 1-11, showing messages transmitted from at least three sites (as distinguished by received power), including replies from the local Coast Guard site. These raw data were processsed to give message length statistics similar to those shown in Figure 1-12. Figure 1-12 shows message lengths grouped into various 1-s bins, with the highest number of messages falling into the 0-1 s bin. Two types of data are shown in Figure 1-12. The message length statistics are shown with solid lines, and the message interval statistics are shown with dotted lines. At the present time, only small samples of signals have been analyzed, but this small sample suggests a Poisson distribution of message lengths.

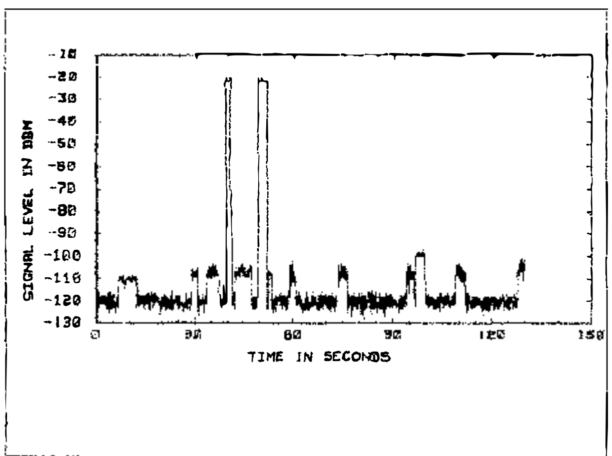


Figure 1-11. Signal level measurements of the 156.8 MHz Distress Calling Channel 16 made at Eatons Neck Point on August 16, 1985.

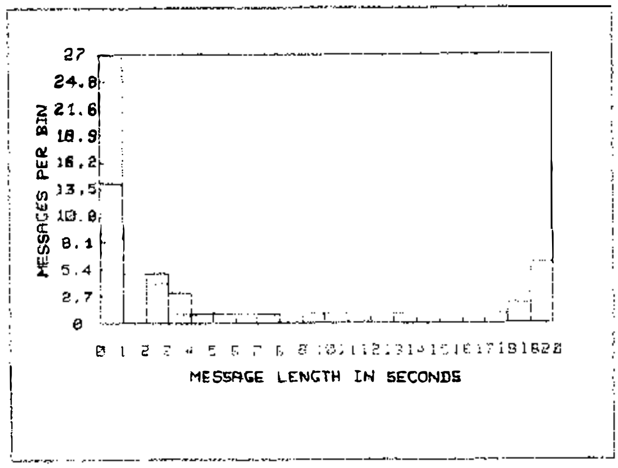


Figure 1-12. Message length statistics derived from the data of Figure 1-11 for the 130-second period beginning at 1610 EST on August 16, 1985.

An interest in low frequency (LF) radio frequency noise resulted in the Medium Frequency (MF) Signal and Noise Measurements to determine rf levels in the 10 to 100 kHz frequency range in the office environment. These areas typically include computer systems and devices that range from microcomputers for local office use to minicomputers for larger interoffice systems and large mainframe computers in banking complexes and large data handling facilities.

A compact portable measurement system was assembled as depicted in Figure 1-13. It consisted of a digitizing spectrum analyzer, a desk-top computer, two shielded-loop antennas, and a 1/2-inch magnetic tape drive. This system would allow efficient operation without being a distraction for the office workers.

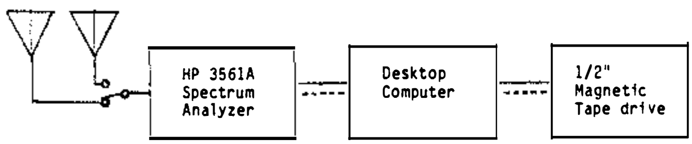


Figure 1-13. Block diagram of measurement system.

The antenna system consisted of two crossed-loop antennas, which were sensitive to the magnetic fields only, connected to the spectrum analyzer through a selector switch. This allowed a data set to be taken from each antenna and later combined in software. This would avoid the inherent directivity of the loops and eliminate the need for hardware phasing circuits. The selector switch was controlled through the spectrum analyzer circuits.

The spectrum analyzer is the type that digitizes the incoming signal at a 250 kHz rate. It then performs a Fast Fourier Transform (FFT) on the digitized data. This instrument is capable of an operating frequency range of from 0 to 100 kHz in either a single frequency span or in smaller spans with a resultant higher frequency resolution. The data from either the frequency spectrum display or the raw digitized time data can be recovered and stored for later processing.

Data storage for the measurement system was on magnetic tape. The selected unit operated at 1600 bits per inch at 12.5 inches per second. This could hold enough data to allow unattended operation of the system for at least two days.

The overall system control was provided by a desk-top computer. This provided the required speed of data transfer between the analyzer and magnetic tape as well as graphics capability for minimal on-site data processing.

System calibration was performed at the antenna range of the National Bureau of Standards using a known field strength and recording the output from the spectrum analyzer, thus taking into account all of the system components and reducing the uncertainties. Data were represented in units relative to 1 pico-Tessla (dBpT).

Radio frequency measurements were made in three office buildings in the Boulder/Denver area and two buildings in New York City--the World Trade Center and the New York Stock Exchange. Figures 1-14 and 1-15 show the measurement system and its placement in a World Trade Center office area.

Data were collected at all hours of the day and through the weekend in order to be able to characterize the areas as to cyclic activity. Data collection was generally made on a 55-minute cycle to avoid any hourly repetitive events. During these periodic collection times, measurements were made by first taking 40 records of 1000-point time samples each and storing the time-sample data for later use. A frequency stepping mode was then performed in which 20 FFT traces of 400 points each were taken and averaged at each 1 kHz step of 1 kHz bandwidth across the frequency band from 1 to 99 kHz. These two modes were repeated twice, once for each antenna selection, on each hourly measurement cycle.

Data processing routines were developed on a larger office computer system while the measurement system was collecting data. The magnetic tape unit provided the required data interfacing and compatibility between the two systems.

Several types of analysis were performed on the data. Initially the tapes were processed to collect the peak, RMS average, and minimum amplitude points per frequency throughout the duration of the tape. These processed data were then stored on disk files for ease of access. Then the frequency spectrum was plotted and major contributors identified as much as possible. An example of this linear frequency output is shown in Figure 1-16. The traces show the amplitudes in dBpT, the maximum value on the top trace, then the RMS average on the next lower trace, and finally the minimum value at each point on the trace for the 2-day period. Ten of these traces comprise a set of plots from 1 to 99 kHz.

These linear frequency plots represent a 10-to-1 compression of the original 400-point FFT plots by taking the peak value in a group of 40 points and plotting that as a single point; likewise, the average and minimum values.

Diurnal variations of signals are shown in Figure 1-17. This is 2-days' data processed as to time of day from 0 hours to 2400 hours. The traces show the RMS average of the signals for each frequency from 1 to 99 kHz with 10 frequencies per graph.

Logarithmic frequency plots are shown in Figures 1-18 and 1-19. These plots are from the same processed data as the linear frequency plots only plotted against a log frequency scale.

Amplitude probability distributions (APD) were generated by reinserting the stored time-domain data into the spectrum analyzer. This allowed the data analysis program to control the performance of the FFT on discrete time records. From each FFT, then, the amplitude of each of nine frequencies was recorded and plotted on a Rayleigh distribution. A sample of these APD's is shown in Figure 1-20. Each APD is a result of approximately 4300 samples. The lower solid line on the plot depicts the theoretical Gaussian noise distribution.

Results of the measurements and data analysis show that each of six sites selected for measurements exhibits characteristics that differ from each of the other sites in many aspects. Two of the sites, the Broadway Building in Boulder and the New York Stock Exchange in New York City, display similarities in the time domain data with each showing pronounced 60 Hz fields, probably owing to the old masonry construction and electrical wiring. The newer facilities showed some similarities in signal activity. Most locations showed more signals than could be located in the accessible areas of the measurements, indicating radiation from adjacent areas or conduction by power wiring.

When the Naval Research Laboratories was planning to develop a new satellite communications system, they came to ITS to help them determine whether the selected frequency bands would be free from interference at all of the planned ground station sites. Under the NRL Site Survey Consultation project, ITS developed a proposed site survey technique, which would provide the maximum opportunity to detect harmful interference for a minimum survey time.

This plan considered the types of signals that might cause interference to the satellite system, including their angular location with respect to the ground station, signal power and modulation characteristics, operational duty cycle patterns, and other factors. Based on these characteristics--and similar characteristics of the satellite

Figure 1-15. Measurement system at Site #4b.

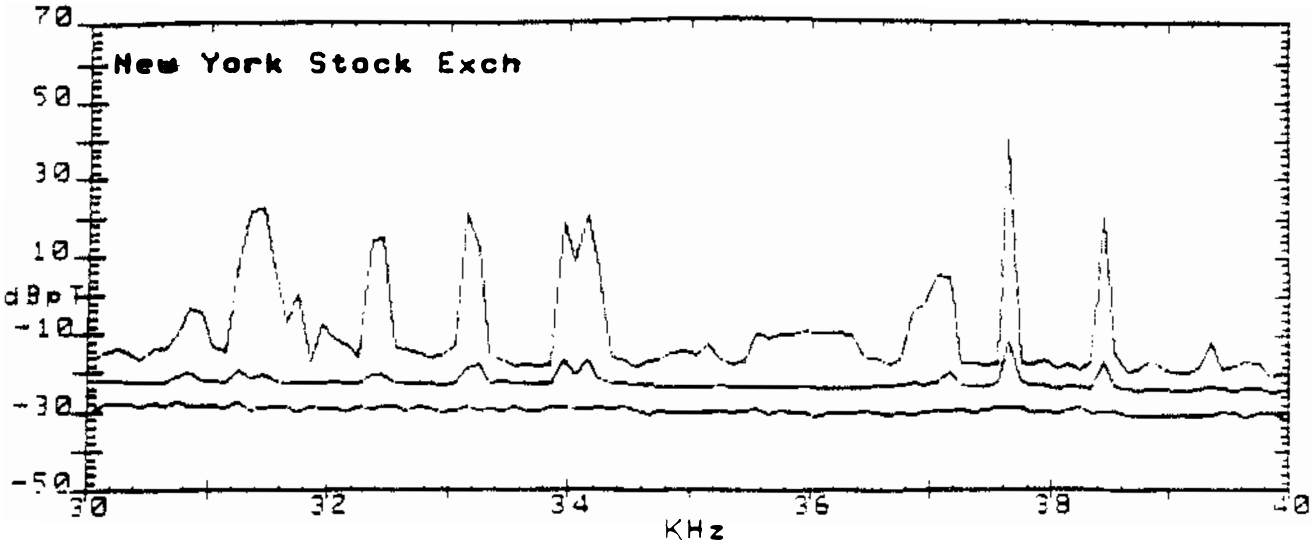


Figure 1-16. Sample of 10 kHz processed span linear frequency graph.

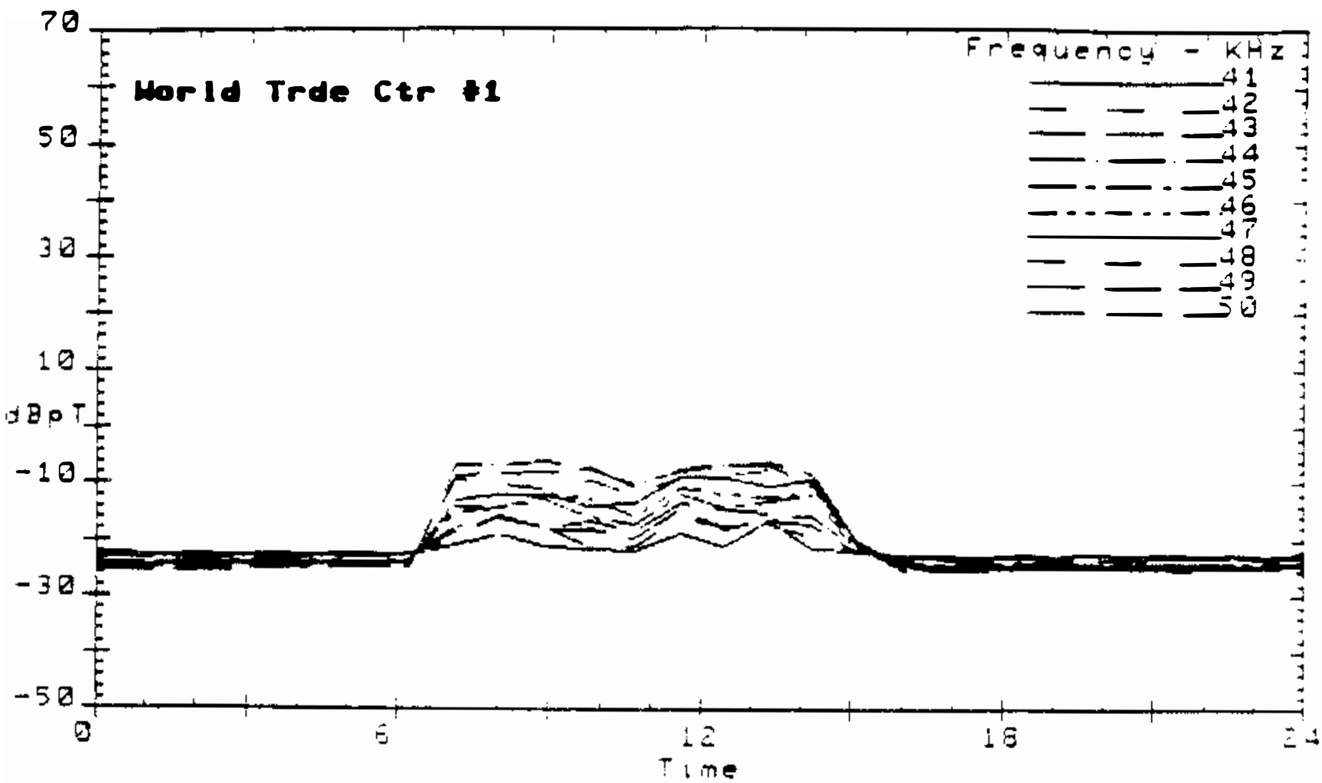


Figure 1-17. Diurnal variation of signals in the 41 to 50 kHz range.

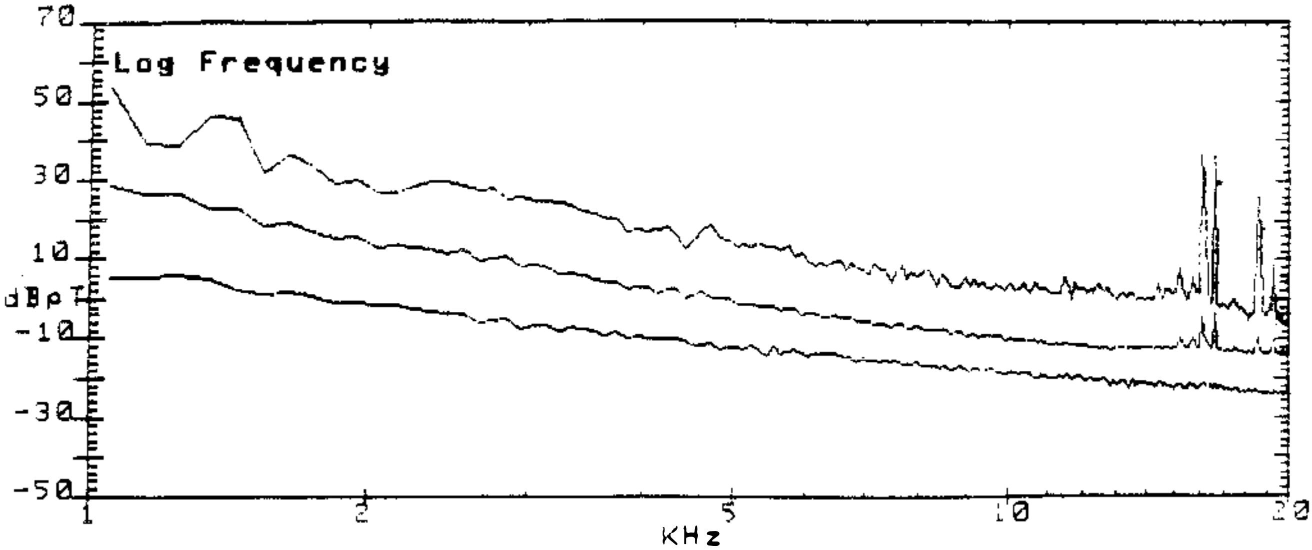


Figure 1-18. Logarithmic frequency versus amplitude, 1 to 20 kHz.

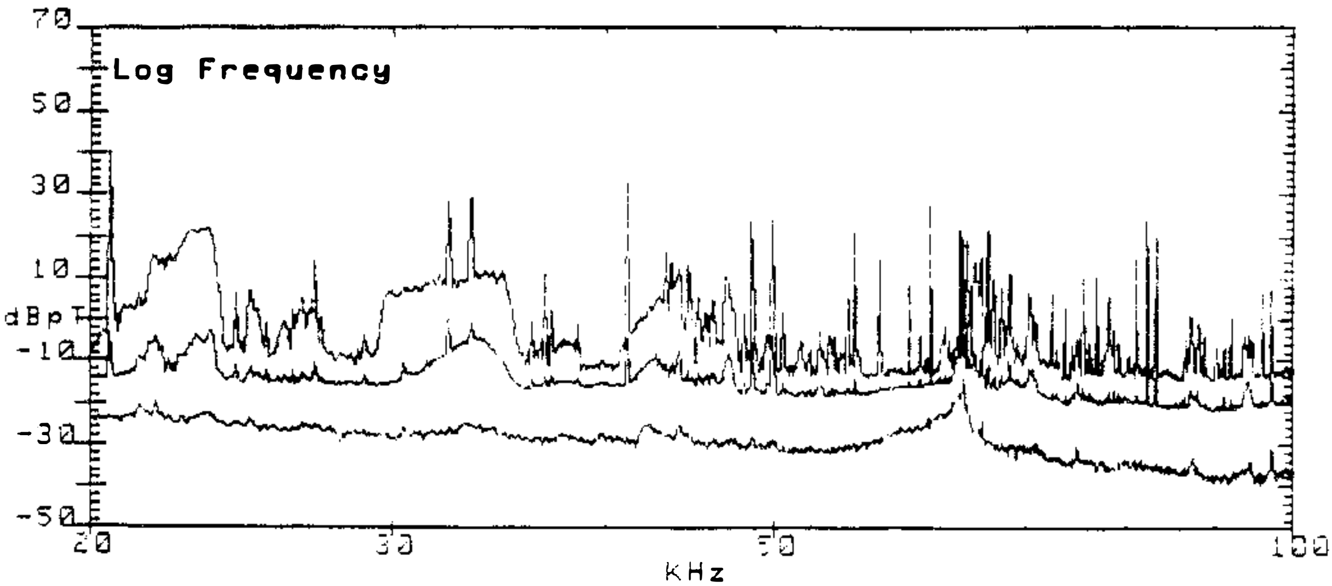


Figure 1-19. Logarithmic frequency versus amplitude, 20 to 100 kHz.

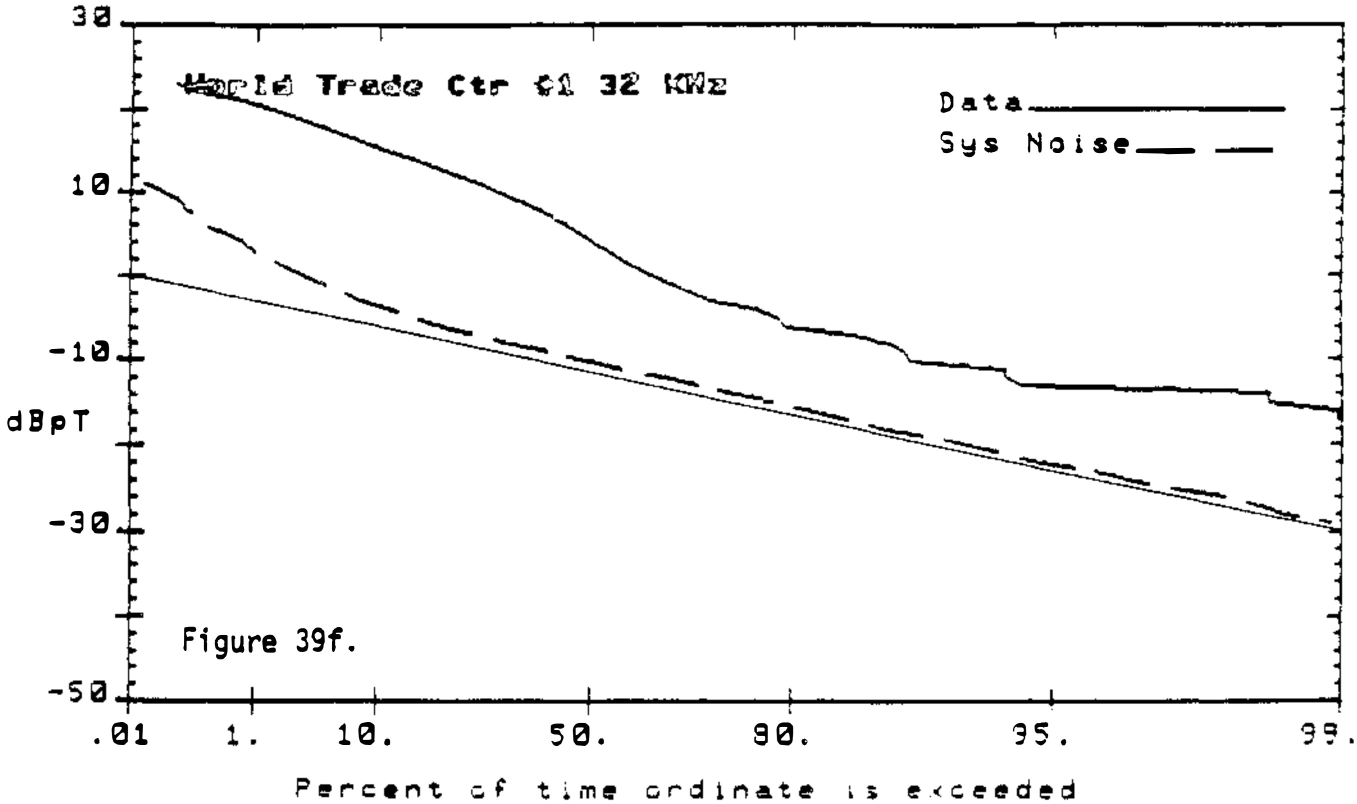


Figure 1-20. Example of amplitude probability distribution.

system--the characteristics of an efficient site survey program were determined. This program included the frequency bands to be measured, required bandwidths and antenna gains, antenna pointing angles, and a recommended total measurement time.

The recommended program was considered, along with other frequency management options, to ensure that the satellite system would not be degraded by unintentional interference. At the current time, other frequency management techniques are being used to determine the likelihood of harmful interference.

The Institute has provided technical support to the Air Force during the procurement of the AN/MSR-T4 Receiver System. The design is based on a prototype model developed by the Institute which served as the basis for the production decision by the Air Force Systems Command.

The AN/MSR-T4 is a mobile, fully automatic, multiple receiver system that is to be employed by the Air Force to acquire, analyze, and output key operational parameters/characteristics of radar threats and electronic countermeasure equipment during electronic warfare tests and exercises.

The effort of ITS has been primarily technical guidance to the 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.

A study of some of the F-15 Maintenance Consultation problems was undertaken by the National Bureau of Standards (NBS) to check whether lack of sufficiently accurate standards and test methodology was responsible for some maintenance problems occurring on the U.S. Air Force's F-15 fighter aircraft. The Institute became involved in this work jointly with NBS because of its experience with automatic test systems and the F-15 radar.

The work involved several orientation trips to Air Force bases where F-15's were being maintained, familiarization with the test procedures being used, and sorting through many, many maintenance records. These maintenance records were put into a suitable data-base form and sorted to show correlations between certain test procedures and higher-than-normal maintenance problems.

The Air Force Geophysical Laboratory (AFGL) of Hanscom AFB, Bedford, MA, was tasked to make atmospheric measurements during the operational tests of the AN/TRC 170 tropo radio. For project AFGL/LYT Refractometer Consultation, ITS developed a microwave refractometer and assisted AFGL personnel in making the atmospheric refractivity measurements throughout the tests.

The AN/TRC 170 is a military tactical radio in the 4 GHz frequency band. It uses the troposphere as a scattering medium to make nonline-of-sight, two-way communications in the range of about 300 to 500 km. A series of tests were proposed by Mitre Corporation, the test director, to collect real-time data under different weather conditions and over a variety of terrains.

The paths were from Biloxi, MS, to Eglin AFB, FL, for a coastal path; from Phoenix, AZ, to Ft. Huachuca, AZ, for a high plains desert path; from Bentwaters, England, to the Hook of Holland for a sea path; from Eglin AFB, FL, to Montgomery, AL, for a wooded path; and from the Everglades to Tampa, FL, for a low marsh path.

The atmospheric refractivity in the region where the two antenna beams met (the common volume) needed to be studied while the radio was in operation to determine what weather conditions affected the radio. To make these measurements, ITS developed an airborne microwave refractometer for AFGL that could give the refractive index versus altitude and also the atmospheric turbulence at any given altitude. Personnel from AFGL and ITS developed a flight pattern that could best measure the atmospheric refractivity in the common volume.

A small aircraft was rented in the area of the test and instrumented with the refractometer. The aircraft, piloted by ITS personnel, and the data collection equipment, operated by AFGL personnel, would fly a climbing spiral path in the common volume from the surface to about 3900 m. This would give a refractive-index-versus-altitude profile to determine where the layers were and how severe they were. Then, level runs would be made in areas of interest, determined by the vertical profile, to measure the turbulence throughout the common volume.

These data will be compared with the operational data obtained from the radio to best determine the best weather conditions for the radio.

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.

1.4.1 Radio Propagation in the Lower Atmosphere

Properties of radio propagation systems that depend upon the structure of the lower atmosphere are discussed in this section.

Three areas of model evaluation and update resulted from field measurements in the project devoted toward Millimeter Wave Model and Experimental Data Acquisition. In the first area, the ITS atmospheric millimeter-wave propagation model (MPM) was updated and tested with experimental data from horizontal, line-of-sight links when there is no precipitation. The MPM computer program predicts attenuation and delay properties of moist air over ranges in frequency from 1 to > 300 GHz. Input variables are radio path distributions of pressure, temperature, relative humidity, and a suspended droplet concentration simulating haze and fog conditions.

Terrestrial propagation experiments in the 10 to 100 GHz range were conducted over various path lengths (0.1 to 27 km) employing continuous wave and broadband (> 1 GHz) signals. In order to compare MPM predictions with realistic data, absolute intensity measurements were performed of phase-coherent signals at 11.4, 28.8, and 96.1 GHz over a 27.2 km path located in Boulder, CO. Calibrated levels of received signal amplitudes have been processed for time periods free of precipitation to obtain mean values $\bar{s}$(dB) and variances $\sigma_s(dB^2)$ as indicators for atmospheric losses and fluctuations introduced by water vapor, turbulence, and possible layering effects. Attenuation (dB/km) was measured at 28.8 and 96.1 GHz when the atmosphere was well mixed (Figure 1-21). Calibrated mean signal levels permitted studies of water vapor losses. Path data from other millimeter-wave propagation experiments included in the analysis are shown in Figures 1-22 and 1-23. Good agreement is obtained with the MPM for test frequencies up to 430 GHz. In addition, a spectral analysis was performed of clear-air scintillations caused by turbulence and multipath interference (Figure 1-24).

Measurements from the second study area gave three main results: the demonstration of the climatic dependence of rain rates and associated signal amplitude attenuations, the comparison of measured attenuation with values predicted from raindrop-size distribution models, and verification of the EHF Telecommunication System Engineering Model (ETSEM). The millimeter-wave rain attenuation measurement system (a transportable probe) was operated at sites in northern California and central Colorado. The probe data consist of simultaneous measurements of the received signal levels at 28.8, 57.6, and 96.1 GHz and rain rate.

The probe was installed on a 1-km (line-of-sight) path at Gasquet, CA, in January and operated through April 14. During this period, rain occurred on 27 days with an accumulation of 514 mm (20.25 in). The probe was returned to Colorado and installed on a folded 300-m path in Boulder (total effective path length of 600 m) and operated from May 10 through August 2. During this period, rain occurred on 21 days with an accumulation of 123 mm (4.85 in).

Analyses performed on these data include calculations of cumulative distributions of rain rate and signal attenuations for both sites. From these distributions, specific attenuations (dB/km) are determined for the three measurement frequencies. A plot of the cumulative distributions of rain-rate for Gasquet, CA, and Boulder, CO, is shown in Figure 1-25. Markedly different rain characteristics are observed from these data. In California, rain fell nearly 10 percent of the monitoring period, and maximum rates of 50 mm/hr were observed; while in Colorado, rain fell approximately 1 percent of the monitoring period, but rain rates approaching 90 mm/h were recorded.

Cumulative distribution curves of signal attenuation at 28.8, 57.6, and 96.1 GHz are shown in Figure 1-26 for the California and Colorado monitoring periods. Higher attenuations and a more uniform frequency dependence is observed in the California data compared to the Colorado data.

Plots of specific attenuation as a function of rain rate for the three frequencies are shown in Figure 1-27. The much higher attenuations (for given rain rates) and more uniform frequency dependence observed in the California data compared to the Colorado data are a function of raindrop-size distributions. These differences are consistent with the smaller raindrop size associated with the "widespread" rain characteristics of the northern California area in winter and spring and the larger raindrop size associated with the "convective" rain storms in Colorado in late spring and summer. Raindrop size, shape, velocity, and temperature all contribute to the resultant signal attenuations.

Values of a and b for the aR^b relationship were computed for the three frequencies and two climates and compared to the values computed for popular theoretical dropsize distributions.

Cumulative distributions of signal attenuation determined from the measured data at California and Colorado were compared to cumulative distributions of signal attenuations based on predictions from ETSEM for 28.8, 57.6, and 96.1 GHz. Sample results at 57.6 GHz are shown in Figure 1-28. Further analyses and comparisons of these data and data resulting from the FY 86 measurements in the southeast United States are planned. These analyses will permit further testing and update of the ETSEM model.

At the inception of the millimeter-wave rain attenuation experiment at ITS, it was believed that the three frequencies of operation (28.8, 57.6, and 96.1 GHz) would provide sufficient information from which path-averaged raindrop-size distributions could be determined. In the third model evaluation and testing effort, a procedure, known in the literature as the "quadrature method," was applied to some of the three-frequency rain attenuation data with the intent of extracting a feasible representation of the raindrop-size distributions along the measurement path. However, this procedure was unsuccessful because the set was too sparse or the quadrature approximation was too crude or both. Subsequent to the discovery that three frequencies of measurement were insufficient, it was decided that more points could be added by interpolating between measured-frequency data to increase array sizes in the quadrature method. But even an increase to 50 frequencies by this scheme failed to improve the character of the results.

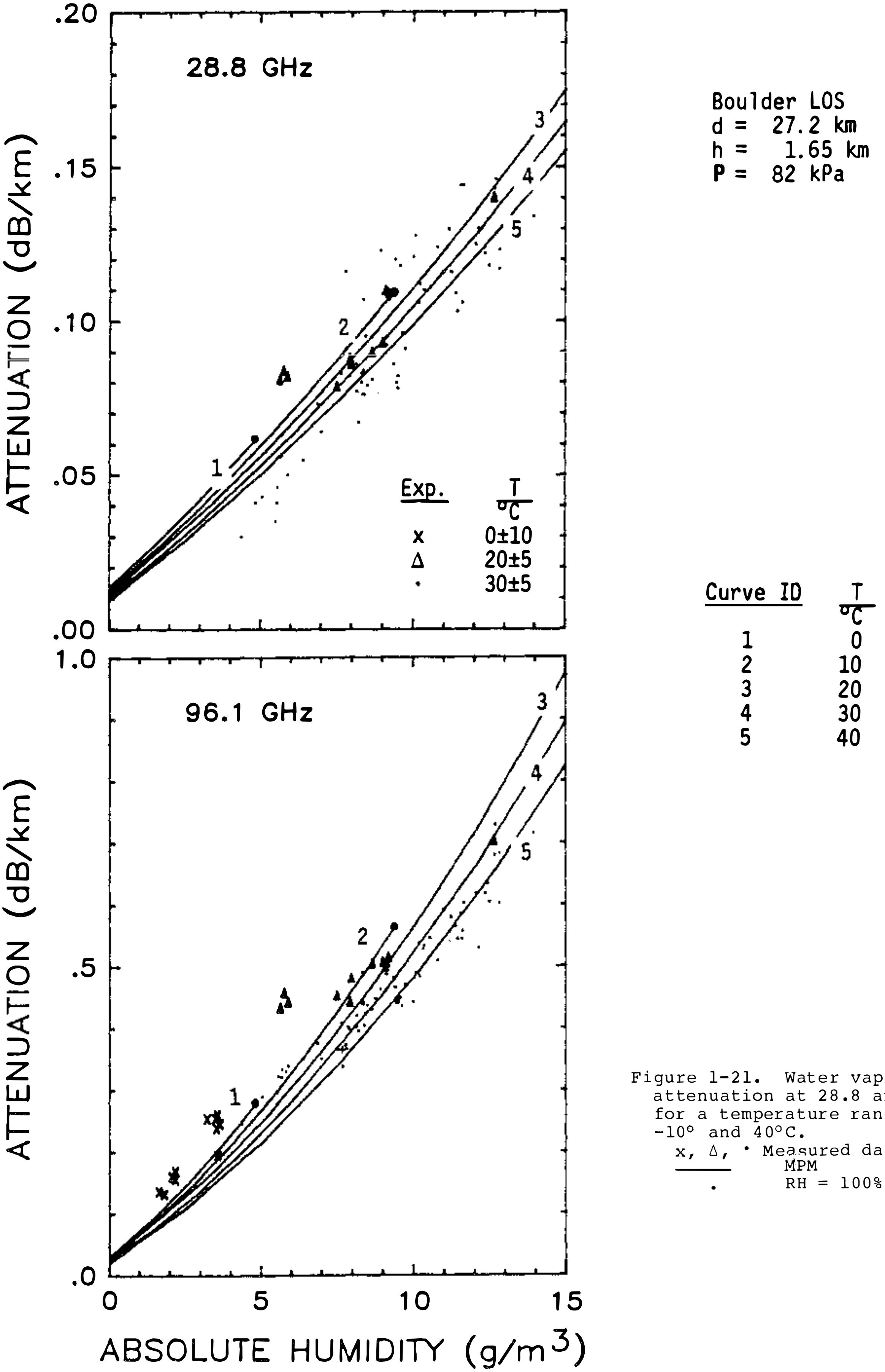


Figure 1-21. Water vapor attenuation at 28.8 and 96.1 GHz for a temperature range between -10° and 40°C.

x, Δ, • Measured data (14±22°C)

—— MPM

• RH = 100%

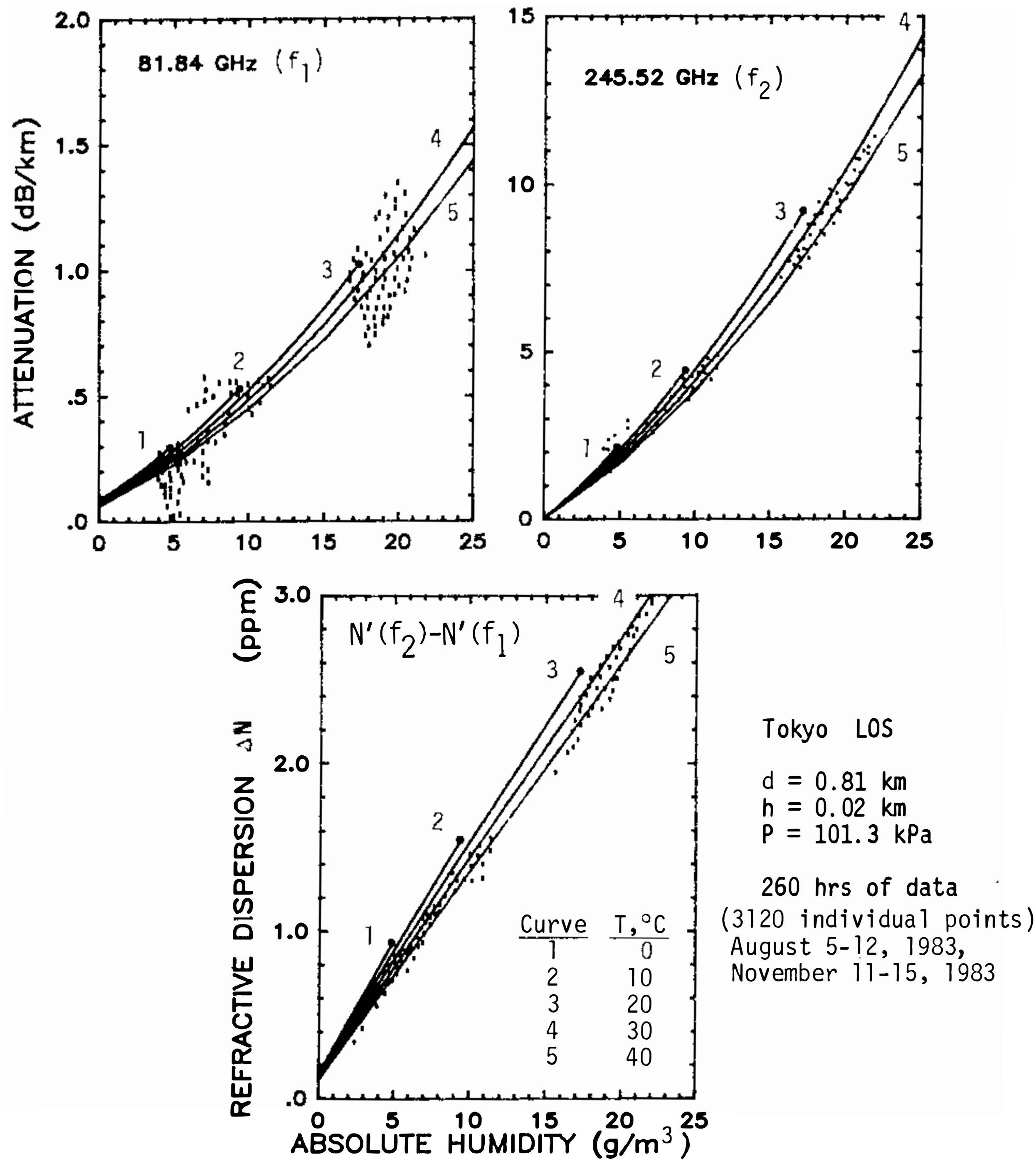


Figure 1-22. Specific attenuation α and refractive dispersion $\Delta N = N'(f_2) - N'(f_1)$ for humid air and temperatures every 10°C ranging from 0° to 40°C at two frequencies $f_{1,2}$ of a Tokyo propagation path:

' Representative of measured data clusters

—— MPM, • RH = 100%

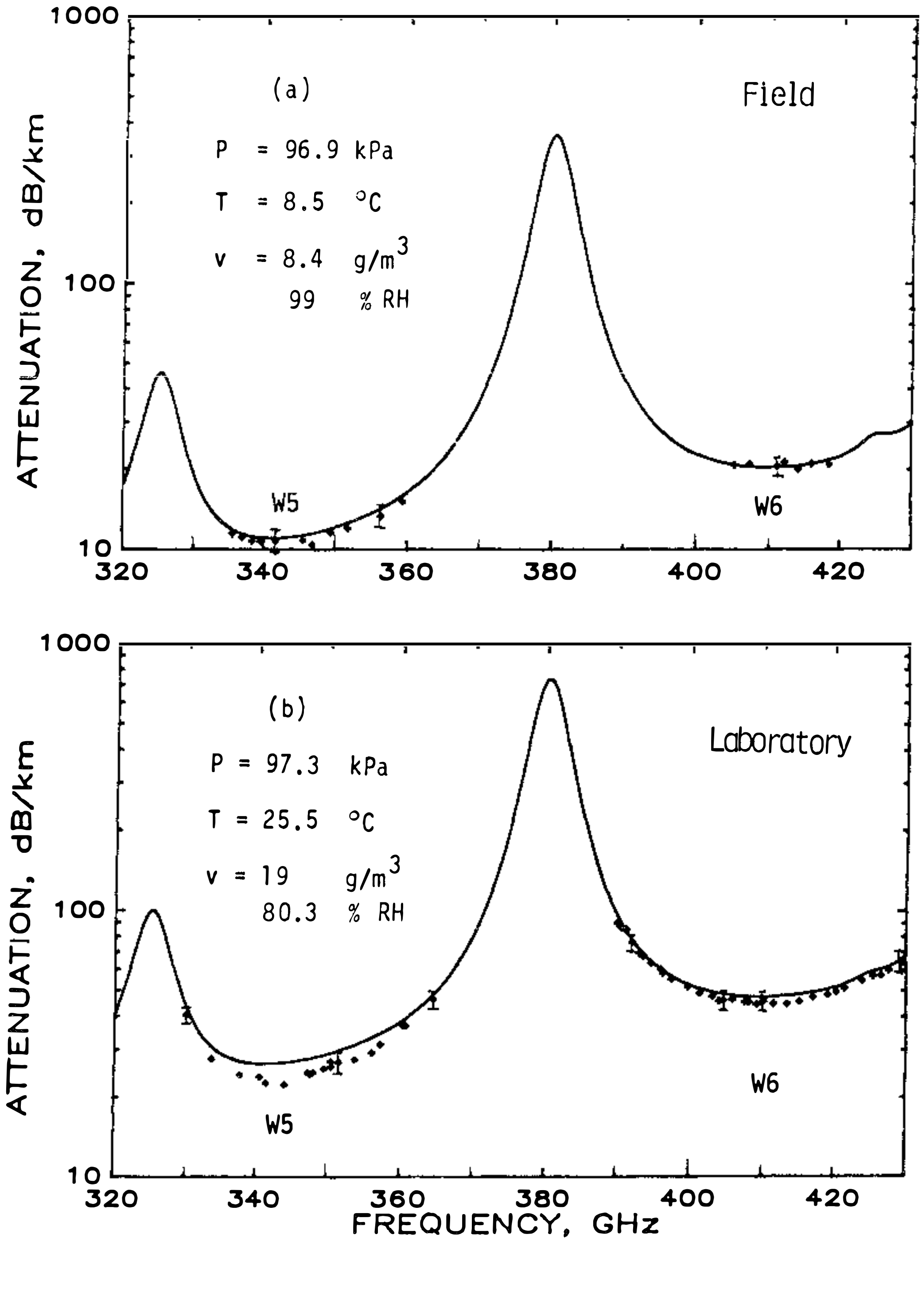


Figure 1-23. Water vapor attenuation rates $\alpha(\nu)$ across the atmospheric window ranges W5 and W6 at two temperatures, 8.5° and 25.5°C:

+ measured data

—— MPM

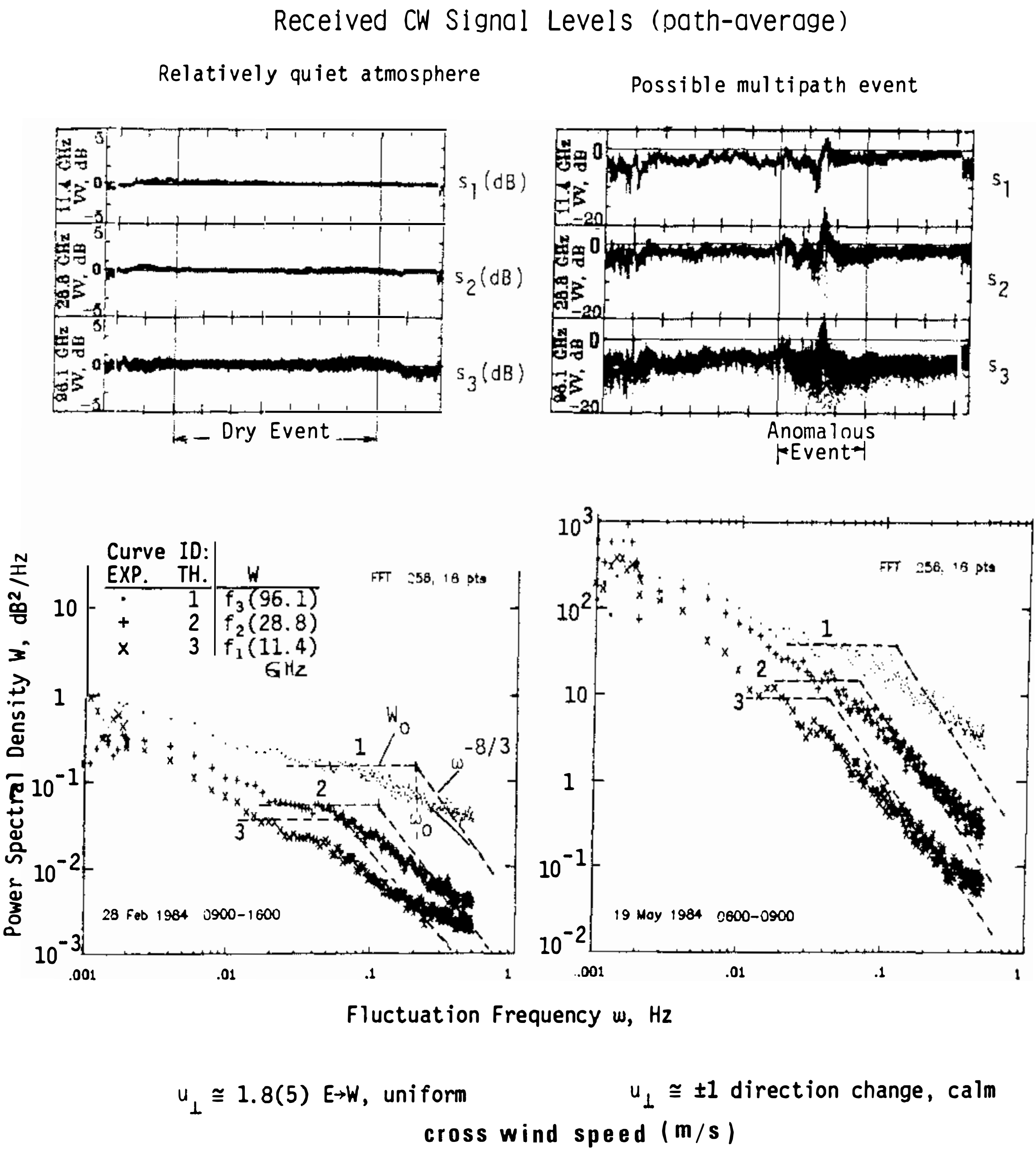


Figure 1-24. Typical daily records of received signal levels $S_{1,2,3}$ for Boulder LOS link (L = 27.2 km) taken at a sampling rate, τ = 1 s. Shown are event time series for a relatively quiet atmosphere ("dry" scintillations) and a possible multipath event, both with the associated power spectral density W(ω).

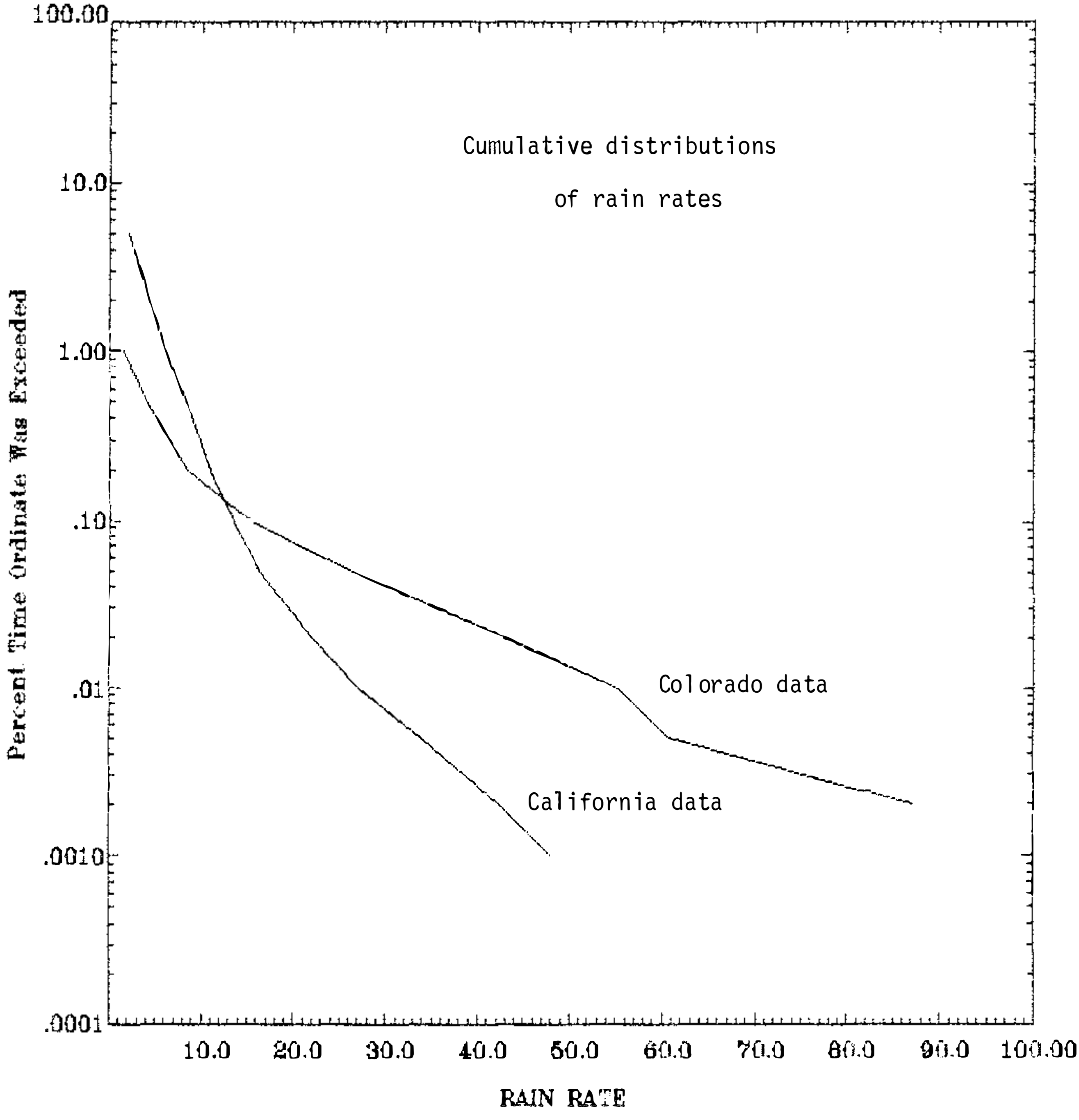


Figure 1-25. Cumulative distributions of rain rate for Gasquet, CA, and Boulder, CO.

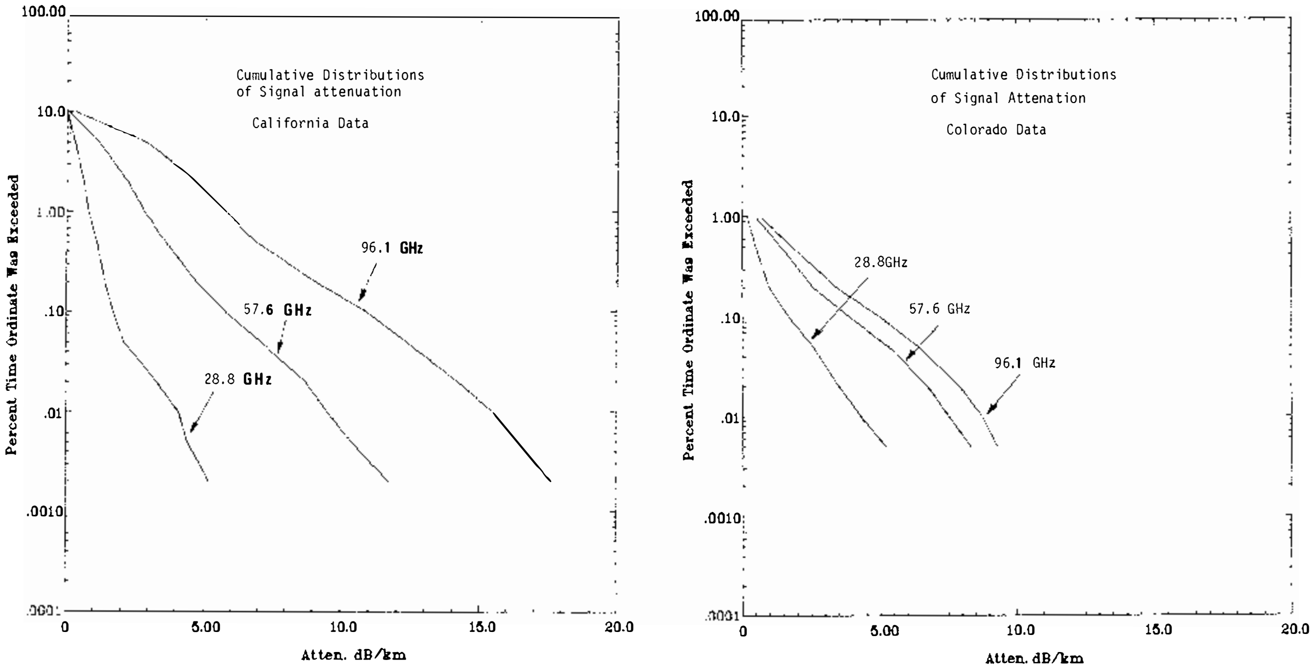


Figure 1-26. Cumulative distributions of signal attenuation at 28.8, 57.6, and 96.1 GHz for Gasquet, CA, and Boulder, CO.

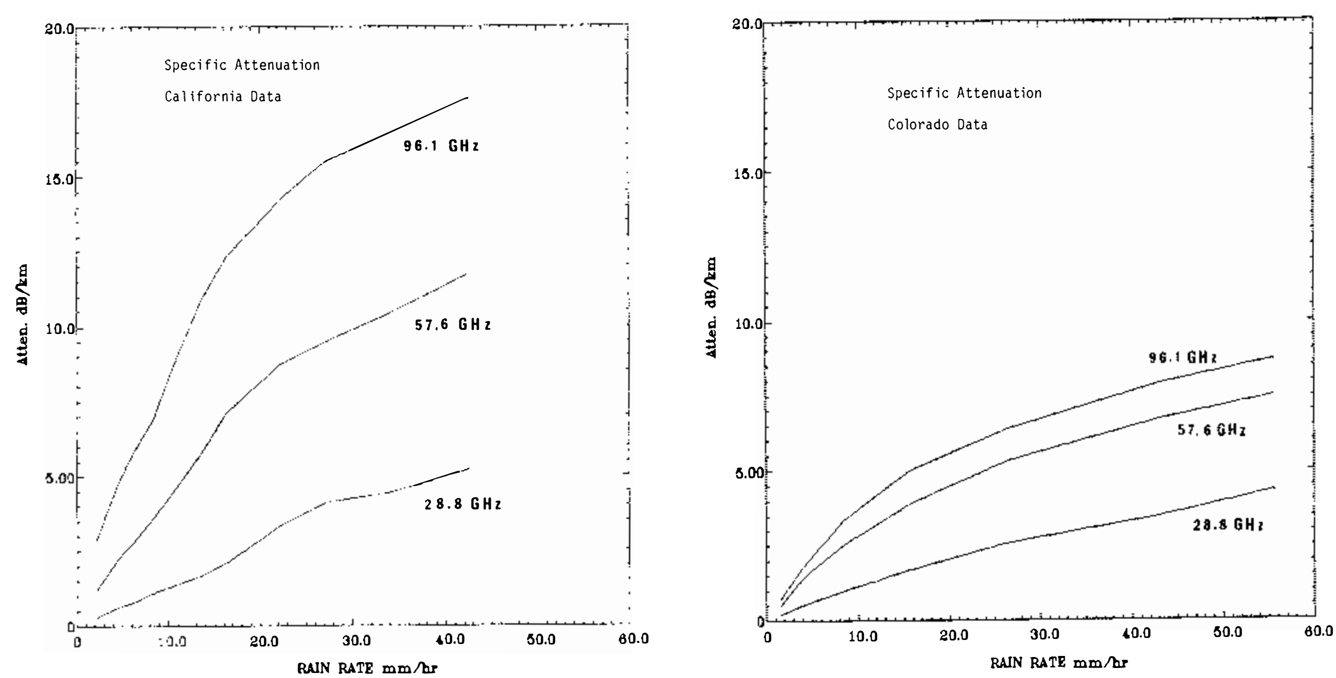


Figure 1-27. Specific attenuation plots as a function of frequency for Gasquet, CA, and Boulder, CO.

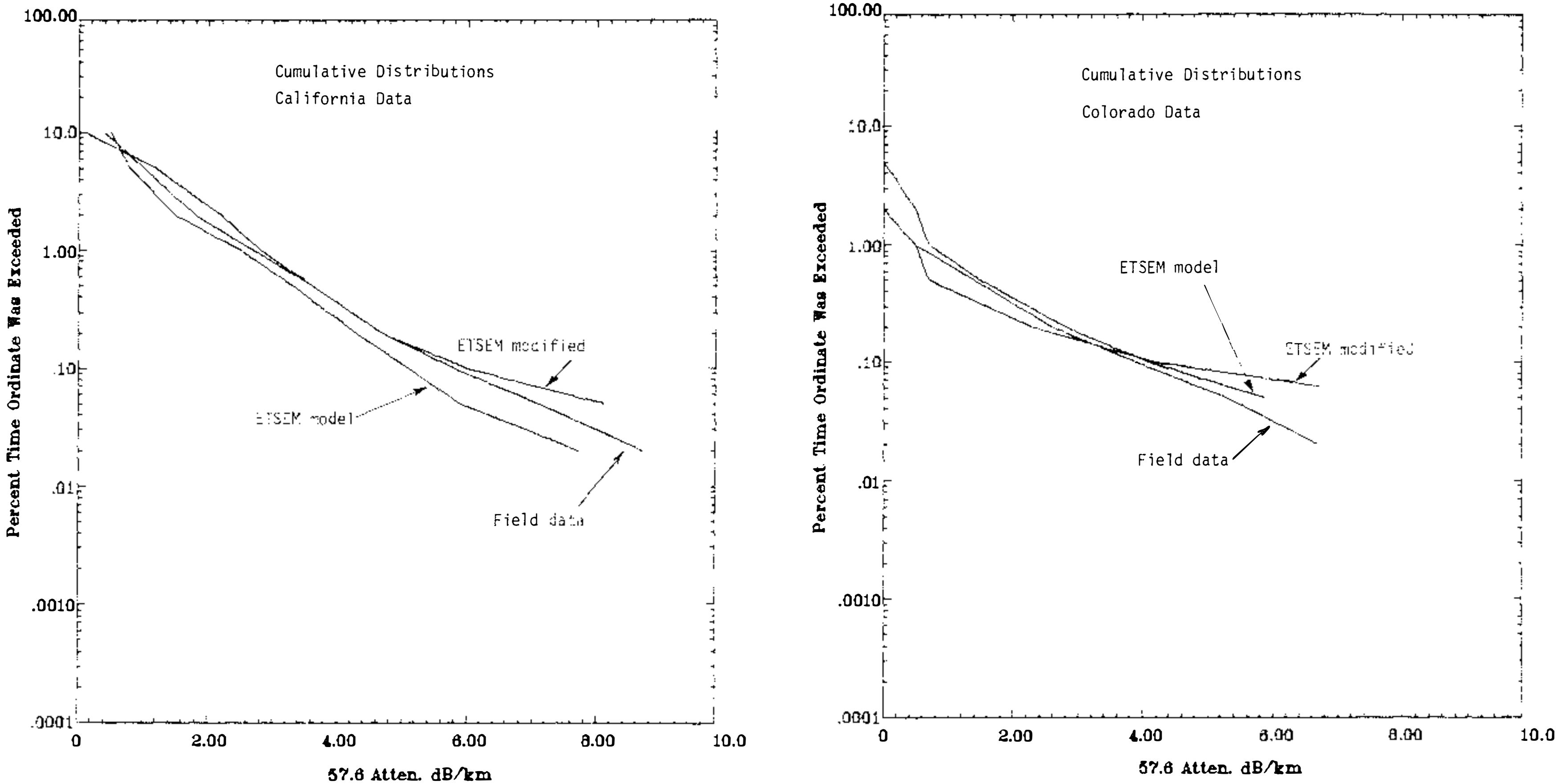


Figure 1-28. Comparisons of cumulative distributions derived from measured data and from model predictions at 57.6 GHz.

Two other methods developed at telecommunications laboratories other than ITS also originally looked promising, but apparent gaps and inconsistencies in their respective developments have prevented their implementation for our analysis purposes as well. These are a maximum-entropy method and an exponential function-fitting procedure. It appears, then, that while there is considerable need to obtain raindrop-size distribution information in order to accurately predict millimeter-wave rain attenuation, there does not at the moment seem to be an adequate method of obtaining this information from the recent ITS millimeter-wave data. Instead, two other procedures for analyzing these recently obtained millimeter-wave rain attenuation data have been examined.

The first of these procedures is fitting a power-law relationship to the obtained values of specific attenuation (dB/km) $\alpha(f)$ and rain rate, R, in millimeters per hour of the form

$$\alpha(f) = a(f)\, R^{b(f)}, \qquad (1)$$

where a(f) and b(f) are frequency, f, dependent coefficients. Equation (1) is a statistical "best-fit" relationship, and as such, while it tends to indicate the relationship between $\alpha(f)$ and R, it loses much of its glamour as a prediction method. This is because of the considerable variability among various fits of the form of (1) as is exemplified in Figure 1-29 for $\alpha(f)$ and R data taken at 28.8 GHz during the summer of 1984 at Boulder, CO. There is also considerable variability about any one given fit of the form of (1) to a data set, as seen in Figure 1-30 for the relatively large January 27 through February 19, 1985, data set taken at 28.8 GHz at Gasquet, CA. Because of this considerable variability, it was desirable to examine a more straightforward approach to the prediction of link performance via "worst case" estimation.

Since most systems are designed on the basis of reception reliability requirements, either for a worst month or on a yearly basis, it is desirable to represent the data collected by the ITS millimeter-wave experiment in terms of distributions. Using the 9 rainy days in the period January 27 to February 19, 1985, as a "standard sample" of daily distributions, a hypothesized annual distribution of specific rain attenuation has been developed. An example of this annual distribution, which is based on the use of the statistical procedure of least-squares quadratic regression, is shown in Figure 1-31. In Figure 1-31 the dashed lines represent the 9 rainy-day distributions, and the two solid lines represent the regression fit and a projected "worst case" upper bound at Gasquet, CA, at a frequency of 28.8 GHz.

Absorption of moist-air measurements were made in the Millimeter Wave Laboratory Studies. Spectroscopic data consist of more than 450 parameters describing local O_2 and H_2O absorption lines. Dry air and water vapor continuum terms must be added to the selected group of local O_2 and H_2O resonance lines in order to correctly predict atmospheric millimeter-wave attenuation in window ranges between lines. Laboratory measurements at 138 GHz of absolute attenuation rates of α for moist air with water vapor pressures up to saturation were performed in order to formulate an improved water vapor continuum. Specifications for the experiment are:

- Resonator. Fabry-Perot reflection-type, semi-confocal arrangement, 10 cm mirror diameter and 20 cm spacing; micrometer tuning is 0.3175 mm/turn with 1.3×10^{-4} mm resolution; loaded Q-value is Q = 436,000 equivalent to an effective path length of L_R = 0.151 km.

- Excitation. Linearly frequency-modulated klystron with stabilized (lock-on scheme between klystron and resonance f_R) center frequency; sweep rate is 500 Hz with a sweep width of 5 MHz.

- Detection. Liquid-helium-cooled (4.2 K) InSb square-law detector, 10^{-11} w/$\sqrt{Hz}$ noise level, 30 kHz bandwidth, 4.2 V/mW response; reflected signal levels for the evacuated resonator are a_o = 40 mV for the resonance peak and A_o = 727 mV for the power peak; sensitivity $\alpha_{min} \approx$ 0.1 dB/km equivalent to $\Delta\alpha \approx$ 0.2 mV and stable over several hours; dB-calibration accuracy better than 5 percent for >1 dB/km.

- Data Run. An example of measuring attenuation α by detecting the resonance peak signal a_1(Pk) with reference to vacuum (a_o) is shown in Figure 1-32. First, water vapor is introduced (e = 32.3 torr), which is then mixed (ca. 60 min) with air at the total pressure of P = 801 torr and, in the end, pumped down to vacuum.

  The computer controlled program for the spectrometer is written in BASIC with about 500 lines of code to control eight temperature, two pressure, and three detector signal measurement channels and store all data for future processing. The program is time-controlled; the minimum time for one measurement cycle is 30 seconds.

- Experimental Results. Pressure scans of moist-air attenuation rates α were taken at 137.96 GHz and 287, 296, 306, and 315 K for RH $\leq$ 90 percent and P $\leq$ 800 torr. Control measurements with "loss-free" dry air were extended to P=1300 torr to simulate the refractive tuning properties of moist air. Fitting the extensive parametric data set leads to a tentative result on pressure and temperature dependences that is given by

$$\alpha = [2.6\, e^2\theta^{6.2} + 0.091\, ep\, \theta^{-0.7}]\, 10^{-3} \text{ dB/km}, \qquad (1)$$

where e and p = P - e are in torr and $\theta = 300/T(K)$. When the local lines are treated with a Van Vleck-Weisskopf shape and subtracted from (1), then the remaining 94 percent of the e^2-term and 62 percent of the ep-term constitute the continuum contribution. Water vapor continuum absorption possesses a negative temperature dependence ($\approx$ - 2%/K).

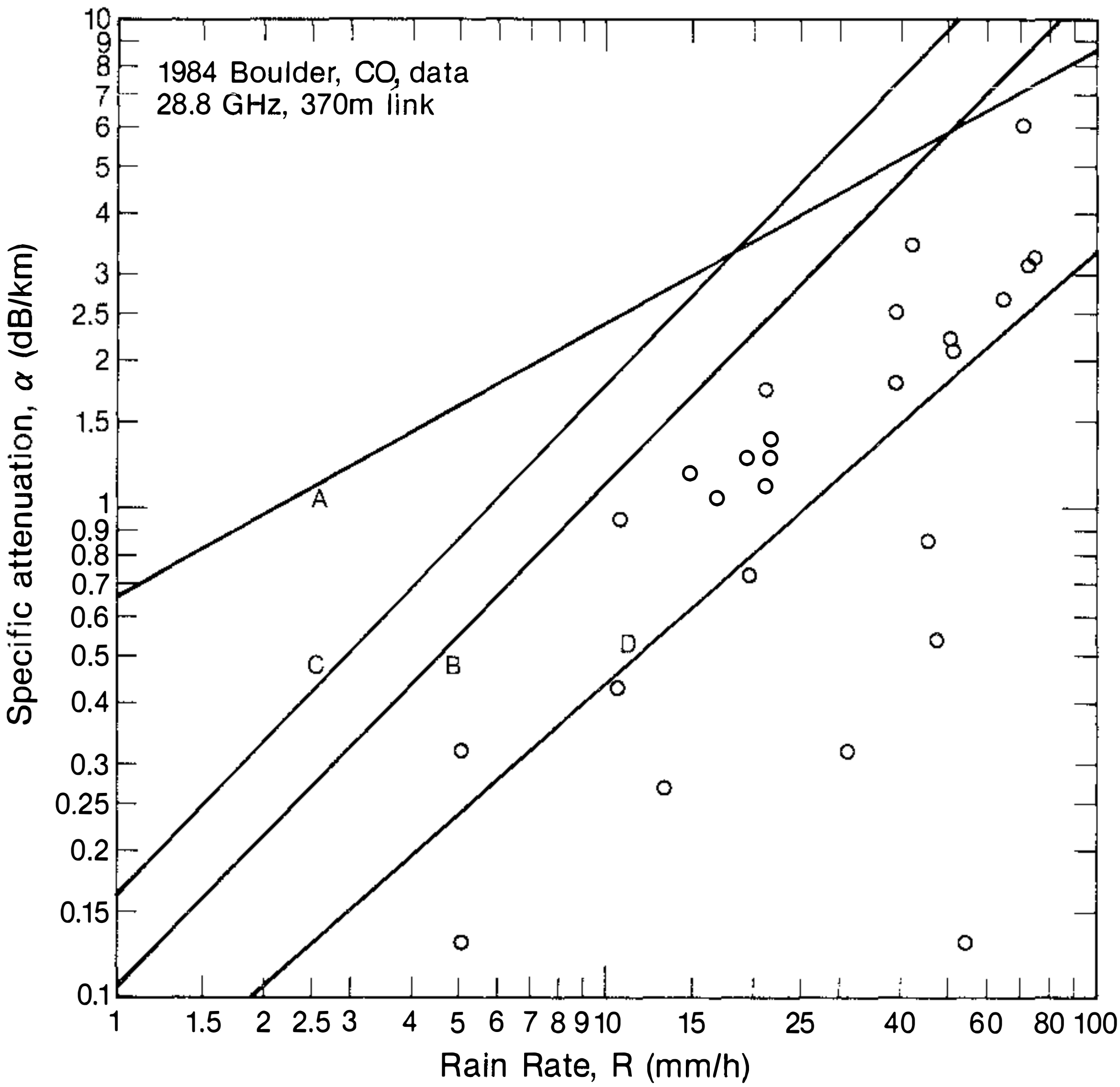


Figure 1-29. Rain attenuation and rain rate data taken during the summer of 1984 at Boulder, CO, at 28.8 GHz. Lines A and B represent specific attenuation predicted from climatically filled expressions for a dry climate. Line C represents results predicted using a Marshall-Palmer drop-size distribution. Line D is a least-squares fit to the data. Data are indicated by small circles.

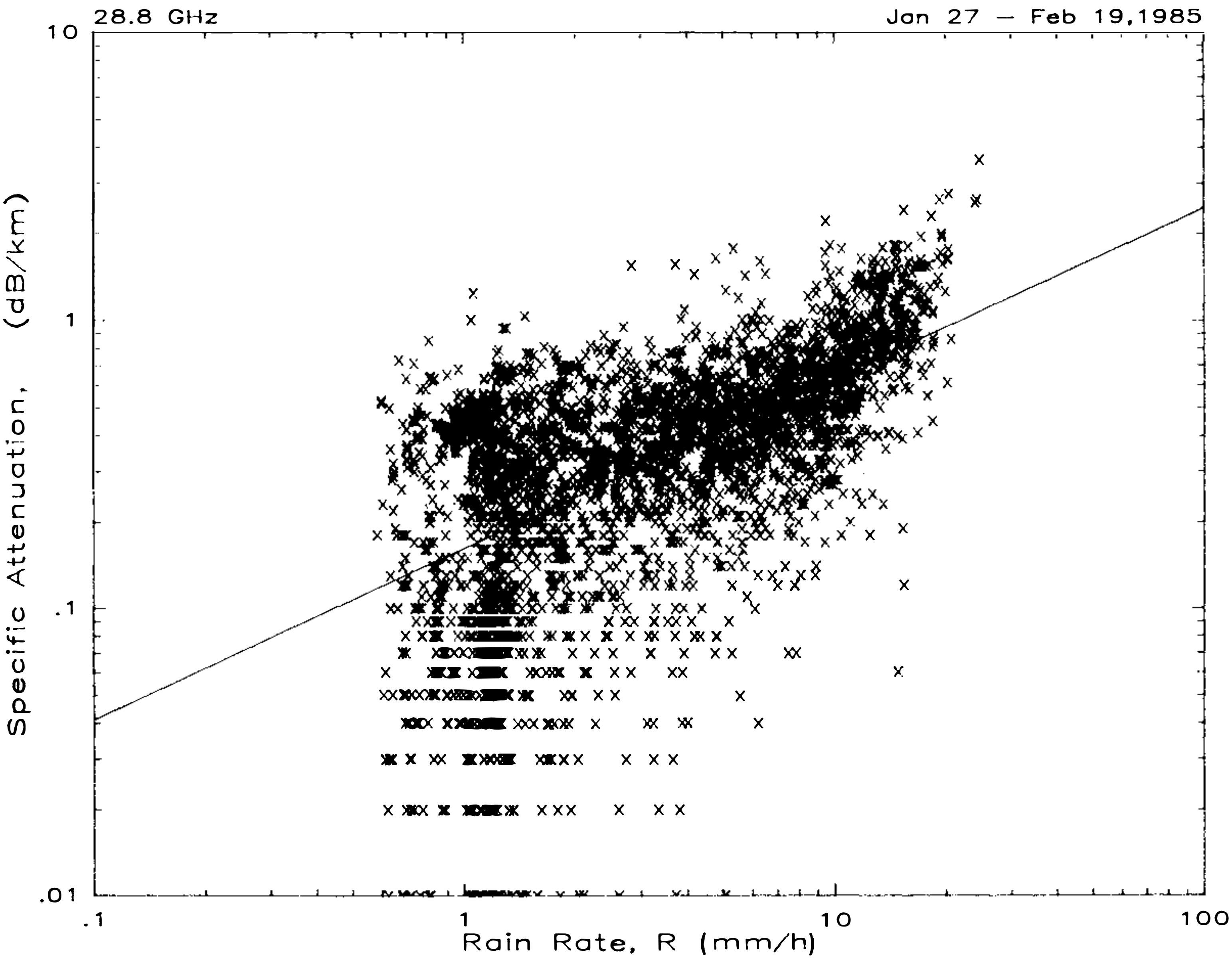


Figure 1-30. Rain attenuation and rain-rate data taken in early 1985 at Gasquet, CA, at 28.8 GHz. The solid straight line is a least-squares fit to the data.

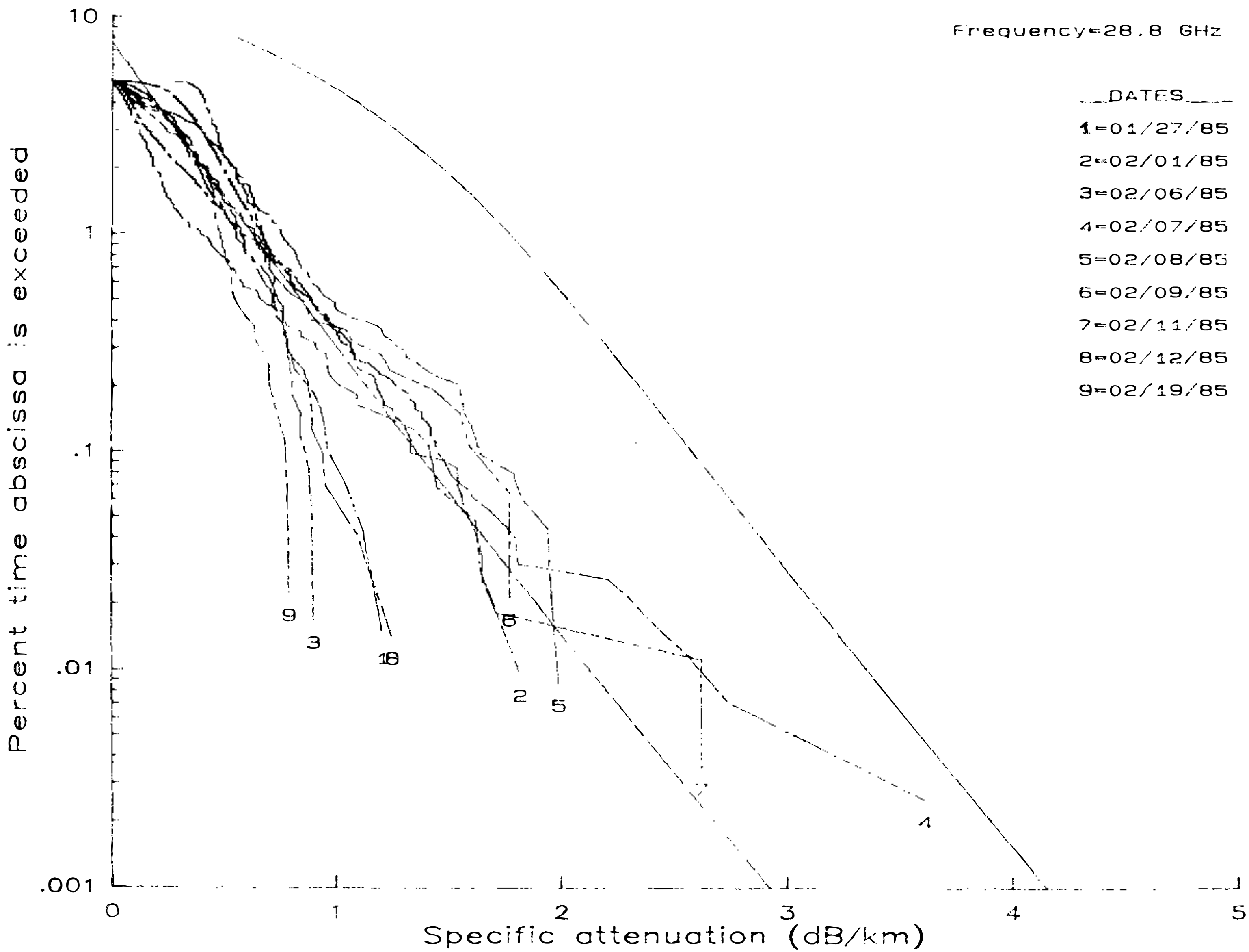


Figure 1-31. Quadratic regression best-fit curve and an empirically derived worst-case distribution (solid curves) derived from the January 27 to February 29, 1985, standard sample of daily specific rain attenuation distributions at 28.8 GHz.

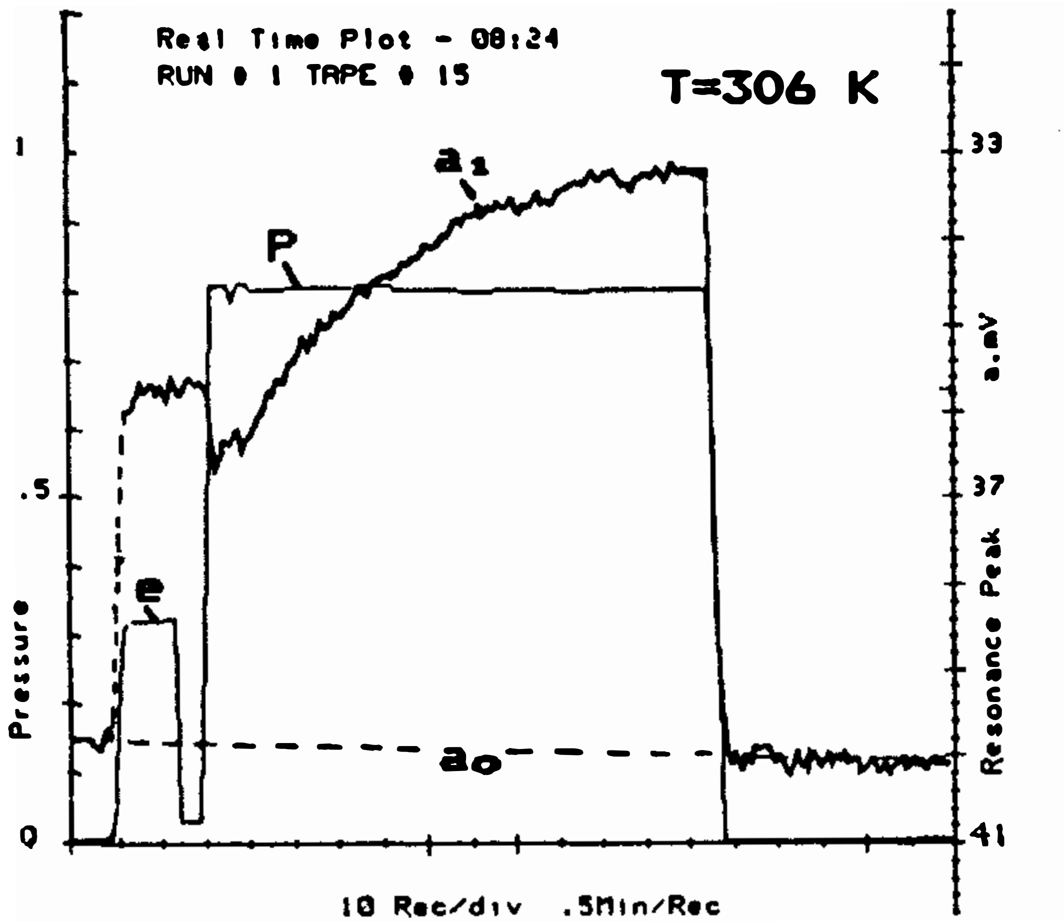


Figure 1-32. A computer display (100 min) of water vapor (e) and moist air (P) absorption signal a, and changer pressure (e, P).

A theoretical model has been suggested based on the assumption of simultaneous contributions from monomer pressure-broadening and absorbing dimers.

It is planned to extend these controlled laboratory measurements to frequencies within the 95 GHz and 220 GHz atmospheric window ranges.

The initial Millimeter Wave Propagation Studies, begun in 1983 and 1984, were continued with measurements in urban and suburban areas. The objective of the program is to be able to predict millimeter-wave channel performance in a city environment with emphasis on communications applications.

Measurements were conducted at frequencies in the micro/millimeter wave bands to obtain data on propagation characteristics in urban and suburban environments. The measurements were made for two distinctly different configurations, namely, (1) nonline-of-sight and (2) line-of-sight (LOS) paths. The non-LOS paths were concerned with absorption by buildings and signal loss for other propagation modes, as for example, diffraction from edges of obstructions using test frequencies of 9.6, 28.8, and 57.6 GHz. Attenuation of rf energy when passing through material used in domestic buildings such as plasterboard and plywood was small. However, when there was a high moisture (water) content within the material, a very high rf absorption was observed. Two paths, obstructed by reinforced concrete buildings without windows, attenuated the direct propagated energy beyond the detection threshold or more than 80 dB at the higher two frequencies. Signal levels above the -132 dBm detection threshold were recorded when the rf energy was transported by apparent double-edge diffraction mode over the tops of these buildings or by diffraction from objects within the common volume of the antenna beams. In general, for all the above measurements, the amount of signal loss increased with an increase in frequency.

Non-LOS paths through an office building constructed primarily of glass produced results that were sharply contrasting. Buildings with large areas of clear or tinted glass produced very small losses, depending on path geometry, and the signal levels were about the same as a clear-air LOS path. However, many of the recently constructed office buildings use a fused metalized coating on windows to reduce heat and light transfer into the building. A building with windows using the metalized coating was measured, and the received signal level was reduced at least 50 dB below an LOS path.

Measurements in a variety (in density of homes) of residential areas were taken for non-LOS path lengths of from 0.1 to 1 km. These measurements were conducted during midsummer, and the dominant absorber for nearly every path recorded was trees. As with the high absorbing commercial buildings in the path, paths obscured by tree-laden residential properties provide the strongest signal levels when a mutual LOS edge or scattering surface was illuminated in a common volume of each antenna (transmitting and receiving). Illuminated trees would predictably produce detectable signal levels that were a function of the propagated signal frequency--that is, the highest path losses at the highest frequency. For longer, non-LOS paths through residential areas, the largest signals for all measured frequencies occurred with one terminal elevated, such as positioned on a hill or overlook. This is not surprising even though the path is not LOS; the density of the obstructions is definitely less.

The second series of measurements involved only LOS paths in an urban environment. All of these measurements were recorded in Denver, CO, on 17th Street. During recording periods, the receiving van was parked at one of two locations, and the transmitting van traveled at as uniform a speed as possible (approximately 8 km/h) toward the receiving terminal. Signal fading as a function of transmitter position was plotted at 11.4, 28.8, and 30.3 GHz, as shown in Figure 1-33. The highest two frequencies were used to compare fading between a very narrow bandwidth channel at 28.8 GHz (3 kHz) and a wide bandwidth channel at 30.3 GHz (750 MHz). As expected, the wide-band channel fades were not as deep as the narrow-band channel. Fades in excess of 30 dB on the narrow-band channel were common and not obviously dependent on antenna polarization, vertical or horizontal linear. There was a significant difference in multipath fading when the data from the two receiving terminal positions were compared. Fading data comparing a receiving antenna beamwidth of approximately 2.5° (run #6) to a wide beamwidth antenna of 30° (run #1) produced the expected increase in number of multipath components in the narrow bandwidth channels of 11.4 and 28.8 GHz. In the wide bandwidth channel, however, received signal fading was less because numerous fades and enhancements occur simultaneously in the 750 MHz channel.

An important and unique millimeter-wave diagnostic tool for study of the performance of a propagation channel is the impulse probe. With the impulse probe, multipath signals can be measured in terms of amplitude and delay time with a 1 ns resolution. Not only does the impulse measurement allow an analysis of the reflection characteristics of objects, which produce multipath signals along a path, but it also allows channel distortion to be predicted, so that usable bandwidth or modulation rate limitations can be determined.

Impulse measurements recorded on the 17th Street path in Denver showed only minor distortion using a 2.3° receiving antenna beamwidth when the path length was less than about 350 m. However, deep fading still occurred for path lengths less than 350 m, but they are the result of strong multipath signal reflection from the street surface. Delay times relative to the direct path for street reflections are considerably less than 1 ns for the antenna heights used. Therefore, very little distortion of the impulse envelope occurred for these path lengths, and likewise very wide channel beamwidths are available before distortion from these multipath signals create a problem. For path

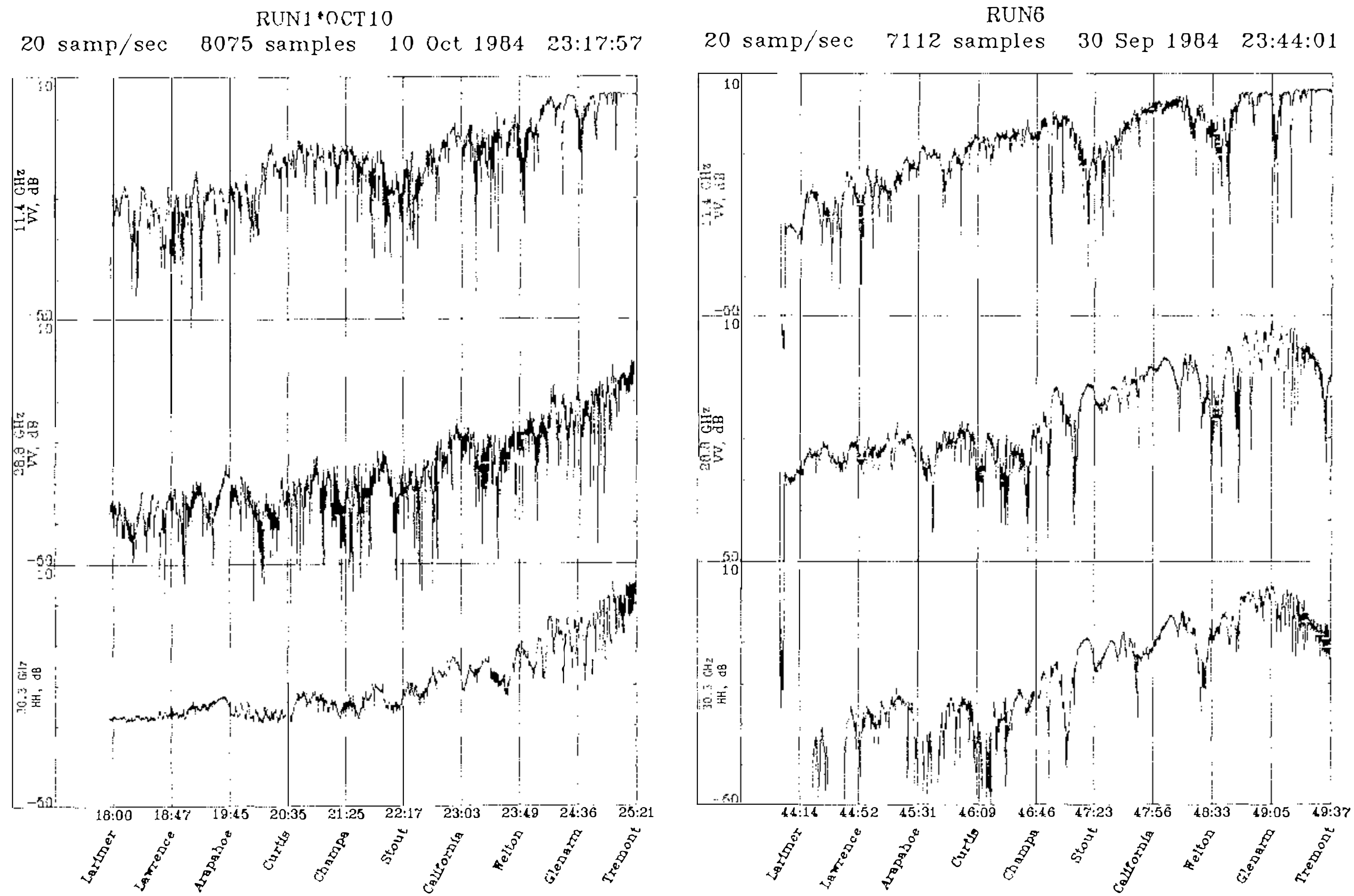


Figure 1-33. Received signal levels from run #1 (wide-beam antenna) and run #6 (narrow-beam antenna) along 17th Street (Larimer to Tremont) in Denver, CO.

lengths between 350 and 900 m, multipath signals nearly equal in amplitude to the direct signal were observed at delay times up to about 5 ns. As mentioned above, two receiving terminal locations were selected at random, and the number and strength of multipath signals were very different, indicating that a study of position dependence is required.

A 30° beamwidth antenna was installed on the receiving terminal (the same as on the transmitting terminals), which approximates the channel performance of a link with omnidirectional antennas. The main difference between omnidirectional antennas and a broadbeam directional antenna is the possibility, when using the omnidirectional antenna, of a much longer delayed multipath reflection from a surface behind either terminal. Data for the wide-beam antenna showed that strong, long-delay, multipath components were very numerous at path lengths of 100 to 400 m. Multipath signals within about 3 dB of the direct path with delay times of up to 10 ns were recorded.

Figures 1-34a, 1-34b, and 1-34c are samples of three different propagation conditions for which impulse measurements were recorded. The sequence in Figure 1-34a was taken over a 120-m test path, which is free of vertical reflecting surfaces with impulse measurements at 2-s intervals. This sequence demonstrates the stability of the high data rate hardware (500 Mb/s) and the cross-correlation technique used to generate the impulse responses. Also shown is a slight multipath reflection occurring at the trailing edge of the impulse curve at about a -25 dB level, which is the sidelobe suppression level, indicating a reflection from the ground between terminals. The impulse curves in Figure 1-34b were taken at roughly 10-s intervals with the transmitter terminal traveling at about 8 km/h on a Denver street at a distance of about 600 m from the receiving terminal. The receiver for these impulse measurements used a 2.3° antenna beamwidth. Very strong multipath levels within 5 dB of the direct signal (the first impulse peak) were seen out to delay times of about 5 ns. Each nanosecond of delay time represents approximately 30 cm of added path length. Figure 1-34c displays the same conditions as in Figure 1-34b except the receiving antenna beamwidth is 30°. With the 30° beamwidth, strong multipath levels are seen out to 10 ns or more.

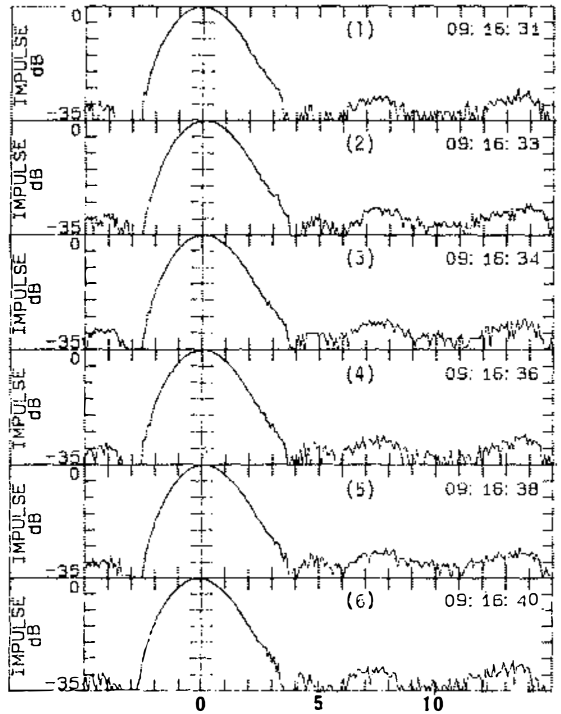
For a complete run down the street with the transmitter starting 1 km away from the receiving terminal, about 60 impulse measurements were recorded. Also on alternate runs, bit error rates were recorded on the 500 Mb/s channel so that a correlation between signal-to-noise ratios during fades and intersymbol interference resulting from multipath distortion could be performed.

The Institute has also developed extensive propagation models for determining the ability to monitor communication systems from selected receiver sites. This work has been based on knowledge of the system parameters (transmitter locations, power levels, antenna characteristics, antenna orientation, detailed terrain conditions, receiver antenna, and receiver performance). To determine the resultant communication reception coverage from a network of transmitters currently requires the use of a mainframe computer and extensive computational time and personnel. This includes providing reception characteristics for nonengineered (nonoptimized) marginal communication links. This also requires extensive analysis of "off axis" (not in the main antenna beam) communication conditions. This approach provides a link-by-link analysis of the communication system or network receivability at specified receiver sites. When the problem becomes one of determining the extent of coverage for land mobile or maritime receiver operations, the problem becomes intractable, given the link-by-link analysis previously utilized. This has necessitated the formulation of a simpler yet still meaningful area coverage approach to determine the ability of a mobile receiver to monitor. The first phase of the propagation analysis was to formulate a Wide Area Propagation Model. This new model changed from the previous approach of analysis of individual links to a coverage procedure represented by generic individual links to reduce data complexity, computation, and personnel requirements.

This model development is specifically tailored to determine receiver coverage of microwave frequencies. This model includes only the most significant propagation effects so as to permit relatively facile assessment of relatively large areas that would be associated with land-mobile or near coastal maritime receiver operations. The Area Coverage Model models the LOS conditions: multipath, surface refractivity, and antenna orientation. A statistical approach has been used to incorporate multipath, surface refractivity, and antenna orientation. This model provides a relatively fast methodology for assessing communication coverage over large areas. Computational requirements have been greatly reduced by this approach.

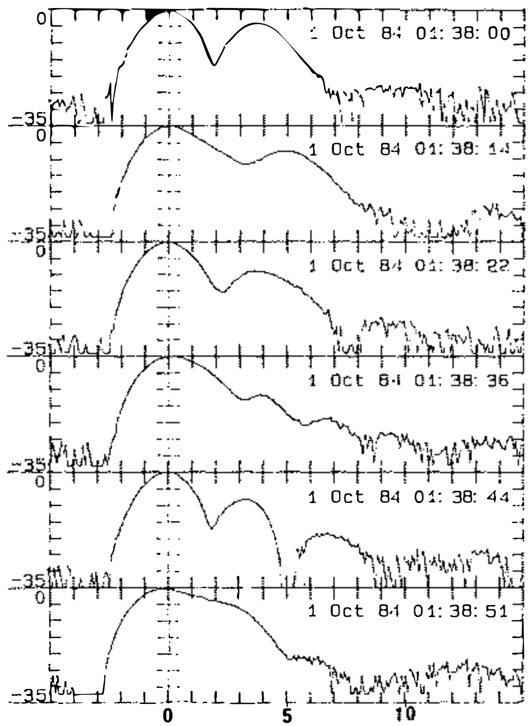
Phase II of this project consisted of adding atmospheric ducting and layering effects to the Wide Area Model. These effects can have a very significant impact on microwave radio communication distances. Geographical location (latitude), land-sea interfaces, temperature, and seasonal and diurnal effects can significantly alter the modeled propagation parameters. A review of the causes of duct formation has been conducted along with assessment of the variables that describe ducting. The objective has been to provide a probabilistic model for the purpose of determining the potential increase in communication distances over that predicted by the Wide Area Model. This ducting model serves as an additional analysis capability that has been added to the Wide Area Model.

The Ducting Model portion incorporates two data distributions to utilize data from both the East and West Coast areas of the United States. Further investigations are needed to characterize other regions of the country to refine propagation prediction processes. Special emphasis has been placed on providing analysis of coastal maritime reception.



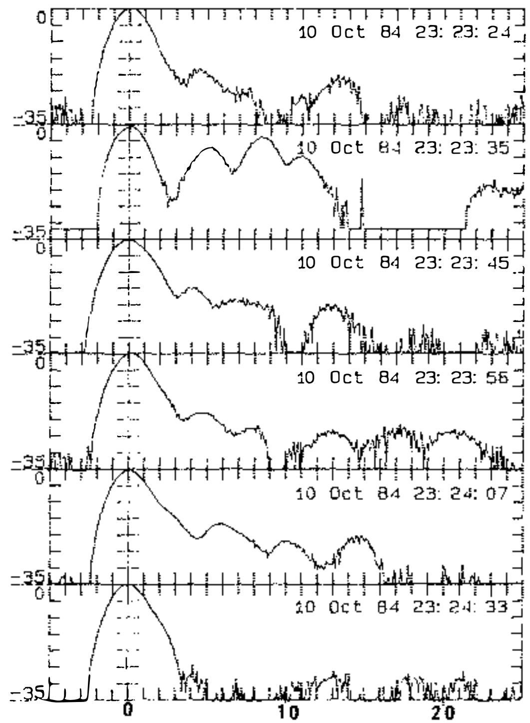
A

Impulse sequence taken on a 120-m test path.



B

Impulse sequence taken with one terminal in motion on an approximately 600-m urban street path using a 2.3-deg receiving antenna.



C

Impulse sequence as in Figure 2B, except receiving antenna has 30-deg beamwidth.

Figure 1-34. Examples of impulse response data for three different propagation conditions.

Statistical analysis is necessary to determine the frequency of occurrence of these ducts and the resulting extension of communication boundaries. A duct tends to restrict propagation to the horizontal direction and hence provides a signal strength that is approximately inversely proportional to distance. This is contrasted to the usual inverse square relationship that normally occurs when ducts are not present. This effect, together with an extension effect of normal radio horizons, can significantly increase the resultant signal reception distance when ducts are present. The duct effectiveness depends on the angles of arrival (critical elevation angles) and minimum critical frequencies (frequencies that cannot be effectively coupled into the duct). These parmeters are a function of the duct's location, thickness, and altitude.

Results of this ducting model are being used to assess added communication coverage that results from ducting. Significant coverage increases above the nonducting coverage have been predicted, especially in coastal regions. In both ducting and nonducting situations, this composite model has provided an effective analysis tool without the necessity of utilizing a mainframe computer.

The Institute has also provided a propagation analysis service for the Federal Aviation Administration (FAA). 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 provide much of this information. In recent years, most of the project effort has been devoted to developing and running computer programs that contain the IF-77 (ITS-FAA-1977) propagation model to assist in the updating of various FAA Handbooks.

The IF-77 propagation model has a 0.1 to 20 GHz frequency range and is applicable to air/ground, air/air, ground/satellite, and air/satellite paths. It can also be used for ground/ground paths that are either line-of-sight or smooth earth. A coherent mathematical description of IF-77 has been published, i.e., "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, NTIS Order No. ADA 134504.

This model has been incorporated into 10 computer programs that are useful in estimating the service coverage of radio systems. These programs may be used to obtain a wide variety of computer generated microfilm plots such as transmission loss versus path distance or the desired-to-undesired signal ratio at a receiving location versus the distance separating (station separation) the desired and undesired transmitting facilities. A report covering the 28 plotting capabilities available has been published: i.e., "Applications Guide for Propagation and Interference Analysis Computer Programs (0.1 to 20 GHz)," by M. E. Johnson and G. D. Gierhart, FAA Report No. FAA-RD-77-60, March 1978, NTIS Order No. ADA 053242.

Three tasks are currently under way:

1. Production of computer-generated propagation and interference predictions as requested by the FAA.

2. Conversion of the programs from CDC Fortran 4 to CDC Fortran 5.

3. Development of an interactive menu-driven program capable of guiding an inexperienced user through the process of specifying a desired set of predictions and submitting the required program with appropriate input data for batch processing.

The VHF/UHF Propagation Studies project has been validating the Irregular Terrain Model (ITM) and making improvements in the model in order to include urban and forested situations. In the original development of the model, data were used from measurements where the receiver antenna was fixed in location and the transmitter was set up at "random" locations and not moved during the measurements. The resulting measurements were spot measurements. In the present measurements, the transmitter antenna is fixed, and the receiver is on a mobile van. Thus, the receiver system makes continuous measurements of the received signal level as the van moves along a planned measurement path, and the data are recorded on digital tape. The measurement system is able, in the UHF band, to make measurements at intervals of 0.001 to 1 wavelength; for the current set of measurements, data were taken every wavelength. After all the data have been collected for the planned path, they are processed to remove the short-term influences (multipath effects). The effects are removed by grouping the data into blocks defined to be all the data collected in intervals of 100 wavelengths, for example. Within each interval, the signal level distribution is found, and the distribution's median and upper and lower deciles are determined. We can change the block interval size to determine what size best fits the data to remove the short-term variability.

During the past year, measurements have been made over gently rolling terrain at 880 MHz from a transmitter antenna at a height of 150 ft above ground to a receiver antenna on a van at a height of 11.6 ft above ground. Figure 1-35 shows the raw measured signal levels over one path that were made by sampling the received signal every wavelength while the vehicle traveled at a speed of 40 mph. Figures 1-36 and 1-37 show the median, the lower, and the upper decile values of the measured data in 30 ft (27 wavelengths) and 60 ft (54 wavelengths) intervals, respectively. To compare the measured data with predictions made by the ITM, the path profile is first calculated from the digitized terrain data base and then the ITM is used to estimate the signal level at each interval along the path. Figure 1-38 shows the predicted signal levels along the path. Figure 1-39 shows the predicted signal coverage for an area surrounding the transmitter at two different field strengths.

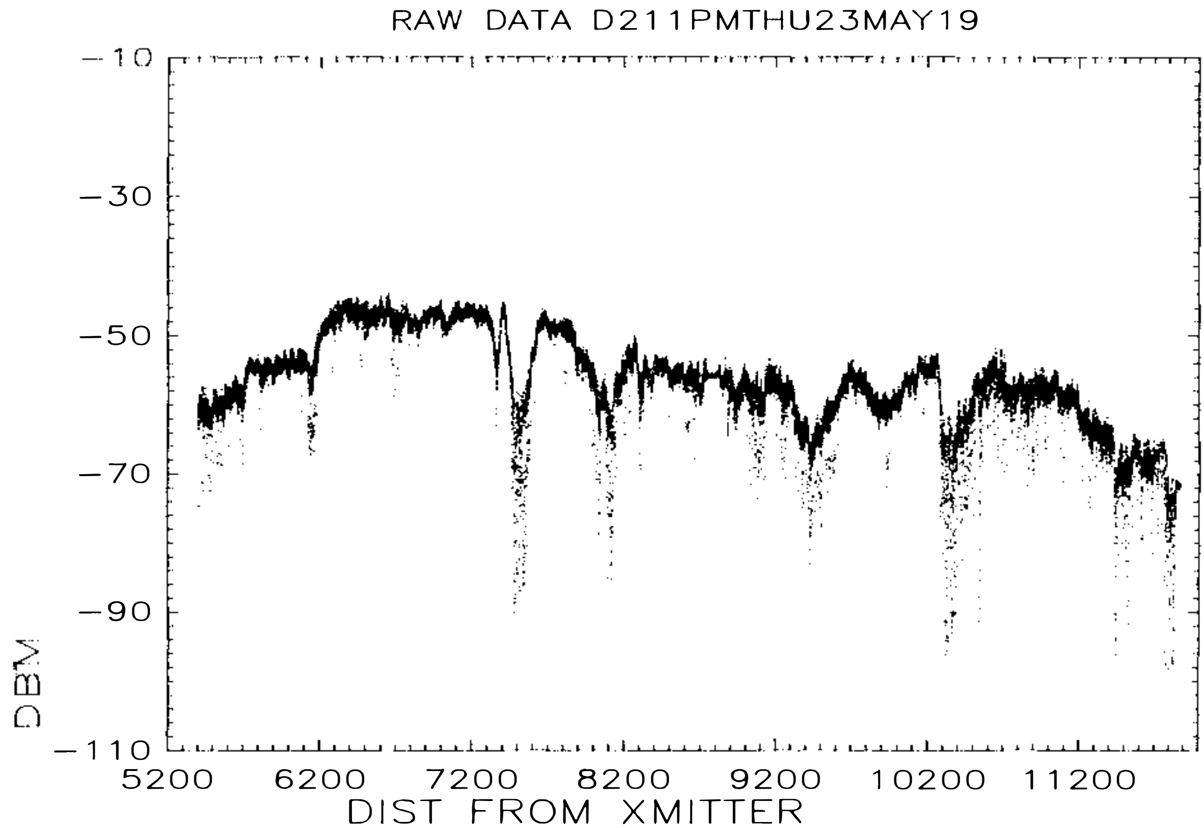


Figure 1-35. Raw received signal levels measured at 880 MHz by mobile receiver traveling at 40 mi/h.

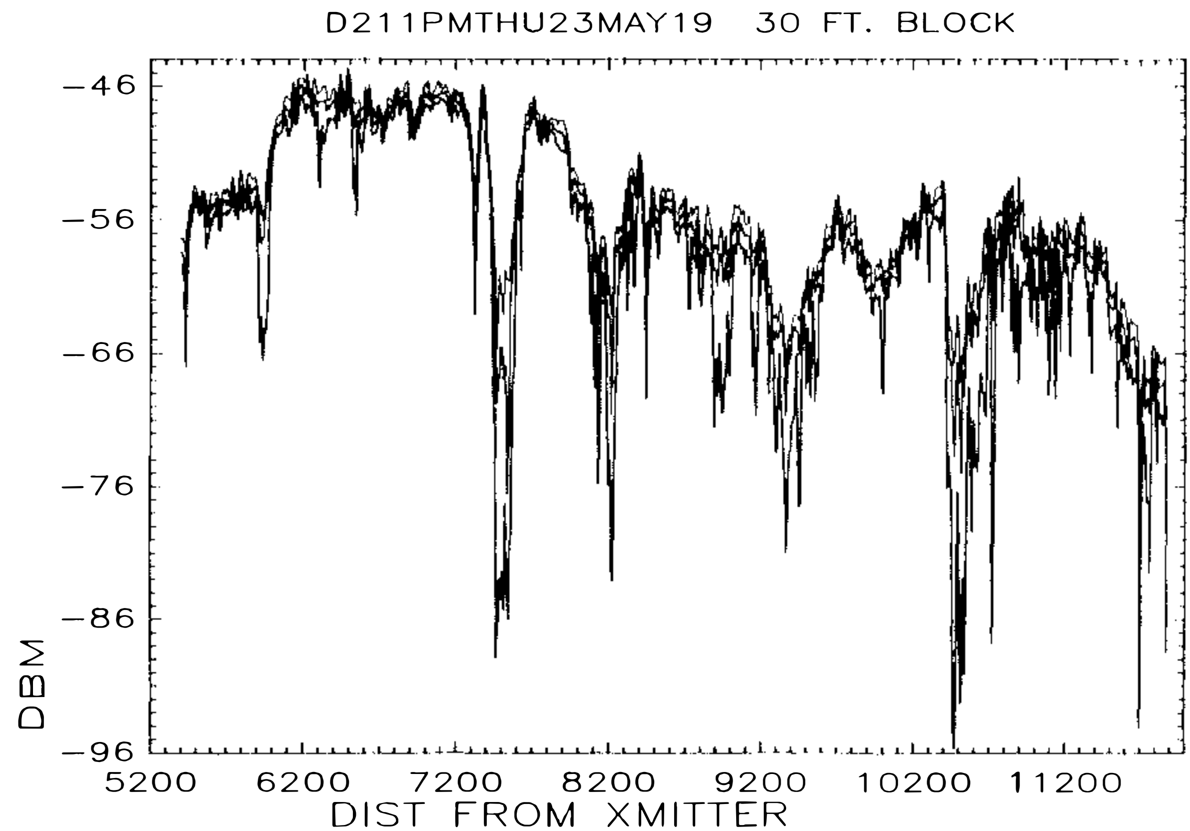


Figure 1-36. Upper, median, and lower decile of measured mobile received signal levels within 30-ft intervals at a frequency of 880 MHz.

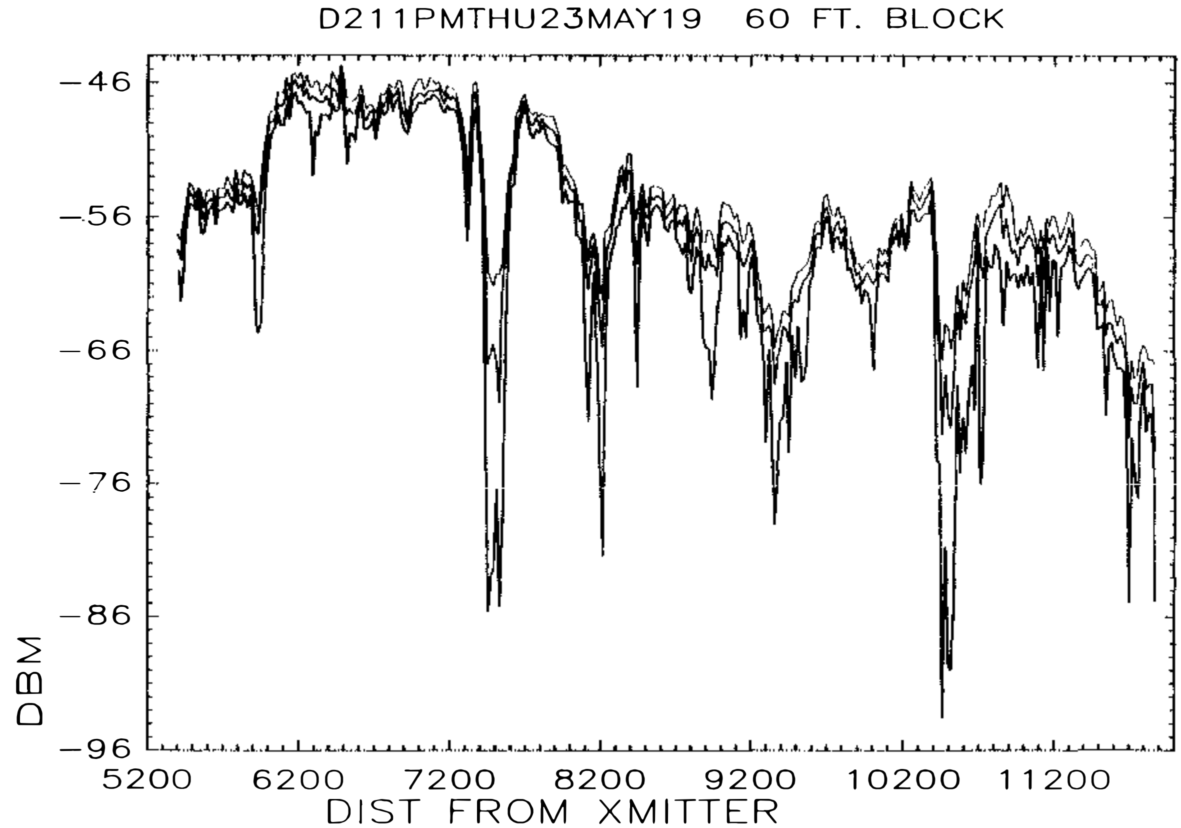


Figure 1-37. Upper, median, and lower decile of measured mobile received signal levels within 60-ft intervals at a frequency of 880 MHz.

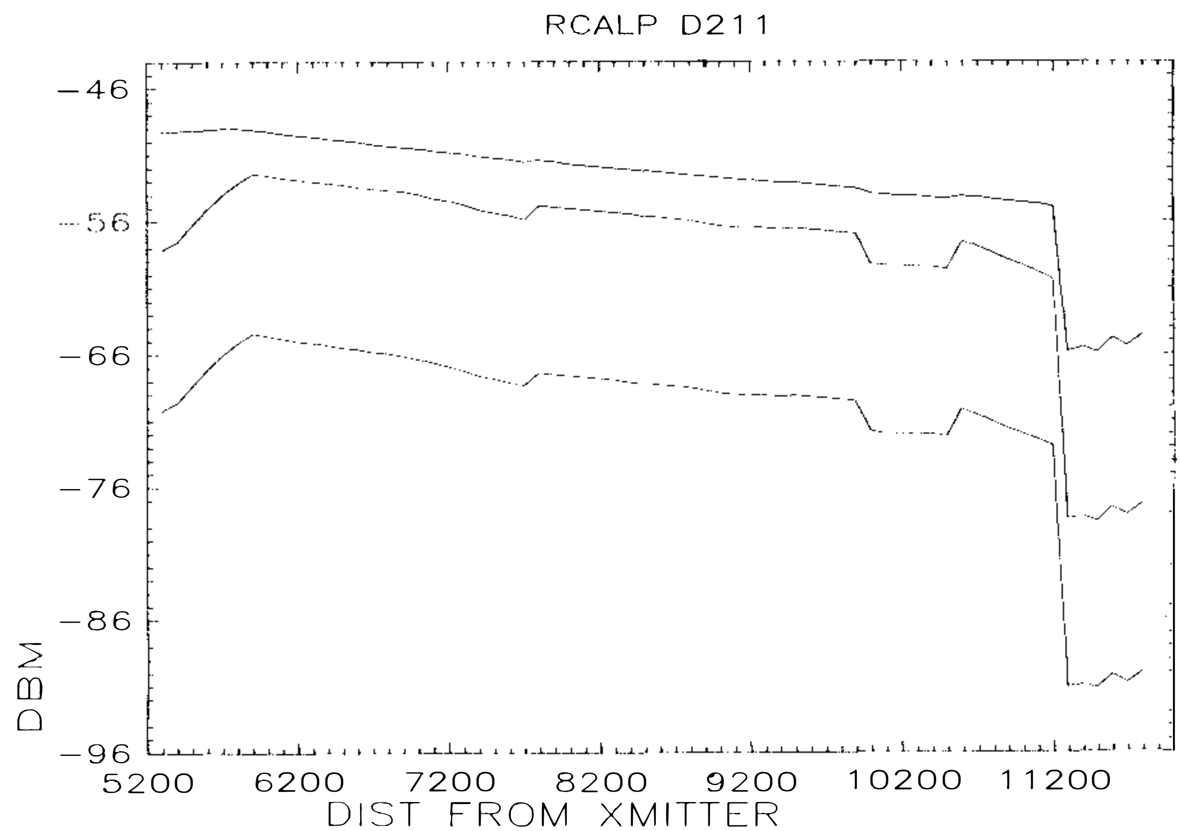


Figure 1-38. Predicted upper, median, and lower decile received signal levels using the ITS Irregular Terrain Model for the path of Figures 1-36 and 1-37.

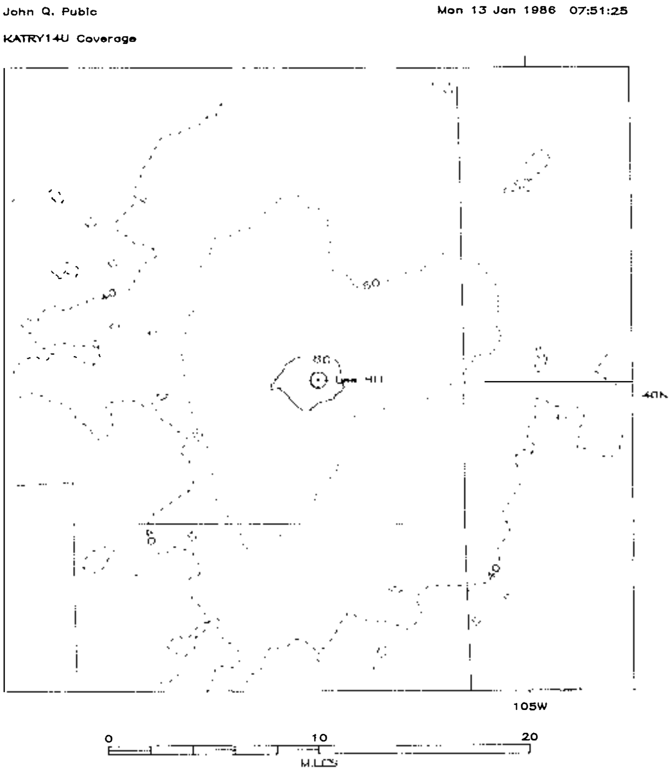


Figure 1-39. Predicted field strength (34 dBu) contours for transmitter at location labeled Boulder Cell Site.

The U.S. Army is conducting an experimental program to develop the basic data needed for the evaluation of modern wide bandwidth VHF-UHF communication systems. The current wide-band systems have been developed using existing propagation models that consider only narrow-band signals. With this experimental program, data will be collected to either validate the existing models or it will be used to develop the models valid at the band-widths of the proposed systems. Under the Wideband Consultation project, the Institute is assisting the Army in developing experimental test plans for the collection of data and in providing recommendations and other consulting as necessary in the development of the actual measurement and data collection system. It is expected that data will be needed over a wide variety of situations that will include both line-of-sight paths and beyond line-of-sight paths in most environments that are expected to affect the propagation of radio signals. The initial experiments will be designed to test the measurement system before extending the data into more complex environments.

1.4.2 Radio Propagation in the Ionosphere

The Institute has a long history of ionospheric research and propagation prediction development. The activities currently being addressed by the Institute that relate to ionospheric propagation are discussed below.

A continuous effort is undertaken at the Institute to improve the HF propagation prediction programs that have been developed over the years. Depending upon the needs of the users, these improvements are directed to either specific components of the programs or to the entire programs. In the past year, the Institute continued its study of improvements to the global maps of the F2 region ciritical frequency, foF2. These maps are crucial in determining realistic HF propagation predictions for monthly median conditions. The current set of CCIR numerical coefficients that represent the global maps of foF2 was developed by ITS over 20 years ago. Within the past 2 years, ITS has developed a new set of numerical coefficients that combine observed values of foF2 with values deduced from theoretical calculations. Studies have been undertaken to determine the relative accuracy of the new set of coefficients and the current CCIR coefficients. These studies are continuing, but the results obtained to date indicate that in ocean areas the new coefficients give better results than the CCIR coefficients. In land areas, the CCIR coefficients give better results for some times. This is due to the fact that the new coefficients and the CCIR coefficients have the same number of terms. The data used to generate the new coefficients have more structure as a function of latitude and longitude than the data used to generate the CCIR coefficients. The numerical fit to the data (using the same number of terms for the coefficients) results in a better fit to the data for the CCIR coefficients than for the new coefficients. An investigation is under way to determine yet another set of coefficients that contain higher terms so that the overall fit will be improved.

A complementary study was undertaken that was directed at investigating if a particular solar or ionospheric index is significantly better than any other index for predicting foF2. The indexes studied were the 12-month running mean sunspot number (R_{12}) and the ionospheric index IG_{12} sometimes referred to as the global effective sunspot number. The new coefficients and the CCIR coefficients for foF2 were used with the two indexes. The results obtained indicated that there was no significant difference between the predicted values of foF2 using either the index R_{12} or IG_{12} when compared to actual observations.

The Institute has provided continued support to NSA in using ionospheric circuit prediction methods, and in the evaluation of propagation paths that may include both sky-wave and ground-wave propagation. During this past year, ITS has implemented specific analysis capabilities that allow analysis of many types of HF circuit configurations as a function of both time of day and the radio frequencies used. In addition, a ground-wave model was implemented on a microcomputer for quick access to predictions of these types of circuits.

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 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, Propagation Engineering Division.

One task of this project was to develop analytic techniques to validate and locate differences in various implementations of propagation prediction programs. Another task included modification of the IONCAP interactive input processor for specific U.S. Army requirements. A third task was development and implementation of specific output modules to be utilized with the IONCAP program to provide standard AUTODIN transmission of various propagation predictions including all of the standard IONCAP output.

The Voice of America (VOA) has the task of designing several new transmitter sites for its HF broadcast radio coverage of the world. In order to design the transmitters, they must first know what the predicted losses are between the proposed sites and the desired coverage areas. The losses can be estimated by running the ITS IONCAP program. Because of the seasonal and diurnal variability of HF broadcasts, the losses change as functions of month, hour, sunspot number, and transmitter and receiver locations. For 1 transmitter site, 60 receiver sites, 2 sunspot numbers (1 high, 1 low), 4 months, and 24-hour intervals, there are 11,520 predictions of required power and take-off angle at each of 10 possible frequencies. After making the predictions, the designer is left with the problem of choosing the best frequency with the lowest required power for the times the VOA wishes to broadcast to particular sites.

The IONCAP Summary Program project was developed to summarize the predictions for the VOA designers. The output of the program is a series of tables and plots that provide the best frequencies with the lowest required gain. In addition, the program can apply algorithms for selecting the best frequency, for culling receiver sites that should be given less importance because of smaller populations using a particular language, and for limiting the transmitter take-off angle or limiting the transmitter antenna gain. Figure 1-40 is an example output showing the required transmitter antenna gain from a possible location in Tangier to 13 selected sites in Poland. By choosing various options for analysis, the VOA designers can determine the best antenna pattern needed to cover the desired areas with broadcasts in desired languages.

The U.S. Coast Guard is considering the feasibility of using a network of HF shore stations to provide emergency communications for maritime vessels. The basic concept is that if a vessel could transmit its location, emergency conditions, etc., to a large number of monitoring shore stations, then with a high probability of success, at least one of the monitoring stations would receive the message. The Institute under the Coast Guard Consulting project developed the methodology for computing the communication probability between a simulated distressed ship and the worldwide shore stations.

An NTIA Report entitled "Communication Probability for the U.S. Coast Guard Digital Selective Calling System in the North Atlantic," by Adams and Cavcey, presents the methodology and the results of the preliminary study. The ionospheric propagation model IONCAP was used to compute a data base of individual ship-to-shore circuit reliabilities. Figure 1-41 shows the 26 receiver sites located around the world that are attempting to receive communications from the 62 ship locations (cells) of the North Atlantic, shown in Figure 1-42. For the study, four HF frequencies, four local times, three seasons, and two sunspot numbers were used. An example output plot is shown in Figure 1-43. For this and the other plots in the report, the communication probability (C_p) of all the 26 shore stations able to communicate with each ship (cell) was computed and plotted, where:

$$C_p = 1 - \prod_{n=1}^{26} (1-R_n) ,$$

and R_n is the probability of communication to the n^{th} shore station.

The dashed line in the cell indicates the reliability was 100 percent. In the North Atlantic area, the probability of successful communication is given in Table 1-1.

Table 1-1. Tabulation of C_m Averaged Over All 56 SSP for the Indicated Times Assuming All Four Frequencies Are Active

	Local Time	January	April	July
	0600	100	100	99
	1200	100	100	100
SSN=20	1800	100	100	99
	2400	100	100	100
	0600	100	100	99
	1200	95	93	92
SSN-120	1800	99	99	99
	2400	98	97	96

In the area of applied HF studies, the ITS was a leading participant in a major field experiment termed BATTLETOAD. This project, the name of which stands for Beacon Assisted Technique To Locate Emitters using Time Of Arrival Differences, was directed at determining the usefulness of known beacon locations to aid in determining the position of noncooperative emitters. An experiment involving 5 receiving locations, 10

Benchmark run 10:31 AM FRI., 8 NOV., 1985 T:TNGR L:BHMK R:0 Cut:5 Case:2 Main Region

Highest/90% Required Power Gains for Best Frequency for All Time Blocks

Angle	3.97	4.90	6.07	7.20	9.70	11.85	13.70	15.35	17.72	21.65	25.88	Angle	Maximum
						Frequency							
40												40	
39												39	
38												38	
37												37	
36												36	
35												35	
34												34	
33												33	
32												32	
31												31	
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20												20	
19												19	
18												18	
17				20	15		16					17	20
16			15	20	20	20	20	14				16	20
15		13	19	20	20	20	20	20				15	20
14		14	20	20	20	20	19	20				14	20
13		16	20	20	20		12	20				13	20
12		18	20	20	20	20						12	20
11		16	20	10	20	20	17		14			11	20
10				5		15	19		15			10	19
9				5		16	17		14	11		9	17
8				14	12	12	17		15	12		8	17
7		11		15	13	17	18		17	12		7	18
6		12	14	16	20	18	17	11	16	20		6	20
5		12	14	18	15	20	16	12	19	18		5	20
4		10	15	20	18	20	17	17	19	20		4	20
3		11	17	20	20	20	20	17	20	20		3	20
2					15	20	20		20	20		2	20
1												1	
0												0	
	0	4075	2445	7335	12225	6520	8150	1630	1630	1630	0		

Number of Times per Frequency

Total Number of Samples: 45640

SSN	Mean	SD	Upper Decile
10	15.0	5.24	21.7
120	12.0	4.77	18.1
Both	13.5	5.23	20.2

Figure 1-40. An example table shows the required transmitter power gain (dBi) versus transmit take-off angle and frequency for HF transmissions from Tangier to receiver sites in Poland for all broadcast hours (05, 06, 16, 17, 18, 19, and 20 X100GMT), four seasons, and two sunspot numbers.

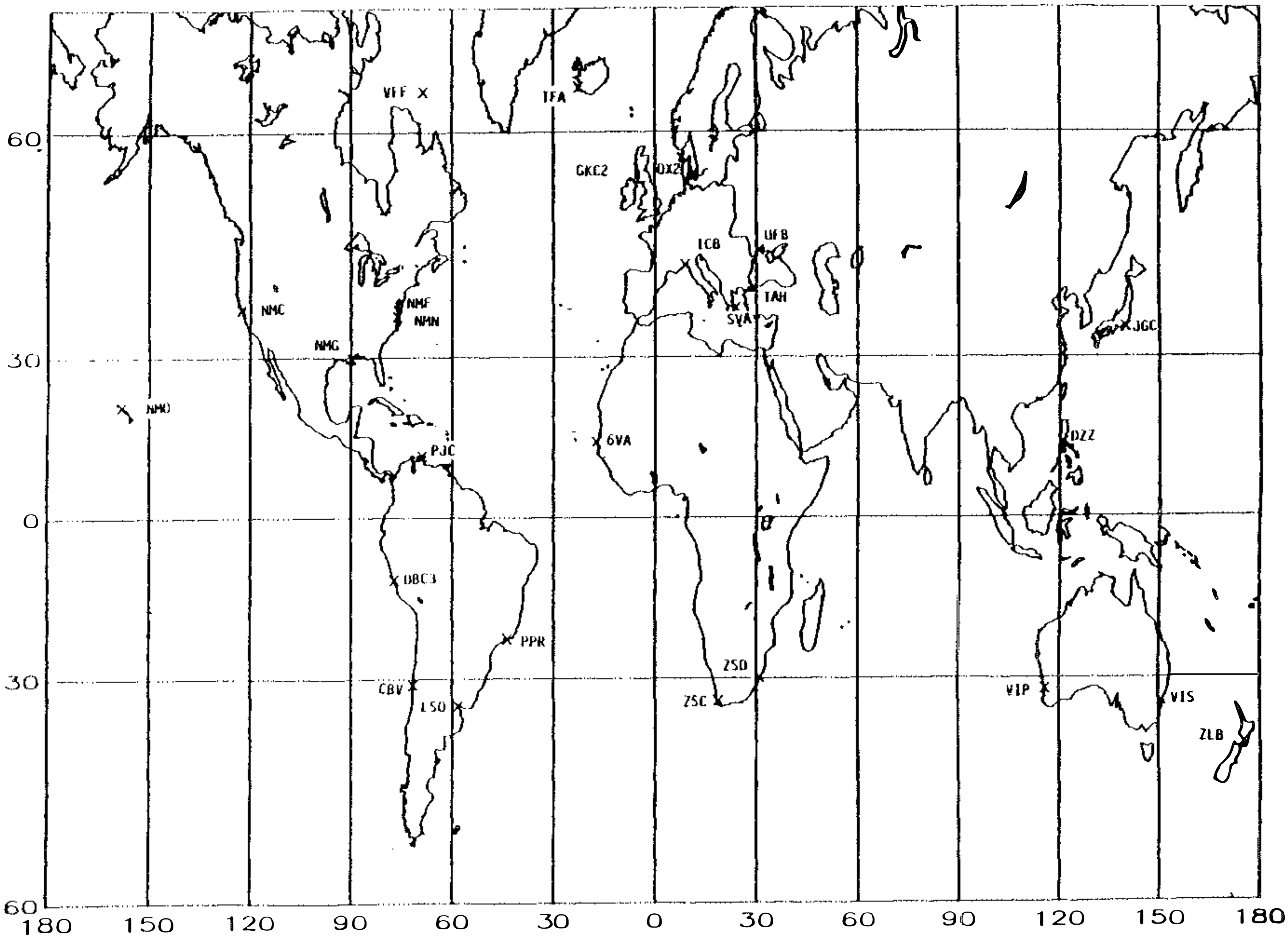


Figure 1-41. Map shows the locations and call signs of Coast Guard HF monitoring stations.

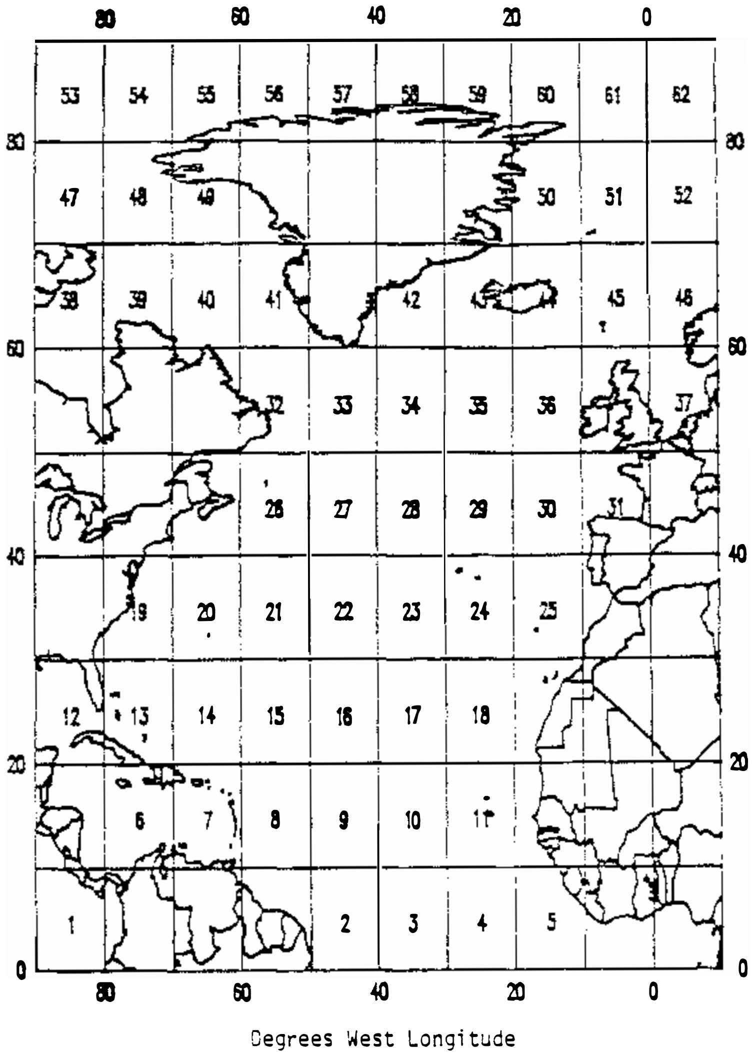


Figure 1-42. Map shows the cells used to simulate ship positions in the North Atlantic.

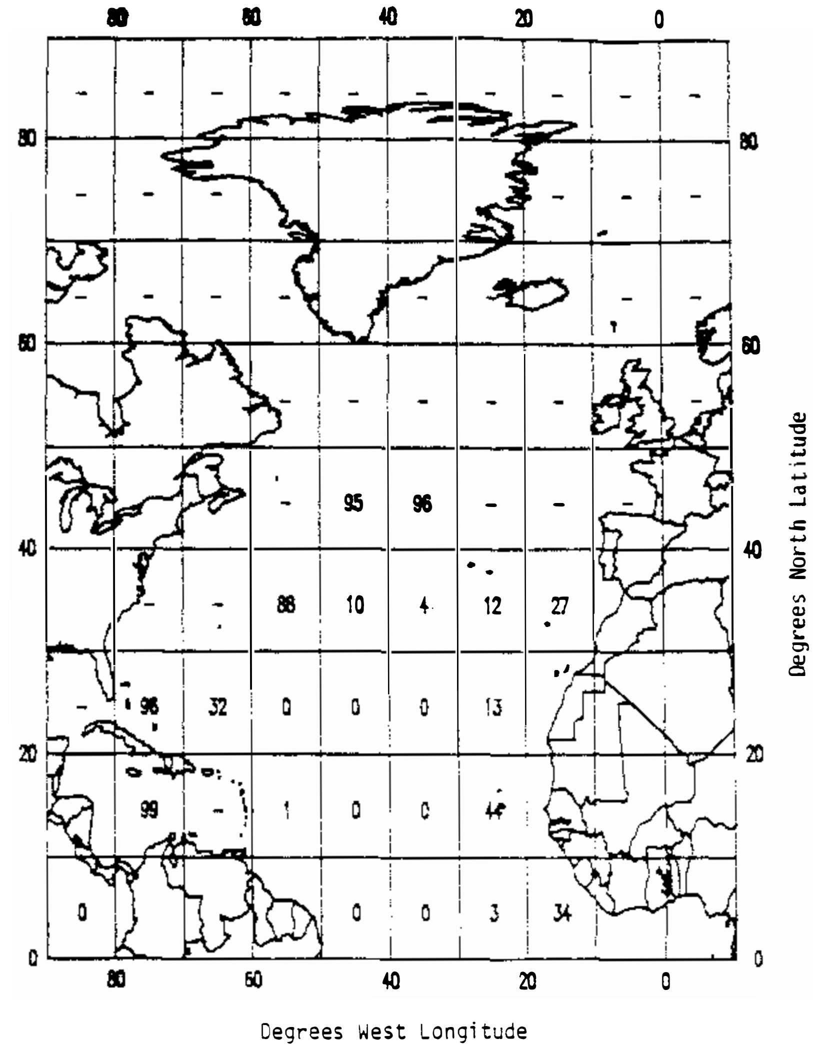


Figure 1-43. Map shows the communication probability in each 10° x 10° cell for January, 1200 h, 6 MHz, and sunspot number 20.

transmitting locations, and 3 vertical-incidence ionosondes was conducted in October 1984. The experiment was centered in Kansas, Colorado, Wyoming, Utah, New Mexico, Arizona, and Nevada. The exact locations of the transmitters and receivers are given in Figure 1-44, which is reproduced from last year's Annual Report. The radio paths for which data were collected extended from 10 km to nearly 1600 km.

The experimental operation involved the transmission and simultaneous reception of two signals at each of the receiving sites. A transmission from one of the transmitter sites was emitted continuously for a period of nearly 1 hour and was measured at each receiver site. Transmissions from the other transmitter sites were monitored at the reception sites in 5-minute intervals. The frequencies that were transmitted were chosen to assure continuity of measurement as well as providing a representative sampling of frequency differences between the two simultaneously received signals. Because one of the major objectives of the experiment was to determine the usefulness of beacons in minimizing geolocation errors, the experiment was conducted in such a manner to assure a wide range of observations that could be used to determine how close in frequency, time, and space the beacon signals have to be to the signal of the unknown emitter to aid in minimizing location errors.

Currently the data that were collected during the experiment are undergoing extensive analysis by the Department of Defense and their contractors. Of the planned 110 hours of operation, data were collected for 104 hours. The high rate of data collection was due to the operational procedures implemented during the experiment and the use of real-time ionosonde information to provide the basis for frequency management. The frequency management scheme adopted during the experiment was to adjust long-term predictions of the performance of each circuit according to the ionosonde information that was provided continuously during the experiment. The observations made at the ionosondes were transmitted over phone lines to the experiment net control (located at ITS) where they were used to update the circuit performance predictions calculated according to the IONCAP HF propagation program. A simple percentage change to the long-term prediction of the optimum frequency band was applied to determine the updated optimum band. This updated prediction was then given to the transmitter and receiver locations (also in constant telephone contact with net control) and was used as a specific signal.

Figure 1-45 shows the results of the frequency management scheme in terms of the observed performance during the experiment. The parameter plotted is percentage of time (called hearability) that the signal on any frequency that was transmitted could be heard by a receiver. The hearability is plotted as a function of distance between the individual transmitters and receiver locations. It can be seen that the hearability decreases as the distance between transmitter and receiver increases, as is not unexpected. What is somewhat surprising, however, is the relatively large values of the hearability out to distances of 1000 km. This will be studied further.

Another area of applied HF studies being undertaken by the Institute is the work directed at developing an HF broadcasting service planning model with direct support from NTIA. The First Session of the HF Broadcasting Conference decided upon the criteria that are to be used to test HF broadcasting planning principles. The testing is to be done in the period between the First and Second Session of the Conference. The International Frequency Registration Board (IFRB) has been tasked to implement the planning principles and to test the planning procedures. The Institute is also undertaking the task of implementing and testing the HF broadcasting service planning principles. This is being done to assist in the development of United States positions in preparation for the Second Session of the HF Broadcasting Conference.

The Institute has implemented most of the procedures outlined in the Report to the Second Session of the HF Broadcasting Conference. The computer program has been used to study the likelihood that United States broadcasting requirements will be satisfied with the levels of protection decided by the First Session of the Conference. Also, numerous tests have been undertaken to investigate different frequency assignment algorithms in an effort to optimize the frequency assignment process.

An example of the type of the results obtained from the studies undertaken is given in Figures 1-46 and 1-47. These two figures show contours of calculated field strength (in dBu) determined by use of the sky-wave propagation prediction program decided by the First Session of the Conference. Figure 1-46 shows the field strength coverage provided by a Voice of America broadcast service operating toward the Soviet Union on a frequency of 11835 kHz, at 2000 h UTC, during March 1985. In calculating the field strength, the transmitter power was assumed to be 250 kW and the antenna was assumed to be an HR 2/2/0.3. Figure 1-47 shows comparable results for a BBC broadcast from Cyprus on 7230 kHz, at 1900 h UTC, during March 1985. This transmission is also directed toward the Soviet Union. In calculating the field strength, a transmitter power of 270 kW and a 4/2/0.5 antenna was used. The powers and antennas assumed for the calculation in Figures 1-44 and 1-45 were determined from specific broadcast requirements and are consistent with operational conditions. Figures of the type illustrated in Figures 1-46 and 1-47 have been used to determine the area that a quality broadcast service is likely to cover using the criteria included in the planning process.

Another example of the type of results obtained is given in Tables 1-2 and 1-3. These tables show results of the entire planning process for two different levels of cochannel (first) and adjacent-channel

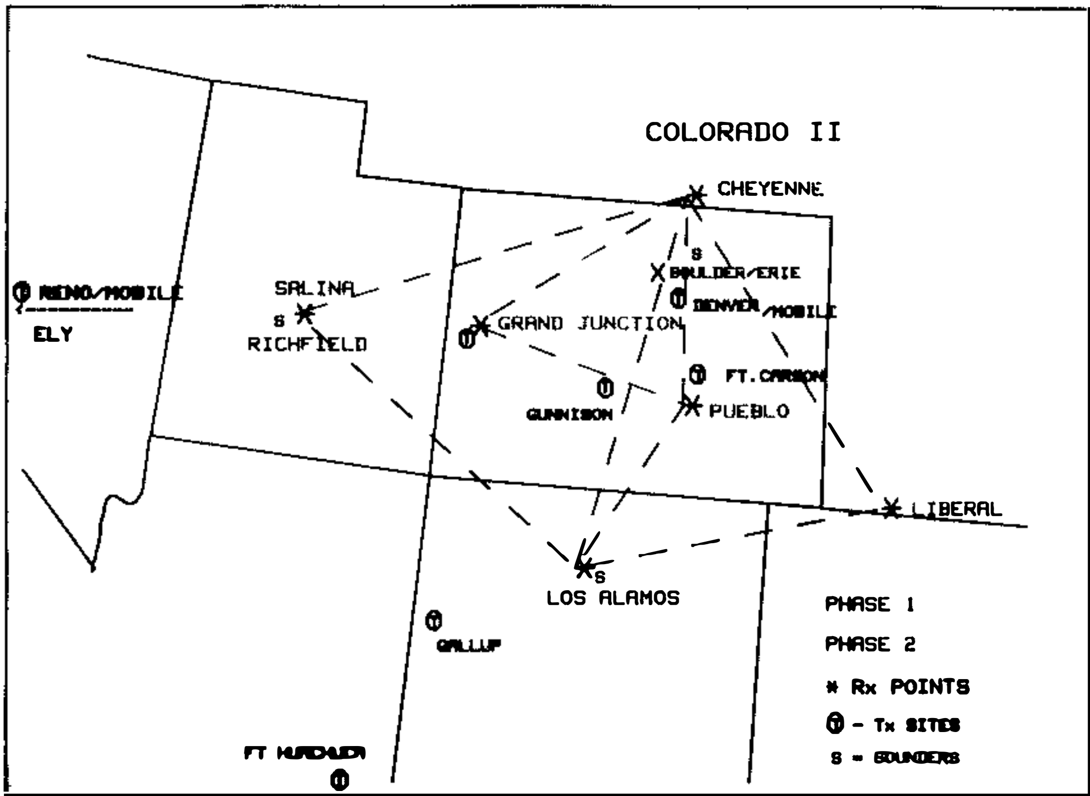


Figure 1-44. Locations of transmitters and receivers for BATTLETOAD experiment.

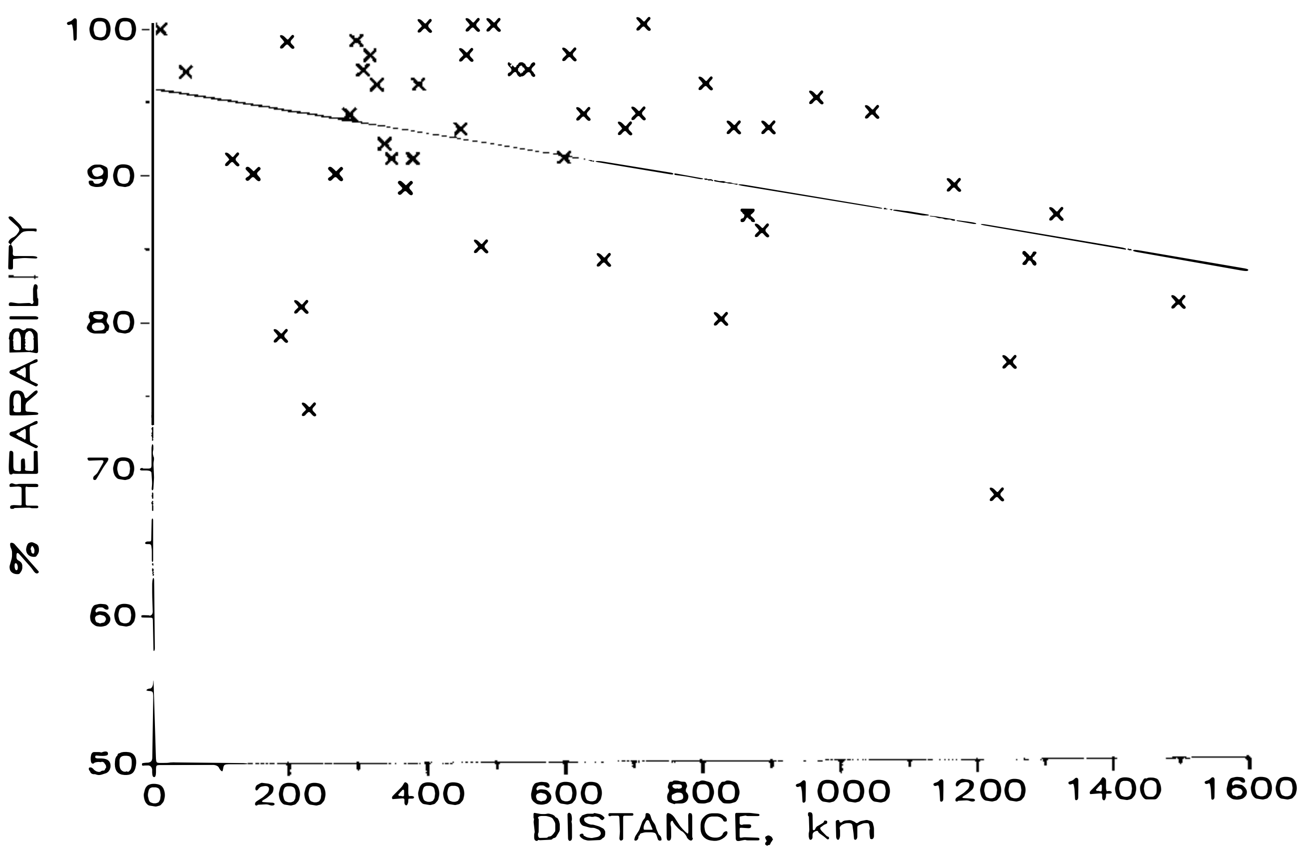


Figure 1-45. Observed percent hearability vs distance during the BATTLETOAD experiment.

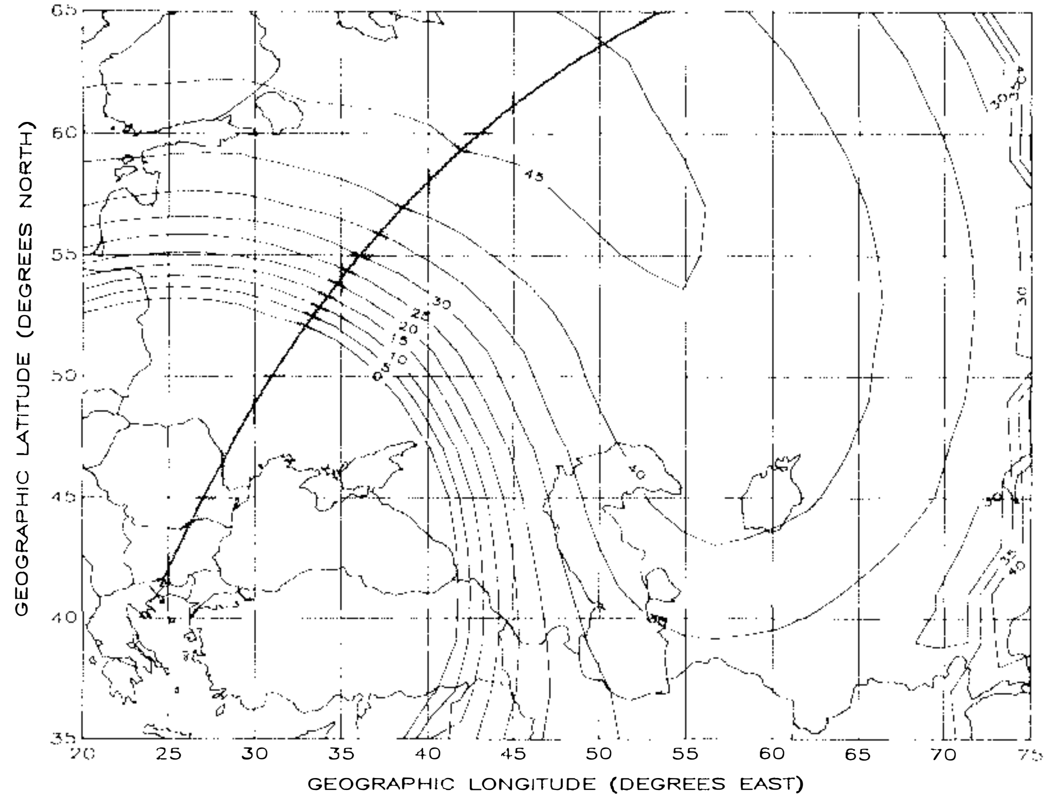


Figure 1-46. Contours of calculated field strength (in dBu) for a VOA transmission from Kavalla, Greece, on 11835 kHz with a power of 250 kW and an HR 2/2/0.3 antenna for March 1985, 2000 h UTC. The heavy line depicts the antenna boresight.

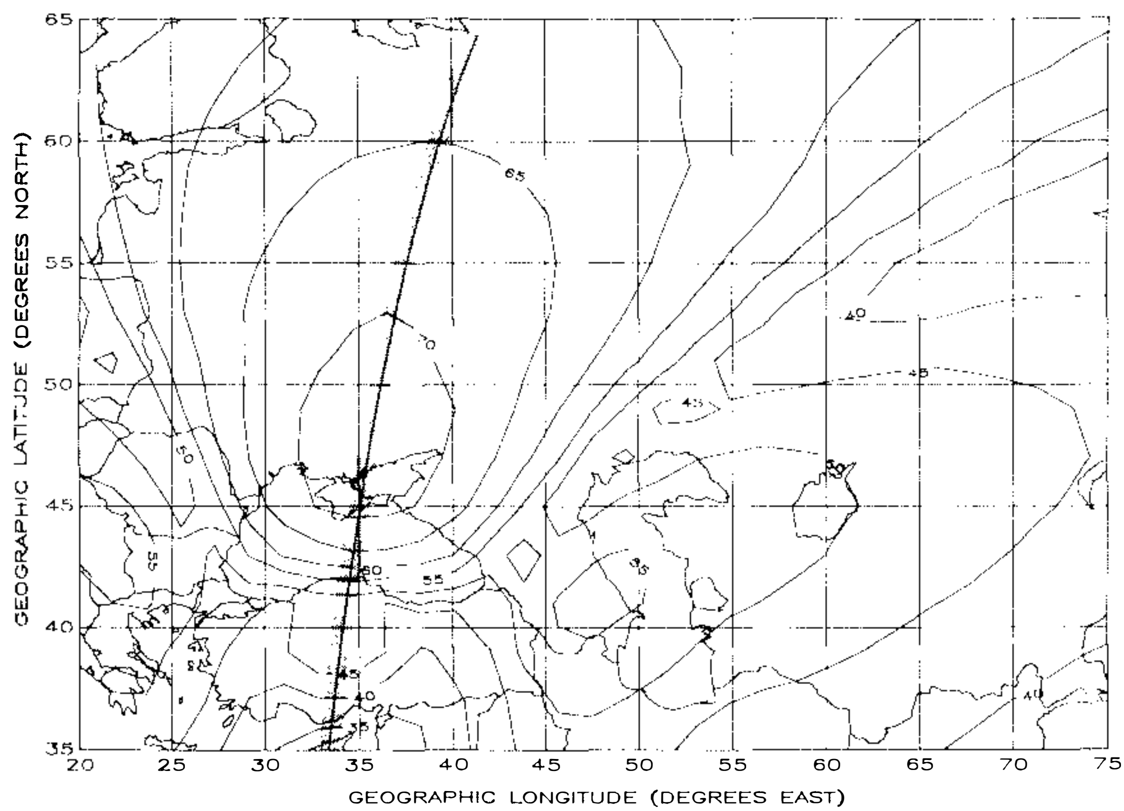


Figure 1-47. Contours of calculated field strength (in dBu) for a BBC transmission from Cyprus on 7230 kHz for a power of 270 kW and an HR 4/2/0.5 antenna for March 1985, 1900 h UTC. The heavy line depicts the antenna boresight.

Table 1-2. Results of Testing the Model for September 1984, 1800 h UTC, for Protection Ratios of (27, -8) dB

MHz	CHANNELS	REQUIREMENTS	LOWER BOUND	HFBC ALGORITHM REQ. SATISFIED	DENSITY
6.1	35	34	23	33	.717
7.2	20	123	104	32	.955
9.6	40	219	192	60	.920
11.8	40	270	235	59	.925
13.7	20	249	185	41	.926
15.3	50	178	129	80	.900
17.8	35	137	94	66	.864
21.6	40	165	104	68	.924
25.8	43	111	83	60	.944
TOTAL:	313	1486	1149	499	

Table 1-3. Results of Testing the Model for September 1984, 1800 h UTC, for Protection Ratios of (17, -18) dB

MHz	CHANNELS	REQUIREMENTS	LOWER BOUND	HFBC ALGORITHM REQ. SATISFIED	DENSITY
6.1	25	34	22	34	.570
7.2	20	123	87	49	.800
9.6	40	219	154	92	.810
11.8	40	270	163	102	.842
13.7	20	249	115	65	.818
15.3	50	178	89	113	.761
17.8	35	137	67	92	.694
21.6	40	165	82	106	.757
25.8	43	111	63	82	.848
TOTAL:	313	1486	842	734	

(second) protection ratios (27, -8) dB and (17, -18) dB. The results shown were deduced from broadcast requirements typical of those for September 1984, 1800 h UTC. The requirements were deduced from the Tentative Frequency Schedule published quarterly by the IFRB. The results are presented for each of the frequency bands allocated to the HF broadcasting service. The number of requirements for each frequency band is given in the second column of the tables. The number of channels available in each band is given in the third column. Column four shows the number of requirements that were satisfied using the frequency assignment algorithms developed by ITS. It is clear by comparing the results given in the two tables that there are more requirements for broadcasting than can be satisfied and more requirements are satisfied when the protection ratio is reduced.

The studies being undertaken by the Institute to support U.S. HF Broadcasting Conference preparation will continue up to and during the Second Session of the Conference, which is scheduled for January to March 1987. Another study directed toward preparation for the Second Session of the HF Broadcasting Conference relates to determining the location of emitters causing intentional harmful interference to the HF broadcast service. This study is being supported at the Institute by the Voice of America and is part of a worldwide program to monitor the occurrence of intentional harmful interference (jamming) to the HF broadcasting service.

The IFRB, following from the decisions of the First Session of the HF Broadcasting Conference, has implemented worldwide monitoring programs of the occurrence of jamming in October 1984 and March/April 1985. The duration of both of these monitoring programs was three weeks. As part of these worldwide programs, selected Administrations in the world have agreed to undertake a more coordinated monitoring effort. The stations that are providing observations as part of this coordinated program are listed in Table 1-4 along with the coordinates and the type of monitoring antenna used at the station.

Observations made at the stations indicated in Table 1-4 have been provided directly to the Institute where the data were checked, grouped, and subjected to further analysis. This analysis included determining the location of the emitters of jamming signals by using the observations of the bearing of the signals recorded at the monitoring stations. The location process was made possible by the fact that most instances of jamming are associated with emitters that send out two-character call signs as part of the jamming signal. Assuming that the two-character call sign is associated with a specific location, procedures were adopted by the Institute to determine the likely location of the emitter. Figures 1-48 and 1-49 show the location of various jammers observed to be operating in Eastern Europe and the western part of the Soviet Union during the October 1984 (Figure 1-48) and the March/April 1985 (Figure 1-49) time periods. The two-character identifier is shown in both figures at the likely location that was determined in the analysis process.

Results of the occurrence of jamming and the locations of the emitters of intentional harmful interference have been forwarded to the IFRB as part of the official monitoring programs. Additional monitoring periods will be undertaken in January 1986 and June 1986. The results of these periods will be provided by the Institute for submission to the IFRB. The results will also be used by the United States to develop positions in preparation for the Second Session of the HF Broadcasting Conference.

1.4.3 Ground-Wave Communications Projects

For several years, ITS has been involved in model development, analysis, and study efforts in ground-wave communications at HF (3-30 MHz) and lower frequencies. Model development for use in communication systems analysis using numerical calculations of ground-wave and sky-wave propagation has been an ongoing effort at ITS. The following three related projects are currently under way: a ground-wave communication system analysis computer model for the U. S. Army, an MF ground-wave broadcast system analysis computer model for the Voice of America (VOA), and a combined MF ground-wave and sky-wave system performance and interference analysis program, also for VOA. In addition to these three ground-wave related programs, ITS has been performing specialized studies of commercial broadcast systems in support of the Federal Communications Commission (FCC) and the commercial broadcasters. One study currently funded in this category is the AM Clear Channel Broadcast Study.

In the past, ground-wave propagation models have been developed at ITS for both smooth and irregular terrain using elementary short dipole and monopole reference antennas. The resultant models have been compared with measured data for verification. The measured data were taken using the same elementary antenna configurations that were used in the models. A need was then recognized by the U.S. Army and VOA for a model that more closely resembled typical communications and broadcast systems with more than elementary antennas. The models had to be valid for all ground constants and antenna geometries. In addition, the models had to be user friendly such that the model could be used by individuals of moderate skill levels with little or no training for rapid analysis of many different communications systems in different geographic areas and under varied operating conditions. The ground-wave models currently being developed contain special antenna models and are user friendly to meet these new requirements.

The U.S. Army Ground-Wave Automated Performance Analysis (GWAPA)

The U.S. Army Information Systems Engineering Support Activity (USAISESA), Fort Huachuca, AZ, has recognized that communications using UHF and microwave satellites are quite

Table 1-4. Locations of Direction-Finding Stations and Antenna Type

STATION	CODE	LATITUDE	LONGITUDE	ANTENNA TYPE
ANCHORAGE, ALASKA	AN	61°09'43"N	149°59'55"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
BELFAST, MAINE	BE	44°26'42"N	69°04'58"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
DOUGLAS, ARIZONA	DS	31°30'02"N	109°39'12"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
FERNDALE, WASHINGTON	FE	48°57'21"N	122°33'12"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
FT.LAUDERDALE, FLORIDA	FL	26°06'08"N	80°16'42"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
GRAND ISLAND, NEBRASKA	GI	40°55'21"N	98°25'42"W	ROTATING ADCOCK TYPE
KINGSVILLE, TEXAS	KI	27°26'29"N	97°53'00"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
LAUREL, MARYLAND	LR	39°09'54"N	76°49'17"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
LIVERMORE, CALIFORNIA	LV	37°43'30"N	121°45'12"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
POWDER SPRINGS, GEORGIA	PS	33°51'44"N	84°43'26"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
SABANA SECA, PUERTO RICO	SS	18°27'23"N	66°13'37"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
WAIPAHU, HAWAII	WP	21°22'45"N	157°59'54"W	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
OTTAWA, CANADA	OT	45°25'00"N	75°43'00"W	NO BEARING INFORMATION
NEDHORST DEN BERG, NETH.	NE	52°14'31"N	05°04'38"E	8-ELEMENT ADCOCK ANTENNA
KREFELD, GERMANY	KR	51°26'00"N	06°28'00"E	ADCOCK ANTENNA
NORWAY	NO	58°48'48"N	05°40'09"E	ADCOCK ANTENNA
NORWAY, STATION 1	N1	66°10'48"N	12°33'33"E	ADCOCK ANTENNA
NORWAY, STATION 2	N2	69°16'34"N	16°08'40"E	ADCOCK ANTENNA
NORWAY, STATION 3	N3	71°04'34"N	24°06'58"E	ADCOCK ANTENNA
CROWSLEY PARK, U.K.	UK	51°30'55"N	00°57'13"W	BANDWIDTH MEASUREMENTS ONLY
SEOUL, SOUTH KOREA	SO	37°30'00"N	128°54'00"E	LOG PERIODIC ANTENNA
OSAKA, JAPAN	OS	34°30'00"N	135°30'00"E	CIRCULAR ARRAY OF MONOPOLES
TOKYO, JAPAN	TU	35°34'00"N	139°45'00"E	8-ELEMENT ADCOCK
TEL AVIV, ISRAEL	TA	32°04'00"N	34°47'00"E	UNKNOWN
ITZEHOE, GERMANY	IT	53°54'00"N	09°31'00"E	ADCOCK ANTENNA
KONSTANZ, GERMANY	KO	47°41'00"N	09°12'00"E	ADCOCK ANTENNA
MUNCHEN, GERMANY	MU	48°10'00"N	11°28'00"E	ADCOCK ANTENNA (8-30 MHZ ONLY)
BERLIN, GERMANY	BL	52°34'00"N	13°18'00"E	ADCOCK ANTENNA
BALDOCK, U.K.	BD	52°00'00"N	00°08'00"E	FIXED MONOPOLES WITH GONIOMETER (WIDE APERTURE)
DARMSTADT, GERMANY	DT	49°51'00"N	08°40'00"E	ADCOCK ANTENNA

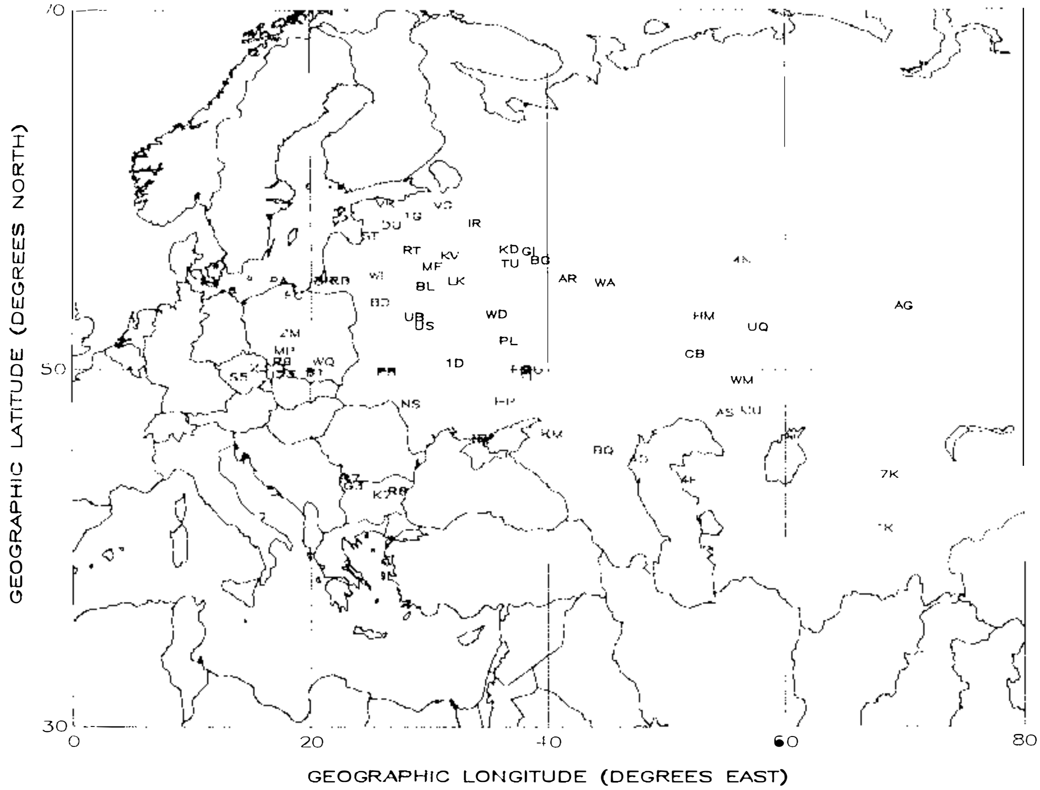


Figure 1-48. Locations of emitters of intentional harmful interference, indicated by marker ID, in Eastern Europe and Western Soviet Union during October 1984.

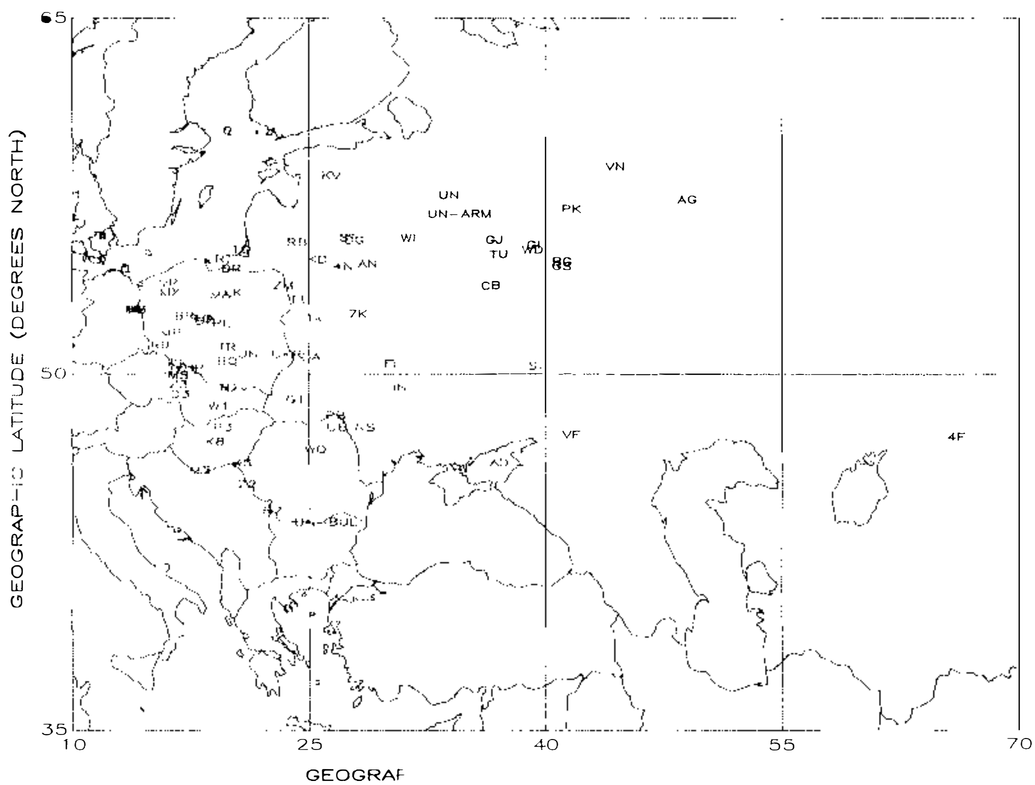


Figure 1-49. Locations of emitters of intentional harmful interference, indicated by marker ID, in Eastern Europe and Western Soviet Union during March/April 1985.

vulnerable during a military conflict. A satellite cannot singly be relied upon to provide uninterrupted communications, because it can be easily jammed or destroyed. HF and lower frequency communications via the ionosphere could provide a backup to UHF and microwave satellites, but in the event of widespread nuclear explosions, communication via the ionosphere may not be possible. However, the ground wave at HF and lower frequencies will provide reliable communications capability under these conditions for shorter distances.

A computer program is presently being developed at ITS for USAISESA 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 GWAPA is a structured set of a number of computer programs that predict propagation loss, electric field strength, received signal power, noise, signal-to-noise ratio, antenna factors, and system calculations. 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 irregular terrain model accesses terrain files automatically given the appropriate transmitter and receiver latitudes and longitudes or the latitude and longitude of the transmitter with bearing and distances to receiver. The user may also enter terrain manually.

The computer program combines the propagation, system, and antenna models into a user friendly analysis model. The computer program is being designed with a major emphasis on user friendliness and convenience. The computer model also provides the capability to calculate the achievable distance given the required-signal-to-noise ratio and reliability, as well as the achievable reliability given the required-signal-to-noise ratio and distance. The antenna model contains simple lookup tables and algebraic algorithms to describe the performance of several antennas as a function of antenna geometry, ground conductivity, ground dielectric constant, frequency, and azmuthal direction. The lookup tables and algorithms were derived from extensive method of moments calculations using the Numerical Electromagnetics Code (NEC)-Version 3.

The antenna model allows fast prediction of antenna performance since all complex and time consuming electromagnetic calculations have been previously performed "off line." The NEC is used to determine the gain of a short dipole over lossy earth with respect to an isotropic radiator in free space for all ground conductivities, ground dielectric constants, and frequencies. A ratio called the relative communication efficiency is then calculated for each subject antenna referenced to a short dipole as a function of ground constants, frequency, and antenna geometry. The combined net result is the equivalent gain of the subject antenna over lossy earth with respect to an isotropic radiator in free space.

The entire GWAPA program is expected to be delivered to the sponsor by January 1986.

The Voice of America Ground Wave (GWVOA)

The Voice of America (VOA) requires a groundwave analysis capability for performance prediction for MF broadcasting purposes. The VOA has tasked ITS to modify program GWAPA specifically for MF analysis purposes and install the program on ITS Telecommunications Analysis Services (TA Services). The VOA computer program will have all of the capabilities of the original GWAPA program with the exceptions of the Army Antenna Model. The modifications to the GWAPA program include special input/output configurations and a specially tailored MF antenna model implementation. The Voice of America will use the resulting model to predict VOA station coverage. The terrain access subroutine also had to be modified to accept coarse (8 km spacing) terrain data for prediction over irregular terrain.

The computer program can provide fast turnaround predictions presented in a report ready format. The computer program has been written in such a manner to permit workers with moderate skill levels to perform the necessary calculations with little or no training.

The resulting computer program will be called GWVOA and will be resident on TA Services October 1985.

The Voice of America Combined MF Ground-wave and MF Sky-wave Integrated Performance and Interference Analysis Program (MF RESYDE)

The VOA has tasked ITS to develop a complete system performance and interference model (MF RESYDE) for analysis of MF broadcast systems. The model will be used to assess present and future VOA site performance and determine potential interference problems with site design. The MF RESYDE will be composed of three major systems of programs that the user can select. Each system will be able to draw on a set of ground-wave models and sky-wave models. The set of ground-wave models that will be available to MF RESYDE will be Smooth Earth, Smooth Earth Mixed Path, WAGSLAB (irregular terrain), the FCC ground-wave model, and the International Frequency Registration Board (IFRB) ground-wave model. The MF RESYDE will also be able to draw upon a set of MF sky-wave models. The models that will be available are the FCC Interregional Sky Wave Model, the CCIR model recommended at the last Plenary Assembly (1982), the model developed by J. C. H. Wang (Ref: IEEE Trans. on Broadcasting, March 1985), and the model used by the IFRB.

The three major systems of programs contained within MF RESYDE are:

System 1

A combination of five ground-wave models and four sky-wave models that will compute the sky-wave signal strength for 10, 50, and 90 percent of the time; the ground-wave signal strength, the noise level for 10, 50, and 90 percent of the time; and signal-to-noise ratio for 50 percent of the time (based on the larger of the ground-wave and sky-wave signals).

System 2

This model contains System 1 capability with the addition of a channel occupancy model. This model lists the interference interactions that will take place in a user specified population center when VOA broadcasts on each of the channels in the AM band. This model will predict the field strength, signal-to-noise ratio, and signal-to-interference-plus-noise ratio for the VOA signal. The model will also predict frequencies on which there is no interference to or from the VOA signal in the reception area being examined for various interference margins.

System 3

This system will be used to produce plots of field strength contours from the VOA station, field strength contours of other stations operating within 30 kHz of the VOA station, and regions by interference to and from the VOA station. The contours will be drawn on top of computer-drawn maps with different user-selected scale factors.

The computer program MF RESYDE will be completed in June 1986.

AM Clear Channel Broadcast Study

Powerful, Class I-A clear channel AM broadcast stations have long been protected from harmful interference by restricting cochannel Class II-D stations to daytime operation. Recently the Federal Communications Commission (FCC) in BC Docket No. 82-53 and RM 3983, amended Part 73 of its Rules and Regulations to allow II-D daytime stations to operate presunrise and postsunset. Operation of the II-D stations is now allowed if no harmful interference occurs to the I-A clear channel stations.

Interested parties have requested the FCC to review the protection given to Class I-A clear channel stations and determine if current listening patterns of AM patrons would allow some loosening of present restrictions placed on daytime AM stations. The FCC has agreed to consider the matter with a possible goal of permitting greater operation times to daytime stations.

Subsequent to this, NTIA was given the task of assessing the appropriateness of FCC Rules and Regulations regarding the operational limits of Class II-D daytime only stations.

After technical considerations, NTIA has elected to survey AM radio listeners in rural areas and determine their listening habits. These listening habits should reflect choices based on programing content and/or available signal quality.

In the first phase, a rural town (Clinton, NC) and the area around it will be surveyed. This particular area lies within more than 20 protected contours of the powerful Class I-A clear channel stations and has two Class II cochannel stations as well as several nearby AM stations. The second phase, if pursued, will utilize information obtained in the first phase to help design surveys in several regions of the contiguous United States to determine national trends in AM radio listener patterns.

The outcome of the survey should help in decisions involving protection contours and hours of operation for daytime only and present class I-A stations.

SECTION 1.5 APPLICATION OF PROPAGATION MODELS

A number of studies have been undertaken that apply the results of more basic studies to improve the performance and design of telecommunication systems. The studies are addressed in this section.

Advanced Radar Test Methodology

Military C-E systems in the Concept and the Early Engineering Development Life Cycle phases are exploiting advanced ECCM (Electronic Counter Countermeasure) techniques to maximize performance and operational support capabilities in the complex EM environments indicated by current scenarios. Increased environmental stress concerns the EM interference (EMC), friendly and hostile force countermeasures (ECM), and the future High Power Microwave (HPM) interferors.

This program addresses the identification of the characteristics and capability requirements for advanced Army radar systems, defining specific test requirements for the Development Test (DT) phase, and detailing AEPG/TECOM facility enhancements to support the DT requirement. A second phase of this program in FY 86 will detail test planning and implementation procedures and define data analysis and correlation techniques.

Advanced radar systems include air defense, counter intrusion, surveillance, and weapon control applications. Air defense and surveillance systems include threat and engagement assessment capabilities. The advanced EM control and interaction functions employed by these radar systems are listed below:

- Wide-band modulation technology, including frequency hop and special correlation code modes.
- Array antennas with multiple null capabilities. Currently one system will use VLSI configurations for the antenna, transmitter and receiver, and control computer modules.
- Look-through modes using a wide-band monitor receiver to control burst operation.
- High-resolution signal processing to enhance target recognition and S/I and S/J track stability.

- o Distributed apertures to maximize survivability and detections and track accuracies.

The DT requirement includes initialization and operational modes. Initialization includes sector organization and clutter filter parameter setting. Operational functions include detection, scan control, identification, track, ECCM responses, alarm/action events, and assessment.

This initial test methodology development phase includes the listed areas:

- o Operational scenario selection procedure specification, including terrain, meteorology, target density variations, and ECM actions. The scenarios would include European (AIR-LAND 2000) and contingency operations.

- o Structuring of functional time-event models to indicate functional priorities for radar equipment and software elements.

- o Utilities of the Electromagnetic Environment Test Facility (EMETF) and Stress Load Facility (SLF) in development of EM environments relative to operational actions, detailed propagation-related signal distortions, and specific iterative procedures for statistical evaluation. These considerations are required for the sensitivity analyses in test planning and execution of functional tests.

Analysis of the Antenna Test Facility addressed the utility of near field measurements and the use of a Compact Range. The latter provides overriding advantages in data collection efficiency (cost and time) for adaptive antennas where measurements will include spatial patterns (call modes and frequencies), adaptive null depth and width, null loop stability, null loop transient response, and pattern distortions caused by the carrier vehicle or masting.

Advanced Antenna Characteristics and Measurement Requirements

The dynamic EM environments associated with combat scenarios in the 1985-1995 period have required the exploitation of software controlled array antennas for communications, radar, electronic warfare (EW), and radiometry applications. Dynamic apertures are important for interference rejection, noise reduction, and frequency reuse.

The review of Army C-E concept and developmental programs indicated a significant increase in the use of adaptive antenna configurations. This includes systems operating in HF, VHF, UHF, microwave, and millimeter-wave bands for the previously indicated applications. The dynamic and dense EM environments (EMC, ECM, and EW intercept issues) are the primary drivers for use of these antennas. Adaptive antennas include gain variability and control of 1 to 10 simultaneous nulls, using analog, hybrid, and digital control techniques.

The existing Antenna Test Facility at AEPG is useful for low-gain (~ 10-15 dB range) antennas having sophisticated control capabilities. For moderate and high-gain antennas with adaptive capabilities, the Compact Range will be required. These antennas involve gain in the 30 to 60 dB range, nulls of 30 to 40 dB depth, and in many systems sidelobes < 40 to 60 dB below the mainbeam.

The existing Antenna Test Facility is being improved by addition of a larger computer for control and data analysis, the design of a more accurate turntable, and mechanical modifications to the sensor tracks. Additional modifications will be required in reflective and diffraction multipath reduction and cross polarization control to accommodate HF to UHF low-gain antenna subsystems that have adaptive features.

Specifications for the Compact Range were developed--test area plane wave tolerances, dynamic range, frequency range, and atmospheric and seismic environment isolation requirements. The advantages in test program costs and logistics in the physical integration of the ATF and SLF were detailed. This is particularly evident in evaluating C-E system performance in complex and dynamic EM environments (e.g., 100 to 500 sources illuminating an aperture) if antenna and other functional tests are accomplished with the same test configuration(s).

The primary antenna measurements required are listed. These tests must include coverage of all operating frequencies and modes. Data accuracies were also derived based on the C-E system functional modes associated with the listed antenna parameters:

- o mainbeam gain and width (sum and difference patterns)

- o sidelobe peak amplitude and null depths and spatial distributions

- o adaptive null(s) depth and spatial position(s)

- o pattern distortion (mainbeam and sidelobes) with active null(s)

- o null loop(s) jitter when tracking stationary and moving sources, with varying source amplitudes

- o null loop transient response with varying source amplitudes.

A subsequent phase of this program will address specific Compact Range design and verification test issues.

EW Simulator Design

The USAISC is responsible for the planning, engineering, deployment, and operation of communications systems in the Echelons Above Corps (EAC) areas in the Army combat doctrine, Army base communications, elements of host country communications facilities that would support military operations, and strategic and tactical gateway systems. One principal operational readiness area for

USAISC concerns the Electronic Warfare (EW) threat.

As related to USAISC life-cycle responsibilities, an ECM Environment Simulator is required for susceptibility evaluation of the Engineering and Operational phases. Operator proficiency must be included in the Operational phase for USAISC systems. This simulator will provide ECM signal and operational mode replication and the recording of C-E system response to ECM excitation.

The simulator design provides ranges of intelligent and "brute force" jammer modes as defined by EM threat specifications for the 1985-1995 period. Connection to the C-E systems allows evaluation of all functional responses and protects secure signals from external detection.

The system design features modularity, expandable software control and data processing, and signal format variability. Validation test requirements for specific tropospheric scatter, microwave line-of-sight relay, and satellite terminal systems have been defined.

Development of a prototype model has been initiated. This simulator will be evaluated at CONUS sites having communications facilities as specified in the Validation Test Requirements. This model and the associated documentation will form the basis for procurement of 5 to 10 units through industry contract.

CS^2 System Evaluation

In response to Army combat doctrine, a basic architecture has been defined for the Army Command and Control System (ACCS) and the interface structure for the Echelon Above Corps (EAC) systems. The ACCS architecture is being upgraded and message requirements defined for the ACCS elements--Air Defense, Combat Service Support, Intelligence, Fire Support, and Maneuver Control.

This program for FY 85/86 will specifically examine the data elements and transmission priorities of the CS^2 component and develop the specifications of the models required to evaluate the CS^2 operational support capability. The model will include scenario snapshots derived from AIR-LAND 2000 and selected contingency operations, communications system and traffic event and message descriptors, and dynamic friendly and hostile force EM sources controlled by scenario events. Fuzzy set analysis techniques are required because of the statistical relationships between functions and decision elements in the operational and communications element descriptors.

Link models will include meteorological and terrain signal modifiers in the propagation modules to extend the realism in dynamic snapshot zones. Both link sets and scenario snapshot models will operate off-line to the communications model.

For the CS^2 evaluation, the assumed message profiles for the other four ACCS elements will be used until subsequent evaluation of the data requirements for these elements. This updating will be accomplished over a 3-year period to be compatible with the "fine tuning" of force structures, ACCS architecture, and EAC-ACCS gateway specifications.

Evaluation model development for the CS^2 element will involve a cooperative effort between ITS, USA TRADOC (Training and Doctrine Command), USA ISC Engineering Agency, and USA/AIR-MICS. The final model will be used by AIR-MICS and TRADOC for communications functional and operational support analysis requirements. This capability will be fundamental in evaluating doctrinal, architectural, system functional, and procedural developments with evolving combat doctrine.

Spread Spectrum Communications Test Methodology

Army communications systems are using spread spectrum techniques because of significantly expanded requirements for signal security, jamming susceptibility reduction, and spectrum usage efficiency. Frequency hop and PSN modes are employed. Applications include strategic area and tactical networks and dedicated service links.

This program included review of Army development agencies to define operational support requirements and functional characteristics for spread spectrum systems, specification of Development Test requirements, analysis of AEPG/TECOM facilities for test planning and execution, and the detailing of the test planning and implementation procedures.

The test methodology includes the following elements:

- Selection of operational scenarios and snapshots that indicate maximum and medium levels of EM environment stress.
- Specification of functional and empirical models to be used by the EMETF for interference and jammer sensitivity testing. Time, space, and propagation distortion factors are included in this sensitivity evaluation. These sensitivity tests are used in test planning to determine specific measurement priorities, specify the EM environments required for testing, and derive the priority propagation-related distortion events. These exercises allow specification of the EM environment sources, scenario-related control and parameter selection events, propagation parameters, and measurements required for testing.
- Specification of data analysis procedures for the system measurements. Functions measured include minimum usable signal, signal acquisition transient response, synchronization function response, ECCM mode responses, and data error envelopes.
- Definition of the functional integration of the EMETF and SLF in test execution

for scenario control, parameter variation, and real-time analyses.

- Definition of techniques for relating system performance scores with scenario events to derive operational support capability ranges. This information can be related to the Required Operational Capability initiated through TRADOC or user commands for specific mission requirements.

- Specification of propagation models for the EMETF that would allow modal sensitivity testing and represent the signal parameters required for adaptive wide-band systems. Parameters include variable statistical windows for amplitude, Doppler, and space and time coherence. Modes include direct line-of-sight, reflection, refraction, and scatter; varying through a dynamic snapshot as dictated by geometry and control events. Fuzzy set analysis techniques are employed for determining the likelihood of decision and control events in the operational and functional interconnection trees that relate communication performance measures to scenario operational actions and events.

CHAPTER 2. SYSTEMS AND NETWORKS

The Systems and Networks Division conducts research and analysis programs in four principal areas:

1. development and promulgation of national and international telecommunication standards.

2. user requirements analysis, system design, and network architecture planning

3. development and application of measurement methods and prototype measurement tools for telecommunication performance assessment

4. identification and resolution of technical issues influencing telecommunication policy development.

The Division's programs promote domestic competition and international trade in telecommunication products and services, assist other Federal agencies and private sector users in efficiently meeting their telecommunication needs, and strengthen NTIA contributions to domestic and international telecommunication policy forums.

The Division's outputs consist of basic research results, such as statistical models of system and network component performance; engineering tools and analyses, such as transmission link simulators, performance measurement software, technology impact studies, and cost/benefit evaluations; technical standards and related documents, such as system acquisition, operation, and improvement guidelines; and expert services such as technical leadership of national and international standards committees. Most of these outputs are documented in technical publications. Typical published outputs are NTIA Technical Reports and Memoranda, articles in technical journals, contributions to national and international standards committees, and filings with the Federal Communications Commission. Division programs also produce prototype hardware and software systems that are used in telecommunication propagation media simulation, performance prediction, system design and analysis, performance measurement, and network management.

The Division's technical programs are supported roughly equally by Department of Commerce and other-agency resources. The Commerce-sponsored programs provide technical support to the Administration and the Department in achieving Federal telecommunication policy objectives. 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.

The Systems and Networks Division comprises four groups: the Switched Networks Analysis Group, the Satellite Network Analysis Group, the System Performance Standards and Definition Group, and the System Performance Engineering Analysis Group. The specific FY 85 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 network that nearly everyone is familiar with is the public telephone network. In this country, it was owned and operated largely by the Bell system from around the turn of the century until 1984. Other switched networks, such as the Federal Telephone System (FTS), public and private packet switched networks, and local area networks (LAN's) are familiar to many large telecommunications users. Technology advances and, in particular, the AT&T divestiture have greatly expanded the number and diversity of independent switched networks in the United States and have considerably increased the need for network interoperability and performance studies.

The Switched Networks Analysis Group in the Systems and Networks Division of ITS conducts research and engineering programs involving all aspects of switched telecommunications networks. Group projects encompass both analog and digital systems; cable, radio, and satellite transmission media; circuit, message, packet, and hybrid switching technologies; and a range of user applications extending from military command and control under conditions of national emergency to routine interoffice communications within a Federal building or office complex. A particular focus of the Group's work is the development of interoperability and performance standards for fiber optic networks.

Support for the Group's programs comes from various Government agencies with different missions and telecommunications needs. Research during the past year included studies on the modeling and simulation of networks that use a variety of transmission media (wire, radio, etc.), the characterization of a military communications access area, and a survey of LAN technology and applications. Other work examined methods of interfacing customer premise fiber optic LAN's with an ISDN, assessed the state of the art in digital switch technology, and examined ISDN addressing and signaling issues. Economic and technical impact assessments were performed for several new modem and encryption standards.

One aspect of a network, or a channel, is how well it preserves the transferred information. Work in this area comprises two of the Group's research programs that are directed at how to quantitatively assess voice quality, or its degradation, through a network or channel. In one project, the use of expert pattern recognition techniques to automatically, and objectively, evaluate voice quality is being studied. In the other project, the voice quality of a new modulation scheme for land-mobile radio is being evaluated using classical voice scoring techniques.

Most of the Group's programs include involvement in standards development. Group members are active in the American National Standards Institute (ANSI), the Federal Telecommunications Standards Committee (FTSC), the Institute of Electrical and Electronic Engineers (IEEE) selected military standards committees, and the International Telegraph and Telephone Consultative Committee (CCITT). New technologies involving modems, the digital encryption standard (DES) and other cryptographic techniques, cable and fiber sizes and types, and voice quality are some of the topics dealt with at meetings with the various standards committees.

In what follows, the Group's technical programs and projects are each described in more detail. The majority of the Group's projects are funded by the Technology and Standards Group of the National Communications System (NCS). The "ISDN Technical" project was funded by NTIA. Other project sponsors are identified where appropriate.

Multimedia Network Modeling and Simulation. The Rome Air Development Center (RADC) of the U.S. Air Force is developing specialized test equipment for modeling and performance simulation of communication channels and future multimedia networks. The ITS Switched Networks Analysis Group is supporting this work in two separate tasks.

The first task is concerned with the individual link impairment models. It attempts to establish a comprehensive set of link "descriptors" for various classes of links (e.g., HF sky wave, troposcatter, VHF meteor-burst, satellite, terrestrial microwave, the switched telephone network, and others). Since the most useful models tend to evolve from joint analysis of theoretical and experimental results, this effort strives to combine theory with measured data. Specifically, several simple 2-state Markov and 3, 4, and 5-state Fritchman models have been fitted to bit-error statistics of the above-mentioned channels. Several statistical functions of measured data, such as the error gap distribution, the block-error probability, and the probability of undetected block error, have been fitted remarkably well to the Fritchman model. An example is presented in Figure 2-1, which compares the error gap distributions of 2-state and 5-state Fritchman models for a 1971 data sample from a switched public network channel.

The second task addresses the issues of all-digital networks. Specifically, the study seeks to identify parameters, factors, and models that are needed for end-to-end performance simulation of military digital networks. The key factors to be emphasized appear to be the network topologies, the multimedia links, the switching (and other) nodes, the protocols, the traffic, the stress scenarios, and the network performance criteria that are relevant to the military end user.

Military Access Area Characterizations, EISN Experimentation, and LAN Assessment. This project covers three major task areas, as listed in the title. It was initiated in 1984 by the Information Systems Management Activity (ISMA) of the U.S. Army in Ft. Monmouth, NJ. This is a continuing engineering support program with the first phase to be completed in 1985.

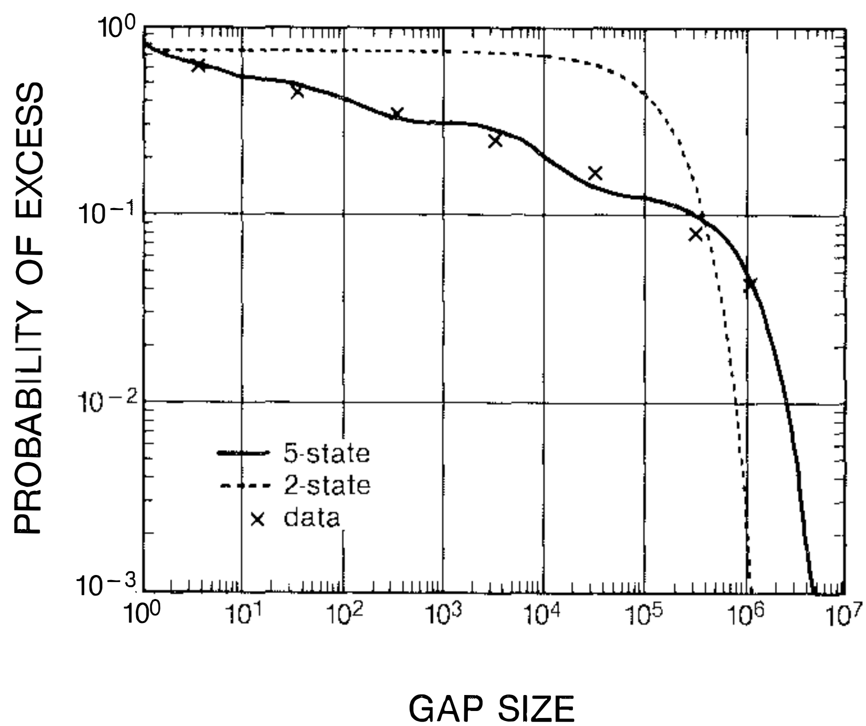


Figure 2-1. Error gap comparison of the two-state and five-state Fritchman models for switched telephone network data.

The study to characterize military access areas consists of two phases. The first phase involved developing the methodology for characterizing access areas based on a number of defining parameters. The second phase will involve structuring the concept for computer implementation and developing plans for the administration, operation, and maintenance of the network. The first phase of the study has been completed and is summarized in NTIA Report 85-185 (Linfield and Nesenbergs) issued in December 1985. A second phase is planned for FY 86. The results of the first phase are summarized in the following paragraphs.

In the past, the military access areas were typically viewed as communities of users, under Military Department (MILDEP) control, who share local switching and transmission facilities and have common access to the long-haul networks (e.g., AUTOVON and AUTODIN). In the future, this simplified viewpoint may no longer apply because the local networks and the Defense Switched Network (DSN) are evolving into a much more complex structure of multiple networks based on digital technologies, and because deregulation and competition are impacting the military communications environment in some very significant ways.

The current post-divestiture situation can be viewed in either of two ways--a complex disarray or an opportunity. Deregulated services and customer premises equipment can and should lead to diversity of services, expanded end-user options, and terminals with greater survivability. Competing industry vendors will be motivated to produce innovative systems, potentially at reduced cost. New technologies will lead to greater hardware and software reliability and, finally, novel features and functions will increase staff productivity.

At the same time, new issues abound. Procurement policies and regulations require the Department of Defense (DOD) to acquire services on a competitive basis. The multivendor equipment and automated systems environment complicates military administration, operations, and maintenance (AO&M) problems. The separation of access area and long-haul network responsibility between the MILDEPS and Defense Communications Agency (DCA) introduces network management, control, and restoration problems similar to those in the post-divestiture commercial sector. There is no single end-to-end responsibility for the network, nor any centralized system for overall management and control. In the present environment, it is difficult to implement a technically sound system concept that provides for integration of voice, data, and other services. This separation also complicates the allocation of the total performance budget across the local and long-haul portions of the network.

These dynamic changes, both realized and contemplated, raise questions about the access area concept. Does any access area concept make sense or benefit the military? Do we need access areas? How many? How are they to be configured? Operated? Managed? What affects their size? Survivability? Security? Cost? What are the staffing requirements?

The Linfield and Nesenbergs report addresses many of these questions directly, and recommends procedures for answering others. The study does not recommend any single definition for all access areas. In fact, it concludes that there is no fixed structure or universal solution. Rather, each collection of posts, camps, stations, air bases or shipyards has its own unique characteristics based on mission and telecommunications needs. These needs can be perceived as a combination of three critical features seen by the users: overall performance, survivability, and often the most important item--low cost!

An ultimate objective of the project is to develop goal architectures for all access areas that provide the framework for defining standards to access the long-haul networks, for routing intra- and interarea traffic, and for developing end-to-end procedures or protocols for data recovery, security, and error control. A substantial simplification would occur if a single architecture could satisfy the needs of all locations. For the end user, such a goal architecture would ideally 1) meet mission requirements including security requirements, 2) meet both local and long-haul performance objectives, 3) provide survivable/endurable service, and 4) be cost effective. For the network planner, this goal architecture would 1) identify locations and types of nodes and terminals, and specify traffic intensity with allowance for its growth; 2) assign transmission links including media types, connectivity, and their capacity; 3) specify control signaling for switch control, routing, network management; and 4) define interfaces for interaccess area trunking.

When one considers the mission requirements and their effect on telecommunication features (e.g., on electronic mail) and the functions to be performed by the network (e.g., preemption), it appears prudent to permit each base to be quite different from other bases. Even if the feature and function lists were identical, the performance requirement numbers, traffic levels, and destination statistics would differ. It is concluded that there can be no single set of parametric requirements defining every access area.

This report recognizes two broad classes of parameters that pertain to the access area definition--nontechnical and technical. The nontechnical parameters have their roots in the national chain of command and the legal, economic, commercial, political, and regulatory arenas. Nontechnical issues such as the impact of deregulation and divestiture on military communications are covered in the early sections of the report. Technical system parameters including size, topology, switching, concentration, administration, operation, and maintenance are also addressed.

The approach used to characterize an access area is explained in Figure 2-2. Given a set of fixed inputs (e.g., subscriber numbers and locations) and a set of variable inputs (e.g., candidate hub capacities and locations), one can conceive a large number of architectural choices for a region. Each choice is evaluated based on critical factors, such as cost and survivability. New choices are made by changing some or all of the input variables until an apparent optimum choice is synthesized. The values of all the input parameters then define the goal architecture.

The above is a fairly standard process for selecting optimum alternatives in any study. The problem is that the extremely large number of access area related inputs, both fixed and variable, effectively prohibit a comprehensive manual assessment. A key recommendation for the next phase is that the process be implemented with a fast, automated computer model.

To make any model realistic, certain requirements must be satisfied or basic assumptions made. Consider the long-haul Defense Switched Network (DSN), which most local areas must access. The assumed DSN architecture has important consequences on the access area characterization. For example, if one assumes that all interaccess traffic must flow through a single gateway to the backbone network, then each subscriber location (post, camp, or station) must be tree or star connected to the gateway node, and the problem is reduced to defining the number of nodes, their locations, and their trunking capacity. If, on the other hand, one assumes a mixed-media architecture that allows each subscriber location to take maximum advantage of all available facilities, then optimization of the access area topology and trunking becomes far more complex. All of these aspects will be considered in future model development.

The Experimental Integrated Switched Network (EISN) experimentation project required the design of experiments and implementation concepts using EISN nodes as a concept validation facility (CVF) for the Defense Switched Network. The Institute recommended several experiments and developed an experiment plan, including a detailed test equipment list. The experiments were divided into three levels of complexity. These levels were called demonstrations, tests, and evaluations. Demonstrations are qualitative, tests are quantitative, and evaluations involve comparisons to select optimum elements. At each experimental level different attributes of the system can be measured. These attributes include service features (as seen by the user), functions (as performed by the system), or facilities (hardware and software elements of the network). Table 2-1 defines the experimental goals at each level of demonstration, test, and evaluation and for each feature, function, and facility.

The list of experiments included measurements on voice quality, noise and interference tests, voice and data integration demonstrations, common channel signaling tests, LAN demonstrations, video conferencing, and internetworking with the Public Switched Telephone Network.

The third major task was to assess the current status of Local Area Networks (LAN's). This task resulted in an NTIA Report ("Local Network Assessment," by D. V. Glen).

Local Area Networks are used to interconnect terminal equipment, computers, and peripheral devices concentrated in a limited area such as an industrial park or office complex. LAN's exist in numerous combinations of topologies, transmission media, levels of connectivity, signaling, and access methods. They also exist in various degrees of conformance with standards. There are multiple standards because no single network technology serves the needs of all users. Major sections of the NTIA report are devoted to LAN standards.

Standardization of local network protocols has been ongoing since February 1980, when the work on Project 802 was begun in the United States by the IEEE. The planned output of Project 802 is a family of six standards that will define a set of interfaces and protocols that permit user applications to be served by a number of networked devices. The applications include file transfer, graphics, word processing, electronic mail, office automation, digital voice, and digital video. Data devices on the network include computers, terminals, mass storage devices, printers/ plotters, and bridges and gateways to other networks.

The IEEE 802 Committee includes six working groups, 802.1 through 802.6, and two Technical Advisory Groups (TAG's)--802.7 and 802.8. Table 2-2 is a listing of the standards produced by the working groups and the status of their documents. The Broadband Technical Advisory Group (802.7) prepared a Recommended Practice/Guideline with the first draft produced in June 1985. The Fiber Optics Technical Advisory Group (802.8) provides advice to the other groups and is not preparing a standard. The TAG's do not produce standards.

The 802.1 document describes the relationship between the 802 standards and the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Reference Model. It also explains the 802 standards relative to higher layer protocols, internetworking, and network management issues as depicted in Figure 2-3. The 802.2 Logical Link Control (LLC) document specifies protocols to control one or more logical links on a single medium. The 802.3 standard, Carrier Sense Multiple Access/Collision Detection (CSMA/CD), specifies an interconnection technique for stations to share access to a 50-ohm baseband coaxial cable bus. The 802.4 token bus standard specifies an interconnection technique for devices to share access on a bus topology, defines protocols used by the physical layer and medium access control (MAC) sublayer, and relates the LAN protocols to higher layers. The 802.5 token ring standard specifies a point-to-point ring

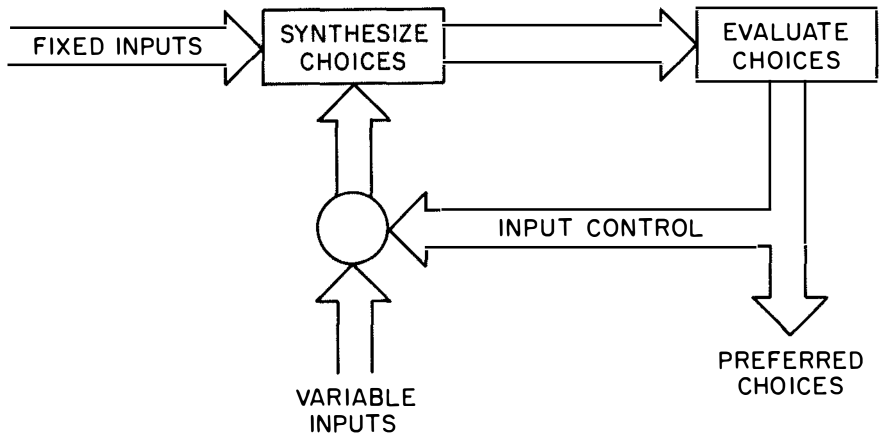


Figure 2-2. Approach to characterizing access areas.

Table 2-1. Experimental Goals

	FEATURES	FUNCTIONS	FACILITIES
DEMONSTRATIONS	Service parameters (e.g., access time, throughput, grade of service, etc.) as perceived by users are deemed acceptable based on subjective, qualitative observations.	Confirmation that switching, transmission, controls, and protocols are operating satisfactorily.	Hardware and software components are reliable and within specifications based on daily operations and outage occurrences.
TESTS	Specific user-oriented performance and engineering parameters are measured and their values are found to be within tolerable limits.	Network functions such as error control, media access, security, and least cost routing are tested and quantities measured indicate pertinent parameters (e.g., error rate, switching time) are within specified values.	Synchronization, signaling, transmission, switching, and other major subsystems meet reliability and availability requirements based on quantitative measures of downtime and MTTR over long periods of time.
EVALUATIONS	Service offerings and transmission media are evaluated by comparing various terrestrial and satellite systems using common quantitative measures of the attributes of each system. Preferred offerings or means are identified based on analysis of cost effectiveness.	Quantitative comparisons between various system alternatives (such as routing algorithms, overload controls, crisis management techniques, and MLPP) provide means to select optimum based on performance and cost.	Administration, operation, and maintenance procedures, and equipments are assessed and control techniques (centralized and distributed) evaluated in order to select optimum network management system.

Table 2-2. IEEE Project 802 Committees' Standards and Status

IEEE STANDARD	TITLE	STATUS
802.1	Overview, Internetworking, and Management	Completion not projected
802.2	Logical Link Control	Published, 1985
802.3	CSMA/CD Access Method and Physical Layer Specifications	Published, 1985
802.4	Token-Passing Bus Access Method and Physical Layer Specifications	Published, 1985
802.5	Token-Passing Ring Access Method and Physical Layer Specifications	To be completed in 1985
802.6	Metropolitan Network Access Method and Physical Layer Specifications	Initial Development

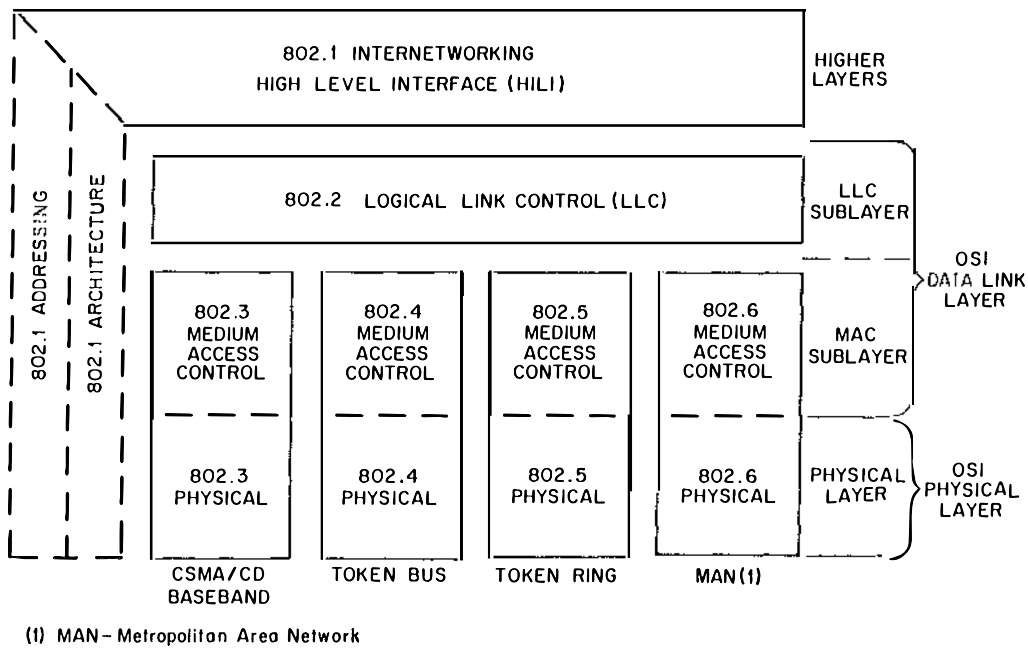


Figure 2-3. IEEE 802 family of standards.

topology and a token passing access method. The 802.6 standard will specify protocols for Metropolitan Area Networks (or MAN's), which encompass larger geographical areas--typically between 5 km and 50 km. This standard is in initial development.

The tutorial local area network survey described here is expected to provide a foundation for future ITS studies of LAN technology, interconnection, and performance in support of ISMA and other Federal agencies.

Optical Fiber Applications to ISDN User Interfaces. Federal agency requirements for intrafacility ("on-premise") data communications have burgeoned as the result of unprecedented growth in office automation and distributed data processing. This growth, not only in aggregate capacity requirements, but often also in higher digital bit rates for individual work stations, has been paralleled by announcements, from several carriers, of near-term offerings of ISDN-type digital transmission services to customer premises. These planned services range from the ISDN Basic Interface rate of 2B + D to the ISDN Primary Interface. The services will be available much earlier than was predicted just a year ago. This is fortuitous for the numerous Federal agencies facing intrafacility communications upgrades to accommodate drastic increases in transmission requirements. While it is still true that some 80% of all data transactions are between end-users within a local site, the long-haul 20% manifestly increases with total traffic load.

The potential availability of digital "pipes" to the outside world offers new opportunities to the planner of on-premise systems, but also presents new challenges and often requires a basic reordering of conventional approaches--e.g., thinking in terms of total required digital capacity rather than multiples of analog voice circuits. Methods of interfacing to outside networks are now of considerable importance to the planner whose primary concern is design of a communications system within a major building or complex. The planner must not only design the intrafacility system (be it a local area network, combined voice/data PBX, or both) to handle maximum anticipated internal load, but must also make certain the system is compatible with external interfacing to ISDN. The penalty for not doing so is, at best, costly future gateways. For a major installation, time between initial budget submission and system cut-over may be 5 years. Planning ahead--in terms of both anticipating traffic requirements and choosing the best available technology to handle them--is crucial in minimizing chances of early obsolescence.

The technology employed exclusively today for new-installation, long-haul cable transmission is fiber optics. Some telephone operating companies are installing fiber in the local loop, and, in addition to serving business customers, have announced plans for "wiring" residential homes with fiber. Fiber is likely to be the primary transmission medium for bringing ISDN services to the end user, and it is therefore a logical candidate for consideration in extending those services to the intrafacility data user.

Near the end of FY 84, the Federal Telecommunications Standards Committee, chaired by the National Communications System (NCS), established an interagency Fiber Optics Task Group (FTSC/FOTG) to:

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

During FY 85, the FTSC/FOTG, chaired by an ITS staff member, held five 2- or 3-day working meetings devoted to fulfilling these goals. To promote information exchange, numerous commercial firms, including carriers and manufacturers/vendors of local area networks, PBX's, and systems components were invited to give technical presentations to FOTG participants representing 15 civil and DOD agencies. Emphasis was on state-of-the-art intrafacility systems, and much valuable information was released to attendees. Importance of ISDN digital interfacing was stressed by several firms. Content of presentations was not limited to systems using fiber optics, but emphasis was on the growing applications, advantages--and systems availability--of optical transmission.

Many FOTG participants represent agencies who face immediate, major updating of intrafacility communication systems. These include the Library of Congress, Department of Agriculture, Department of Human Resources, and Veterans Administration. Others are analyzing near-term requirements. Attendees have been encouraged to describe individual agency needs, as well as potential solutions offered by vendors. The FOTG thus represents an interactive forum for comparing current, mutual problems.

The FOTG has, as the result of vendor interactions, achieved considerable exposure in the private sector, making major potential suppliers more aware of Government requirements, in addition to expediting industry information transfer to the agencies. This exposure also applies to the standards arena: NCS, ITS, and virtually all other FOTG members are active in the FTSC, and many also participate in EIA Working Groups and Accredited Standards Committees of ANSI. The FOTG chairman has kept the group advised of pertinent activities in all domestic standards organizations.

One proposed Federal Standard (pFS) has been originated within the FOTG: pFS-1070, "Standard Optical Waveguide Fiber Material Classes and Preferred Sizes" (a rewrite of EIA RS-458-A). The pFS was prepared by ITS, reviewed by the FOTG, and submitted to the FTSC, which approved it in late FY 85. Final steps prior to formal adoption will be distribution to Federal agencies for comments and publication in the Federal Register for industry comments, followed by an impact assessment. Table 2-3 gives the pFS-1070 recommended sizes for multimode, graded index fibers.

An in-progress joint NTIA/NCS report, to be published early in FY 86, will address activities of the Task Group and summarize the learning experience since its inception. It will also present technical assessments of several current digital Private Branch Exchanges (PBX's) and pertinent technical factors to be included in local area networks and intrafacility wiring plans. The objective of these assessments is to establish some overall guidelines for selecting a PBX and/or a LAN that will optimally serve agency needs now and in the next several years. The number of available PBX's and LAN's makes the selection process very complex. The methods of switching data via PBX's are continuously expanding. PBX's in the 400- to roughly 20,000-line category are being assessed according to architecture, ease of upgrade to Integrated Services Digital Network (ISDN), major application processors, and reliability. The different vendor techniques for integrating voice and data are being compared. No price or feature comparisons will be made.

In the report, technical and performance differences between the many types of LAN's are discussed and specific characteristics of LAN's that are important for fiber optic implementation are presented. Key questions to pose to LAN vendors have been developed.

Work of the FOTG will continue through FY 86, and is expected to result in formulation of Federal guidelines for use by agencies planning to use optical transmission for intrafacility communications.

DES-Related Federal Standards. The Institute has assisted NCS in the development of Federal Standards that specify interoperability requirements for use of the Data Encryption Standard (DES) in telecommunications applications. The typical ITS role in developing these standards has involved 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 assisted in the development of encryption standards for data, voice, and CCITT Group 3 facsimile. The General Services Administration requires that an assessment of the potential technical and economic impact of all proposed Federal Standards be performed prior to their adoption. The Institute's major contribution to the DES-related standards effort during the past year was conducting such an impact assessment for proposed Federal Standard

Table 2-3. Optional Sizes of Optical Fiber Waveguides

Material Class I (Glass Core, Glass Clad)		
Core Diameter um	Outside (Clad) Diameter, um	Nominal Numerical Aperture (NA)
50	125	0.19 to 0.25
62.5	125	0.27 to 0.31
85	125	0.25 to 0.30
100	140	0.25 to 0.30
Material Class II (Glass Core, Plastic Clad)		
Core Diameter um	Outside (Clad) Diameter, um	Numerical Aperture (NA)
200	To be specified	To be specified
400	To be specified	To be specified

Note: All diameter tolerances shall be called out in an applicable detail specification.

1029, which relates to the encryption of digitized speech.

High-Speed Modem Federal Standards. In continuing support of NCS and the FTSC, the Institute has produced two proposed Federal Standards. 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 a modulation technique known as Differential Quadrant encoding.

During the past year ITS also conducted a technical and economic impact assessment for pFS-1005A, which has been submitted to NCS, and is now in formal coordination within the Federal Government. This typically is the last step prior to a Federal Standard's adoption. A draft of pFS-1006A has been published and Government, industry, and public comments have been solicited.

User-Oriented Data Communications Performance Standards. The Institute has pioneered the development of methods and procedures for specifying and measuring performance of data communications systems and services as seen by the end user. The System Performance Standards and Definition Group has conducted measurements on the ARPANET and, more recently, on several Public Data Networks to validate measurement approaches planned for incorporation into national standards. This work resulted in the adoption of the first such document in 1983: American National Standard (ANS) X3.102, "Data Communication Systems and Services--User-Oriented Performance Parameters."

In 1985, the Federal Telecommunications Standards Committee (FTSC) proposed adoption of ANS X3.102 as Federal Standard (FED STD) 1033, to be mandatory for all agency procurement of data communications systems and services. The final action prior to FTSC approval and submission to the General Services Administration (GSA)--who publishes and implements FED STD's--was that of conducting an impact assessment in accordance with GSA requirements.

The primary purpose of the impact assessment is to ascertain probable economic and technological impact of the Standard's adoption, and to survey commercial availability of products required to implement it. An ITS staff member conducted the assessment for proposed FED STD 1033, reviewing formal comments on the document and its predecessor ANS X3.102. He also conducted telephone interviews with data communication users (including Federal agencies/departments and private-sector firms), data communications service providers, and test equipment manufacturers.

This study revealed marked enthusiasm for Federal adoption of the proposed FED STD and documented that voluntary use of ANS X3.102 is growing and is serving a vital purpose for both Federal and private data users. As reflected by the user survey, there is considerable optimism over future cost savings resulting from implementation of a Federally adopted performance standard. One major Federal agency that has most effectively implemented parameters of an earlier version of the standard for data service procurement commented that its "efficiency and cost-effectiveness have been well proven."

Federal Standard 1033 was formally adopted in late summer of 1985. A companion standard on performance measurement methodology, also the result of ITS work, was in the formal balloting process for adoption as an American National Standard in late FY 85. This proposed standard is briefly described in Section 2.3.

Other Work in U.S. Standards Committees. One of the tasks that ITS is fulfilling for NCS is that of representing NCS/TS (Technology and Standards Office) on selected standards committees.

Representatives from ITS have actively participated in work of American National Standards Institute (ANSI) Accredited Standards Committee (ASC) Task Group X3S3.7. The interest of this Committee is reflected in its title, Public Digital Network Access. Meetings of this Committee are 1 week long and occur five to six times per year. Standards contributions are sent to X3S3 (the parent committee) and then, as appropriate, to the International Organization for Standardization (ISO) and the International Telegraph and Telephone Consultative Committee (CCITT). The ANSI is the official U.S. Member Body in the ISO. United States contributions to CCITT are coordinated by the Department of State.

In the past, Task Group X3S3.7 has been a leader in developing CCITT Recommendation X.25, which describes the data terminal equipment (DTE)/data circuit-terminating equipment (DCE) interface for packet switched public data networks. The 1980 version of CCITT X.25 has been adopted by the ANSI as American National Standard (ANS) X3.100 and by the Federal Government as Federal Standard

(FS) 1041/Federal Information Processing Standard (FIPS) 100. Subsequently a new, updated version of X.25 was adopted by the CCITT in 1984.

The Institute cooperated with committee representatives from the National Bureau of Standards (NBS), the National Communications System (NCS), and the American Telephone and Telegraph Company (AT&T) in writing and coordinating approval of a new version of ANS X3.100 based on X.25 (1984). Original drafts were developed and then revised at ITS to reflect comments from X3S3.7 Task Group members. Further changes in the text are expected as the work progresses into the next fiscal year. One of the goals of this work is to align FS 1041/FIPS 100 with the new ANS X3.100 so that there are as few differences as possible between these standards. This will enable the Federal Government to procure, at a more reasonable cost, X.25-based systems that are compatible with X.25 networks in this country. This type of effort enhances the interoperability of government communications systems in times of national emergency.

Among other work, ITS prepares technical reports for the NCS. Short, summary-type technical briefs describe technical and/or economic developments impacting communications systems. Topics dealt with in FY 85 included Computer Inquiries I, II, and III by the Federal Communications Commission, and the Federal Court decision that dealt with the divestiture of AT&T.

An NTIA Report, entitled "Switched Networks and Signaling for the ISDN," is also being prepared. This report describes recent communications network hierarchical structures, signaling, and the changes that are taking place in these networks as a result of the AT&T divestiture. Switches and technology that are involved in these network changes and the evolution to an Integrated Services Digital Network (ISDN) are addressed in detail.

Other standards committees where ITS staff members have represented the NCS include: EIA 30.1 (Signal Quality), EIA FO-2 Committees on Fiber Optics Standards, EIA FO-5 (Industrial Liaison for Government Optical Fiber Systems), the DOD Joint Steering Committee for the MIL-STD-188-Series, and ASC T1D1.3 (Physical Layer).

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, Defense Communication Agency (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, and has 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 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.

A major contribution the past year has been the development of a unique cryptographic design that uses an approved DOD COMSEC device, yet still meets the requirement of meteor-burst communications for low synchronization overhead. Another contribution was the development of the preliminary system design for a shipboard position location system that uses meteor-burst communications.

ISDN Technical. The Director of the Institute for Telecommunication Sciences also serves as the Chairman of the ANSI-Accredited Telecommunications Standards Committee's Technical Subcommittee T1D1 on Integrated Services Digital Networks (ISDN's). This subcommittee coordinates U.S. efforts to develop National standards on ISDN and provides input to the U.S. CCITT ISDN Joint Working Party, which prepares U.S. contributions to the CCITT Study Groups responsible for international ISDN standardization. Where appropriate, ITS performs internal technical studies to assist these committees in exploring and resolving key ISDN issues as they arise.

The International Telegraph and Telephone Consultative Committee defines an ISDN as:

> "A network evolved from the telephone network that provides end-to-end digital connectivity to support a wide range of services, including voice and nonvoice services to which users have access by a limited set of standard multipurpose customer interfaces."

The end-to-end digital connectivity eliminates the requirement for analog voice-band modems to communicate data. However, some form of voice digitization is required.

The original ISDN concept assumed that the ISDN would be a digital successor to the public telephone network and would be transparent to the type of information being transmitted--whether it be speech, facsimile, or digital data. As CCITT studies have progressed, it has been recognized that this may be an over-simplified approach. In the real world it may be necessary to be aware of the types of information being transmitted and to tailor or adapt network facilities to efficiently meet user needs. The concept now is that a limited set of multipurpose user/network interfaces will connect users with "an ISDN" that may be a conglomerate of mutually interconnected networks not necessarily having the same characteristics.

A major premise in ISDN planning is that a broad range of voice and data services will be supported. These services will be integrated through digital connectivity between users. Services such as telemetry, security monitoring, electronic mail, electronic funds transfer, voice, facsimile, graphics, videotex, and bulk data transfer between computers are intended to be available through ISDN. In the United States, the ISDN services will use public and leased data channels and both circuit- and packet-switched facilities and will provide extensive interconnection among networks. Media will consist of wire pairs, coaxial cable, optical fiber cable, and satellite systems. Message-switching does not appear as part of the current planning, but may be offered later.

Existing networks use many interfaces in connecting to user terminals. Most of these would be eliminated as the ISDN interfaces evolve. Existing interfaces (e.g., RS-232-C) could operate in an ISDN environment using a special adapter. Such an interim solution would eventually be phased out.

The basic ISDN user-network interface will have two 64-kb/s "B channels" for information transfer and a 16 kb/s "D channel" for signaling and low-speed data. This is the 2B + D basic channel structure. Multiples and submultiples of these data rates are being determined by the CCITT. High-volume users will have available a 23B + D configuration at the user/network interface. This is a primary rate channel structure for a PABX or LAN connections to the ISDN.

The ISDN is being structured so that current service-dedicated networks may be integrated into "an ISDN" where appropriate and cost-effective. Examples of existing networks that may be integrated into a future ISDN are packet-switched networks and circuit-switched data networks such as telex. Private networks and LAN's are not expected to be integrated, although they may be interconnected to the ISDN as shown in Figure 2-4. The evolution to ISDN is expected to take one or two decades and will probably take place according to national or geographic boundaries, based on national priorities and needs.

Facilities that are already in place are to be part of this transition. The present digital networks will be a point of departure for the integration of services based on economic considerations and technological evolution. Equipment is not being discarded except through obsolescence. The 64 kb/s PCM digital signal, the T-carriers, stored program control, and user-network signaling will all be essential components of the ISDN.

Previous work on ISDN by ITS staff members produced a background report on the ISDN global numbering plan. This year the report has been expanded and revised for publication as an NTIA Report entitled "ISDN: Numbering, Addressing, and Interworking" (by Pietrasiewicz et al.).

In FY 85, the Institute also completed and published a study on voice quality measurements and related standards development (NTIA Report 85-188, Hoffmeyer). This study reviewed current and planned techniques and standards for describing the quality of transmitted speech and pointed out several areas where substantial new research is required. This work will be continued and expanded in FY 86.

A related effort in FY 85 was directed toward developing improved voice quality of service (QOS) standards for telephony systems using signal processing and pattern recognition techniques. The ITS approach involves the use of an expert pattern recognition methodology and system for automatically evaluating and selecting objective voice quality parameters and classifying test data in a manner consistent with the subjective perceptions of humans. Developing this methodology has led to identification of five separate projects: (1) Standard Speech Source Design, (2) Impairment Generator Design, (3) Testbed Development, (4) Statistical Test Design, and (5) Test Set Design. The Test Set is the final output of this project and is expected to be used in testing the performance of operational telephone systems. The test set will make the desired objective parameter measurements (including the effects of delay) from each end and will map the vector of parameter values into one of five classes of quality. The end result could be a readout of one of five performance classes, i.e., excellent, good, fair, poor, or unacceptable, along with an associated measurement confidence level.

The main thrust of the project thus far has been in the planning of the Test Set as described by Figure 2-5. Previous tests measuring loss, noise, and echo parameters have shown that subjective (human) classification spreads over all five classes. These data were regenerated from their summary tables and have been processed using the standard statistical package. The package permitted a quick suboptimum analysis of the data using correlation, regression, and linear discriminant analysis. This analysis shows that with these standard measurements of loss, noise, and echo and using linear discriminant functions, the classifier performance is quite poor. These conclusions support the need for continued development of the expert system classifier in Figure 2-5.

At the close of FY 85, the Federal Communications Commission (FCC) issued a Notice of Proposed Rulemaking (NPR) concerning policy and rules for competitive common carrier services. This notice, known as the Third Computer Inquiry, is expected to have major impact on the telecommunications industry and the future development of ISDN's. The FCC proposes to eliminate structural separation for dominant carrier provision of enhanced services. The Institute provided technical inputs to NTIA policy experts responsible for preparing the Administration's response to this NPR. Technical areas covered included ISDN, Packet Switched Services on the D-Channel, Network Channel Terminating Equipment, Underlying Network Technologies,

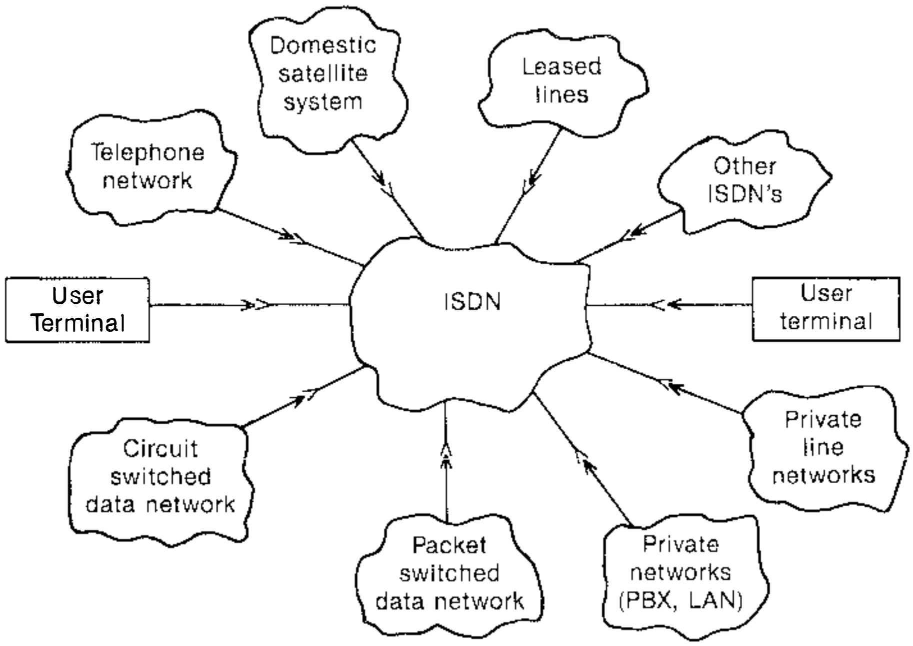


Figure 2-4. Interim interconnection of dedicated networks and ISDN(s) via interfaces.

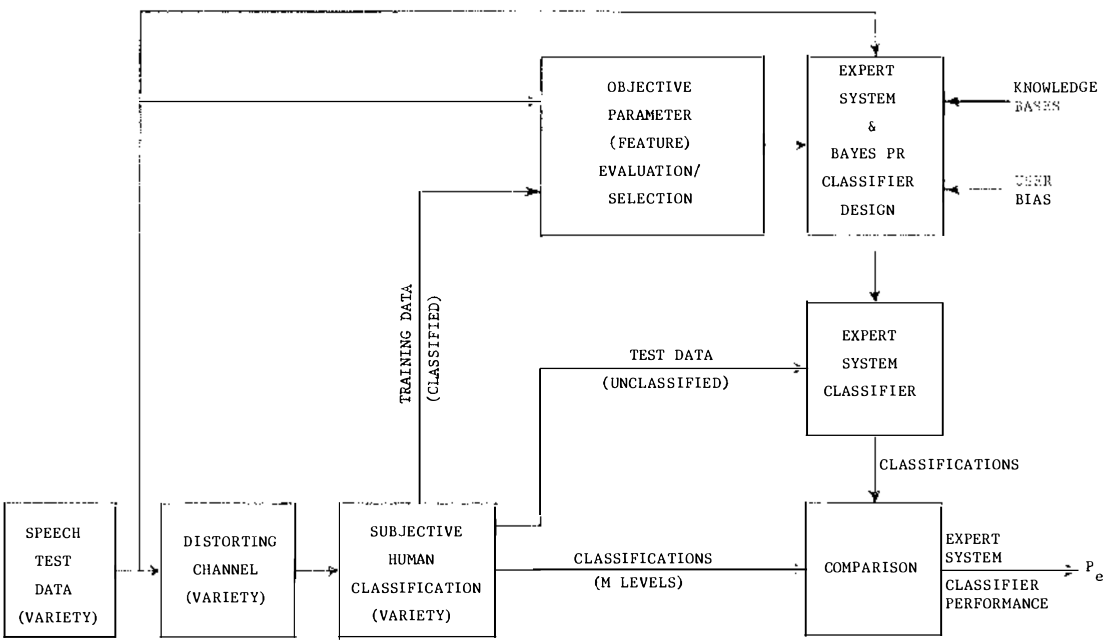


Figure 2-5. Development and testing of expert system for QOS classification.

Comparably Efficient Interconnection, and the existence of possible bottleneck facilities. One concept developed in the ITS input is that regulatory and accounting controls might be directed toward ensuring that dominant carriers provide certain basic functions and signals at equitable rates to potential competitors, rather than ensuring that they provide "comparably efficient interconnection" to bottleneck facilities used in their own competitive offerings. The ITS participation in the Third Computer Inquiry is expected to continue throughout the proceedings and well into FY 86.

Amplitude Companded Sideband (ACSB) Performance Measurements. The introduction of narrowband technologies into the land-mobile bands promises to alleviate the crowding that is becoming a significant problem in metropolitan areas. A Notice of Proposed Rulemaking issued by the Federal Communications Commission (FCC) in April of 1984 describes a channel structure and licensing plan for the use of narrowband technologies on a regular basis in the 150 MHz band of the Private Land Mobile Radio Service. In March of 1985, the FCC released a Report and Order that amends Part 90 of the FCC Rules and Regulations to authorize the use of narrowband technologies in the 150 MHz band by splitting the 30 kHz channels into 5-kHz subchannels. The Report and Order allows for the licensing and use of ACSB radio systems, a narrowband technology, on a noninterfering basis.

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS), working with and for the National Institute of Justice (NIJ), develops performance standards for the full range of law enforcement equipment including radio equipment. Sponsored by the LESL/NBS, the Institute is working on the development of performance measures for ACSB. The purposes of this 2-year project are to identify and/or develop the appropriate performance measures for ACSB, and then to determine the values for these measures that represent the same level of performance that is specified for FM radios in NIJ Standards.

ACSB radio uses a single sideband, amplitude modulated emission with a fully suppressed carrier and includes a pilot tone as shown in Figure 2-6. The pilot tone provides a frequency reference for the receiver, and its level is inversely proportional to the instantaneous amount of compression of the audio signal occurring in the transmitter. The receiver uses the level of the pilot tone to restore the dynamic range of the audio signal. The pair of block diagrams of Figure 2-7 show the major elements of an ACSB transmitter and receiver, respectively. Many claim that ACSB is "as good or better" than FM in terms of range and intelligibility. The effective increase in spectrum efficiency has been estimated to be about a factor of three.

Efforts during FY 85 have been directed at collecting information and making preparations for the actual performance measurements to be made in the next fiscal year. The minimum level of acceptable performance for 25- or 30-kHz FM systems is usually represented by a SINAD value of 12 dB. (SINAD is the ratio of a 1000 Hz test tone + interference + noise + distortion to the interference + noise + distortion as measured at the output of the receiver.) The origins of this de facto standard are unclear; however it appears that an earlier measure of minimum FM performance--20 dB quieting--is equivalent to the 12 dB SINAD. Initial ITS studies indicate that some sort of SINAD measurement is not only appropriate, but also a practical measure of ACSB performance. The SINAD measure for ACSB must somehow include the effects of companding. Two of the several approaches being examined are: SINAD versus the relative levels of the audio tone and the pilot tone, and SINAD versus the baseband audio input level.

During FY 85, various SINAD measures for ACSB were identified, as well as techniques to measure other performance parameters such as peak envelope power. Other activities included a thorough literature search, observations of operating ACSB systems, and preliminary measurements on ACSB radios. In FY 86, the intelligibility (probably represented by the subjective measure called articulation score) of an FM system operating at 12 dB SINAD will be determined. Then, the value of SINAD for an ACSB system that produces the same level of intelligibility will be sought. The study will continue into FY 87.

SECTION 2.2 SATELLITE NETWORK ANALYSIS

The commercial satellite industry is well established and a wide selection of satellite communication services is available. However, strong U.S. efforts to enhance satellite technology and to improve spectrum and orbit efficiency are needed today for two reasons: to assure cost effective and competitive satellite communication services to U.S. users in the future, and to maintain U.S. leadership in the development and application of satellite communication technology. The National Telecommunications and Information Administration is working with other Federal agencies to ensure that adequate frequency and geostationary orbit resources are available to support growth and competition in the U.S. satellite communications industry. The Satellite Network Analysis Group in NTIA's Institute for Telecommunication Sciences conducts research and engineering programs that support this goal. Two objectives are emphasized: supporting U.S. preparation for international negotiations on satellite communication frequency and orbit assignments, and assessing the performance and cost-effectiveness of advanced satellite technologies.

Broad responsibility for international regulation of telecommunications resides in the International Telecommunication Union (ITU). Coordination of spectrum and orbit use among countries is effected through ITU Administrative Conferences. The 1979 World Administrative Radio Conference (WARC) passed a resolution calling for a World Space Administrative Radio Conference (Space WARC)

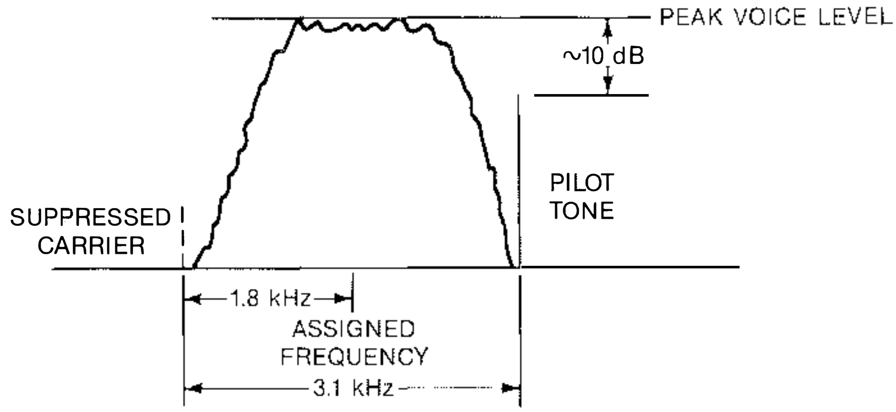


Figure 2-6. Idealized emission spectrum of an amplitude companded sideband (ACSB) radio signal.

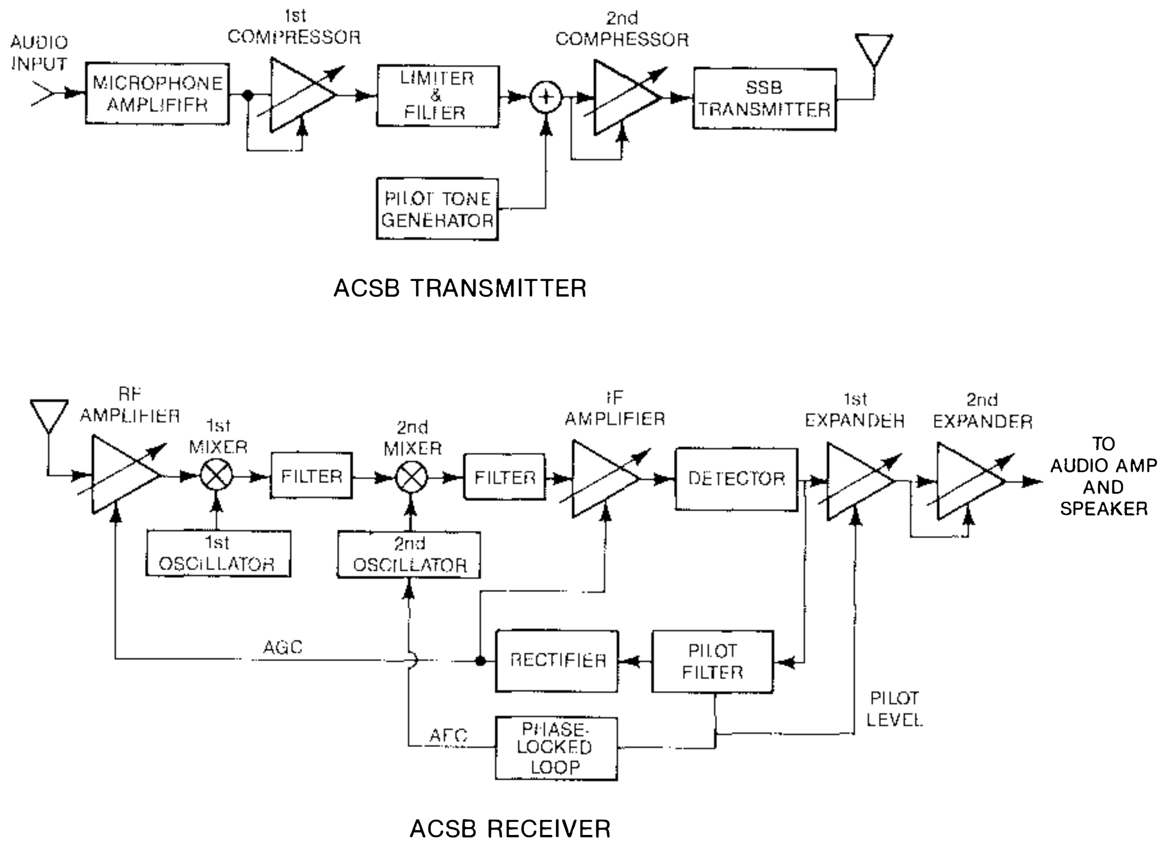


Figure 2-7. Block diagrams of an amplitude companded sideband (ACSB) transmitter and an ACSB receiver.

to be convened in two sessions. The first session was directed to decide which space services and frequency bands should be planned and to establish principles, technical parameters, and criteria for planning. The second session was directed to implement the decisions taken at the first. "Planning" here describes the actions and negotiations necessary to achieve international agreement on the assignment of frequencies and orbit locations for future space (satellite) services. A major objective of the Institute's FY 85 program in satellite communications was to contribute to U.S. preparations for these two conference sessions.

The most promising means of improving spectrum and orbit efficiency in satellite communications require the development of advanced technology. Proposed technology enhancements for satellite communications include:

- higher frequencies that permit narrower beamwidths (for closer satellite spacings) and greater bandwidths (for increased capacities per satellite)
- multiple, switched spot beams directed to relatively small regions of the earth (for increased frequency reuse)
- single and/or multiple scanning spot beams (for enhanced satellite versatility)
- on-board switching (to provide dynamic adaptability to user needs and to realize the full benefits of fixed and scanning spot beams).

The Institute's FY 85 advanced satellite technology work has been aimed at defining experiment criteria and specific experiments needed to realize and optimize these technology enhancements.

The FY 85 work of the Satellite Network Analysis Group comprised five technical projects: a satellite communications project in each of the two areas just described, and three related projects addressing radio channel and equipment characterization. Each project is described in more detail below.

Technical Support to Planning and Preparation for the 85/88 Space WARC. The support by ITS to preparation for the Space WARC encompassed three separate tasks: (1) Enhancement of the Geostationary Satellite Orbit Analysis Program (GSOAP), (2) Studies of Earth Station Antenna Side-Lobe Characteristics, and (3) Participation in the IRAC Ad Hoc 178 group responsible for Space WARC preparatory studies.

A satellite network consists of a satellite and all earth stations associated with it. GSOAP is a software system for analyzing mutual interference among geostationary satellite networks. Figure 2-8 illustrates the interference problem in a very simple case, where only two satellites are in orbit and three earth stations are associated with each. The solid lines connecting the satellites and earth stations represent wanted paths, while the dashed lines represent interfering paths. Each earth-station transmitter acts as an uplink interferer, and each satellite transmitter acts as a downlink interferer, to the other network. The interference power at the final destination of a signal (i.e., an earth-station receiver) is the total of all uplink and downlink interference powers. The actual situation is more complicated because the radio signal in each path shown with either a solid or dashed line consists of a set of multiple transponder signals, each assigned to one of two orthogonal polarizations. The overall carrier-to-interference ratio (CIR) must be calculated for each transponder signal of each network. The CIR's depend on the radiated powers from, and the transponder arrangements of, the wanted and interfering transmitters, the radiation patterns of the earth station and satellite antennas, and the polarization angles, propagation losses, and rain-induced depolarization of both the wanted and the interfering radio signals.

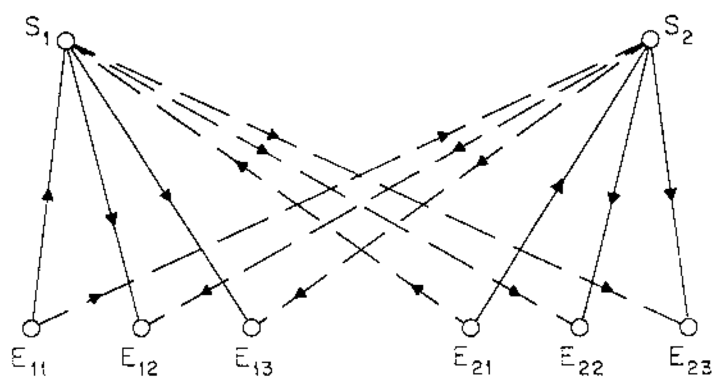


Figure 2-8. Satellite networks. (Two symbols, E and S, stand for satellite and earth station, respectively. A solid line is a wanted path, and a dashed line is an interfering path.)

An initial version of GSOAP was developed at ITS in prior fiscal years. As described in more detail below, GSOAP currently calculates CIR's based on the rectangular-spectrum assumption. GSOAP implements three propagation models--the CCIR, 1977 WARC-BS, and 1983 RARC-BS-R2 models. GSOAP implements 8 and 12 emission patterns for the satellite and earth-station antennas, respectively, either taken from the ITU and Federal Communications Commission (FCC) documents or developed by ITS. It is planned that GSOAP will calculate baseband system performances such as the signal-to-noise ratios (SNR's) or binary error probabilities in the future.

Enhancement of GSOAP has continued throughout FY 85. All technical problems known to date for the double polarization, rectangular-spectrum, single antenna/modulation, and multiple-transponder scenario version have been resolved. Solutions for these problems have been implemented in the latest version of the program. In a double-polarization scenario, each satellite can have up to two orthogonal polarizations. In a rectangular-spectrum scenario, it is assumed that, for the signal passing through each transponder, the shape of both the signal spectrum and receiver passband are rectangular and their bandwidths are identical. In a single-antenna/modulation scenario, each earth point has a single antenna, and a single modulation-type signal is transmitted over the satellite network through each transponder. In a multiple-transponder scenario, each satellite has a number of transponders.

Substantial reductions of required array sizes in GSOAP were achieved in FY 85. GSOAP can now analyze a scenario involving 100 satellites and 1000 earth points on a general-purpose computer. Several improvements have been made in the input data file and output presentation formats.

The ITS effort in developing GSOAP has been coordinated closely with the Office of Spectrum Management (OSM) of NTIA. The OSM plans to use GSOAP in preparing for intersessional meetings and the second session of the 1985/1988 Space WARC, both in the United States and at the site of the conference. It is expected that GSOAP will interface with a data base developed by NTIA/OSM and a scenario synthesis program being developed under a contract from OSM to private industry.

A program called the data retrieval program (also called the interface program) that reads necessary data from the data base and reformats the data as the GSOAP input data files has been developed by NTIA/OSM and transferred to ITS. This version of the data retrieval program interfaces with an earlier version of GSOAP that analyzes only single-polarization and single-transponder scenarios. An effort is under way to adapt the interface program to the latest version of GSOAP.

An algorithm, developed by ITS and implemented in GSOAP, for modeling a shaped-beam satellite antenna was installed on a computer operated by the International Telecommunication Union in Geneva, Switzerland, at their request. This algorithm allows the user to calculate the satellite antenna gain in the direction of an arbitrary earth point when the emission pattern of the antenna is given graphically on the surface of the Earth with several contour lines corresponding to a set of gain values.

Several technical publications on GSOAP were published or completed in FY 85. A polarization angle report, NTIA Report 84-163, was published in October 1984. A draft NTIA Report, technical basis for GSOAP, is under review and will be published early in FY 86. A draft NTIA Technical Memorandum, "User Manual for GSOAP," has also been prepared and will be published in FY 86.

The second task under the 85/88 Space WARC project involved studies of earth station antenna side-lobe characteristics. This work is being motivated by two factors: the mandatory use of reference patterns in calculating interference in the United States, and the scarcity of data describing the performance of earth station antennas used for Fixed-Satellite Service (FSS), particularly at 14/11 GHz.

In response to these needs for technical information, ITS has collected off-axis gain performance patterns of antennas produced by several U.S. manufacturers. Measured side-lobe performance data for all available antennas listed in applications for licensing by the FCC in the 14/11 GHz band for common carrier services have been obtained and analyzed, and the results have been made available to space services planners, including CCIR study/working groups. The Institute is particularly concerned with the system performance effects of interference levels to and from adjacent satellites in light of the FCC's Report and Order, Docket No. 81-704, which will eventually reduce satellite orbit separations from the present 4° to 2°.

The antenna side-lobe study considered the immediate side-lobe region (1° to 7° away from boresight) and also greater angles to the extent that data were available from manufacturers. Actual antenna patterns from different manufacturers were obtained and digitized to produce a data base consisting of 50 separate patterns for 14 antennas in the 11 GHz (space-to-earth) frequency range and 46 patterns in the 14 GHz range (earth-to-space) for the same 14 antennas. The antennas studied range from 3.5 to 11.0 m in diameter with diameter-to-wavelength ratios (D/λ) from 139 to 523.

All antennas evaluated in this study were designed to meet the rules and regulations of the FCC as updated in 1983, as given by:

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

where θ is the angle in degrees from the antenna boresight. The FCC requires this reference diagram 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 CCIR, in Recommendation 580, has adopted a similar design objective for antennas with a $D/\lambda > 150$. That design objective is that at least 90% of the side-lobe peak amplitudes not exceed

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

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 $\theta > 20°$.

Figure 2-9 shows statistical results of ITS analysis for all antennas studied in the downlink (11 GHz) frequency range. Figure 2-10 shows results for all antennas studied in the uplink (14 GHz) range. The region between 1° and 4° away from the boresight is an extremely sensitive interval with respect to interference to/from the earth terminal. The FCC's decision to move U.S. satellites from 4° to 2° separation reduces the level for the reference envelope to avoid unacceptable interference.

From the study results summarized in Figures 2-9 and 2-10, it can be concluded that:

- The performance of some of the new U.S. antennas do not conform with the current FCC requirements. For example, see the analysis results shown in Figure 2-10 for the angular region 1°-4°.
- In their decision to move satellites from their present 3°-4° separation, the FCC has noted that existing smaller antennas (3-7 m in diameter) will not, in most cases, meet the new regulations. The FCC has given users of existing antennas until 1987 to either replace or retrofit these existing antennas in order to conform to the new regulations. In light of our studies, it is probable that even when retrofitted, many antennas still will not meet the rules and regulations, particularly in the region between 1° and 7°.

The third task under the 85/88 Space WARC project was to support the IRAC Ad Hoc 178 Working Group. FY 85 support to Ad Hoc 178 was directed primarily to the development of satellite usage scenarios and analyses of these scenarios using GSOAP. The results of these scenario analyses were reported at Ad Hoc 178 meetings. ITS developed input data for GSOAP to describe a scenario with 44 satellites and 560 earth points. The scenario included 8 INTELSAT satellites, 25 U.S. domestic satellites, 3 Canadian satellites, 3 Mexican satellites, and 5 satellites for Inter- and South-American nations. The actual transponder capabilities (number, operating frequency, and output power) of each satellite were modeled. Variations of this basic scenario were then analyzed to determine conditions that would produce minimum interference. A computer program was also developed to provide statistical comparisons between two analyses of scenarios that included the same number of satellites. This comparison program proved to be very useful in evaluating the analysis results.

Advanced Satellite Communications Technology Studies. Several elements of advanced technology for communications satellites were noted earlier. These technologies provide benefits to both commercial and military users. The advanced technologies and associated benefits and beneficiaries are illustrated in Figure 2-11.

During FY 84, ITS carefully examined the role it should play in supporting the development of advanced technology for satellite communications. It was concluded that the most important initial contribution ITS could make would be to participate as an experimenter in the National Aeronautics and Space Administration (NASA) sponsored Advanced Communications Technology Satellite (ACTS) program. NASA announced in 1982 its intention to fund, develop and launch an Advanced Communications Technology Satellite. The purpose of the program is to advance the state of the art in the use of higher frequencies (20/30 GHz), multiple scanning beams, frequency reuse, and on-board call routing. The prototype system is designed to provide both thin-route, customer-premise service and heavy-route, trunking capabilities. Private industry, Government agencies, and educational institutions were invited to participate as experimenters. In its role as a National telecommunications laboratory, ITS proposed a number of experiments designed to measure end-to-end system performance. NASA responded favorably to this proposal, particularly since no other experimenter had suggested such measurements. The NASA program was fully funded in FY 85 and a prime contract was awarded to RCA Astro Electronics. The launch of ACTS is now scheduled for 1989, with a subsequent 2-year period of program-participant experiments.

The Institute has been successful in obtaining both a Portable Earth Terminal (PET) vehicle from NASA and a Fixed Earth Terminal (FET) from the U.S. Army Satellite Communications Agency. Forty-five companies have expressed their interest or firm intention to be participants in the program. The Institute's capabilities and experience in data communication standards, propagation modeling, and scientific support to both the Government and private sector telecommunication community place it in an excellent position to provide unbiased guidance to all users.

The studies planned by ITS will focus on the following areas:

- footprint characteristics of both fixed and scanning beams utilizing the Global Positioning Satellite (GPS) constellation

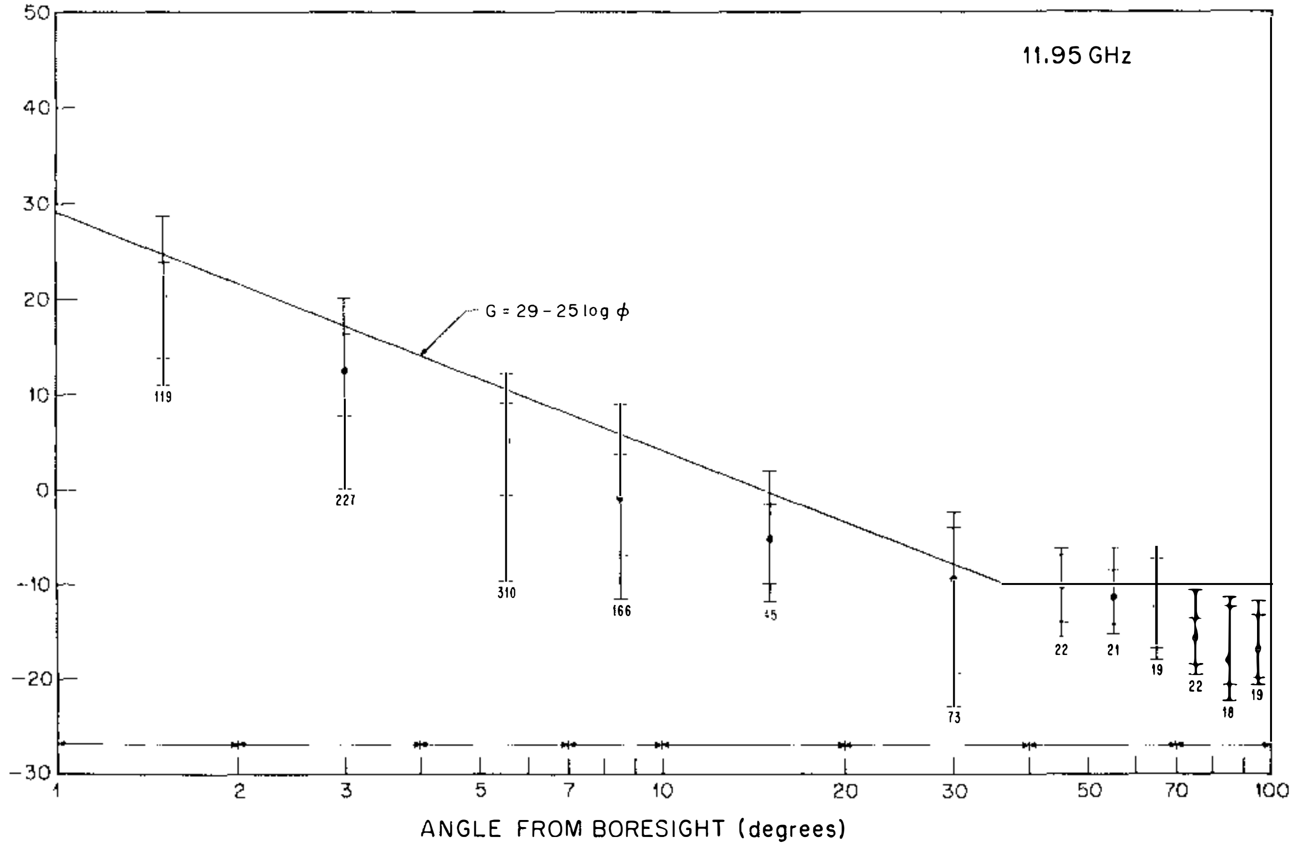


Figure 2-9. Statistical plot of sidelobe peak values for antennas that operate in the 11.700-12.200 GHz frequency range for downlink fixed-satellite service.

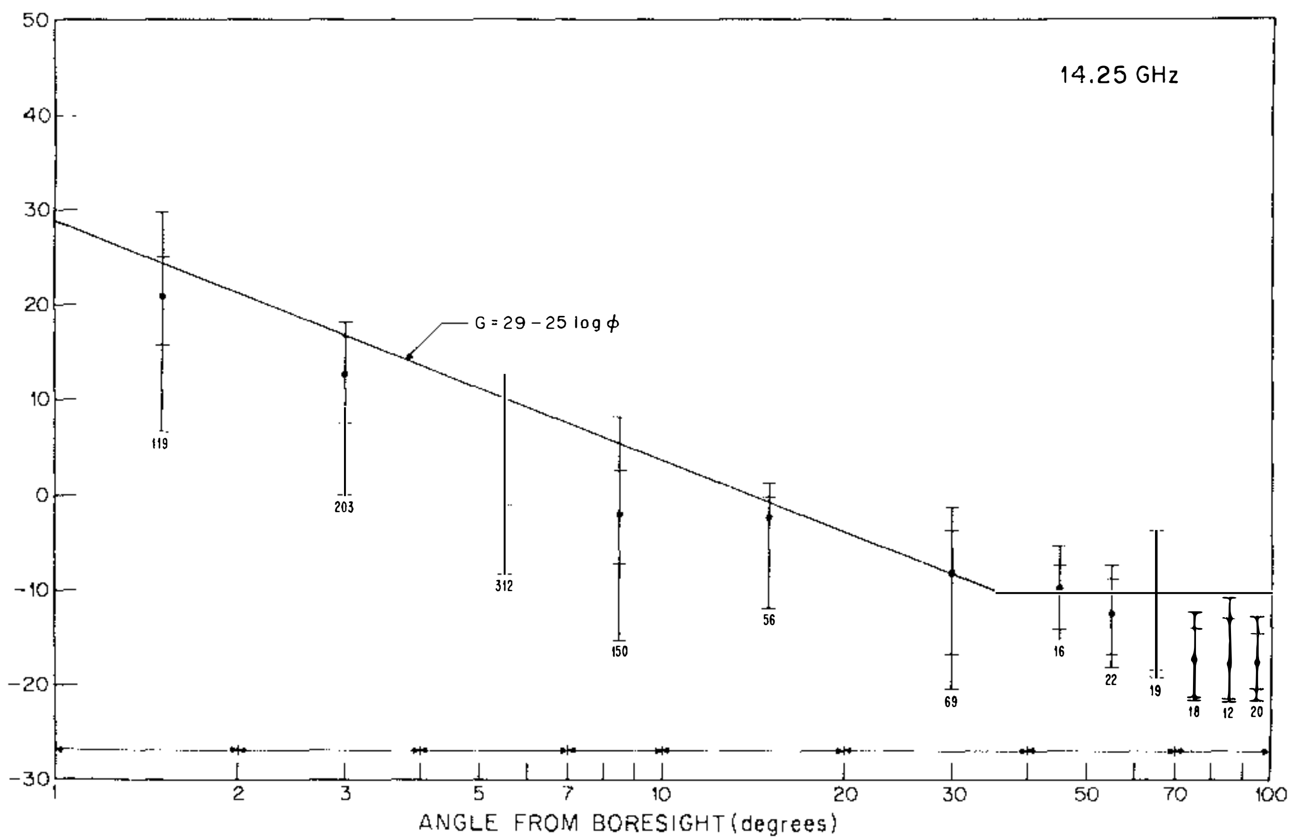


Figure 2-10. Statistical plot of sidelobe peak values for antennas that operate in the 14.000-14.500 GHz frequency range for uplink fixed-satellite service.

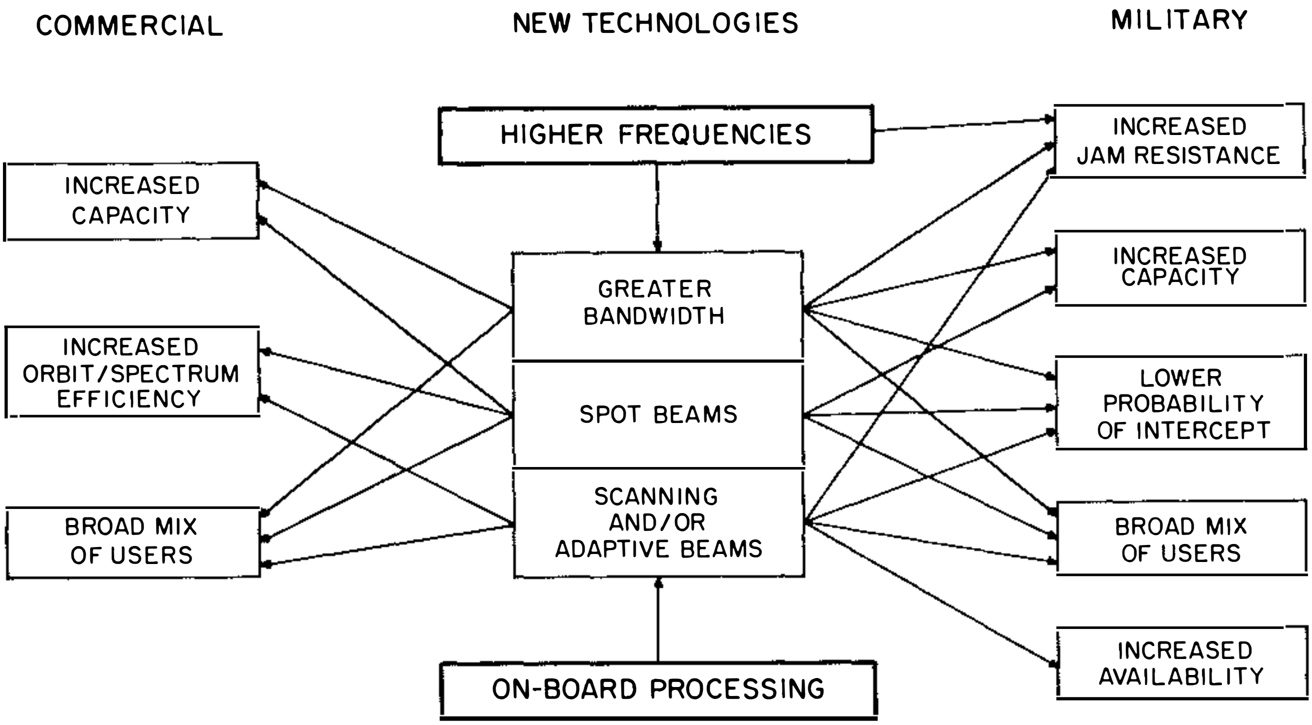


Figure 2-11. The relationships between advanced satellite technologies and associated benefits and beneficiaries.

for extremely accurate positioning and timing data

- o Demand Assigned Multiple Access (DAMA) acquisition, access, and switching delays
- o effects of atmospheric phenomena, including excess attenuation and depolarization
- o impact of encryption schemes such as DES (Data Encryption Standard) on system throughput
- o delays in beampointing and switching.

The ITS experiments will be more fully defined during FY 86, and will be documented in test plans. A detailed program schedule through 1991 will be prepared and all anticipated budget requirements determined. Close coordination with NASA and other experimenters will be continued to ensure maximum benefit for all participants.

Rounded Obstacle Diffraction Studies. The diffraction of electromagnetic waves by a rounded obstacle was investigated in ITS-sponsored studies to extend and correct previously published results. The Institute developed equations and curves for the prediction of diffraction loss that are suitable for both horizontal and vertical polarization and a full range of ground conductivity and dielectric constants. The curves provide attenuation predictions in the transition region between knife-edge and smooth-earth diffraction theory. A paper describing the results of this study was published in the May-June 1985 issue of Radio Science.

Pulse Distortion Studies (Phase II). FY 85 work of the Satellite Network Analysis Group included an analytical study to determine the change in pulse shape for a pulse reflected from the ionosphere. Results from the first phase of the study are published in the November-December 1984 issue of Radio Science. The paper discusses the impulse response for reflection from an ionospheric layer with a sech^2 electron density profile, a constant electron collision frequency, and a vertical component of the Earth's magnetic field. Numerical examples of the response are shown for some representative cases of E and F layer reflection assuming various values of penetration frequency, gyrofrequency, collision frequency, layer thickness, and incidence angle θ.

In the second part of the study, the analysis has been extended to include the distortion effects on a rectangular pulse reflected from the sech^2 model ionosphere and observed at the output of a simple receiver bandpass filter. Stationary phase methods were used to develop an expression, suitable for a small desk-top computer, that calculates the time domain envelope of the received pulse. Ionospheric, source pulse, and filter parameters can be varied to estimate distortion characteristics. A paper discussing the results of this latter work will be published in FY 86.

Stress Loading Facility (SLF) Methodology Investigations. The Stress Loading Facility (SLF) under development by the U.S. Army Electronic Proving Ground (USAEPG) is envisioned as an integrated test system designed to present an electromagnetic (EM) threat test environment to radio frequency (rf) Systems Under Test (SUT) while simultaneously monitoring the response of those systems by measuring key performance parameters. This project involves the investigation and development, by ITS, of Measures of Functional Performance (MOFP's) and recommendations for associated test methods to stress those rf systems whose functional performance is being measured.

It is important that rf systems designed for use in a densely populated EM environment be tested, and have their performance functions stressed, by conditions that are as realistic as possible. It is anticipated that SUT's within the SLF will encounter simulated EM threats that closely resemble those that the system may encounter under "real-world" conditions. An rf system usually has several major functions that it must perform to achieve its purpose. These must be carefully defined to provide a suitable test framework. The performance of the system's major functions must then be tested and measured using carefully designed simulation of the rf environment in which the system is expected to operate.

The purpose of the FY 85 SLF Methodology Investigations was to examine the major functions of two sponsor-selected systems, the performance criteria, the MOFP's used to address each criterion for each function, and the means by which the two systems may be tested and the resulting measured functional performance.

The performance criteria selected for the purpose of this study were:

o Speed - How fast is the function accomplished?

o Accuracy - How correct is the function output?

o Reliability - With what degree of certainty is the function successfully performed?

o Availability - Is the function ready and operable when needed?

o Maintainability - If not ready and operable, is the function readily repaired?

o Vulnerability - Using Data Link Vulnerability Analysis (DVAL) Methodology, how vulnerable is the function to external rf interference, hostile and friendly?

The major system functions selected for the purpose of this study were:

o Signal Detection and Acquisition

o Signal Processing

o Signal Classification and Identification

o Emitter Classification and Identification

o Emitter Location

o Data Communication Link (Intrasystem and Users)

o Target Discrimination.

A matrix that illustrates relationships between performance criteria and major system functions is shown in Table 2-4.

A draft of the report "SLF Methodology Investigations: Volume I - MOFP Development" was delivered to USAEPG in September.

SECTION 2.3 SYSTEM PERFORMANCE STANDARDS AND DEFINITION

Work of the System Performance Standards and Definition Group is focused on the development and application of national and international telecommunication standards. The Group conducts two major NTIA programs. The first, the Data Communications program, addresses a growing need for efficient means of relating the data communication performance requirements of end users with the capabilities of competing system and network offerings. The second, the International Standards program, addresses the need for technically strong, broadly based U.S. contributions to international standards organizations whose published recommendations influence U.S. trade in telecommunication products and services. The two programs are complementary in promoting economic growth and efficient use of telecommunications in domestic and international markets.

Data Communications. Technical projects within the Institute's Data Communications program are directed toward two long-term goals. The first is to strengthen price/performance competition and technology innovation in the U.S. telecommunications industry. The second is to promote efficient procurement and use of telecommunication equipment and services within U.S. Government and private sector organizations. Both goals are being pursued through the development, promulgation, and application of data communication performance standards. Major end products are Federal and American National Standards, which provide a common language for performance description and ensure measurement comparability; prototype test systems, which make implementation of the standards practical and efficient; and technical reports and journal publications, which encourage use of the standards by describing their application in the specification and measurement of representative data communication networks.

Prior work, conducted in cooperation with American National Standards Institute (ANSI) Accredited Standards Committee (ASC) Task Group X3S3.5, has resulted in the development of two standards. The first, American National Standard (ANS) X3.102-1983, specifies 21 user-oriented data communication

Table 2-4. Relationships Between Performance Criteria and Major System Functions for Systems Under Test Using the Stress Loading Facility (SLF)

MAJOR SYSTEM FUNCTIONS	PERFORMANCE CRITERIA					
	SPEED	ACCURACY	RELIABILITY	AVAILABILITY	MAINTAINABILITY	VULNERABIITY
SIGNAL DETECTN/ACQSTN	Signal Detection BW, PW Range, PRI Range, Sensitivity	Frequency Accuracy, Sensitivity	Acquisition Noise BW, Receiver Noise Figure, Detection Probability	(Per Test Incident Report - Army Material Command Regulation 70-13)	(Per Test Incident Report - Army Materia Command Regulation 70-13)	Frequency Range, Receiver Noise Figure, Air Craft Skin/Field Effects
SIGNAL PROCESSING	Signal Processing Time, Signal Digitizing Time, Throughput	System Clock Accuracy, System Clock Stability	Frequency Resolution, Graceful Degradation, FalseAlarm Probability, False-Alarm Rate	"	"	Dynamic Range, Spurious Rejection, Image Rejection
SIGNAL CLASS/IDENT	Time to Classify and Identify a Signal	Frequency Accuracy, A priori Memory Capability	PW Measurement Capability, Percentage Correct, Signal Identification	"	"	
EMITTER CLASS/IDENT	Time to Classify and Identify an Emitter	Frequency Accuracy, PRI Resolution, A priori Memory Capability	PRI Accuracy, PW Accuracy, Percentage Correct, Emitter Identification	"	"	
EMITTER LOCATION	Direction Finder Bandwidth, Time to Locate Emitter	Spatial Resolution, Required DF Accuracy, Azimuth Coverage, Antenna Polarization, Beamwidth, Line of Bearing Accuracy	Percentage Correct, Emitter Location	"	"	
DATA COM LINK (System/Users)	Modulation Technique, Data Rate	C^2 Error Rate, Error Detection and Correction, Bit Error Rate ECM IMPACT ON PROCESSING	C^2 Reliability	"	"	C^2 Susceptibility, Accessibility, Interceptibility, Feasibility (DVAL)
TARGET DISCRIMINATION	Multiple Target Detection Probability, Multiple Target Processing Time	Sorting Time and Accuracy	Multiple Target Signal/Emitter, Identification Probability, Multiple Target Emitter, Location Probability	"	"	

performance parameters (Figure 2-12). The specified parameters provide a method of describing data communication performance that is independent of network technology, topology, architecture, and protocol. This property of system independence makes the parameters useful as a "common denominator" in comparing data communication systems that provide similar services by means of different detailed designs. Because they are system independent, the parameters are also useful in allocating end-to-end performance objectives to network subsystems--the same basic parameters can be used in describing data communication performance at any pair of digital interfaces. ANS X3.102 was formally adopted as a mandatory Federal Telecommunication Standard in July of 1985.

The second standard, proposed American National Standard X3S3.5/135, specifies uniform methods of measuring numerical values for the ANS X3.102 parameters. The basic content of that standard was completed in Fiscal Year 1984. Fiscal Year 85 work resulted in the development of a hypothetical network measurement example that illustrates the standard's use. The example was added to the basic standard as an appendix at the request of Task Group X3S3.5. The resulting document was submitted to ASC Subcommittee X3S3 for formal balloting in April of 1985. The X3S3 ballot was completed successfully, and it is likely that the proposed measurement standard will be published as an approved ANSI standard in FY 86. Federal adoption of the ANSI standard is planned. Widespread use of the two ANSI standards in Federal procurement should provide substantial cost savings by enabling Federal agencies to (1) specify their data communication requirements more precisely, and (2) verify that the performance values stated by equipment and service providers are in fact met.

Technical work in the Institute's FY 85 Data Communications program was directed toward three specific objectives:

1. Development and documentation of the measurement application example, and the presentation of proposed ANS X3S3.5/135 to Government and industry standards committees and potential users.
2. Development of test software and statistical procedures implementing the proposed measurement standards, and their dissemination to U.S. telecommunication service providers and test equipment manufacturers.
3. Detailed analysis of public data network performance measurement data collected by NTIA/ITS during FY 84.

The ANS X3S3.5/135 measurement application example was developed with two objectives:

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

Legend:
- (blank box) Primary Parameters
- (hatched box) Ancillary Parameters

Figure 2-12. Matrix representation of the ANS X3.102 parameters.

1. to ensure that the measurement procedures and guidelines specified in the proposed standard can be efficiently used in planning, conducting, and analyzing practical network measurements

2. to provide initial users of the standard with a realistic prior application to refer to in applying the standard to their particular measurement situation.

As described in the proposed measurement standard, the performance 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.

The application example describes in detail how each phase could be accomplished in a particular, representative measurement situation. In the example, it is assumed that a data communication system is being developed to enable information exchange between application programs in host computers at 100 geographically dispersed sites. The postulated data communication system comprises data transmission, switching, and circuit-terminating equipment capable of connecting any pair of hosts; and the host computer communication access software, including the operating systems. Key components of the example are illustrated in Figure 2-13. The example does not provide a detailed description of the internal design of the data communication network, since only an application program-to-application program (end-to-end) performance assessment is sought. The postulated service could thus be provided via a packet-switched network, a circuitswitched network, or other network types.

The decision context of the experiment is an acceptance test. The test is planned to determine whether the data communication system meets specified performance requirements. These requirements have been defined in terms of acceptance thresholds for a subset of the ANS X3.102 parameters, called the "specified parameters."

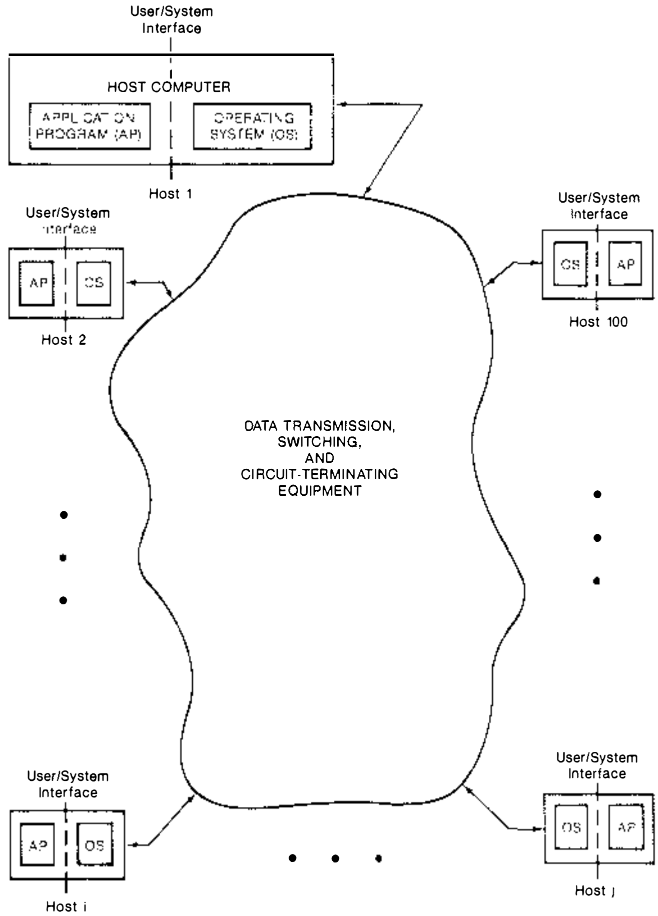


Figure 2-13. Key components of the example.

The objective of the experiment is to determine whether the acceptance thresholds are met under specified conditions. These conditions include: a defined data communication session profile, controlled by application programs specifically developed for performance measurement; fixed values for key performance factors; and a representative background traffic distribution. It is postulated that the outcome of the experiment will be used, with the results of other evaluations, in deciding whether to (1) immediately place the computer communication network in full operational service, replacing an existing network; or (2) subject the system to further development and testing prior to such acceptance. The users wish to accept the system if the true (population) values for all specified parameters are equal to or better than their acceptance thresholds, and to reject the system otherwise.

The acceptability of the system is evaluated by a hypothesis test experiment of the type described in the standard. For each specified parameter, the tested (null) hypothesis is stated as follows:

> The true (population) value of the specified parameter lies in a defined fully satisfactory region.

Precision objectives for the acceptance test are stated by specifying probabilities for the Type I and Type II errors of classical statistics: i.e., the probability of incorrectly rejecting a satisfactory system and the probability of incorrectly accepting an unsatisfactory system. Statement of the experiment objective in statistical terms is necessary to ensure a reasonable compromise between measurement precision and cost.

Table 2-5 summarizes the results of the postulated experiment as presented in the X3S3.5/135 example, and also illustrates how the results of real acceptance tests would be presented in accordance with the standard. For each specified parameter, the following information is presented:

- o the threshold value originally specified in defining the experiment objectives
- o the decision criterion for accepting the tested hypothesis
- o the lower (90%) confidence limit
- o the value measured in the experiment (overall sample mean)
- o the upper (90%) confidence limit
- o a "pass" or "fail" decision based on the stated criterion.

As Table 2-5 indicates, all specified parameters were postulated to satisfy their individual acceptance criteria in the example experiment, and therefore the overall decision would be to accept the system.

Although the experiment described in the X3S3.5/135 appendix is hypothetical, the measurement situation described may be quite typical of that faced by industry and Government communication managers in the procurement and operation of distributed computer networks. The data extraction, data reduction, and statistical design and data analysis software systems described in the example are real programs that are, in fact, being used in experimental measurements of public data networks at ITS and elsewhere. These programs, and related statistical tools developed at ITS during FY 85 and prior years, are briefly described below.

The prototype data extraction software developed by ITS to implement the measurement standard consists of two distinct programs. One program, called XMIT, originates test data communication sessions, transmits user information during established sessions, and records and time-stamps all interface events that occur during such sessions. The second program, called RECV, performs the complementary functions associated with data reception.

Figure 2-14 illustrates the user/system interfaces and interface events monitored by the XMIT and RECV programs during a test. In each computer, the user/system interface is defined to correspond to the software functional interface between the test application program (XMIT or RECV) and the computer's operating system. Signals communicated across these interfaces are of two general types: system calls, which are issued by an application program to request the performance of a particular operating system function; and system responses, which are issued by the operating system to indicate completion of a previously requested function. Each such communication is called an interface event.

The four communication-related interface events that may be initiated by application programs executing in the selected computers are OPEN, WRITE, READ, and CLOSE. OPEN and CLOSE are used to establish and release connections between the test application programs. WRITE causes a specified block of user information to be passed from the XMIT application program to its local operating system for transmission over an established connection. READ causes received user information to be passed from the receiving operating system to the RECV application program. In the normal case, the system's "complete" responses indicate that the previously requested function has been successfully accomplished. System failures are indicated by "complete" responses with special exception codes.

Figure 2-15 shows the normal flow of the XMIT and RECV programs and the interactions between them. During each test, the two programs progress in synchronism through three consecutive phases of operation: a preexchange phase, associated with connection establishment or access; an exchange phase, associated with actual user information transfer; and a postexchange phase, associated with connection release or disengagement.

The XMIT and RECV programs are designed to perform two types of tests: access/disengagement tests and user information transfer tests. The numbers of sessions originated and blocks transmitted in each test (and the delays, if any, between them) are selected by the test operator. In the ITS public data network measurements, each access/disengagement test comprised 20 data communication sessions initiated at regular intervals over a 1-hour period. A single 512-byte block was transmitted during each session. Each user information transfer test comprised a single data communication session in which 10,240 bytes of user information were transmitted. The 10,240 bytes were divided into user information blocks in three ways to examine the influence of block size on performance: 160 blocks of 64 bytes, 80 blocks of 128 bytes, and 20 blocks of 512 bytes. At each block size, two interblock delay selections were used: no delay (other than the clock read time, about 133 milliseconds), and a 1-second delay (plus the same clock read time).

Correlation of event times requires accurate synchronization of clocks in the geographically remote computers hosting each user pair. This is accomplished by the XMIT and RECV programs through the use of a National Bureau of Standards (NBS) time dissemination service provided via the National Oceanic and

Table 2-5. Example Measurement Results Summary

MEASUREMENT RESULTS SUMMARY
(HYPOTHESIS TEST EXPERIMENT)

TESTED HYPOTHESIS: Population value of parameter lies in fully satisfactory range
SIGNIFICANCE LEVEL: 5%

PERFORMANCE PARAMETER	SPECIFIED VALUE	DECISION CRITERION	MEASUREMENT RESULTS			
			ESTIMATED VALUES			DECISION
			LOWER CONFIDENCE LIMIT	MEAN	UPPER CONFIDENCE LIMIT	
1. Access Time	12.0 s	LCL≤10.8 s	10.53 s	10.62 s	10.71 s	Pass
2. Incorrect Access Probability	1×10^{-3}	LCL≤3.16×10^{-4}	3.15×10^{-3}	1.60×10^{-3}	5.20×10^{-3}	Pass
3. Access Denial Probability	1×10^{-2}	LCL≤3.16×10^{-3}	2.16×10^{-3}	4.79×10^{-3}	9.55×10^{-3}	Pass
4. Access Outage Probability	1×10^{-2}	LCL≤3.16×10^{-3}	2.71×10^{-3}	5.59×10^{-3}	1.06×10^{-2}	Pass
5. Bit Error Probability	N/A	N/A		N/A		N/A
6. Bit Misdelivery Probability	N/A	N/A		N/A		N/A
7. Bit Loss Probability	N/A	N/A		N/A		N/A
8. Extra Bit Probability	N/A	N/A		N/A		N/A
9. Block Transfer Time	2.5 s	LCL≤2.25 s	1.94 s	1.94 s	1.94 s	Pass
10. Block Error Probability	1×10^{-4}	LCL≤3.16×10^{-5}	1.83×10^{-5}	9.32×10^{-5}	3.05×10^{-4}	Pass
11 Block Misdelivery Probability	N/A	N/A		N/A		N/A
12. Block Loss Probability	1×10^{-4}	LCL≤3.16×10^{-5}	0	4.66×10^{-5}	1.96×10^{-4}	Pass
13. Extra Block Probability	1×10^{-4}	LCL≤3.16×10^{-5}	0	0	1.94×10^{-4}	Pass
14 User Information Bit Transfer Rate	1000 bps	UCL≥1100 bps	1231 bps	1236 bps	1241 bps	Pass
15. Transfer Denial Probability	1×10^{-3}	LCL≤3.16×10^{-4}	2.92×10^{-4}	7.14×10^{-4}	1.53×10^{-3}	Pass
16. Disengagement Time	3.0 s	LCL≤2.7 s	2.51 s	2.54 s	2.57 s	Pass
17 Disengagement Denial Probability	1×10^{-3}	LCL≤3.16×10^{-4}	0	8.63×10^{-4}	3.62×10^{-3}	Pass
18. User Fraction of Access Time	0.15*	N/A		0.162*		N/A
19. User Fraction of Block Transfer Time	0.13*	N/A		0.154*		N/A
20. User Fraction of Sample Input/Output Time	0.13*	N/A		0.140*		N/A
21 User Fraction of Disengagement Time	0*	N/A		0*		N/A

N/A—Not Applicable in this example experiment
*Values included for refernce only.

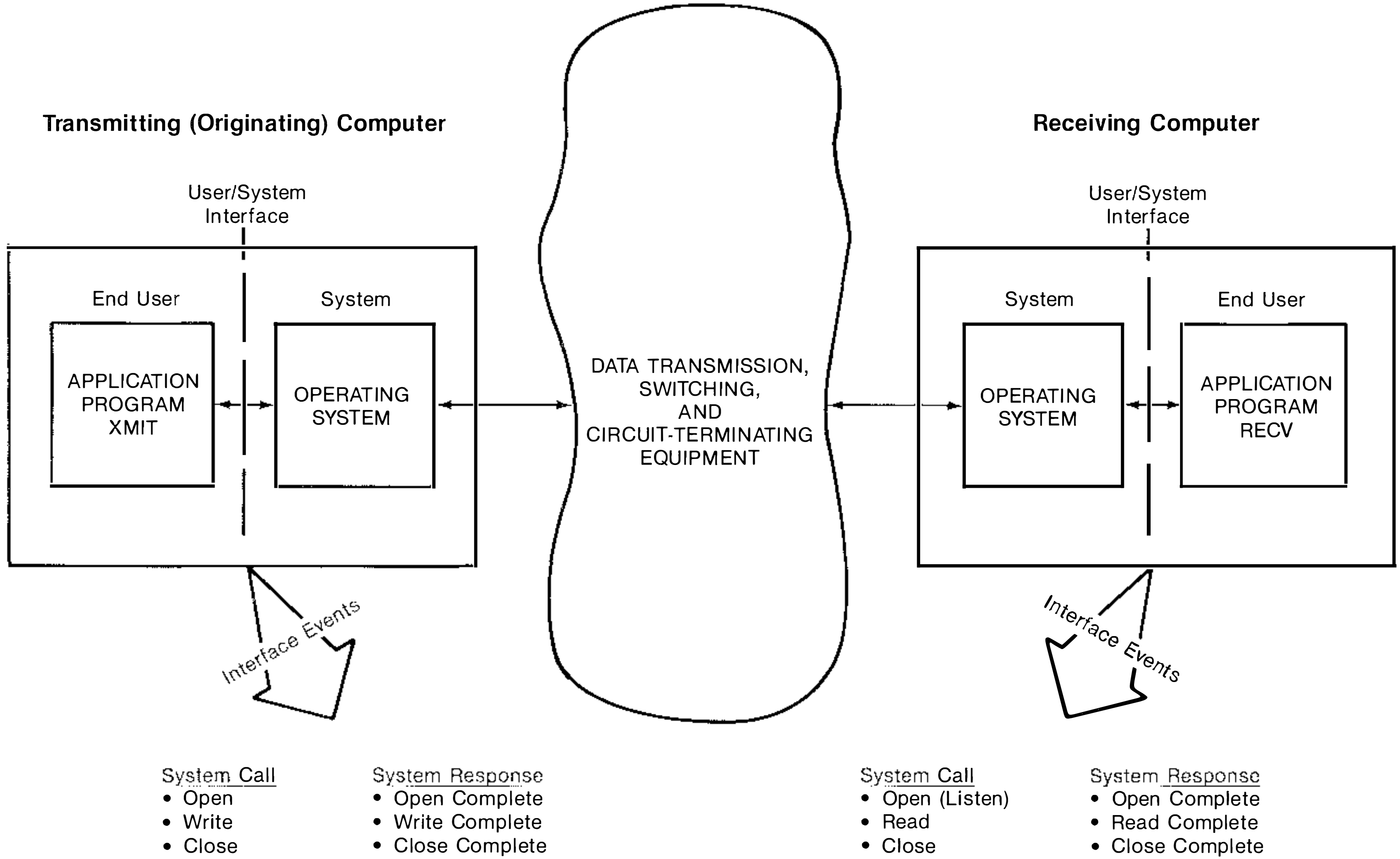


Figure 2-14. User/system interface characteristics.

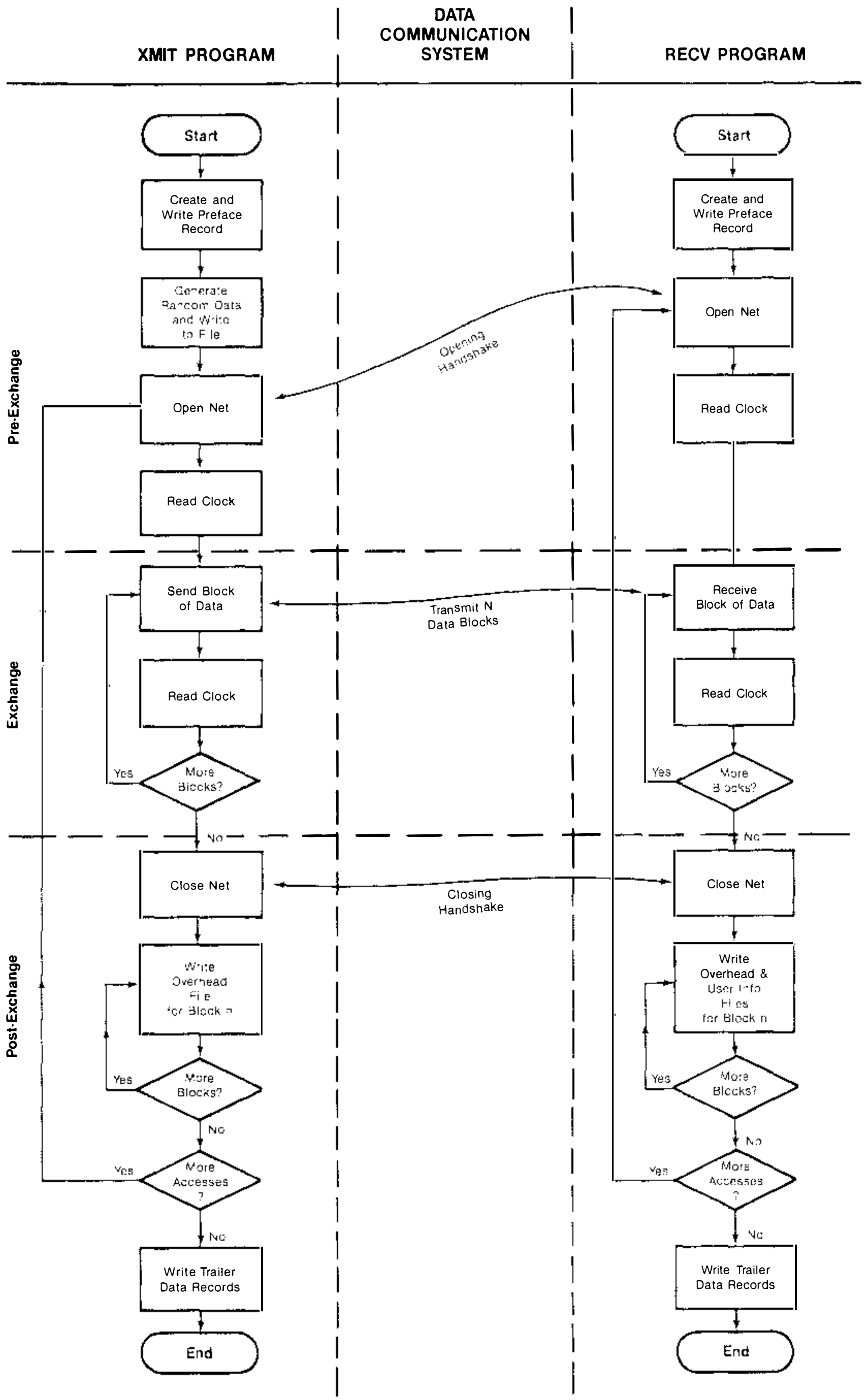


Figure 2-15. Data extraction program flow charts.

Atmospheric Administration's GOES satellite. This service makes it possible to obtain a time signal accurate to within 1 ms anywhere in North America. Several vendors supply a clock receiver unit to obtain time from the satellite. The receiving antenna is 1 ft square and operates satisfactorily inside many buildings. The clock time can be read by external devices through a standard RS-232-C interface. The cost of the unit is about $2,500.

A detailed description and listing of the XMIT and RECV computer programs will be published in FY 86. The programs are written in "C" language and are executable on many 16-bit microcomputers. They are available to Federal agencies and the public. Off-line "C" language programs that consolidate the extracted data, perform time correction, generate ASCII character files for data reduction, and produce specialized measurement results such as delay histograms are also available.

The data reduction software system developed by ITS transforms ASCII-coded records of the interface events observed by the XMIT and RECV programs into estimated values for the ANS X3.102 parameters. The system comprises three FORTRAN programs, each of which implements a distinct phase of the overall reduction process (Figure 2-16). The reduction of extracted test data is accomplished in two types of reduction runs. One type processes performance data from access/ disengagement tests, and the other processes data from block transfer tests. Each reduction run processes the performance data from a single test, and is executed off-line after all data for the test have been recorded and consolidated in one computer.

Each reduction run has an associated specifications input file. This file contains identifiers that characterize the particular run and provide the information needed to control the various reduction procedures. The latter information includes the test type (which determines the set of ANS X3.102 performance parameters to be evaluated) and the performance timeout and threshold specifications to be used in classifying the outcomes of individual performance trials (e.g., access attempts). The performance data batch for each run is the set of ASCII character files representing the events recorded by XMIT and RECV during a particular test, as described above.

PROLOG is the first program executed in a reduction run. It carries out preliminary validation and merging of the input data. PROLOG first reads the specifications input and performance data files and subjects their contents to a series of validity checks. If no errors are detected, PROLOG then combines the source and destination reference event records to create a unified event history.

ANALYZ, the second program executed in a reduction run, is responsible for performance data assessment and parameter estimation. It begins by reading the specifications file generated by PROLOG and initializing relevant performance statistics (outcome counts and

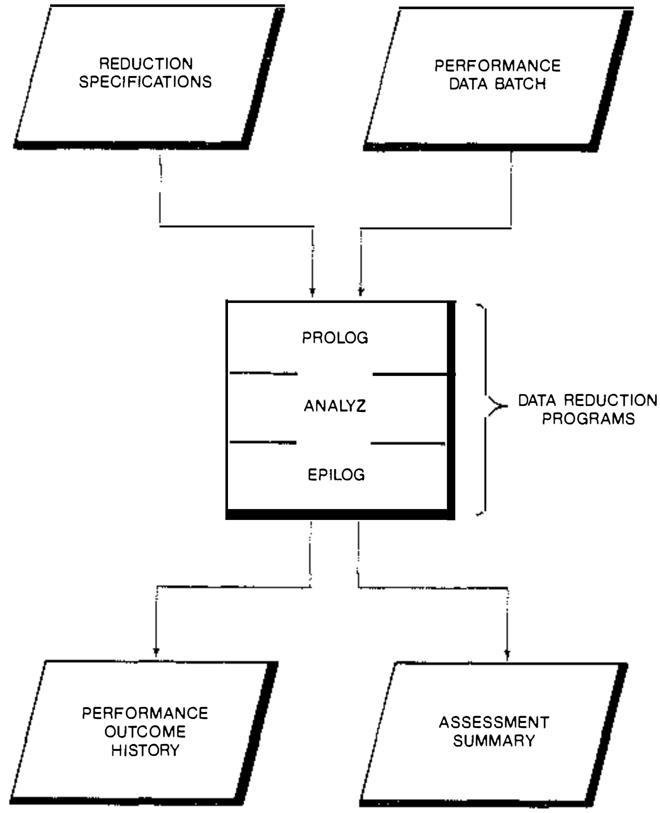


Figure 2-16. Data reduction scheme.

cumulative performance times) to zero. ANALYZ then examines the reference event records to identify individual performance trials and classify their outcomes. As outcomes are determined, ANALYZ updates the affected performance statistics and records each outcome in the appropriate performance outcome file for later data analysis. When performance data assessment for a run is complete, ANALYZ uses the resultant performance statistics to calculate estimated values for the specified ANS X3.102 performance parameters.

EPILOG is the last program executed in a reduction run. It produces the performance assessment summary, a comprehensive listing of reduction specifications, performance statistics, and measured performance parameter values.

These data reduction programs are written in ANSI (1966) Standard FORTRAN and are adaptable for use on most general purpose computers having a word length of 16 or more bits. Because the programs operate on ASCII-coded reference event histories, which are system independent, they may be used to reduce performance data extracted at any pair of digital interfaces. The programs will be updated to ANSI (1977) Standard FORTRAN and will be documented and listed in an NTIA Report in FY 86. The programs are available to Federal agencies and the public.

The third performance measurement software tool developed by ITS is the statistical design and analysis program. This program automates the complex mathematical processes of (1) determining the measurement sample size needed to obtain parameter estimates with a desired statistical precision, and (2) analyzing collected test data to determine the precision actually achieved in a measurement. Although the program was specifically developed to facilitate measurement of the user- oriented performance parameters specified in ANS X3.102, the statistical methods used are equally applicable to any delay, rate, or failure probability measurement. The program is interactive and is normally accessed from a data terminal.

The ITS statistical design and analysis program consists of two major subprograms: the sample size determination subprogram and the data analysis subprogram. The sample size determination subprogram leads the operator through a series of decisions that result in the selection of a measurement sample size for a particular performance parameter. The calculations and decisions are based on operator-specified precision objectives and estimates of performance variability. The data analysis subprogram examines collected data to determine the precision actually achieved in a measurement. This subprogram prompts the operator to enter the measurement results, or reads the data from files, and then calculates the appropriate statistics.

In determining the appropriate sample size for an experiment, all parameters associated with the communication function of interest (e.g., block transfer) are normally considered together. Sample sizes for the individual parameters are determined by successive entries to the sample size determination subprogram. The overall experiment sample size is then determined by the parameter whose measurement precision objective is most stringent.

Figure 2-17 illustrates the computer program logic used in determining sample sizes for delays and rates. The program first asks the operator to select a confidence level for which the parameter value is to be estimated. Either of two confidence levels may be selected: 90 or 95 percent. The second decision is the choice of a test-limiting criterion. Two choices may be made, depending on the operator's test objectives and constraints. In the first, budget is the test-limiting criterion, and no statistical sample-size determination procedure is required (Test A).

In the second case, the operator wishes to estimate a parameter's value with a specified precision. The precision is specified in absolute terms in the case of the time parameters--for example, plus or minus 50 milliseconds for a delay measurement or plus or minus 50 b/s for transfer rate measurement. The program next asks the operator if the variability (maximum standard deviation) of the measured value can be estimated from prior data. If not, it should be estimated from a preliminary measurement (Test B).

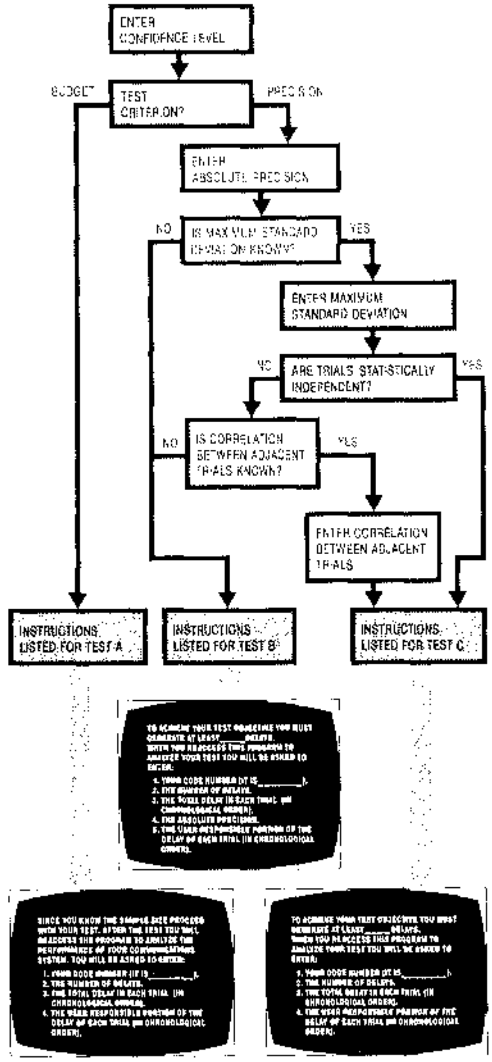


Figure 2-17. Sample size determination for delays and rates.

Once a value for maximum variability is entered, the program inquires about the dependence of successive observations, i.e., whether adjacent trials are statistically independent. If not, the program asks if the correlation between successive trials is known. If not, it should be estimated in a preliminary experiment (Test B). Otherwise, it is entered, and the sample size is determined using the procedure followed when the correlation is zero.

Instructions are listed for each of the three types of tests. When the sample size is determined by a budget limitation (Test A), the instructions simply identify the information that the data analysis subprogram will need to analyze the measured data. When a preliminary experiment is required (Test B), the instructions also specify the number of delays (typically about 10) that should be measured in that experiment. When the sample is determined by a precision objective and no preliminary experiment is required (Test C), the instructions define the sample size needed to achieve that precision goal plus other necessary data analysis values.

One very useful function of the ITS statistical design and analysis program is determining whether data from two or more tests come from the same statistical population. If they do, the data can be grouped to provide a shorter confidence interval, and hence, more information about the performance parameter. Figure 2-18a shows the results of statistical calculations performed by the program to determine if access times from 11 public data network tests conducted by ITS can be considered to come from the same statistical population. The program summarizes the conditions of each test by printing the specified levels for each of four performance factors: the source city (in these tests, Washington, DC); the network used (one of three public data networks, labeled A, B, and C); the day of the week (Monday through Thursday); and the time of day (five periods represented, four daytime and one at night). Also printed are four statistical quantities that characterize each test: the number of trials, the estimate of the mean, the estimate of the standard deviation, and the estimate of the coefficient of variation (i.e., the estimate of the standard deviation divided by the estimate of the mean).

The program computes a statistic, called the F statistic, using data from the tests. It then compares this statistic with the value of the F distribution at its upper 95% probability point. If the computed value of the F statistic is below this point, we can be at least 95% confident that the data from the tests are from the same statistical population. In the case illustrated, the value of the F statistic is 1.18 and the 95% point of the F distribution is 1.83. The ratio of these two numbers is called the acceptance ratio; its value is 0.64. The text printed below these values states that the tests can be grouped and provides the estimate of the mean of the grouped data with associated confidence limits.

Figure 2-18b is a histogram of the grouped data. The 11 tests have a total of 192 trials. The data appear to be approximately normally distributed.

The statistical design and analysis program discussed here can substantially improve the efficiency and economy of performance measurements by providing simple methods of determining the quantitative relationships between test duration and test precision. Preliminary applications of the program indicate that a desired precision can often be achieved with far less measurement time (and cost) than test engineers intuitively expect. Project cost savings from such information can be substantial.

The statistical design and analysis program is written in ANSI (1977) standard FORTRAN. It can be directly executed on most general-purpose computers. The program is documented and listed in NTIA Report 84-153 and is available to Federal agencies and the public.

Substantial progress toward broad industry implementation of ANS X3.102 and X3S3.5/135 became evident during FY 85. A technical paper published by AT&T Bell Laboratories in the ICC 85 Conference Proceedings describes experimental test equipment that is being used to measure key ANS X3.102 performance parameters on an AT&T public packet switching network. The paper states that the measurement equipment "is an implementation of" X3S3.5/135. Another paper, published by Tymnet, Inc., in the GLOBECOM 84 Conference Proceedings outlines a plan to continuously monitor a group of ANS X3.102 parameters on the Tymnet public data network using data collection software to be installed in all network nodes. In the paper, Tymnet states that the ANS X3.102 parameters "are particularly relevant to public packet networks like Tymnet," and predicted that their measurement "will enable Tymnet to respond quickly and effectively to user-perceived network service degradations in the coming era of the sophisticated data communications user." Tymnet now offers Federal user organizations procurement specifications conforming to the X3.102 standard. Several other common carriers, and computer and test equipment manufacturers, are developing or considering performance measurement systems conforming to these standards.

As an adjunct to the statistical design and analysis program (and an extension of earlier statistical studies), ITS completed during FY 85 a draft manuscript that describes in detail the statistical methods that are most useful in evaluating the performance of data communication systems. This 200-page manuscript, entitled "Statistical Methods for Measuring the Performance of Data Communication Systems," defines the following:

- Plausible statistical distributions for the performance parameters.
- Methods of determining the sample size required to obtain a specified precision in measuring performance at a specified confidence level.
- Methods of analyzing test results by computing the "best estimator" of the mean and associated confidence limits.
- Methods of determining if multiple tests can be considered to be from the same statistical population. If so, the data can be combined; the larger sample usually results in closer confidence limits and more knowledge of the mean.
- Methods of determining if data communication systems can be considered to be significantly different in terms of a particular performance parameter.
- Methods of combining delay or failure probability parameters to produce composite parameters describing, for example, the aggregate performance of several links connected in tandem.

An important feature of this work is that it accounts for the dependence that is likely to exist between trials. Specific formulas and

NTIA Statistical Analysis Program for Data Communication
Performance Analysis Using Access files

-----------------------11 Test Files Used--------------------

Test	City	(Other Factors)	Trials	Mean	Std Dev	Coef Var
907	wdc	B mon 3	18	43.863	1.624	0.0370
915	wdc	C mon 4	17	45.477	2.350	0.0517
919	wdc	C mon 5	17	44.434	2.050	0.0461
928	wdc	A tue 1	20	44.500	4.380	0.0984
932	wdc	B tue 2	16	43.604	1.254	0.0288
936	wdc	C tue 3	19	44.537	1.883	0.0423
964	wdc	B wed 2	19	43.455	0.984	0.0226
969	wdc	C wed 2	12	44.265	1.396	0.0315
995	wdc	C thu 3	20	44.922	2.713	0.0604
1003	wdc	B thu 4	18	44.363	1.094	0.0247
1008	wdc	C thu 5	16	44.052	1.993	0.0452

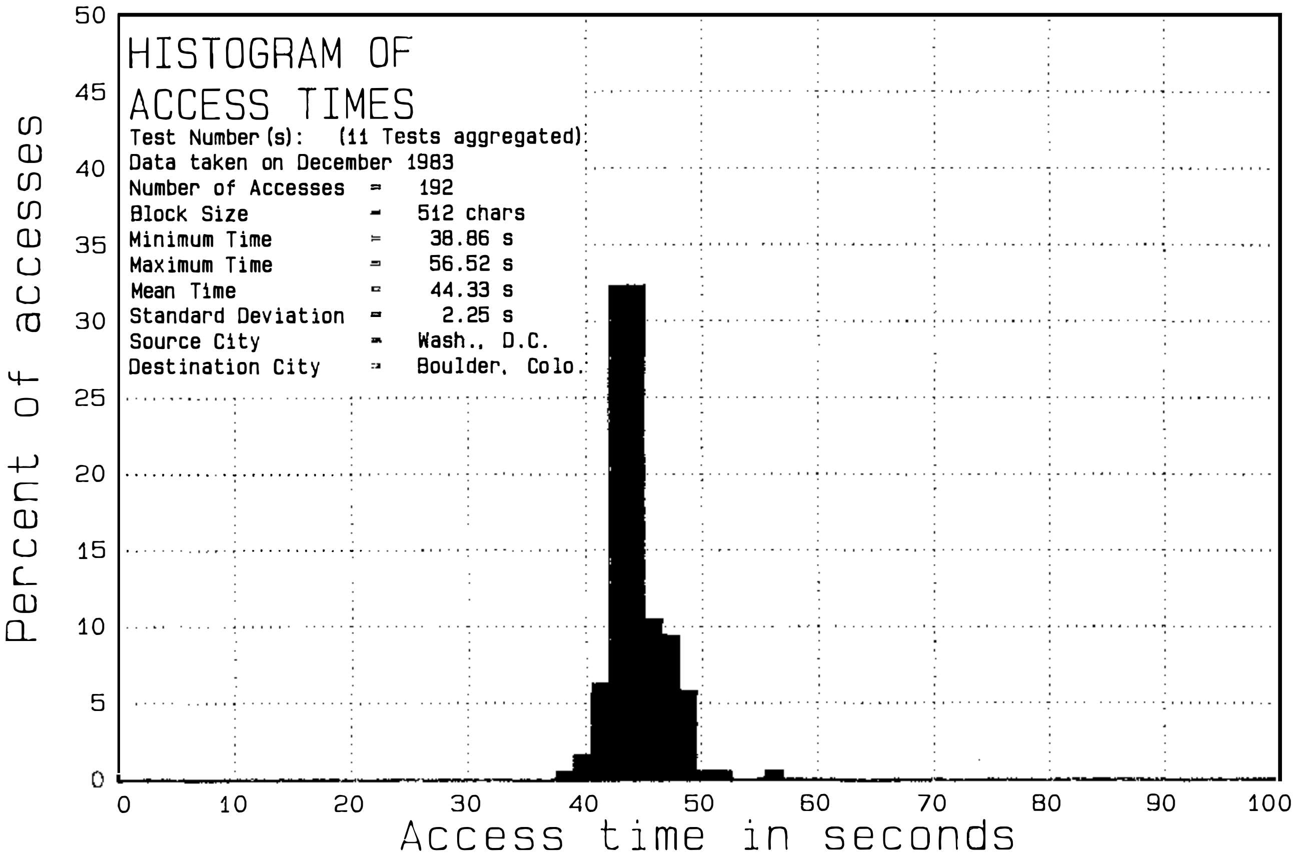
----------------------Calculated Results--------------------

F DIST. VALUE AT 95%= 1.83
F STATISTIC VALUE= 1.18
ACCEPTANCE RATIO= .64

WITH 95% CONFIDENCE THE TRIALS CAN BE CONSIDERED TO COME FROM THE SAME POPULATION. HENCE, THEY CAN ALL BE GROUPED TO DETERMINE A SMALLER CONFIDENCE INTERVAL.

YOUR TESTS RESULTED IN AN ESTIMATED MEAN DELAY OF .44325e+02 . YOU CAN BE 90 PERCENT CONFIDENT THAT THE TRUE MEAN DELAY IS BETWEEN .44015e+02 AND .4463e+02 .

a. Program assessment of the grouping of 11 tests.



b. Histogram of the grouped data.

Figure 2-18. Program test for statistical homogeneity.

procedures are presented for relating confidence limits, precision, and sample size under conditions where dependence exists.

The third major objective of the Institute's FY 85 Data Communications Program was to conduct a detailed analysis of public data network (PDN) measurement data collected during FY 84. Two ITS-developed, microcomputer-based test sets were employed in collecting this data: 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 office of each of three public data networks via 9.6 kbps leased telephone lines. During the operational test phase, the terminal emulator was placed in Federal Government offices in four remote test cities (Fort Worth, TX; Seattle, WA; Washington, DC; and Denver, CO), where it obtained access to the PDN's via the local exchange telephone network. In each test city, the terminal emulator was also able to communicate with the host emulator via the public switched telephone network (PSTN) or the Federal Telephone System (FTS), bypassing the PDN's. Both the local and the long-distance telephone links were operated at 1200 bps.

During actual testing, the remote terminal emulator established connection with the host over each available path 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. The remote terminal emulator and the host were programmed 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 error-controlled lines) to a data reduction and analysis computer located in Boulder. The ITS-developed data reduction and statistical design and analysis programs described earlier were linked in this computer to enable the data extracted in a test to be transformed into parameter estimates and associated confidence limits with a single operator command.

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. The specific events observed at these interfaces have been illustrated earlier (Figure 2-14). Both microcomputers were dedicated to the measurement task to avoid the bias that might result from time-sharing with other applications.

Table 2-6 shows the schedule followed in on-line data extraction during a typical field test. In each remote city, testing was conducted over a 4-day period, Monday through Thursday. Six tests were conducted during each 24-hour period: two morning tests, two afternoon tests, and two night tests. Each of the 4 networks (the 3 PDN's and the PSTN or FTS) was tested once in each of the 4 time slots during the 16 daytime tests. Where possible, each network was also tested twice on one of the four nights.

Over 50 access/disengagement tests and over 200 user information transfer tests were conducted during the experiment. The ANS X3.102 performance parameter estimates obtained in the two types of tests have been collected in summary tables. An excerpt from the access/disengagement summary table is shown in Table 2-7. The left portion of the table identifies the number and relevant conditions of each test as defined earlier (Figure 2-18a). The right portion of the table lists the ANS X3.102 performance parameter estimates (sample means) obtained in each test. The access/disengagement functions are described by six time-delay parameters and five failure-probability parameters.

The user information transfer tests were summarized in a similar manner. These tests involved three additional performance factors:

1. User information block size. Three block sizes were tested: 64 bytes, 128 bytes, and 512 bytes.

2. Utilization factor. Two levels of utilization were tested: a "low utilization" level, in which a 1-second delay was introduced by the XMIT program between each block transmission; and "high utilization" level, in which no such delay was introduced.

3. Use of flow control. Tests were conducted both with and without X-ON/X-OFF flow control on the terminal/PDN access links.

Figure 2-19 presents the results of Block Transfer Time measurements of four networks: the three public data networks (designated A, B, and C) and the public switched telephone network. Each histogram summarizes the transfer times for 80 successfully transferred 128-character blocks. All transfers were conducted during normal business hours under nominally identical usage conditions. The source city is Denver, CO, and the destination city is Boulder, CO, in each test. All four histograms thus describe communication performance within a local telephone calling area.

The PDN block transfer times observed in these particular tests differ significantly in both mean and standard deviation. The sample means for PDN's A, B, and C are 3.66 seconds, 4.08 seconds, and 5.17 seconds, respectively; the corresponding standard deviations are 410 milliseconds, 561 milliseconds, and 939 milliseconds. The PSTN values are substantially lower--1.53 seconds and 42 milliseconds for the mean and standard deviation in this particular test. The longer and more variable block transfer times observed in the PDN tests are, of course, the result of store-and-forward delays in the networks. They represent the performance cost of achieving service economy through transmission resource sharing.

Table 2-6. Typical Test Schedule for Data Extraction

Activity	Local Time	Day - Dates Mon 12/12	Tue 12/13	Wed 12/14	Thu 12/15	Fri 12/16
File Transfer	0700 - 0830	-------------- File Transfer --------------				
Day Test #1	0830 - 1000	Net A	Net B	Net C	Net D	Pack-up
Day Test #2	1000 - 1130	Net B	Net C	Net D	Net A	Leave
File Transfer	1130 - 1330	--------- File Transfer --------				- - - -
Day Test #3	1330 - 1500	Net C	Net D	Net A	Net B	- - - -
Day Test #4	1500 - 1630	Net D	Net A	Net B	Net C	- - - -
File Transfer	1630 - 1900	--------- File Transfer --------				- - - -
Night Test #5	1900 - 0100	Net A	Net B	Net C	Net D	- - - -
Night Test #6	0100 - 0700	Net A	Net B	Net C	Net D	- - - -

Location of Remote Computer: NBS - Washington, DC

Day Tests: Manually started and monitored tests, consisting of three block transfer tests (each in a single access):

- o 160 blocks of 64 characters each
- o 80 blocks of 128 characters each
- o 20 blocks of 512 characters each.

One Access/Disengagement test, with 20 separate accesses and 1 block of 512 characters transmitted in each test.

Night Tests: Automatically run, same four tests as above, but the transfer tests are one each hour, and the access/disengagement test is allowed 3 hours.

Table 2-7. Example Summary of PDN Test Results

ACCESS/DISENGAGEMENT TESTS

TEST #	FACTORS & LEVELS CITY	NETWK	DAY	TIME PER.	MEAN OF PERFORMANCE PARAMETERS TIME ACCESS	USER ACCESS	DISENG(S)	USER DISENG(S)	DISENG(D)	USER DISENG(D)	FAILURE PROBABILITY INCOR ACCESS	ACCESS DENIAL	ACCESS OUTAGE	DISENG(S) DENIAL	DISENG(D) DENIAL
891	WDC	C	S	5	54.2	.00737	13.81	.074	3.60	.173	0	0.100	0	0	0
895	WDC	C	S	6	53.0	.00752	13.53	.074	3.56	.170	0	0.400	0	.0833	0
899	WDC	D	M	1	53.4	.00748	4.29	.255	0.938	.741	0	0.050	0	0	0
907	WDC	B	M	3	43.8	.00910	12.99	.0838	2.10	.334	0	0.100	0	.0556	0
915	WDC	C	M	4	45.5	.00877	14.22	.0727	3.73	.171	0	0.150	0	.0588	0
919	WDC	C	M	5	44.4	.00898	13.60	.0799	3.66	.188	0	0.150	0	0	0
932	WDC	B	Tu	2	43.6	.00915	13.74	.0730	2.54	.249	0	.200	0	.188	0
936	WDC	C	Tu	3	44.5	.00896	13.77	.0780	3.68	.183	0	.050	0	.105	0
941	WDC	D	Tu	4	35.6	.0112	3.26	.282	0.563	.922	0	0	0	0	0
952	WDC	A	Tu	5	39.8	.0100	15.09	.0701	5.23	.125	0	0	0	.150	0
964	WDC	B	W	1	43.5	.0092	13.21	.0777	2.61	.242	0	.050	0	.158	0
969	WDC	C	W	2	44.3	.0090	13.57	.0739	3.26	.185	0	.400	0	.0833	0
973	WDC	D	W	3	35.5	.0112	3.46	.296	0.818	.762	0	0	0	0	0
978	WDC	A	W	4	42.3	.0094	15.00	.0752	5.16	.142	0	.100	0	.0556	0
982	WDC	B	W	5	41.6	.0096	12.94	.0842	2.76	.255	0	.100	0	.111	0
986	WDC	B	W	6	41.6	.0096	13.38	.0813	3.06	.225	0	.050	0	0	0
994	WDC	D	Th	2	36.0	.0111	3.49	.336	0.956	.811	0	.167	0	0	0
995	WDC	C	Th	2	44.9	.0089	13.32	.0772	3.27	.193	0	0	0	0	0
997	WDC	A	Th	3	41.8	.0096	14.52	.0744	4.88	.144	0	.150	0	.0588	0
1003	WDC	B	Th	4	44.4	.00900	13.76	.0745	2.74	.230	0	.100	0	.0556	0
1008	WDC	C	Th	5	44.1	.00906	13.55	.0835	3.46	.212	0	.200	0	0	0

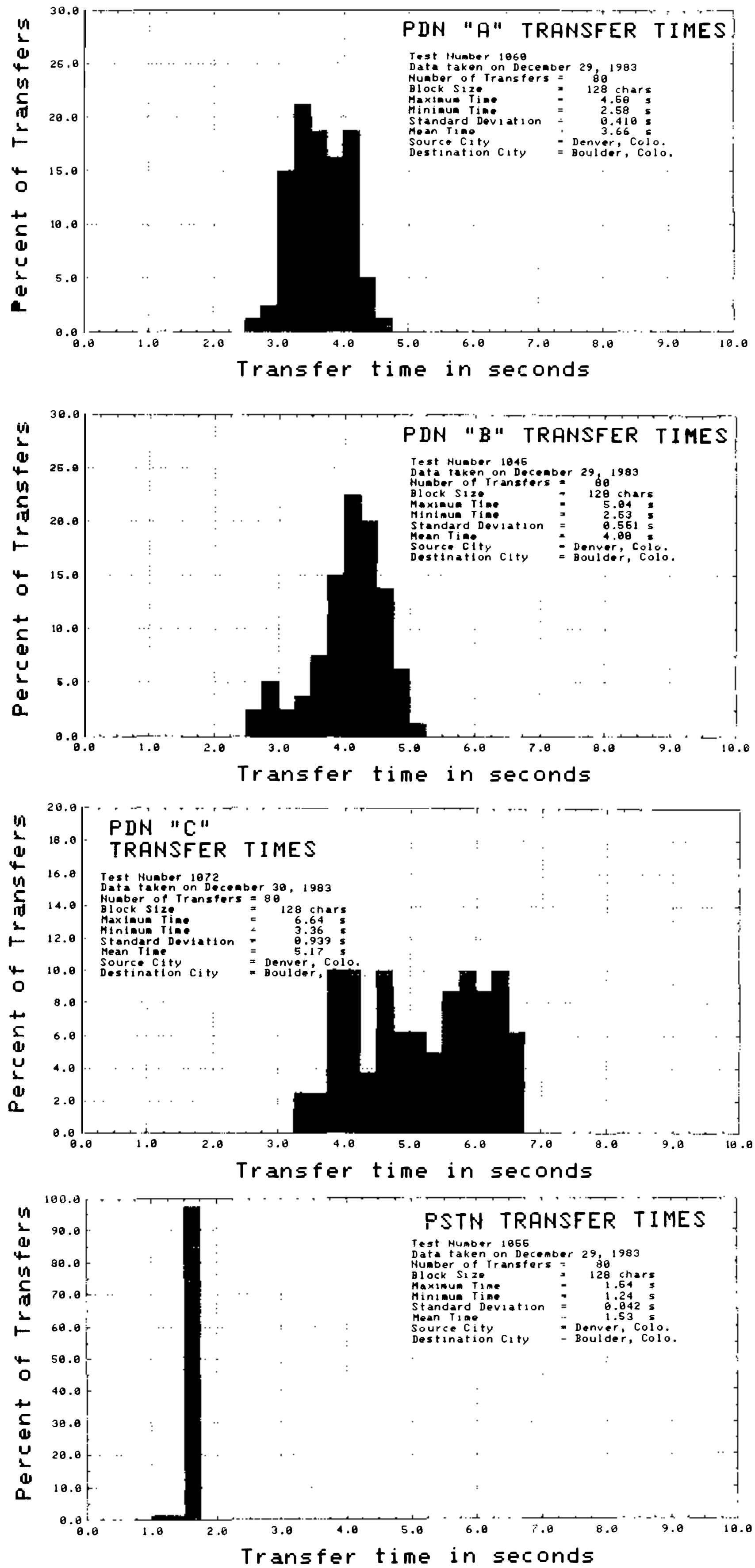


Figure 2-19. Block transfer time histograms for four networks.

Histogram presentations of statistical data have the disadvantage of masking dependence. Figure 2-20 plots the same block transfer times summarized in Figure 2-19 in chronological sequence, and clearly indicates that successive block transfer times are strongly dependent in all four networks. The chronological plots for the three PDN's are of particular interest. The PDN A data show a very consistent "sawtooth" pattern of linearly increasing delays interrupted by periodic (and sudden) drops. The PDN B data show a similar but less strongly periodic dependence pattern. The PDN C delays increase about 31 milliseconds per block in the linear segments between periodic upward steps--or an average of about 41 milliseconds per block overall.

The observed increases in PDN block transfer time with block number are undoubtedly caused by a buildup of user data in network queues. The sudden drops in transfer time between successive blocks are the result of corresponding queue reductions, effected by network flow control at the source user interface.

An implication of the chronological plots shown in Figure 2-20 is that PDN C provides rather large internal buffer capacities for the storage of user data. This is dramatically confirmed in Figure 2-21, which shows histograms and chronological plots of 64-character PDN C block transfer times for transmissions between Washington, DC, and Boulder, CO. Two separate 160-block tests are summarized. Conditions of the two tests are nominally identical with the exception of the user data input rate. In the first test, Figure 2-21a, a 1-second pause was introduced between input of successive blocks. In the second test, Figure 2-21b, the pause was omitted to generate more continuous user data input.

As Figure 2-21a and 2-21b show, omission of the pause has a substantial effect on performance. Block transfer times in the first test range from 1.41 to 2.32 seconds, with a mean of 1.49 seconds and a standard deviation of 83 milliseconds. Block transfer times in the second test range from 1.59 to 7.57 seconds with a mean of 4.97 seconds and a standard deviation of about 2 seconds. Data from the second test are clustered in three distinct time bands separated by two 1-second intervals in which no block transfer times fell.

The reason for this unusual distribution is clarified by the chronological block transfer time plots shown in Figure 2-21c. The chronological plot of the low-utilization test is essentially flat, as one would expect from its histogram. Block transfer times from the high-utilization test increase linearly in three bands separated by abrupt 1-second upward discontinuities. Analysis of the input and output times surrounding these discontinuities showed that user data input remained continuous--blocks following a discontinuity simply remained in the network longer than those preceding it. The cause of the discontinuities cannot be positively established from the user-oriented measurement data, but they appear to reflect a sudden and sustained reduction in the network

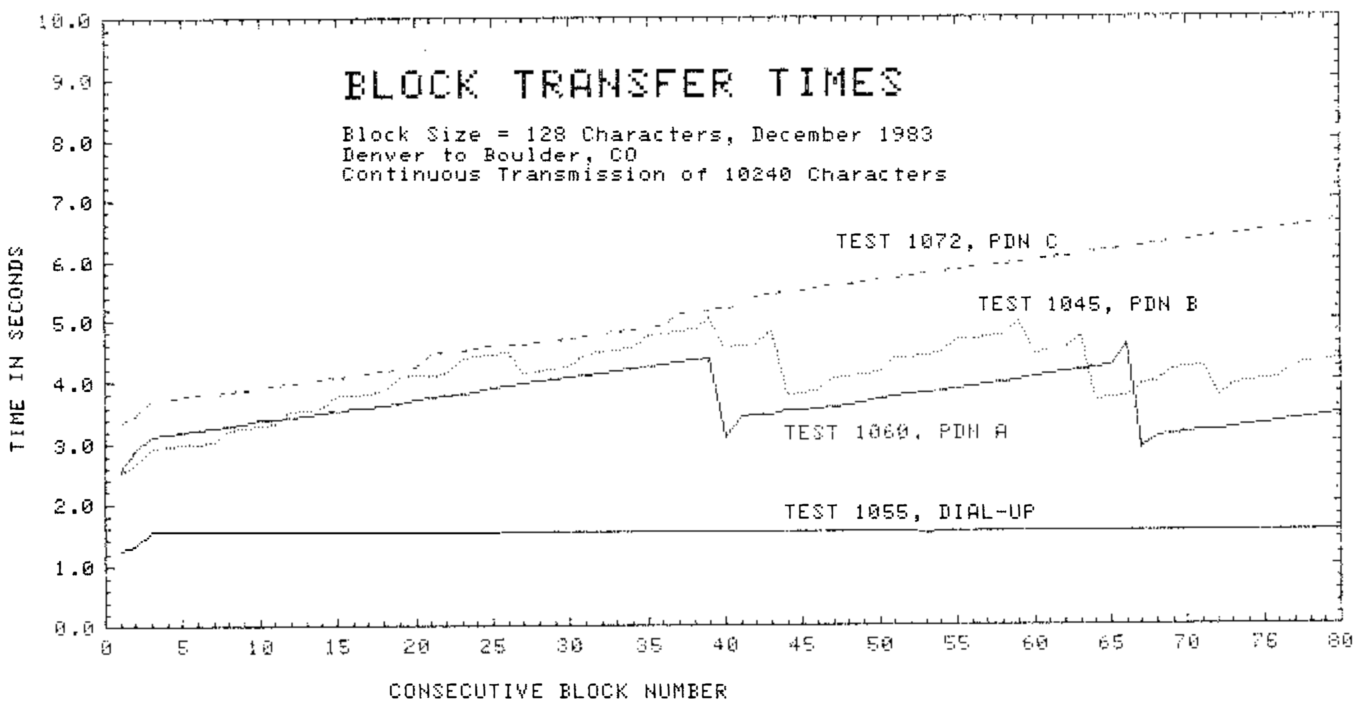
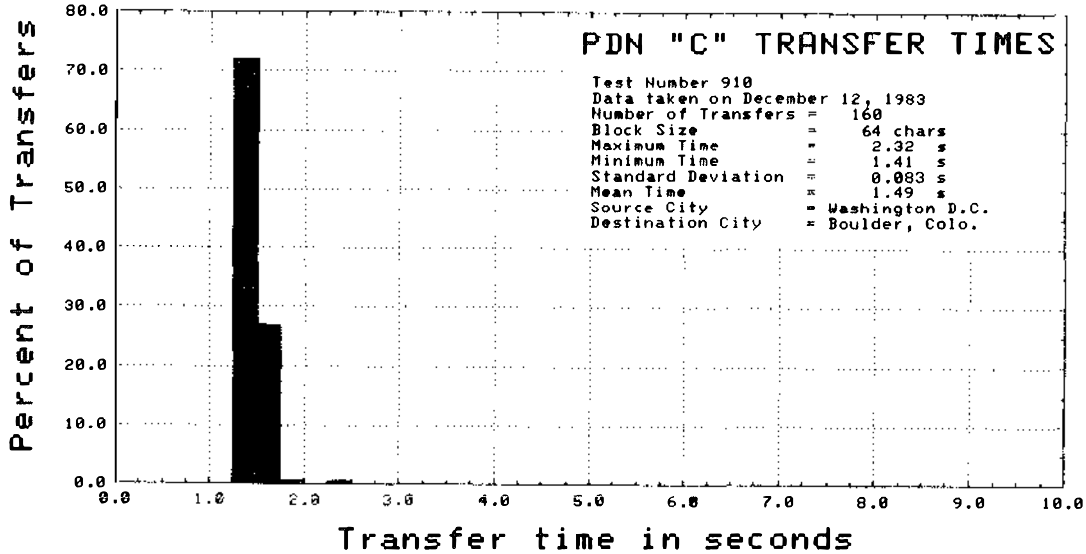
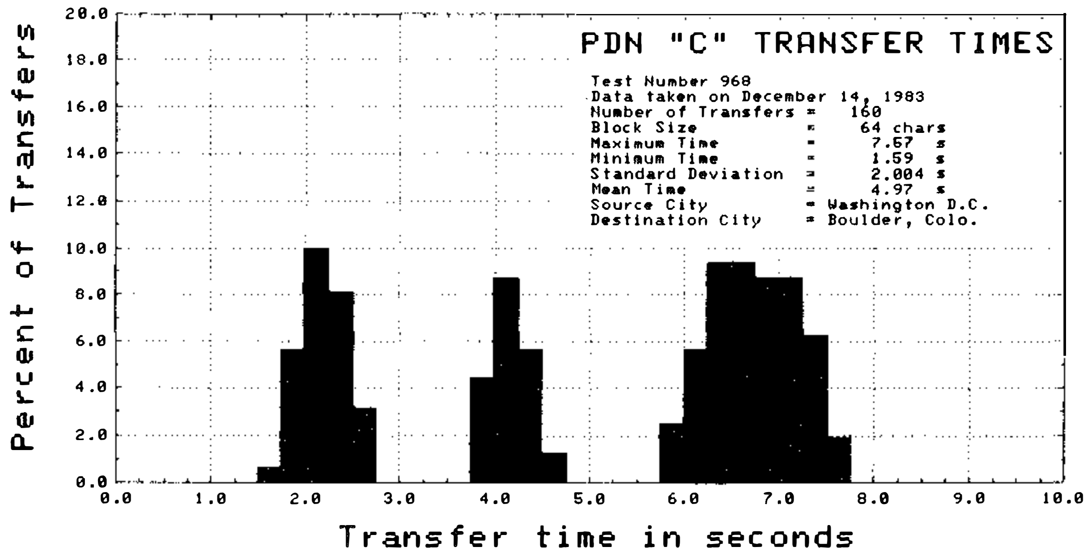


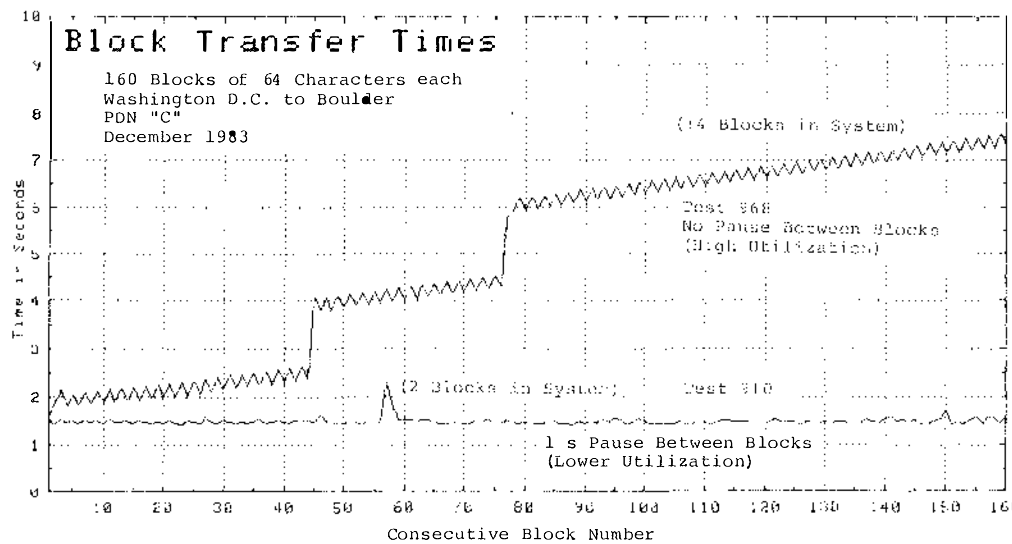
Figure 2-20. Chronological plots of the same data shown in Figure 2-19.



a. With 1-second pause.



b. Without 1-second pause.



c. Chronological plots.

Figure 2-21. Histograms and chronological plots of PDN C block transfer times with and without 1-second pause between block inputs.

capacity allocated to the monitored transmissions. Such a reduction could be a result of the establishment of new virtual circuits for other users.

Buffering (or storage) of user data by the network was examined by comparing block input and output times in each of the tests summarized in Figure 2-21. In the low-utilization test, no more than two blocks were stored in the network at any time. In the high-utilization test, 14 blocks were stored in the system (or were in transit between nodes) just after the last block was input. This is a surprisingly high number for a packet switched network--but still higher numbers have been observed in other PDN C tests. Thus, PDN C allows essentially continuous user data input at a cost of somewhat higher average block transfer times.

The "ripple" effect illustrated in Figure 2-21c is not caused by the XMIT or RECV programs or the network, but by periodic variation in output buffering delays within the UNIX operating system. Recall that the operating system is part of the end-to-end data communication system from the point of view of the end user.

Figure 2-22 presents regression plots that show the dependence of block transfer time on block length in three networks: PDN A, PDN B, and the public switched telephone network. The plotted data represent communications between Seattle and Boulder. Each PDN data point represents the mean transfer time for 160, 80, or 20 blocks of size 64 bytes, 128 bytes, or 512 bytes, respectively. The PSTN data points are similar sample means that fell precisely on the same coordinates and therefore could not be plotted separately. The number of tests represented by the latter points is indicated in parentheses beside each point.

The PSTN block transfer times include modulation and propagational delays only. The PDN block transfer times also include storage and packet overhead transmission delays, which add roughly 1.2 seconds to the overall transfer time irrespective of block size.

The Institute's FY 85 analysis of PDN measurement data also included a detailed examination of bit error, loss, and duplication events. Of a total of 17,752,392 bits transferred in 217 user information transfer tests from four cities, only 21 were received in error. These errors occurred as bursts in 3 tests: 11 errors in 3 consecutive characters in a test from Fort Worth, 6 errors in 3 consecutive characters in a test from Seattle, and 4 errors in a single character in a test from Denver. Only the latter test involved a PDN (network B). Measured bit error rates for PDN tests and PSTN tests were $4/13{,}739{,}848 = 2.9 \times 10^{-7}$ and $17/4{,}012{,}544 = 4.2 \times 10^{-6}$, respectively. The measurements show the expected result that data transfer via telephone circuits, which lack error control, is more subject to bit errors than data transfer via PDN's. The errors observed in the PDN test were almost certainly introduced in the terminal access link, which is a local

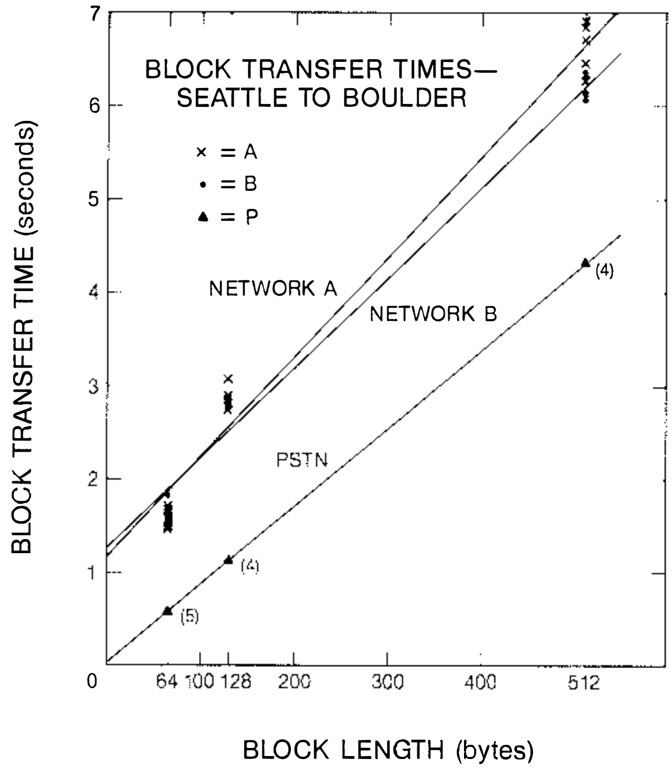


Figure 2-22. Regression plots showing the relationship of block transfer time to block length in three networks.

telephone connection unprotected by error control. The differences in bit error probability among the PDN tests are not statistically significant. The difference in bit error probability between the combined PDN data and the PSTN data is significant at the 0.1% level.

Data loss was found to be strongly influenced by the implementation of flow control in the PDN's. With flow control implemented, only two instances of data loss by PDN's were observed: a string of 114 characters in a test from Denver via PDN B (described later), and a single character in a test from Denver via PDN A. The absence of data loss in PDN C may be due to its larger buffer capacities.

The tests of PDN A included tests in which flow control was not implemented. Instead, a 1-second delay was introduced between successive block inputs to limit the input rate. The failure to utilize flow control resulted in a dramatically higher loss rate: 21,792 lost bits out of 3,112,960 transmitted. This compares with only 8 lost bits out of 1,884,160 transmitted in the flow controlled case. The corresponding estimated bit loss probabilities are 7.0×10^{-3} and 4.2×10^{-6}, respectively. The significance level of this difference is 10^{-7}%.

Figure 2-23 describes an interesting anomaly that occurred in one particular public data network test, and also demonstrates the capability and precision of the ITS-developed data reduction software. The test in question involved transmission of 160 64-character blocks between Denver and Boulder, CO, over PDN B. The specific impairments observed are illustrated in Figure 2-23a and may be summarized as follows:

- o The first 27 characters of block 102 were duplicated in characters 28-54 of the received block, and the overall block length was thereby increased to 91 characters. None of the received characters were altered in transmission.
- o Block 103 was received correctly.
- o The next 114 characters in succession were lost (never delivered). These comprised all of block 104 and the first 50 characters of block 105.

All other blocks transmitted during the test were received correctly.

Figure 2-23b is a chronological plot of the block transfer times observed in the anomalous test just described. A pronounced distortion in the transfer time curve is evident at precisely the point of the anomaly. The transfer time for block 102 was longer than expected because of the extra data it included. The transfer time for block 103 was also longer than expected, presumably because the additional delay in block 102 caused it to be stored longer in a network queue. No block transfer time is plotted for block 104, because this block was not delivered. The transfer time for block 105 was about 700 ms shorter than expected, presumably for two reasons: first, because it spent less time in network queues due to the absence of block 104; and second, because the delivered block itself was 50 characters shorter than normal.

The chronological plot resumes its normal pattern with block 106. No irregularity in data input was associated with the observed anomaly, indicating that (1) flow was not interrupted by the network, and (2) the anomaly did not occur on the terminal access link. It is almost certain that the anomaly occurred in the PDN, since the PDN-host access link (a 1200 bps leased line) was protected by retransmission error control under the X.25 interface protocol.

A more comprehensive analysis of the ITS public data network measurement results will be published in an NTIA report in FY 86.

International Standards. Activities in the International Standards program are directed toward two long-term goals. The first of these is to enhance international trade opportunities for U.S. telecommunication providers by promoting the development and acceptance of nonrestrictive, functionally oriented international telecommunication standards. The second is to ensure that the interests of competing U.S. telecommunication providers (and the interests of users) are fully and fairly represented in U.S. contributions to international standards committees in which NTIA/ITS has leadership responsibilities. In FY 85, special emphasis was placed on contributions to the development of technical standards for Integrated Services Digital Networks (ISDN's) within the International Telegraph and Telephone Consultative Committee (CCITT) and associated U.S. preparatory groups, including the ANSI-accredited Telecommunications Standards Committee, T1.

The Institute's International Standards program involves three major functions:

1. Leading U.S. participation in key standardization efforts of the CCITT, including liaison with related committees of the International Organization for Standardization (ISO) where appropriate.
2. Informing interested nonparticipants of significant accomplishments and opportunities in international standards development.
3. Preparing U.S. contributions to international standards organizations in areas where NTIA/ITS has particular interest and expertise.

The U.S. activities in the CCITT are coordinated by the U.S. Department of State, Bureau of International Communications and Information Policy, Office of Technical Standards and Development. This coordination is accomplished through the U.S. Organization for the CCITT (U.S. CCITT). The U.S. CCITT is composed of a National Committee, which administers U.S. participation in the international meetings, and five preparatory groups, which provide technical review of proposed U.S. contributions to particular study groups. Two of the five preparatory groups were chaired by ITS staff members during FY 85: Study Group D, "Data Communications," which reviews contributions to CCITT Study Groups VII and XVII, and the ISDN Joint Working Party (JWP), which reviews contributions to Study Group XVIII and several other CCITT study groups that deal with ISDN issues. The U.S. study group chairmen organize preparatory meetings, assist in achieving consensus positions on technical issues affecting U.S. organizations, and head the U.S. Delegations to international CCITT meetings.

The prolific activity of the newly formed T1 Standards Committee has markedly increased contributions from the U.S. to the CCITT, and has correspondingly increased the responsibilities of the U.S. CCITT chairmen. In FY 85, ITS personnel organized and chaired four Study Group D meetings and five ISDN JWP meetings. These meetings were typically attended by 50 to 100 telecommunications experts from U.S. industry and Government organizations. In addition, Institute personnel represented NTIA in several U.S. National Committee meetings, to prepare for and report on the 1984 CCITT Plenary Assembly and to discuss U.S. positions in (and contributions to) two special international meetings.

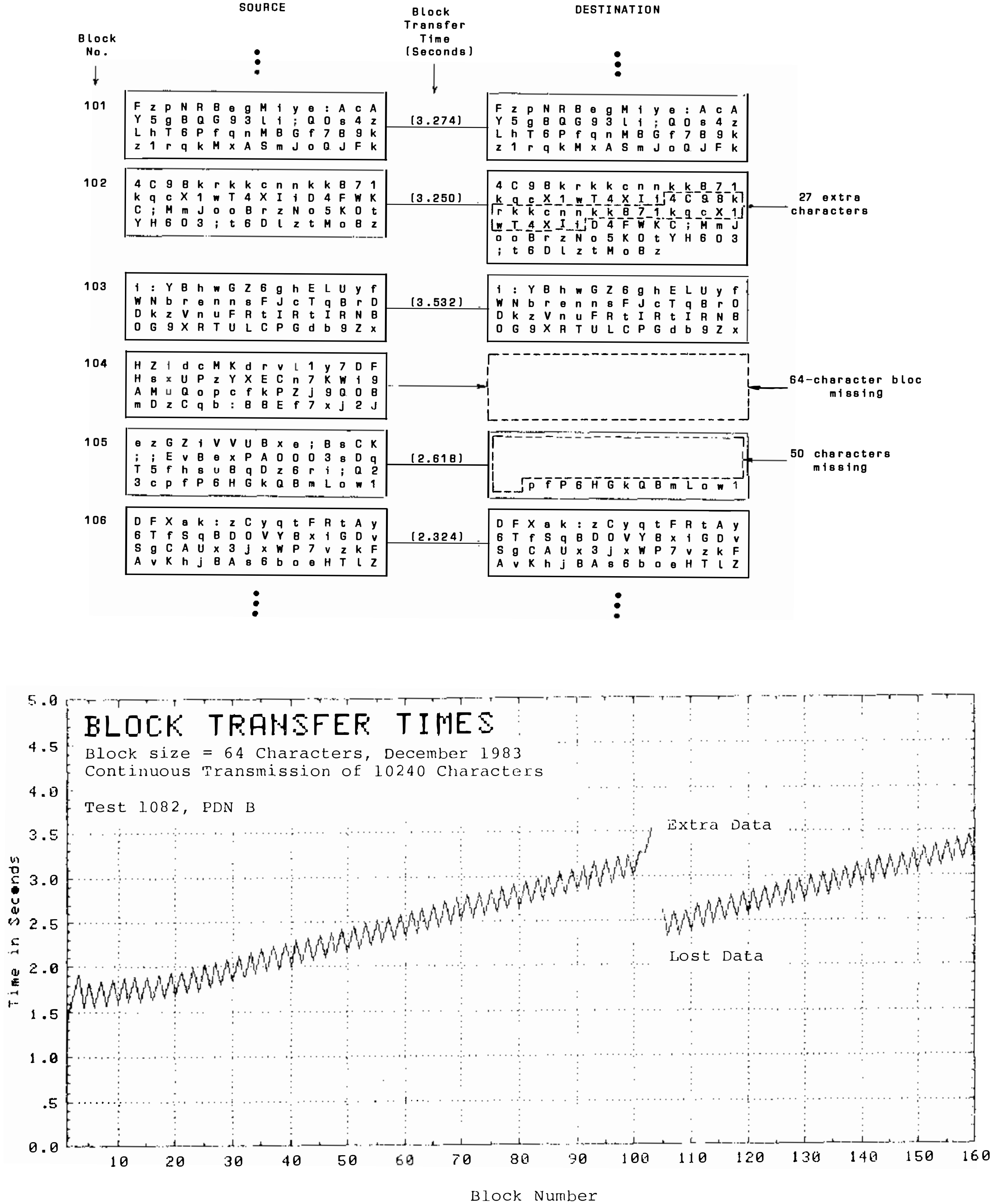


Figure 2-23. Analysis of an observed block transfer anomaly.

Two Institute staff members attended the VIIIth Plenary assembly of the CCITT, held in Malaga-Torremolinos, Spain, October 8-19, 1984. One attended as Deputy Head of the U.S. Delegation and acted as U.S. spokesman in various Plenary and Subcommittee meetings. The other attended as Delegation Advisor on Study Group VII issues to coordinate proposed changes to the Message Handling Recommendations. The Plenary Assembly was attended by 800 delegates from over 94 countries. Two hundred sixty-three new Recommendations and 500 revised Recommendations were approved. These are being published in the new CCITT "Red Books."

Institute staff members contributed to U.S. planning for two special CCITT meetings during FY 85. The first was a meeting of Special Study Group "S", which was established by the Plenary Assembly to consider CCITT reorganization. The second was the Preparatory Committee for the 1988 World Administrative Telegraph and Telephone Conference (PC/WATTC). The U.S. contribution to Special Study Group "S", prepared with ITS participation, proposed criteria to be used in evaluating any changes in study group structure and defined a schedule for completion of the studies. For the PC/WATTC, the United States proposed a complete rewrite of the present international regulations, changing the presently separate telegraph and telephone regulations into a combined set of telecommunications regulations. This is viewed as a major step forward as telegraph and telephone services become more integrated.

Institute representatives played a significant role in coordinating international approval of several CCITT recommendations during FY 85. These include a number of the I-Series Recommendations, which provide international guidelines for the development of ISDNs; the X.400-Series Recommendations, which define access procedures and provide interoperability requirements for international electronic mail (or "message handling") systems; the X.200-Series Recommendations, which specify CCITT defined services and protocols for Open Systems Interconnection (OSI); and the X.130-Series Recommendations, which define Quality of Service objectives for Public Data Networks. An ITS staff member organized a U.S. group of experts to prepare Recommendations for the alignment of ISDN subscriber line and CCITT Signalling System #7 ISDN User Part protocols. Institute personnel organized and chaired the U.S. CCITT Message Handling Working Party, and represented the U.S. in international negotiations leading to CCITT approval of eight X.400-Series Recommendations. An ITS staff member served as international editor of the OSI Network Service Definition standards in both CCITT Study Group VII and ISO TC 97/SC 6, thereby achieving very close alignment between the two completed standards of these independent international organizations. Institute representatives contributed to international negotiations on four Public Data Network Quality of Service recommendations (X.130, X.131, X.135, and X.136), and developed a fifth recommendation (X.140) which defines user-oriented, network-independent performance measures. An Institute staff member was selected to serve as international Rapporteur CCITT on Study Group VII's Question 29, "Quality of Service on Public Data Networks," during the 1985-1988 Study Period.

Institute staff members headed the U.S. Delegation to five CCITT meetings during FY 85. These were: the Interregnum meeting of Working Party XI/6 (November 1984), the Interregnum meeting of the Study Group XVIII ISDN Experts Group (January 1985), the Study Group XI Plenary (March 1985), the Study Group VII Plenary (April 1985), and the Study Group XVII Plenary (April 1985). In addition, ITS organized and hosted several national and international standards meetings at its Boulder facility. One international meeting hosted by ITS, the Study Group XI Special Rapporteurs' meeting, involved 150 representatives from 20 nations.

Institute personnel also held leadership positions in the technical subcommittees of two U.S. ANSI-Accredited Standards Committees during FY 85: Committee T1 (Telecommunications), and Committee X3 (Information Processing Systems). Both committees include in their work the preparation of contributions to the CCITT. The Institute provided leadership in Task Group X3S3.5 (Data Communication Quality of Service); Working Groups T1Q1.3 and T1Q1.4 (Digital Circuit and Digital Packet Performance); Technical Subcommittee T1D1 (ISDN); and the T1 Advisory Group.

The second major function of the Institute's International Standards program is to inform interested nonparticipants of significant accomplishments and opportunities in international standards development. The ultimate goal of this function is to broaden and strengthen U.S. input to the CCITT (and other standards organizations) by adding new, well informed contributors, thereby expanding the "knowledge base" from which U.S. contributions--and positions--may be drawn.

In addition to ongoing, daily responses to information requests, the Institute's FY 85 standards information activities produced several NTIA and open literature publications and a number of professional and industry conference presentations. One major NTIA Report published in FY 85, "Standards in Process: Foundations and Profiles of ISDN and OSI Studies," has made a substantial contribution to the general standards literature and has been of broad use to standards developers both in the United States and abroad. The report details standardization processes internationally and in the United States and describes the many factors that influence standardization efforts. The report places emphasis on two standardization issues of particular importance to the Department of Commerce: the impact of the AT&T divestiture on U.S. standardization, and the impact of international standards on U.S. trade. Emerging ISDN and OSI standards efforts are described as consequences of converging technological advances worldwide. Table 2-8 and Figure 2-24 summarize the major U.S. and international organizations

Table 2-8. Sample Organizations Involved in ISDN Studies and Standardization Efforts

	Groups with Major Interest		Groups Involved	
INTERNATIONAL	CCITT:	SG's VII, VIII, XI, XVII, XVIII	CCITT:	SG's I, II, III, IX, XV
	CCIR:	SG 4	ISO:	TC 97 (e.g., SC 6 and SC 16)
			IEC:	TC 83
REGIONAL	CEPT:	GS1	ECMA:	TC's 23, 24, 25
UNITED STATES	U.S. CCITT:	ISDN Joint Working Party	EIA:	TR's 29, 30, 40
	FCC:	CCB	IEEE:	Project 802 (and Telecommunication Committee)
	ASC T1:	T1D1	NBS/ICST:	FIPS Program
	NCS:	FTSP	ANSC X3:	e.g., X3S3, X3T5

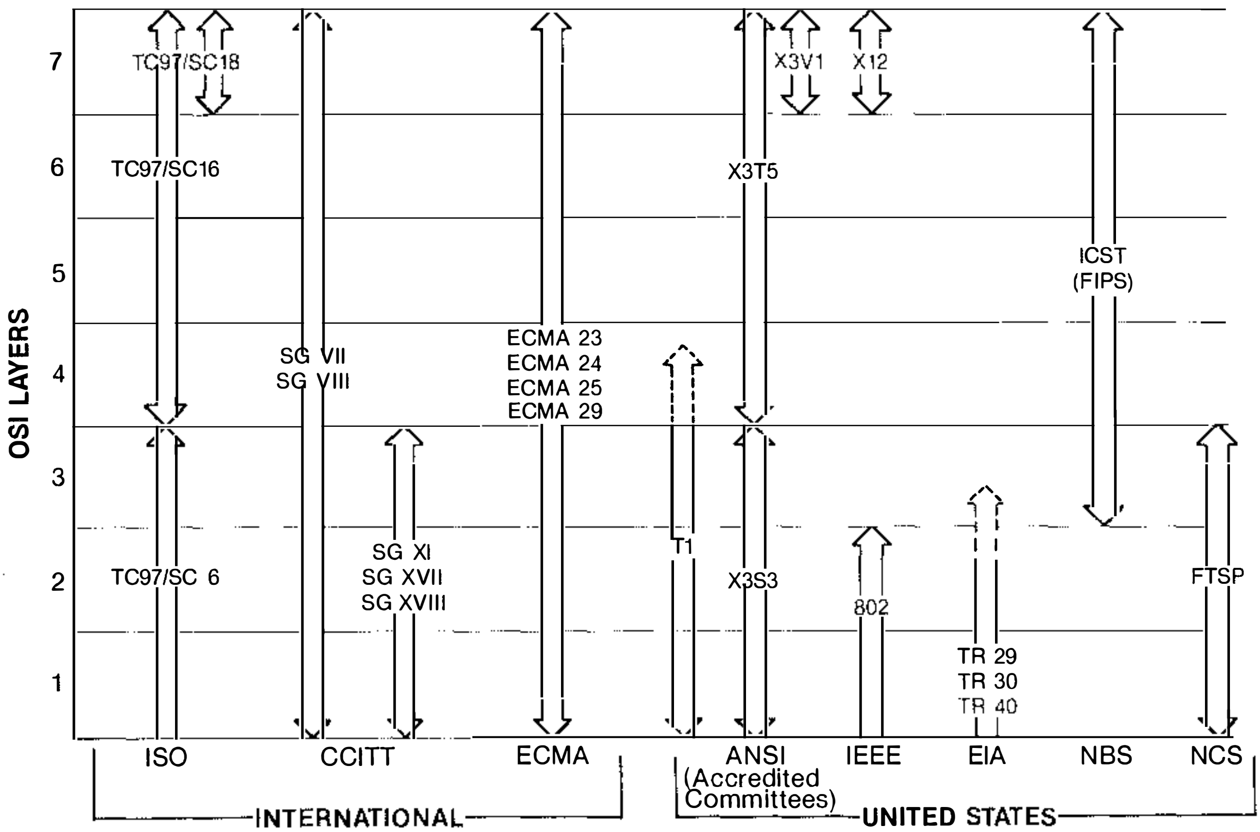


Figure 2-24. Selected international and U.S. standards organizations that contribute to OSI work. The layers of interest to each are indicated.

participating in these two standards efforts as detailed in the NTIA Report.

Another NTIA Report developed under the FY 85 International Standards program is entitled "The OSI Network Layer Addressing Scheme, Its Implications, and Considerations for Implementation." This report describes the context within which the OSI Network layer addressing scheme was developed, the problems it seeks to solve, the alternative approaches given consideration, and the details of the plan finally arrived at. The report discusses the implications of the use of the Network Layer Addressing Scheme in an environment of real systems and networks, and identifies issues that must be resolved if the scheme is to be successfully implemented.

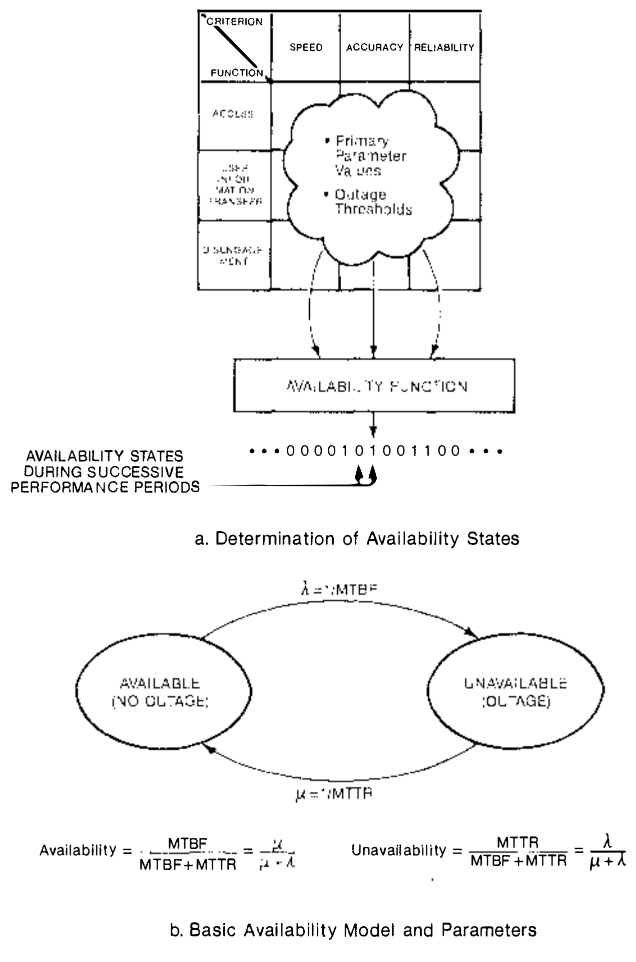
In addition to these major NTIA Reports, ITS staff members published three papers on issues of interest to international standards developers in technical journals and conference proceedings: one on the U.S. CCITT, one on the OSI Network Layer, and one on the modeling of communication error occurrences under conditions of dependence. The latter paper is significant in providing a simple way of combining the error probabilities of tandem links or networks.

Institute personnel were also active in presenting international standards information to workshop and conference audiences during FY 85. Staff members delivered two presentations on OSI standards, two presentations on message handling, a presentation on the OSI network layer, a presentation on statistical measurement principles, and several presentations on the CCITT and its U.S. preparatory committees during the past fiscal year. These presentations collectively reached over 1,000 listeners. The Institute organized and hosted a highly successful conference on CCITT's newly-approved Message Handling Recommendations in cooperation with the Electronic Mail Association in November 1984. Almost 200 people attended.

The third major function of NTIA's International Standards program is to prepare U.S. contributions to international standards committees. Such contributions are undertaken on a very selective basis, in situations where (1) substantial U.S. economic or technological interests are at stake, and (2) NTIA/ITS has special expertise or resources not readily available to other U.S. contributors. A total of 10 such contributions were prepared in FY 85, dealing with two principal topics: alignment of the CCITT and ISO Network Service Definition Standards, and the specification and measurement of Quality of Service. Three of the QOS contributions are briefly summarized below.

The first contribution proposes an overall framework for describing quality of service and network performance in digital networks, including ISDN's. Seven general principles that should be followed in performance description are defined. Two basic types of quality of service (and network performance) parameters are distinguished: primary parameters and availability parameters. The primary parameters describe quality of service and network performance during periods of normal operation. The availability parameters describe the frequency and duration of service or facility outages (including periods of severe performance degradation). It is proposed that the primary parameters be developed separately for each of three primary communication functions--access, user information transfer, and disengagement--and that the performance of each function be considered with respect to three general performance concerns (or "criteria") frequently expressed by communication users--speed, accuracy, and reliability. The resultant 3x3 performance matrix, illustrated in Figure 2-25a, is similar to that defined in an NTIA-developed American National Standard, ANS X3.102. It has been found to be useful in achieving clarity and completeness in performance description.

Figure 2-25 also illustrates the proposed method of developing the availability parameters, which describe the frequency and duration of outages. The NTIA/ITS contribution proposes that outages be defined by comparing values for selected primary parameters with specified outage thresholds during successive performance periods. A



a. Determination of Availability States

b. Basic Availability Model and Parameters

Figure 2-25. Availability definition approach.

defined availability function (e.g., inclusive or) maps threshold violations into outages. Key availability definition issues are the selected parameters, the outage thresholds, the performance period(s), and the availability function. The proposed approach reflects the view that an outage is an unacceptable degradation in performance that may or may not involve a total service cutoff or facility "crash."

Figure 2-25b illustrates a simple two-state availability model and the associated parameters. Under the (common) exponential assumption, transitions between the available and unavailable states are represented by the failure rate λ and restoral rate μ--or equivalently, by their reciprocals, the Mean Time Between Failures (MTBF) and Mean Time To Restoral (MTTR). The availability (A) and unavailability (U) may be calculated directly from these quantities as shown in the figure. The parameters λ, μ, MTBF, MTTR, A, and U are all candidate availability parameters. Specifying any two nonreciprocal parameters defines the rest. All six parameters may be calculated from a single related parameter, the outage probability, in the special case where (1) the performance periods are of equal duration, and (2) successive outages are independent. Additional parameters may be defined to describe the dependence or "clustering" of outages if the exponential assumption is inappropriate.

The framework contribution was well received by CCITT Study Group XVIII. The seven performance description principles were accepted by Working Party XVIII/6 with minor changes and one addition. The 3x3 performance matrix and its associated availability function were accepted as a basis for further studies toward the development of ISDN QOS parameters.

A second NTIA/ITS contribution specifies a set of packet level reference events to be used in defining performance parameters for packet switched public data networks (PSPDN's) whose interfaces conform to CCITT Recommendation X.25 or X.75. These events may also be used in defining performance parameters for the network interfaces themselves. Major components and conceptual boundaries of the two types of interfaces are described. Each interface is seen to consist of the physical circuit (or set of circuits) interconnecting the Data Terminal Equipment (DTE) and the Data Circuit-Terminating Equipment (DCE), or the two Signaling Terminals (STE's), and the level 1-3 protocols implemented in the equipment at each of the two physical circuit end points (see Figure 2-26). The outer boundaries of the interface typically are functional boundaries between the X.25 or X.75 protocols and other functions in the interconnected equipment. A consequence of defining the DTE/DCE and X/Y interfaces to include the level 1-3 protocols in the interconnected equipment is that the interface itself must be viewed as a communication subsystem with distinct entry and exit points.

Two distinct classes of performance-significant interface events ("reference events") are defined: packet entry events and packet exit events. Particular reference events are then specified by identifying (1) the type of packet transferred, (2) the event class, and (3) the state of the interface (as perceived by the DTE, DCE, or STE involved) just after the event. Each reference event corresponds to an interface state transition defined (explicitly or implicitly) in Recommendation X.25 or X.75. The specified events include those identified in the existing PSPDN Quality of Service Recommendations (X.135 and X.136).

The packet level reference events defined in the NTIA/ITS contribution (and the events defined in the existing X.130-Series Recommendations) typically take place within the communication software that performs level 1-3 processing in a customer computer

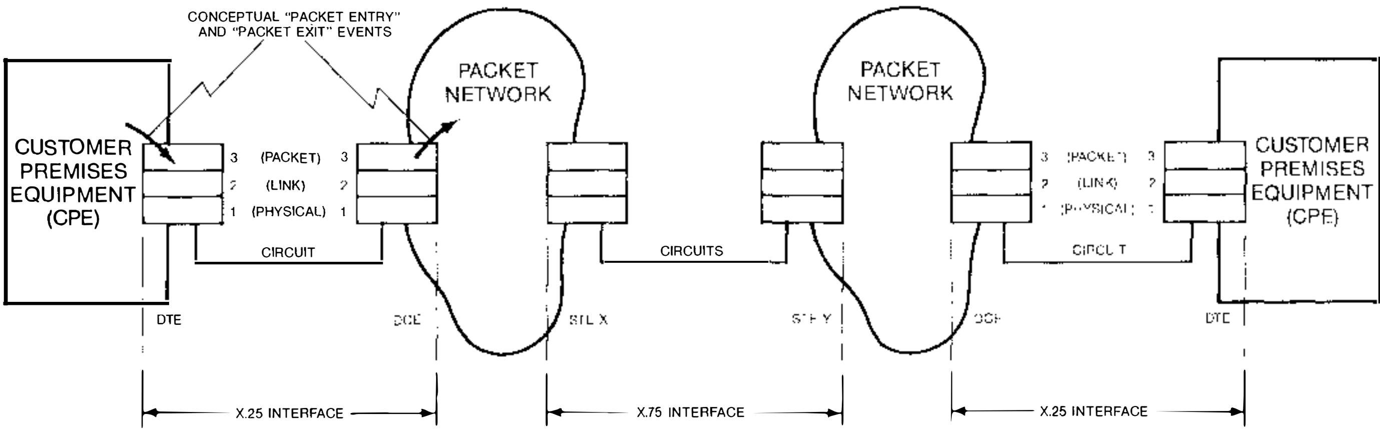


Figure 2-26. DTE/DCE and STE X/STE Y interfaces with conceptual "packet entry" and "packet exit" events.

or network switch. While such events can be monitored directly by software embedded in the level 1-3 implementation, their estimation will often be more practical from observations at the physical DTE/DCE or X/Y interfaces.

Figure 2-27 illustrates a possible method of performing estimation at the physical interface. A passive monitoring device (e.g., X.25 protocol analyzer) is attached to the physical circuit interconnecting a DTE and DCE. The monitor observes all packets transferred across the interface (in both directions) in real time, decodes frame level and packet level overhead and acknowledgments, and calculates performance parameter estimates based on the nature and time of occurrence of the observed physical level frame transfers.

As indicated in Figure 2-27, the physical circuit event that most closely approximates the time of occurrence of a "packet entry" event is transmission of the first bit of the corresponding frame. Similarly, the physical circuit event that most closely approximates the time of occurrence of a "packet exit" event is reception of the last bit of the corresponding (successfully delivered and accepted) frame. Successful delivery and acceptance at the packet level may be confirmed by physical level observations of subsequent frame transfers.

An obvious concern in physical level monitoring of packet level events is the time difference between the occurrence of an event at the packet level (e.g., entry of a data packet into a packet level queue) and the transmission of the associated frame on the physical interchange circuit. Packet level and corresponding physical circuit events would have identical event times if processing and queuing delays in the intervening layers were zero. These delays will often be negligible; in such cases, physical circuit event times may be used directly in calculating estimates for packet level performance parameters. Where processing or queuing delays in intervening layers are substantial, they may be estimated to improve the precision of physical level monitoring. Where appropriate, estimation errors attributable to queuing delays can be minimized by restricting system usage.

The packet level reference events and estimation principles defined in the NTIA/ITS contribution were accepted as a primary basis for packet network performance description by the CCITT Question 29/VII Rapporteur's Group at a meeting in Boulder in September 1985. Use of the generic events should make individual parameter definitions in future CCITT Recommendations briefer and more precise. Specific parameter definitions based on these reference events will be proposed in subsequent U.S. contributions.

The third NTIA/ITS contribution on Quality of Service was addressed to CCITT Study Group II. It proposes an improved statistical method of estimating the call cutoff probability of international telephone connections. This

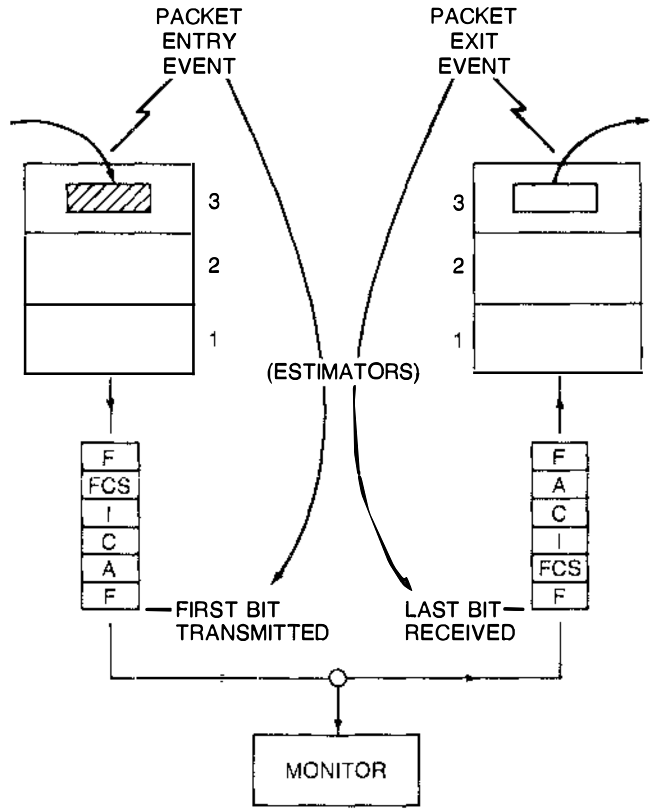


Figure 2-27. Physical level monitoring of packet level events.

contribution made three principal points: (1) measurements of call cutoff probability can be designed to a desired relative precision without assuming beforehand what the unknown call cutoff probability is; (2) the measurements can be designed, with no increase in sample size, so as to estimate the effect of duration of call on the normalized call cutoff probability; and (3) the sequence of cutoff and non-cutoff events should be recorded in order to estimate the degree of dependence among successive cutoff events (and thus better to estimate the precision of the call cutoff probability estimate). These improvements will be incorporated in future revisions to Recommendations G.180 and G.181. This and other NTIA/ITS contributions on statistical parameter estimation suggest and may stimulate a broad program of new work on that subject in CCITT, potentially leading to improved precision and economy in international communication performance measurements.

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, system analyses, and experimentation, with a strong focus on transmission systems engineering. Over the past several years, the Group has developed a number of analytical and experimental tools for the specification, design, testing, and operational evaluation of radio equipment, transmission links, and end-to-end communication channels. Many of these tools have quite broad utility, and all are relevant to both Government and commercial applications. Their development, enhancement, integration, and use are principal activities of the Group. This section describes specific FY 85 projects of the System Performance Engineering Analysis Group with a focus on these internally developed transmission engineering tools. We begin with a brief overview of the Group projects and the available tools.

Figure 2-28 illustrates the general categories of transmission engineering projects undertaken by the System Performance Engineering Analysis Group. At the base of the pyramid are experimental field and laboratory measurement projects. These projects gather new information about radio channel characteristics and provide a factual basis for higher-level studies. The channel modeling and simulation projects reduce the results of experimental measurements and associated analyses to physical or mathematical models of channel performance, and they embody these models in hardware simulators. The simulators are used in testing radio equipment, and the models are collected and presented to users in link engineering computer programs. Tests of operational radio links are undertaken, on a selective basis, to assess equipment capabilities and to verify the link engineering programs and models. Typically, several more fundamental transmission engineering tools are used in network design and evaluation projects. Work of the System Performance Engineering Analysis Group is focused on digital transmission systems in recognition of the growing importance of data communications and Integrated Services Digital Networks (ISDN's).

The specific transmission engineering tools used by the System Performance Engineering Analysis Group are listed in Table 2-9. These tools have been developed over a period of several years. The Group's FY 85 efforts were focused on enhancing and applying them. These FY 85 efforts resulted in the integration and joint use of several tools and revealed considerable synergy among them.

The channel probe and radio performance data acquisition system are field measurement instruments that simultaneously measure the characteristics of a fading channel and the performance of a digital radio in that channel. Simultaneous measurements are required to correlate digital radio performance with fading.

The Multipath Analysis Software Package (MASP) is a program that provides a detailed statistical analysis of data obtained from the channel probe. This data is useful in the development of LOS channel models and simulators and as input to the ITS link engineering programs. The MASP, which was developed during FY 85, provides an important linkage between several previously independent Group programs and contributes strongly to the synergy mentioned earlier.

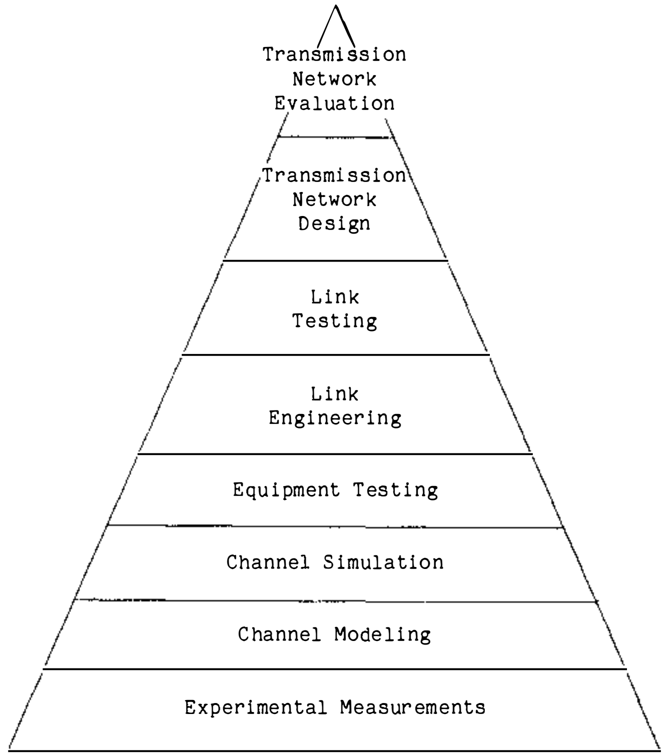


Figure 2-28. Hierarchy of projects undertaken by the System Performance Engineering Analysis Group.

Two channel simulators are currently used within the ITS System Performance Engineering Analysis Group: a narrow-band, high-frequency (HF) channel simulator and a line-of-sight (LOS) microwave channel simulator. These are useful in radio system specification and acceptance testing. The Institute has begun a study that is expected to lead to the development of a wide-band channel simulator capable of testing spread spectrum HF radios.

The ITS-developed link engineering software is useful in calculating the expected performance of digital or analog radios over specified transmission links. It is implemented in user-interactive form on a desk-top microcomputer.

The Transmission Monitor and Control (TRAMCON) System is useful in assessing and controlling operational digital transmission systems. It can simultaneously monitor the status of radio and multiplexer equipment at many remote network nodes, and it can provide performance data as well.

Proposed MIL-STD-188-100A is a network planning guide that should be widely useful in the specification of future military digital communication systems. It specifies performance and interoperability requirements for terminals, loops, trunks, and switches, and is applicable to both long-haul and tactical networks.

Table 2-9. Available Tools

o	Channel Probe and Data Acquisition System
	Microwave Line-of-Sight Channels Troposcatter Channels Satellite Channels
o	Multipath Analysis Software Package (MASP)
	Microwave Line-of-Sight Channels Troposcatter Channels
o	Channel Simulators
	HF Narrowband Channels Microwave Line-of-Sight Channels HF Wideband Channels (Planned)
o	Link Engineering Software
	Microwave Line-of-Sight Links Microwave Beyond-the-Horizon Links
o	Transmission Monitor and Control (TRAMCON)
	Line-of-Sight Networks Transmission Networks Mixed Media Networks
o	MIL-STD-188-100A
	Performance Requirements Interoperability Requirements

Figure 2-29 depicts the application of the tools listed in Table 2-9 to the major transmission engineering problems. Table 2-10 shows how these tools can be used throughout the life cycle of a system, starting with specification and continuing through design, testing, and operational performance evaluation. As shown, the tools can be utilized at the radio equipment level, the link level, or the network level.

Collectively, the tools described above offer several important benefits:

- They promote efficient specification, design, testing, and operational performance evaluation of transmission equipment, links, and networks.
- They enable the design of highly efficient modems for digital radios.
- They reduce the time required to test digital radios.
- They reduce cost of testing.
- They facilitate the design of both LOS and beyond-the-horizon transmission links.
- They greatly reduce the costs of maintaining operational networks.

The latter advantage is a specific benefit of the TRAMCON system. Because this system can be used to remotely monitor and control radios and multiplexers, the number of maintenance personnel required can be reduced. This reduction in personnel will decrease operational costs.

A corollary benefit of these tools is that they can be used to develop better models of LOS and troposcatter channels. Improved channel models will, in turn, improve the accuracy of the channel simulator and link engineering design software.

These tools and their recent applications in Group projects are now described in more detail, in the following order: Channel Probe and Data Acquisition System, Multipath Analysis Software Package, LOS channel simulator, link engineering software, Transmission Monitor and Control System, and MIL-STD-188-100A. A standard telecommunication glossary developed in part by ITS is also briefly described.

Channel Probe and Radio Performance Data Acquisition System. An important objective in testing LOS and tropospheric scatter radio systems is to assess their performance in a fading environment. Although valuable testing can be accomplished in the laboratory using a channel simulator like the one discussed later in this section, some field testing is usually also necessary. Typically, several characteristics of the channel must be measured and correlated in time with the performance of the radio. The Institute for Telecommunication Sciences has developed a channel probe and radio performance data acquisition system to facilitate such correlated field testing.

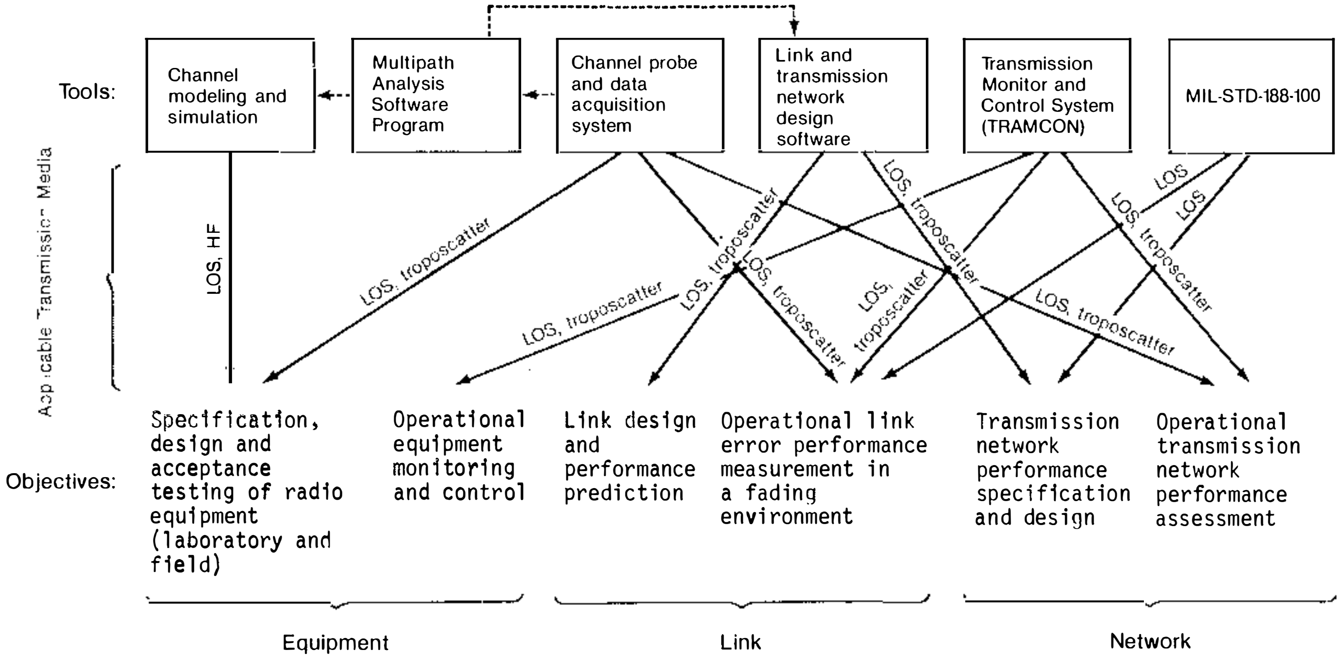


Figure 2-29. Application of tools developed by the Institute to digital transmission problems.

Table 2-10. Application of Software/Hardware Tools in the Life Cycle Phase

Life Cycle Phase	Radio Equipment	Link	Network (end-to-end)
Specification	Channel Simulator	MIL-STD-188-100A	MIL-STD-188-100A
Design	Channel Simulator	Link Engineering Software	
Testing	Channel Simulator Channel Probe and Data Acquisition System MASP	Channel Probe and Data Acquisition System MASP TRAMCON	Channel Probe and Data Acquisition System MASP TRAMCON
Operational Performance Evaluation	Channel Probe and Data Acquisition System MASP TRAMCON	Channel Probe and Data Acquisition System MASP TRAMCON	Channel Probe and Data Acquisition System MASP TRAMCON

In testing either LOS or tropospheric scatter radios, three types of data must be collected:

- o radio performance data
- o channel fading data
- o meteorological data.

The performance parameters typically measured on digital radio links are bit error rate (BER) and synchronous error seconds (SES). These error measures describe a link's performance in user-relevant terms. The channel fading data consist of the channel impulse response. From this data one can determine statistical information about multipath. This is described in more detail in the section on the Multipath Analysis Software Package. Meteorological data is needed to determine the refractivity of the atmosphere. The required data consists of dry and wet bulb temperatures and the pressures at various altitudes. NTIA Report 83-126 ("Digital Microwave Transmission Tests at the Pacific Missile Test Center, Pt. Mugu, CA," by R. W. Hubbard) describes the use of these three types of data in more detail. The following paragraphs describe the channel probe and several projects conducted during 1985 using the channel probe and radio performance data acquisition system.

A basic block diagram of the NTIA/ITS channel probe is shown in Figure 2-30. The upper part of the figure illustrates the transmitter. A stable reference oscillator is used to develop both the intermediate frequency (IF) and the clocking rate for a standard shift register that produces a pseudonoise (PN) binary code. The code is biphase modulated onto the IF carrier, which is then mixed with a subcarrier frequency for transmission over the test channel. The subcarrier frequency is developed from the same synthesizer chain so that all of the signal components are coherent.

The receiver portion of the probe is shown in Figure 2-30(b). The frequency reference chain is similar to that used in the transmitter. However, the reference oscillator is generally controlled with a phase-locked-loop (PLL) circuit so that the receiver reference will track the fluctuations due to instabilities, transit path length changes, Doppler and other propagation factors of the channel.

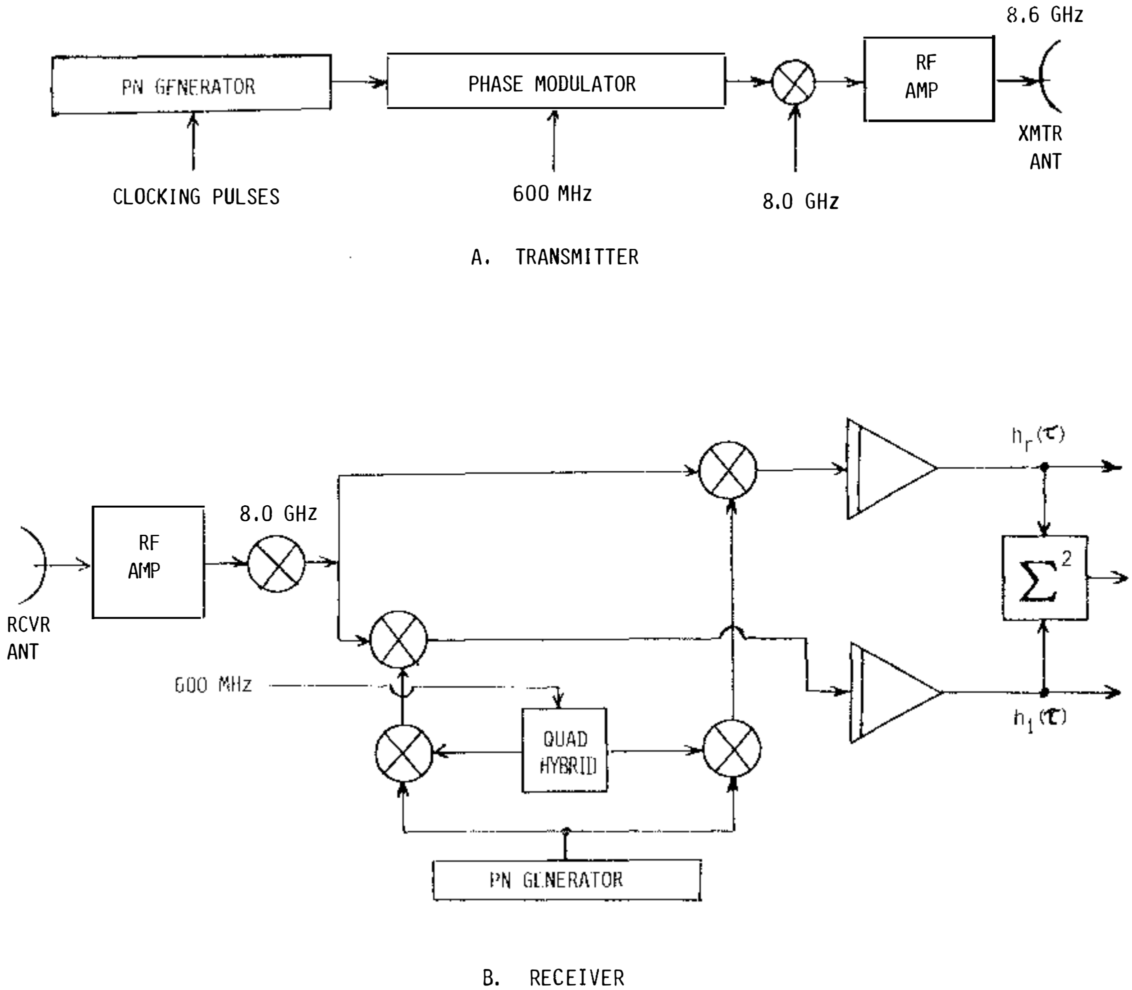
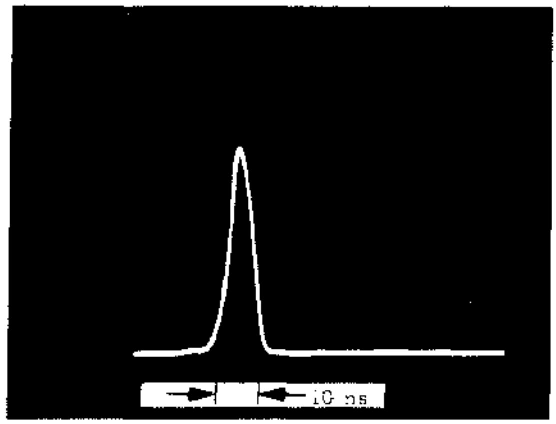


Figure 2-30. Functional block diagram of the NTIA/ITS channel probe.

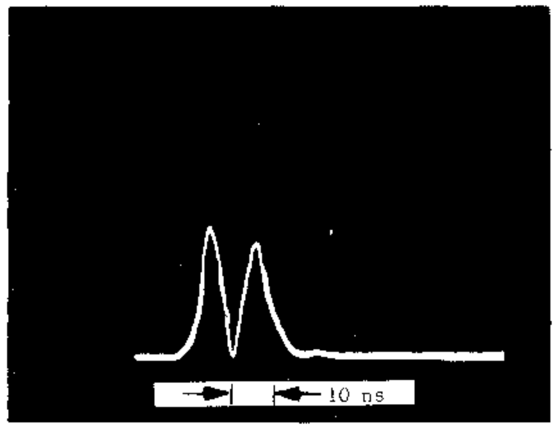
The received signal is power divided and fed to two quadrature detection channels, where the local IF signal is applied to two mixers in quadrature phase. The local PN code is generated with the same pattern as that used in the transmitter, and it biphase modulates the local IF. The modulated signals are then applied to the correlation detectors, where they are correlated with the received signal at the IF level. Thus, there are two output signals developed that are the quadrature components (real and imaginary) of the impulse response of the measured channel. The quadrature functions are also processed in a sum of the squares circuit to produce the envelope, or the power impulse response function.

A multiplexed correlator signal is developed by using a "slow clock" to develop the local reference PN code. The local code is allowed to slip very slowly with time with respect to the received PN code. The result is a slow but continuous measurement of the delay parameter τ.

An example of a measurement using the channel probe on an LOS channel is shown in Figure 2-31. In this case, the PN clock rate was 150 MHz. Part (a) of the figure illustrates a measurement of a clear (no multipath) channel. Part (b) shows a multipath signal that is comparable in magnitude to the direct path signal, but delayed on the order of 10 ns. From this example it can be seen that if the delay were short compared to the base width of the direct path response, the impulses of the two responses would begin to overlap. High resolution is therefore required.



(a) Clear channel response; impulse width is 13.3 ns.



(b) Response with a multipath component delayed 10 ns.

Figure 2-31. Example of channel probe output signals.

The Institute has developed two channel probes: one for troposcatter channels and one for LOS channels. The troposcatter channel probe has a 70-MHz interface to the troposcatter radio, and a 5, 10, or 20-MHz PN clock rate. The LOS channel probe operates at radio frequencies (2-15 GHz, in this case) and has a 150 to 1000-MHz PN clock rate. Because the LOS channel probe operates at rf, it is typically multiplexed onto an existing waveguide and antenna system along with other rf signals.

The radio performance data acquisition system consists of a commercial minicomputer system including peripherals, an analog-to-digital (A/D) conversion system, and a test instrument for measuring the digital error performance of the radio. The primary data storage medium is a digital magnetic tape. The system has the capability of recording 16 A/D channels, three 16-bit parallel digital data bit streams, and the digital burst-error data. The analog signals from the channel probe are sampled in the A/D interface and then recorded on the digital tape. The analog information recorded also includes the received signal level (RSL) measurements for multiple channels. The 16-bit parallel interfaces are used to record various digital parameters of the radio under test. The burst-error data for the radio under test are recorded from a first-in-first-out (FIFO) buffer interface. This data comes from a test instrument that compares the received digital bit stream with a local (receive end) copy of the transmitted bit stream. The bit error information is derived from this comparison.

The channel probe and radio performance data acquisition system were applied in several equipment and link performance evaluation projects during FY 85:

- Digital Radio and Multiplex Acquisition (DRAMA) radio performance evaluation (field tests at Pt. Mugu, CA)
- angle-diversity antenna performance evaluation (field tests at Pt. Mugu, CA)
- propagation tests on two LOS links in Korea.

In addition, a project for evaluating the performance of a digital modem on a tropospheric scatter link between Berlin and Bocksberg, West Germany, was initiated during FY 85. The angle-diversity and Korea LOS applications are briefly described below. An application of the PN probe concept to the measurement of multipath in land mobile satellite radio channels is also briefly described.

Microwave radio systems commonly use space or frequency diversity to combat multipath fading. A third, more experimental form of diversity that can potentially discriminate against multipath signals is angle diversity. Angle-diversity techniques attenuate multipath signals by exploiting known characteristics of the receiving antenna gain pattern. One particularly simple angle-diversity technique involves purposely tilting a receiving antenna vertically off the boresight line. This attenuates the direct signal somewhat but can attenuate a multipath signal even more, thereby reducing the resultant multipath fade. Such a technique was tested by ITS in prior work and found to be effective in certain circumstances.

A similar approach, involving a vector combination of signals in the antenna pattern, was the subject of a test program conducted by the Institute at Pt. Mugu, CA, in FY 85. The angle-diversity antenna used in these tests employed a sum and difference beam approach suggested by a contractor to the U.S. Army Information Systems Management Activity (ISMA) at Fort Monmouth, NJ. The contractor implemented this approach in an angle-diversity feed for a 1.2-m (4-ft) diameter parabolic reflector. The Institute was asked to assess the performance of the resultant diversity system.

The test link, at the Pacific Missile Test Center (PMTC) at Pt. Mugu, CA, is an LOS path between Laguna Peak (LP) on the California coast and San Nicolas Island (SNI) in the Channel Islands Chain some 104.6 km (65 miles) offshore. The link is quite long, and is one in which significant multipath conditions develop as a result of atmospheric inversions that set up strong refractive layers in and above the radio path. Surface reflections have been found to be very minor, primarily as a result of the patterns of the parabolic antennas and the height of the link terminals. The link is considered ideal for the study of multipath propagation problems.

The tests were conducted in two phases. The first phase investigated the fading characteristics of the monopulse type antenna (see "Angle Diversity Reception for LOS Digital Microwave Radio," by R. W. Hubbard, in the MILCOM 85 Conference Proceedings). The second phase compared the performance of the angle-diversity system with a conventional space-diversity system operating concurrently in the same transmission channel. The objective was to evaluate the effectiveness of angle-diversity reception in a multipath environment.

Initial tests suggest that the tested form of angle-diversity has merit. At times, the angle-diversity system performed better than the space-diversity system. At other times, performance of the two systems was nearly the same. The angle-diversity system performed poorer than the space-diversity system on only one of nine test days.

Future tests of the angle-diversity technique are being planned, in which line losses will be reduced and the signal-to-noise (S/N) will be improved. These tests will incorporate new switching algorithms for the DRAMA radio and a form of predetection combining.

The U.S. Army has noted for some time an unusual and sometimes severe fading problem on a number of LOS microwave links in the Republic of Korea. The cause of the fading problem was not known, but several factors had been considered, including multipath. The Institute used its PN probe in testing these links for possible multipath at the request of the Army Electronic Systems Engineering Installation Activity (ESEIA), Fort Huachuca, AZ, during February and March 1985.

Two LOS links were tested. The first was an 85-km east-west link south of Seoul. The site terminals are known as Madison (MSN) and Paegunsan (PSN). The second link was a 104-km north-south link north of Taegu. The site terminals are known as Yonghwabong (YWB) and Palgongsan (PAL). Each of the site terminals is located on the top of a high mountain, and the propagation paths traverse mountainous terrain.

Path profiles for the two test links are shown in Figures 2-32 and 2-33. Each figure shows the locations of the site terminals, their elevations, and the location of the antennas above ground. Both links are designed for vertical space diversity, but only one antenna is currently installed at PAL. The diversity spacing at the other sites is 7 m. The path profiles were plotted by the link engineering software described later in this section.

The test instrumentation was first installed on the MSN-PSN link. The probe transmitter was located at PSN and was unattended. The transmitter was operated remotely from MSN. All of the receiving and recording equipment was installed at MSN. Tests were conducted between February 4 and 25, 1985.

The instrumentation was then moved to the YWB-PAL link. Testing over this link was conducted between February 27 and March 11, 1985. Transportation and other logistic considerations dictated that the receiving/recording equipment be installed at PAL. These tests, therefore, did not involve the use of space diversity.

Figure 2-32, showing the path profile of the MSN-PSN link, indicates that under certain refractivity conditions a diffracting ridge located approximately 23 km from the MSN terminal could become a problem. The direct ray path in this figure has been shown for an Earth-radius factor of k=0.81, and it is seen to be grazing at the heights of the trees on this ridge. Calculations using an ITS-developed LOS link design program indicate that the refractive index producing this condition is a slope of approximately +37 N

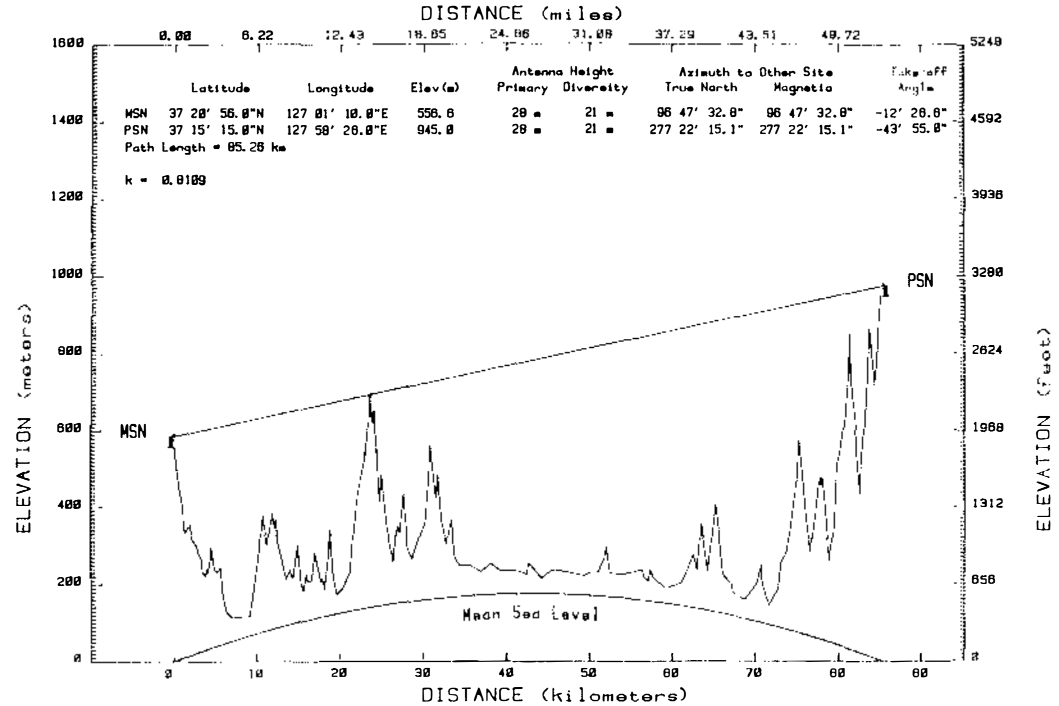


Figure 2-32. Path profile for the Madison-Palgongsan link.

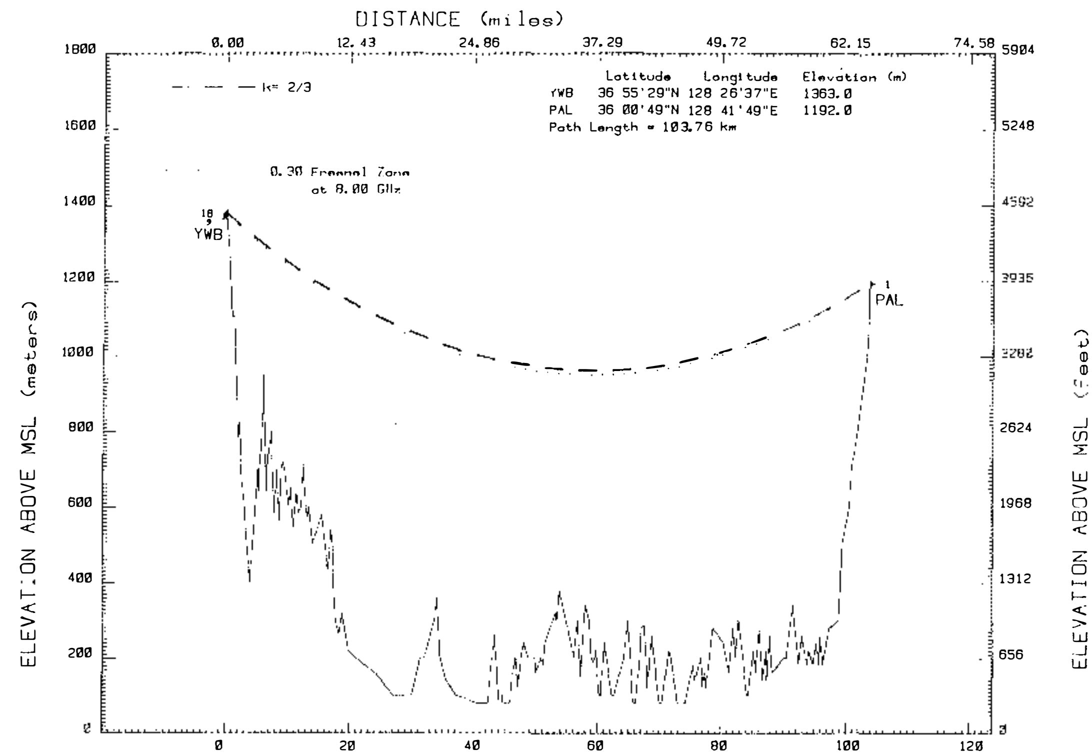


Figure 2-33. Path profile for the Yongwhabong-Palgongsan link.

units/km (a k=1 is the condition for zero slope). A positive refractive slope is an unusual condition. Positive gradients can and do develop over these links, but only within layers of limited thickness in the atmosphere. Review of the meteorological data collected during these tests showed that a profile that would permit a diffraction problem is improbable. In addition, earlier received signal level (RSL) measurements performed by ESEIA personnel had shown that the fading phenomena occurred over multiple links within the same periods of time. This included periods where fading was observed at almost the same time over the MSN-PSN and YWB-PAL links. As can be seen from Figure 2-33, the YWB-PAL link has no potential obstruction such as that in the MSN-PSN path. Thus, the possibility of significant diffraction fading over the MSN-PSN link during the test period was ruled out.

Multipath was also tested as a possible cause of the observed signal fades. The following signals were recorded:

- o RSL of each diversity channel
- o impulse response of each diversity channel
- o error data in the digital signal.

A six-channel strip chart recorder was used to provide continuous records of the RSL voltages so they could be monitored conveniently on site. These signals were recorded in parallel with those fed to the magnetic tape recorder. The hourly time code was recorded on one channel of the strip chart.

The channel probe was interfaced with the operating radio system such that the impulse response was measured over the same transmission paths. The probe operated at a fixed frequency of 8.6 GHz, above the frequency band of the operational radio. Thus, it could be multiplexed into the operating system without interference. The probe data confirmed that multipath was not the cause of the observed fading.

A third possible cause of the observed signal fades was power fading. Based on the test data collected, it was concluded that a form of power fading called decoupling loss was the primary cause of the observed link outages. Decoupling loss can be reduced significantly by using smaller antennas with larger apertures. However, this approach will reduce the overall fade margin for the links by reducing the antenna gains. It will also increase the risk of multipath by illuminating new terrain and atmospheric regions. The Institute recommended that these factors be investigated thoroughly before a change in antenna size is specified.

Angle diversity was considered as another possible solution to the Korean link fading problem. If the receiving antennas at each terminal were pointed slightly down from the boresight, it is possible that the refracted energy might be refocused. The system would be operating most of the time on the upper antenna path, with the stronger signal. As the refractive fading developed, less fading might exist in the lower antenna path. Measurements were outlined to test this approach.

As a part of propagation studies for Land Mobile Satellite Service, the Institute examined methods of measuring multipath in satellite channels for the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA. The objective of this study was to investigate the feasibility of using existing satellite signals from the Global Positioning System (GPS) in a PN channel probe of the type developed by ITS to measure the multipath. The study involved a detailed investigation of the GPS signal structure, a distortion analysis for time multiplexed correlators, and the development of specific measurement approaches. Results of this study are summarized in a report, "Multipath Measurements in the Land Mobile Satellite Radio Channel," by John J. Lemmon and Robert W. Hubbard. A detailed design for such a multipath experiment, including specific time and cost estimates, was also prepared.

The central conclusion of the study was that, in the absence of time and cost constraints, the GPS satellites and a suitably modified GPS receiver would provide a viable system for multipath measurement. Alternative means of carrying out a multipath experiment (for example, using the ITS channel probe with the transmitter in an aircraft or balloon) were also considered.

Multipath Analysis Software Package. The Multipath Analysis Software Package (MASP) is a new tool developed at ITS during FY 85 for the detailed statistical analysis of multipath fading data collected by the ITS channel probe. As suggested earlier (Figure 2-29), MASP performs a valuable function in linking the channel probe, an important source of real-world fading data, with the ITS-developed LOS channel simulator and link engineering software, whose designs are based on such data. This linkage will directly benefit future work in microwave radio system analysis and design.

The MASP software is divided into several programs. The first is the multipath recognition program. This program performs a pattern recognition function: it detects and evaluates the direct and indirect (i.e., multipath) components in successive 1-second impulse responses from the channel probe. The raw data used by this program are the following channel probe outputs:

1. power impulse response from Channel A
2. power impulse response from Channel B
3. cophase function from Channel B
4. quadrature function from Channel B.

Typically, Channels A and B of the channel probe receive data from two space-diversity antennas respectively. Future tests using the channel probe will include phase information from both channels as well as the power impulse response.

Several multipath situations of interest have been identified in previous analysis of the channel probe data. "Normal multipath" describes the common situation where the direct signal is stronger than the reflected or refracted signal. "Abnormal multipath" describes the opposite situation, where the reflected or refracted signal is stronger. (These are sometimes referred to as the "minimum phase" and "nonminimum phase" cases, respectively, in transmission engineering literature.) "Hidden multipath" describes the situation where direct and multipath signals are very closely spaced in time and may only be resolved by observing a deformation of the channel probe impulse response. "Three-component multipath" describes the situation where two reflected or refracted signals are received in addition to the direct signal. Each of these multipath situations is illustrated in the channel probe outputs plotted in Figure 2-34. The MASP multipath recognition algorithm automatically detects all of the above situations.

The multipath recognition program's ability to detect three-component multipath may prove to be very important in future channel simulator development. Most LOS channel simulators currently used are based on a two-component model. If three-component multipath is shown by MASP analysis of channel probe data to be statistically significant, it may be worthwhile to modify future channel models and channel simulators to generate an additional multipath component.

The second major MASP program is the multipath analysis program. This program summarizes the data produced by the multipath recognition program in statistical distributions. These distributions fall in two categories: general multipath statistics and dynamic multipath statistics. The former category includes: multipath power distribution, multipath delay distribution, multipath delay vs multipath power, distribution of multipath phase, and abnormal multipath statistics. The dynamic multipath statistics developed by MASP include: rate of change in multipath power, rate of change in multipath delay, rate of change of multipath phase, rate of collapse and development of multipath, impulse response width statistics, and amplitude slope statistics.

Very little data is available in the literature on these multipath statistics. This is especially true of the dynamic statistics. Future statistical analyses using MASP will lead to a better understanding of the propagation channel, more realistic models of the channels, and more realistic channel simulators used in the laboratory evaluation of digital LOS or troposcatter radios. It will be helpful in the design of future digital radios. The statistical information is needed for the development of techniques for combating multipath fading (e.g., adaptive equalizer design and space diversity combining or switching algorithms). Figure 2-35 depicts the role of the MASP software in linking several Group projects and their end products.

Line-of-Sight Channel Simulator. Channel simulation has been used in transmission engineering studies for at least 20 years. During this period, systems have been developed to simulate HF, LOS, and troposcatter channels. Most have been implemented at intermediate frequencies (IF). Simulation at IF has the disadvantage that some of the critical components of the signal path through the radio are omitted. These critical components include the phase locked loop (PLL) and automatic gain control (AGC). The LOS channel simulator developed at the Institute differs from those developed elsewhere in that it operates at radio frequencies (rf). All components of the signal path can therefore be tested. The simulator is based on a two-path propagation model and is implemented using delay lines constructed from semirigid coaxial cable.

The specific objective of the LOS channel simulator project was to develop a hardware/software system capable of providing a realistic simulation of a frequency-selective fading LOS microwave channel. At the early stages of the project the following two-path model of the channel transfer function was chosen:

$$H(\omega) = a(1+be^{j\omega\tau}).$$

Here, "a" represents flat fading, "b" represents the amplitude of the indirect path relative to the direct path, "τ" represents the relative delays between the two paths, and "ω" represents the carrier frequency in the band of interest.

Figure 2-36 is a functional block diagram for implementing the two-path model given by the above equation. The relative delay (τ) between the direct and indirect paths is provided by switching in various lengths of semirigid coaxial lines in the switched delay sections. The programmable attenuator in the indirect path represents the parameter "b." The other programmable attenuator represents the parameter "a," i.e., the flat fading parameter. The manual attenuator at the input to the simulator reduces the signal level of the transmitter under test to levels that are compatible with the receiver section of the radio being tested.

One concern throughout this project has been to design the system such that changes in relative delay between the two paths would not change the relative signal level between the two paths and vice versa. That is, relative phase and relative amplitude of the two paths must be independently controlled. Great care was taken in the design and implementation of the system to ensure that this was accomplished. For this reason, a signal leveler is needed in the indirect path so that the signal level does not change when additional delay is placed in the indirect path by switching in additional delay sections. The purpose of the attenuator and

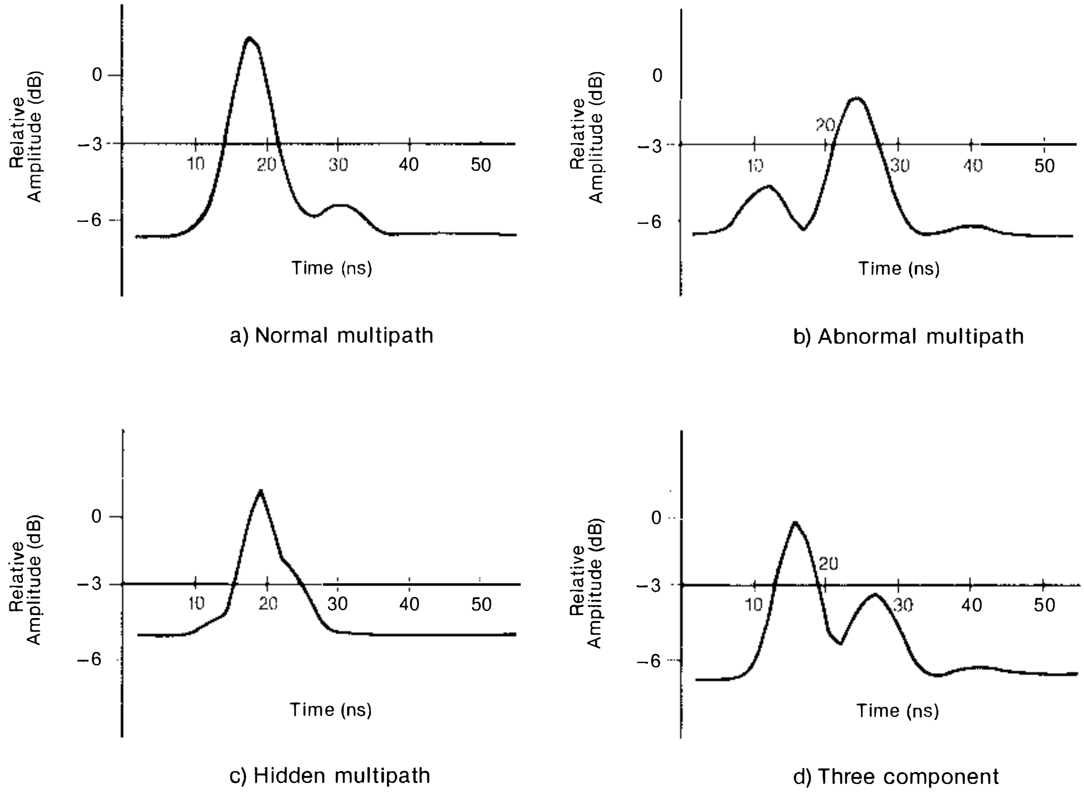


Figure 2-34. Multipath situations detected by MASP.

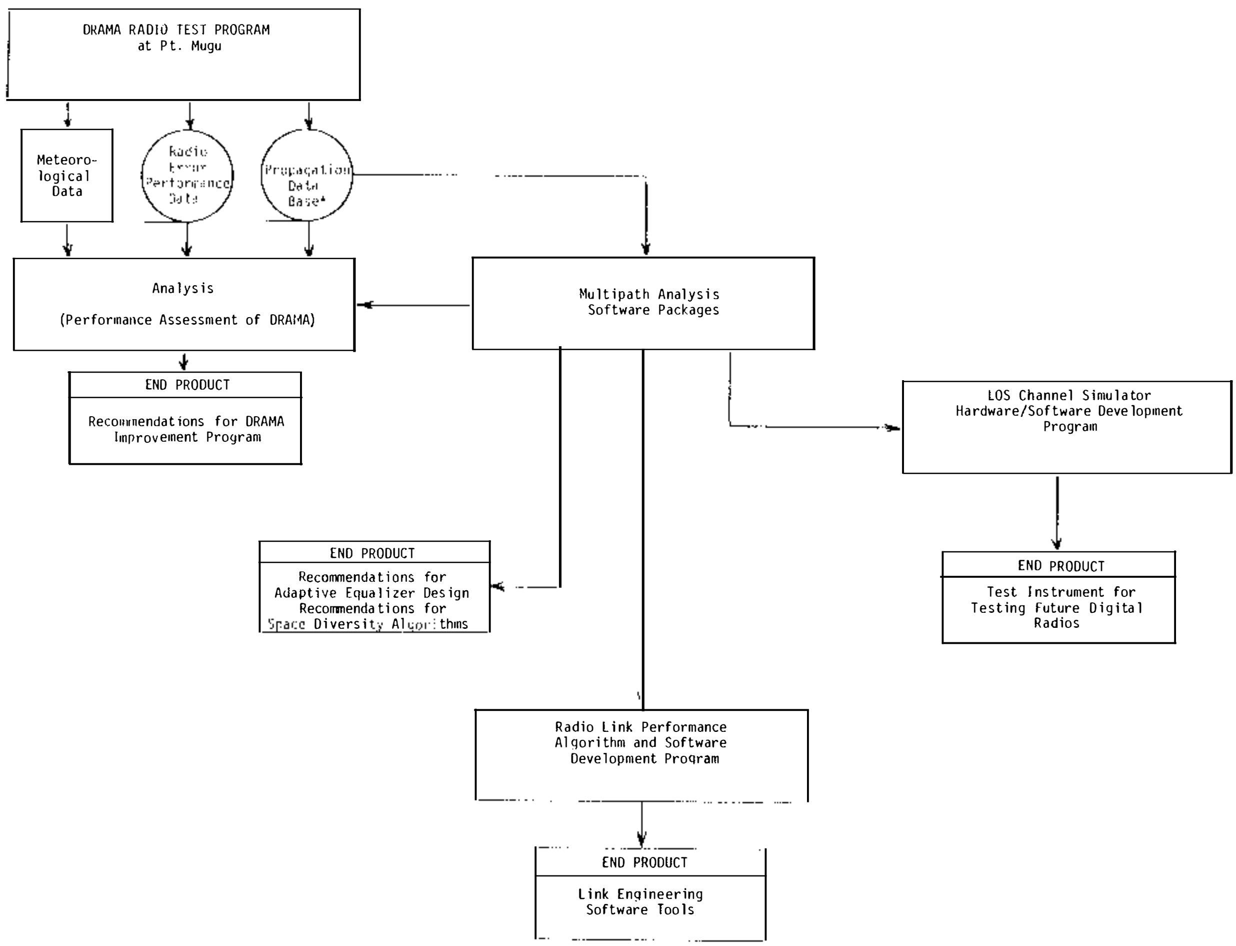


Figure 2-35. Interrelationship of several projects with the MASP software.

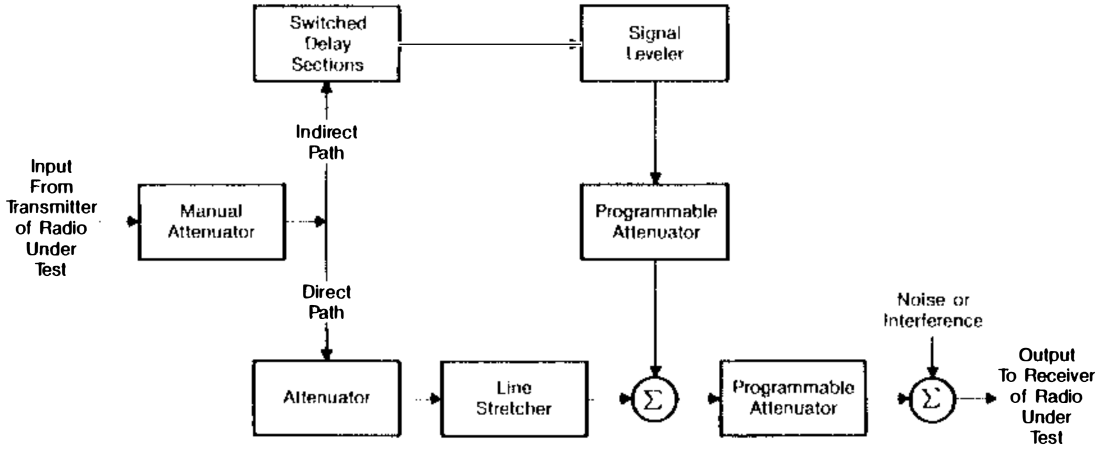


Figure 2-36. Functional block diagram of the LOS channel simulator (only one channel shown).

line stretcher in the direct path is to make the delay and the attenuation of the indirect and direct paths equal when there is zero relative delay in the indirect path.

Figure 2-37 provides more detail of the block in Figure 2-36 labeled "switched delay sections." There are eight such sections, each having different lengths of semirigid coaxial cable. This cable has delay characteristics that effectively simulate delays typical of LOS microwave channels. The maximum range of delay reported in the literature for measurements on typical communications links is on the order of 18 ns. In the simulator that has been developed, delays of 19.125 ns are achievable. The first delay section has a nominal delay of 0.075 ns. Each successive delay section has twice the delay of the previous one. Thus, the eighth (last) delay section has a delay of approximately 9.6 ns.

The line stretcher shown in Figure 2-37 is used to adjust the amount of delay in each section, thereby placing strong signal attenuations or "nulls" at the proper locations in the spectrum regardless of the operating center frequency. The purpose of the attenuator is to ensure that attenuation through the delay section is approximately the same regardless of whether the delay path or the nondelay path is switched in. This helps reduce the requirements on the load-leveler circuitry previously described. These attenuators are only placed in the two longest delay sections because the amount of attenuation inserted is less than 1/2 dB for the short delay sections.

There were a number of uncertainties at the start of this project regarding the general simulation concept and implementation approach described above. These uncertainties included:

- the ability to implement the device at rf without reflections that would degrade the performance of the device
- the control of the relative amplitude and phase of the two paths
- whether the simulator could be easily adjusted or calibrated for different operating frequencies
- the repeatability and stability of the simulator transfer function.

All of these uncertainties have been resolved. It has been demonstrated that the simulator as constructed can be adjusted for phase and amplitude differences, is usable over a wide range of frequencies, is stable and repeatable, and is amenable to computer control.

Figure 2-38 shows the results of measurements using a spectrum analyzer set at f_0 = 8.0 GHz, 20 MHz/div horizontal scale and 10 dB/div vertical scale. Figures 2-38(a), (b), and (c) show the resulting spectrum respectively for switched delay sections 1, 5, and 8 switched into the indirect path. Figure 2-38(d) shows the spectrum when all switched delay sections are switched in. Figure 2-38(e) shows an overlay of four traces, each with the same delay, but with attenuation of 0, 1, 3, and 8 dB in the delay component.

One can verify that notches in the spectrum occur as expected by examining Figure 2-38(d). With all switches on, there is a total delay in the indirect path of:

$$\sum_{i=0}^{i=7} (0.075)2^i = 19.125 \text{ ns.}$$

The spacing between nulls is $1/\tau$. With τ equal to 19.125 ns, the null spacing should be approximately 52 MHz. This is roughly apparent in Figure 2-38(d) where the scale is 20 MHz per division. This was verified more accurately in the laboratory using a precision signal generator and a power meter.

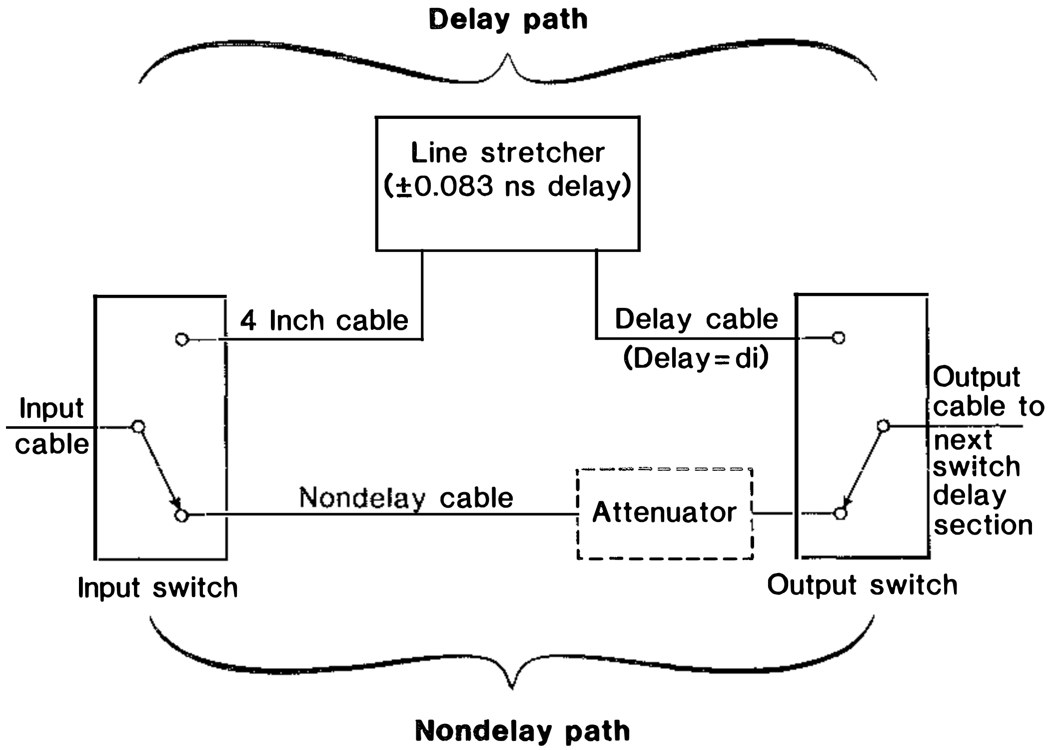


Figure 2-37. Physical implementation of a switched delay section.

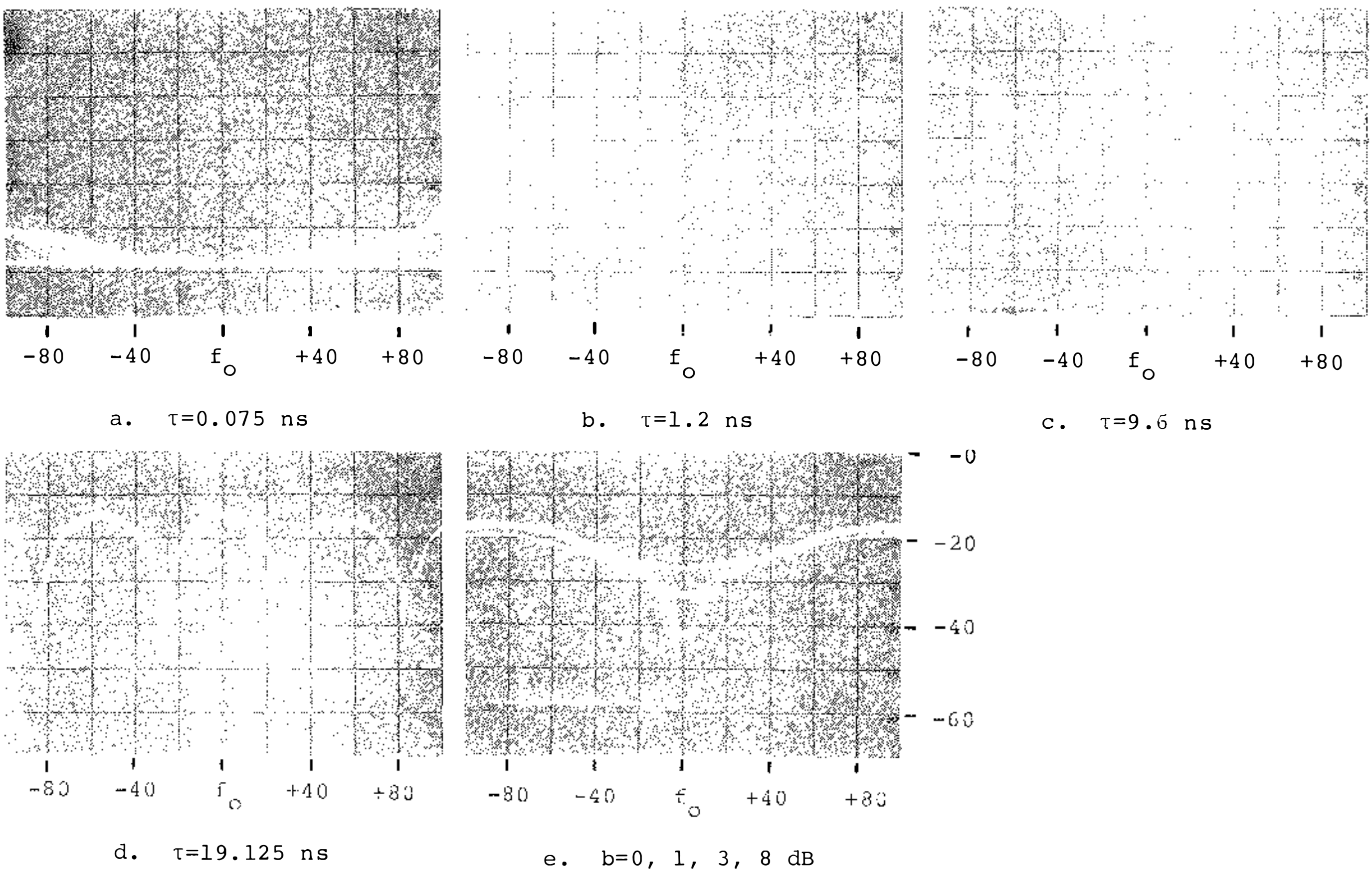


Figure 2-38. Simulator output as displayed on a spectrum analyzer.

Achievable notch depth was also verified accurately in laboratory measurements. Notch depths of 60 dB were measured.

Because of the initial uncertainties and questions about simulator design and implementation, the project was broken into the following phases:

1. development of proof-of-concept prototype hardware
2. automation of the simulator control (via a minicomputer) and building a second channel for testing of space diversity radios
3. exercising the simulator with a DRAMA (Digital Radio and Multiplexer Acquisition) radio
4. development of a jamming system applique unit.

Phase 1 has been completed. Work on Phases 2 and 3 is in progress. Phase 4 is more applicable to the performance evaluation of the next generation (mid-1990's) digital microwave radios for the Defense Communications System (DCS). Before any Phase 4 effort can, or should, be initiated, the results of previous electronic warfare (EW) threat-definition studies will be reviewed.

Link Engineering Software. 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 loss 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 terminal sites in low terrain using short towers, thus sheltering the relatively wide-beam terminal antennas from interfering sources.

The need existed for an automated prediction technique to estimate the performance of passive repeater links. This need was filled efficiently using a desk-top computer with a set of interactive programs that provide the design engineer with fast turnaround 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 USAESEIA. These programs perform two principal functions: (1) calculate the optimum orientation values for passive repeaters from the Earth geometry and characteristics values of the terminal and repeater sites; and (2) calculate the performance of the link based on the passive repeater size, antenna gains, other equipment parameters, and atmospheric and terrain parameters.

Three repeater types are considered:

- separate interconnected parabolic antennas
- one-plane reflectors
- two-plane reflectors.

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

Because 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 analysis structure is designed such that an ordinary line-of-sight link is a special case of repeater analysis. This greatly expands the utility of the program set.

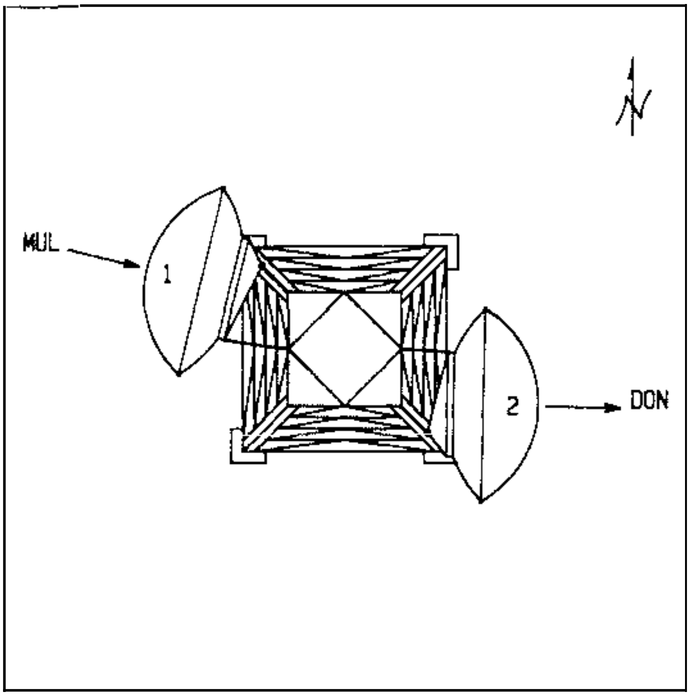
Examples of some of the program's outputs are shown in Figures 2-39 through 2-42. Figures 2-39 and 2-40 are examples of diagrams providing antenna and reflector information, which is necessary to the building and aligning of repeaters. In order to predict the performance of a link, the distribution of carrier-to-noise ratio and the single receiver transfer characteristic is needed. An example of these two relationships is shown in Figures 2-41 and 2-42.

These terrestrial radio link algorithms are presently being used to calculate the performance of communication links in both military and civil applications. The line-of-sight link programs are especially useful for nonmilitary applications. A convenient capability for comparing performance of passive and active repeater alternatives leads to savings in both money and spectrum while maintaining or enhancing the reliability and performance of communication systems. The military applications of the programs are equally applicable to both tactical and strategic systems. Because the programs run on desk-top computers, they are especially useful for the Army in the field.

The project was completed early in FY 85.

During the past 4 years, ITS has produced three sets of interactive programs for USAESEIA. These programs are used to predict the performance of three major types of terrestrial radio transmission systems. The program sets are: WORLD for beyond-the-horizon radio links, POMMP for marginal line-of-sight, and ARROWS for line-of-sight.

WORLD was the first of these programs to be developed. It covers the topic of Wideband Over-the-horizon Radio Link Design. WORLD



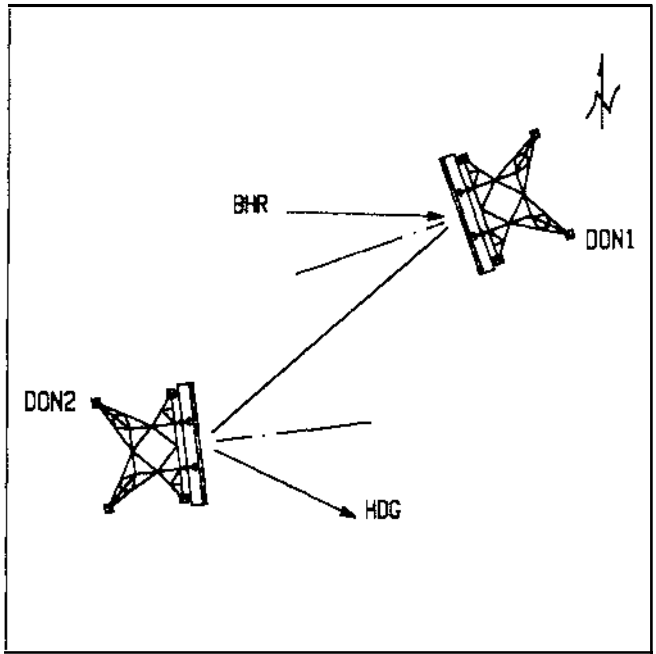
BHR1 Receiving Antenna Data:

1.	Primary Freqency	GHz	7.4000
2.	Polarization		Vertical
3.	Latitude	d/m/s	49 38' 08.0"N
4.	Longitude	d/m/s	7 19' 33.0"E
5.	Tower Base Elevation Above msl	m	563.00
6.	Beam Azimuth To MUL	d/m/s	283 17' 60.0"
7.	Beam Magnetic Azimuth To MUL	d/m/s	288 17' 60.0"
8.	Primary Beam Elev Angle Toward MUL	d/m/e	24' 13.6"
9.	Primary Antenna Diameter	m	3.00
10.	Prim Ant Center Ht Above Tower Base	m	14.50
11.	Diver Ant Center Ht Above Tower Base	m	4.50

BHR2 Transmitting Antenna Data:

1.	Primary Freqency	GHz	7.4000
2.	Polarization		Vertical
3.	Latitude	d/m/s	49 38' 08.0"N
4.	Longitude	d/m/s	7 19' 33.0"E
5.	Tower Base Elevation Above msl	m	563.00
6.	Beam Azimuth To DON	d/m/s	91 14' 24.3"
7.	Beam Magnetic Azimuth To DON	d/m/s	96 14' 24.3"
8.	Primary Beam Elev Angle Toward DON	d/m/s	00' 28.3"
9.	Primary Antenna Diameter	m	3.00
10.	Prim Ant Center Ht Above Tower Base	m	14.50
11.	Diver Ant Center Ht Above Tower Base	m	4.50

Figure 2-39. Example passive repeater configuration.



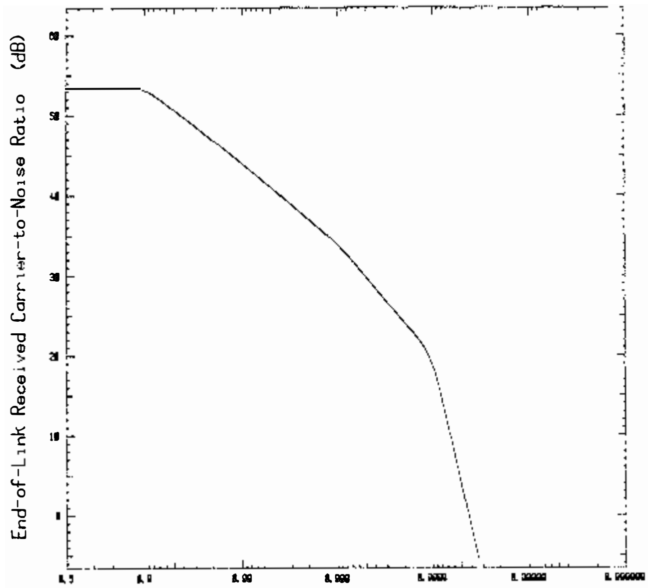
DON1 Receiving Reflector Data:

1.	Reflector Center Latitude	d/m/s	49 37' 32.5"N
2.	Reflector Center Longitude	d/m/s	7 55' 10.7"E
3.	Tower Base Elevation Above msl	m	685.00
4.	Beam Azimuth To BHR	d/m/s	271 41' 33.0"
5.	Beam Magnetic Azimuth To BHR	d/m/s	276 41' 33.0"
6.	Primary Beam Elev Angle Toward BHR	d/m/s	-17' 52.3"
7.	Reflector Vertical Dimension	m	12.00
8.	Reflector Horizontal Dimension	m	15.00
9.	Reflector Center Ht Above Tower Base	m	7.00
10.	Reflection Surface Normal Azimuth	d/m/s	250 48' 06.1"
11.	Reflection Surface Normal Elev Angle	d/m/s	8 57' 29.6"
12.	Angle Between Normal and Beam Center	d/m/s	22 46' 23.8"
13.	Projected Area	sq m	165.97

DON2 Receiving Reflector Data:

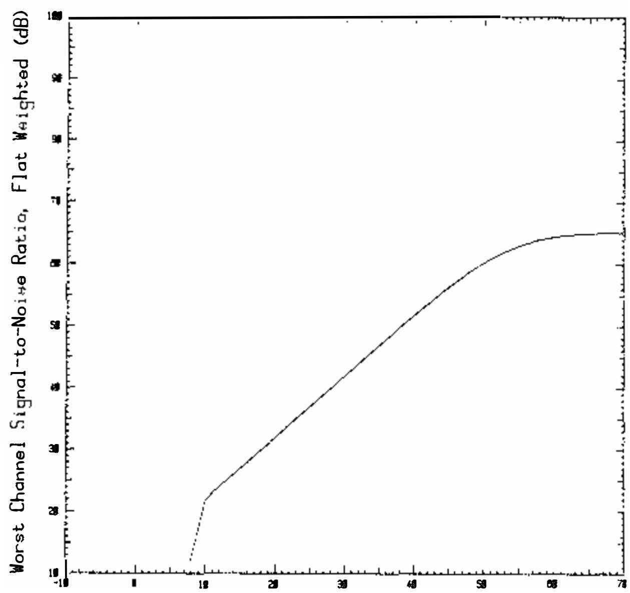
1.	Reflector Center Latitude	d/m/s	49 37' 31.5"N
2.	Reflector Center Longitude	d/m/s	7 55' 09.1"E
3.	Tower Base Elevation Above msl	m	685.00
4.	Beam Azimuth To HDG	d/m/s	115 20' 28.5"
5.	Beam Magnetic Azimuth To HDG	d/m/s	120 20' 28.5"
6.	Primary Beam Elev Angle Toward HDG	d/m/s	-44' 58.7"
7.	Reflector Vertical Dimension	m	12.00
8.	Reflector Horizontal Dimension	m	15.00
9.	Reflector Center Ht Above Tower Base	m	20.00
10.	Reflection Surface Normal Azimuth	d/m/s	82 57' 40.2"
11.	Reflection Surface Normal Elev Angle	d/m/s	-10 34' 12.8"
12.	Angle Between Normal and Beam Center	d/m/s	33 38' 32.3"
13.	Projected Area	sq m	149.85

Figure 2-40. Example flat configuration.



Number of Paths in the Link		4
Rain Attenuation Confidence Band, J		0.900
Median Received C/N at Heidelberg	dB	53.415

Figure 2-41. Example link received carrier-to-noise distribution.



Carrier Frequecy	GHz	7.40
Per Channel Deviation	kHz	140.00
Median Carrier-to-Noise	dB	53.42
Equipment NPR	dB	55.00
Transmitter Feeder Echo S/N	dB	77.32
Receiver Feeder Echo S/N	dB	76.32
Receiver Noise Figure	dB	3.00
Number of Voice Channels		600
Highest Modulation Frequency	kHz	2460.00
IF Bandwidth	kHz	15182.04

Figure 2-42. Example equipment transfer characteristic (FDM/FM).

incorporates programs on topics such as diffraction, tropospheric scatter, and quadruple diversity performance.

POMMP is a set of programs covering Performance Of Mixed-mode Microwave Paths. It is used to analyze paths with marginal terrain clearance. The basis for path analysis is an algorithm for calculating the probability distribution of the gradient of the atmospheric index of refraction.

ARROWS is a set of programs used in Autodesign for Radio Repeater Optimum Wideband Systems. It is used to predict the performance of links comprised of as many as four line-of-sight paths. It calculates radio path geometries and antenna and reflector orientations. Its algorithms predict such things as the attenuation loss distribution due to high rain rates and multipath.

Because of the constant updating of standards, evolution of the technology, improvements in path modeling, and the changing communications requirements of the U.S. Army, it is essential that these programs be enhanced and kept up to date. Some of the enhancements, changes, and additions that are needed are:

- the addition of a digital link performance algorithm that takes multipath distortion into account on line-of-sight paths
- preparation of utility programs such as one to obtain refractivity profiles from meteorological data
- modification of programs for more convenient use
- modification of outputs to improve presentation formats.

The purpose of the first item is to prepare a new program module to be incorporated into ARROWS. This module will be designed to estimate the performance of a digital LOS link in the presence of multipath distortion. It will be designed to use multipath delay and fading data for a given path, diversity configuration data, and the bit error rate signature of a particular radio set in the presence of combinations of multipath delay and fading values. The program will be designed to permit workers with moderate skill levels to perform the calculations necessary to estimate whether a particular link will perform at an acceptable level. The model will cover links operating at carrier frequencies between 1 GHz and 40 GHz. The project is expected to be completed early in FY 87.

Transmission System Monitor and Control (TRAMCON). The Transmission Monitor and Control System is being developed as a minicomputer-based communication system monitor, to be used by the Department of Defense to improve the performance and reduce the operating costs of the Digital European Backbone (DEB) and, potentially, other digital radio transmission systems. Development of the system began with an initial effort to provide an interim system to monitor 13 microwave sites in the first stage of the DEB implementation. This interim system provided field operators 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. Each DEB installation phase provided valuable feedback from users in the field. Many user suggestions for improvements in functions and in data presentation have been incorporated into TRAMCON software enhancements.

The objective of the current TRAMCON system is to monitor, collect, and display data that reflect the operational status of a digital radio transmission system. These data typically are status and alarm indications designed into the transmission system hardware, and analog and pulse parameters that describe transmission quality.

The major components of the TRAMCON system are a master unit (containing a minicomputer, disc storage, tape drive, and display terminals) and a remote unit. The remote unit is currently a hard-wired logic system capable of acquiring changes in two-state inputs, sampling analog voltages, counting random pulse occurrences, and providing relay contact closure for control.

The TRAMCON system is divided into segments, each of which consists of a series of interconnected, contiguous transmission facilities. Each segment contains a remote monitoring unit for each monitored facility, plus two TRAMCON minicomputer-based masters, usually at each end of the segment. A segment may consist of up to 24 remote units.

The responsibility of the TRAMCON 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 remote unit is responsible for sensing electrical parameter changes that indicate the operating parameters of a digital microwave system at a location, formulating those changes into a response, and transmitting this changed information to the master upon request.

During FY 85, revisions to an earlier released software version were made to implement improvements suggested by the initial operational test and evaluation. The corrected version (1.6) has now undergone testing at the Army test facility at Ft. Huachuca and is ready for field test on the Frankfurt North/Berlin segment. In addition, several enhancements were made to the software to accommodate a multisegment function. Three master units were installed during the year at Berlin, Feldberg, and Linderhofe in Germany. These three masters are configured with the Version 1.6 software, which has been expanded to handle the parameters from a digital troposcatter system.

Other FY 85 efforts were focused on developing more formal test procedures and plans, improving operator manuals, and documenting, in military standard format, the TRAMCON software design. Efforts have begun to examine the options for a next-generation master hardware system and to reevaluate the criteria for intelligent remote units.

Update of MIL-STD-188-100. The project to update MIL-STD-188-100 is being performed by the Institute for the Defense Communication Agency's Defense Communications Engineering Center (DCEC). The purpose of the effort is to prepare an updated version of the highest-level military communication standard to replace the current version, which was issued in June 1971. This standard provides the network interoperability and performance requirements for the entire Defense Communications System.

The development of standards for military communication assets is guided by the necessity for ensuring that the equipment, subsystems, and systems procured by all branches of the service interoperate fully, both electrically and in system protocol, so that continuity of communication is assured. A secondary purpose of the standards is to require performance levels sufficient to ensure that the interconnected network will provide satisfactory end-to-end quality to users.

Although the state of the art in communication system engineering has advanced to include digital microwave and troposcatter radio transmission, optical fiber cables, and microprocessor-controlled communication terminals, the basic problem of ensuring interoperability at the communication subsystem interfaces is little changed from 15 years ago. Furthermore, the most common and most important traffic is still the transmission of human voice signals in electrical form, whether analog or digital. These factors suggest that the scope of the standard, as well as many of the values standardized, may remain unchanged in the 1985-86 revision and for some time to come.

During FY 85, the technical parts of the standard were completed in draft form and were submitted to the sponsor for consideration by a standards working group. Most of the sections were reviewed by the working group and their comments were reflected in the preparation of final draft sections. The working group is expected to meet early next year to review the completed document. Once their final comments are incorporated, a coordination draft of the revised standard, to be designated MIL-STD-188-100A, will be disseminated for consideration by the entire military communication engineering community. The approved standard should provide that community with a comprehensive, up-to-date framework for communication system planning.

Update of FED-STD-1037, Glossary of Telecommunication Terms. Deregulation, divestiture, and a rapidly developing communications technology have brought about significant growth in the number and kinds of equipment, service features, and transmission facilities available in the telecommunications marketplace. As the technology has expanded, so has the language that describes it.

In the specialized vocabulary that sprang up, some words were borrowed freely from the disciplines of physics and communications engineering, while others were coined independently. In this process, inevitably, some ambiguity and imprecision resulted. More significantly, some terms have been used to specify a product--and are beginning to be accepted by manufacturers and users--but are not accurate descriptors beyond rather narrow limits.

The absence of a precise, common language among researchers, manufacturers, systems designers, and users is a hindrance to effective technology development and implementation. The need for such a common language has become pronounced as numerous standards working groups, in both Government and the private sector, have become engaged in preparation of performance standards covering components and systems.

The Institute for Telecommunication Sciences contributed substantially to the fulfillment of this need in FY 85 through participation in the development of the "Glossary of Telecommunication Terms," FED-STD-1037A. This standard, an update of Federal Standard 1037, is a compendium of terms, definitions, cross-references, synonyms, and acronyms covering all aspects of modern telecommunications. It defines more than 5,000 technical telecommunication terms in language that can be understood by scientists and lay persons alike. The draft version is over 300 pages long.

The revised Federal Standard will aid both Government and private sector organizations in telecommunication procurement by defining service features, transmission processes, and other parameters of interest in generic, product-independent terms. Extensive cross-references are provided to assist the buyer who knows a service or product only by a particular proprietary name, but who wishes to consider competitive alternatives in a functional procurement. This feature will also aid designers and purchasers who are interested in retrofits and interoperability.

Federal Standard 1037A will provide the nucleus of a commonly agreed-upon language for the MIL-STD-188-100 series and the FED-STD-1000 series standards. In addition, since 1037A includes fiber-optics terminology and definitions as well as some terms from other new technologies, it will assist such international standards groups as the Joint CCITT/IEC Working Group "O."

Federal Standard 1037A culminates over 10 years of ITS work in the precise definition of telecommunication terms. The initial data base for the glossary was MIL-STD-188-120, "Military Communication Standard: Terms and Definitions," edited by ITS and published in 1975. This portion of the vocabulary was extensively reviewed and updated by DOD agencies to keep abreast of advancing technology and continuing revisions of the MIL-STD-188-100 series dealing with tactical and long-haul communications. The revision of MIL-STD-188-120, again edited by ITS, became FED-STD-1037. This glossary contained more than 2,000 terms, a larger number of the additions coming from the 700 new terms and definitions suggested by the Federal sector. Many were drawn from evolving Federal performance standards such as FED-STD-1033, also developed by ITS. The 1037 glossary was published in 1980. Development of Federal Standards 1037 and 1037A was funded by the National Communications System and the U.S. Army Communications Command/Communications Electronics Engineering Installation Agency (USACC/CEEIA), now the USAISESA, U.S. Army Information Systems Engineering Support Activity.

The most recent revision of FED-STD-1037 was begun in early 1984. A score of DOD and civil Federal agencies submitted more than 3,000 new terms and definitions for consideration by the FED-STD-1037A working group. In five working group meetings and two resolution meetings, participating agencies screened, developed, and coordinated new definitions and updated many of the existing 1037 definitions and cross-references. The revised document includes key terms from the increasingly important vernacular of Integrated Services Digital Networks (ISDN's), local-area networks (LAN's), and fiber optics. The latter terms and definitions are taken largely from two NTIA-developed optical communications glossaries: NTIA Special Publication 79-4, "Optical Waveguide Communications Glossary" (published in 1979), and NBS Handbook 140 (of the same title, published jointly by NTIA and NBS in 1982). The latter glossary has since been published as a stand-alone dictionary (IEEE '82) by the Institute of Electrical and Electronic Engineers. The evolution of FED-STD-1037A is illustrated in Figure 2-43.

As Fiscal Year 1986 begins, the final draft of FED-STD-1037A is in preparation. It is scheduled for review by the Federal Telecommunications Standards Committee in December 1985. Publication is scheduled for early 1986.

In addition to developing most of the fiber optics definitions, Institute personnel were responsible for integrating all comments from the working group and resolution meetings into a final data base. An Institute staff member acted as overall document editor and recorded all of the comments of all of the agencies and groups represented. The ITS work was funded by the U.S. Army Information Systems Engineering Support Activity, who has maintenance authority for the standard.

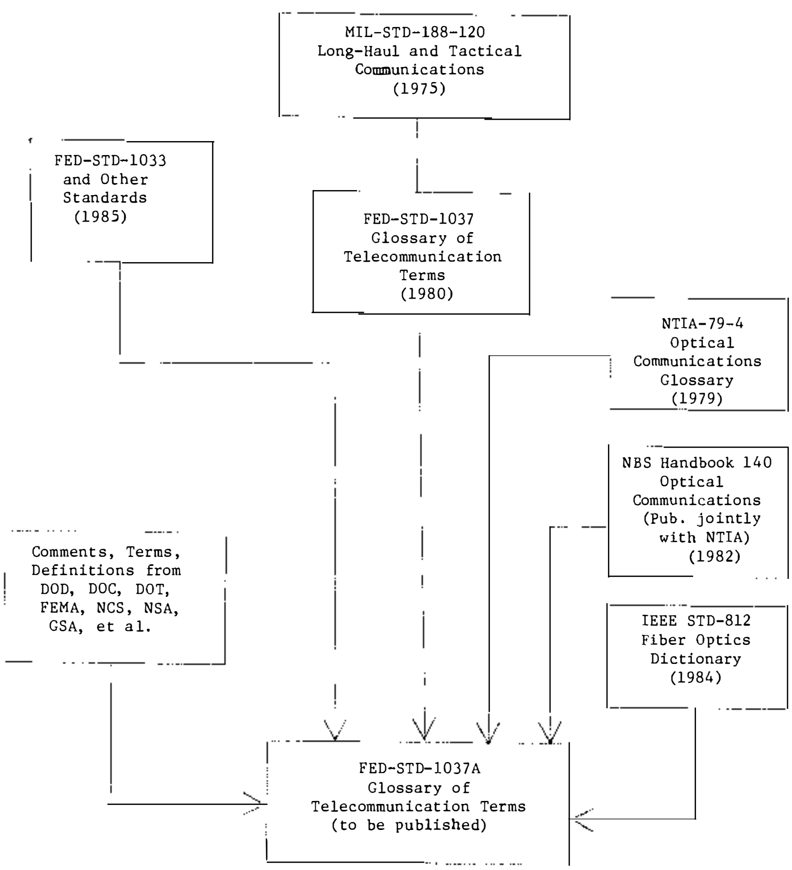


Figure 2-43. Origins and development of FED-STD-1037A.

ANNEX I
ITS PROJECTS FOR FISCAL YEAR 1985
ORGANIZED BY DEPARTMENT AND AGENCY

COMMERCE, DEPARTMENT OF

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Army Electronics (EPG)

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ANNEX II

ITS PUBLICATIONS FOR FISCAL YEAR 1985

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ANNEX III

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, 1985) a full-time permanent staff of 94 and other staff of 26. In FY 1985, its support consisted of $3.5 million of direct funding from Commerce and $4.7 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 provided by the Mountain Administrative Support Center. 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 prior to 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, CRPL was renamed Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the Institute for Telecommunication Sciences was created. It contained the telecommunications-oriented activities of ITSA. Dr. Ernest K. Smith served as an interim director for 1 year and was followed by Richard C. Kirby who was director for the ensuing 3 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 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, a former 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 non-Government or Government organizations. It is also a matter of policy that all sponsored work reinforce NTIA's overall program and that it be clear that other agencies, industries, or universities could not serve equally well or better.

Within these policy guides, ITS aspires to being the Federal laboratory for research in telecommunications. It is clear that the Government has a responsibility to pursue long-range studies in telecommunications that are not economically profitable for industry. It is also clear that the Government must have its own, independent laboratories to assess the significance of research conducted elsewhere. Toward these ends, ITS strives to maintain a knowledgeable staff working on the frontiers of technology and in touch with the telecommunications problems of the Federal Government. The Department of Defense has long been the primary source of advanced technolgy. 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 IV
ORGANIZATIONAL DIRECTORY

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

Name	Mail Code	Ext.	Room
DIRECTOR'S OFFICE			
UTLAUT, William F. - Director	ITS.D	3500	3020
GEISSINGER, Marcia L. - Secretary	ITS.D	5216	3020
O'DAY, Val M. - Executive Officer	ITS.D1	3484	3024
WALTERS, William D. - Budget & Support Services	ITS.D2	5414	3019
CAHOON, Lenora J. - Technical Publications	ITS.D3	3572	3020
SALAMAN, Roger K. - Special Technology Liaison	ITS.D6	5397	3015
SPECTRUM DIVISION			
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Propagation Model Development and Application SPAULDING, A. Donald - Chief	ITS.S3	5201	3415
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Satellite Network Analysis JENNINGS, Raymond D. - Chief	ITS.N2	3233	2235
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