INSTITUTE FOR TELECOMMUNICATION SCIENCES

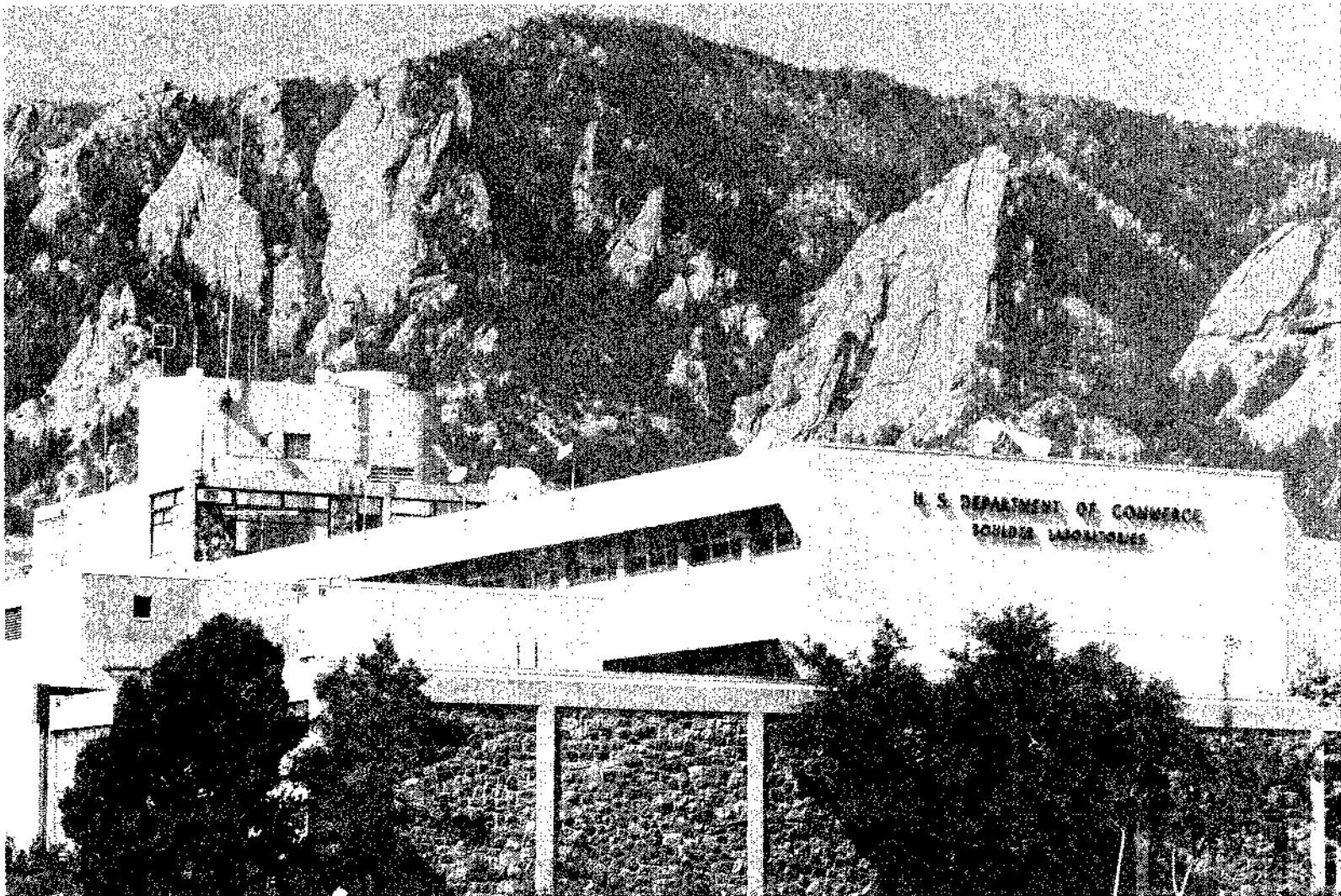
OF THE

NATIONAL TELECOMMUNICATIONS AND

INFORMATION ADMINISTRATION

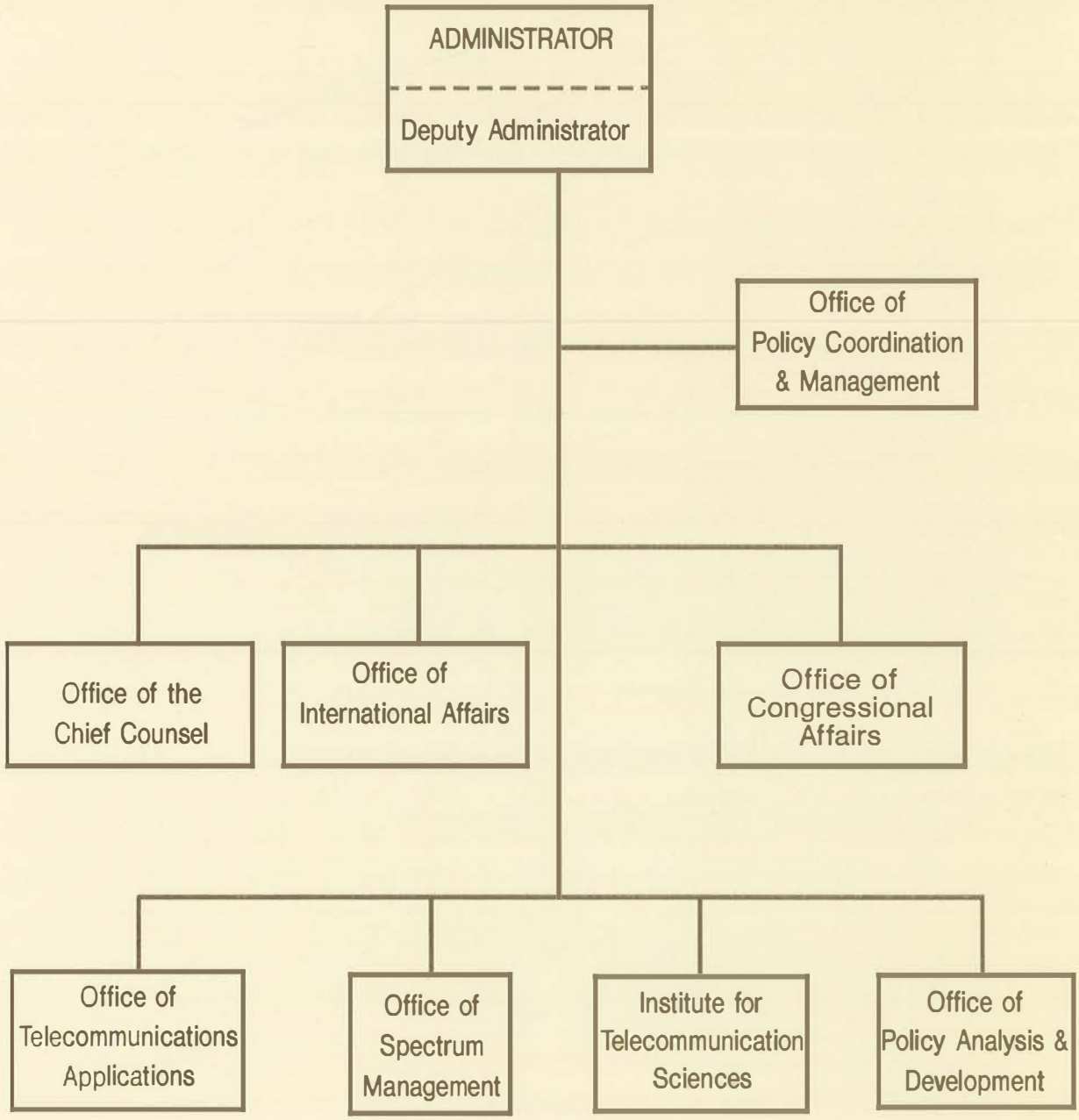
# ANNUAL TECHNICAL PROGRESS REPORT 1989

For the Period October 1, 1988 through September 30, 1989



# U.S. DEPARTMENT OF COMMERCE

## National Telecommunications and Information Administration



# ITS

## ANNUAL TECHNICAL PROGRESS REPORT 1989

For the Period
**October 1, 1988 through September 30, 1989**

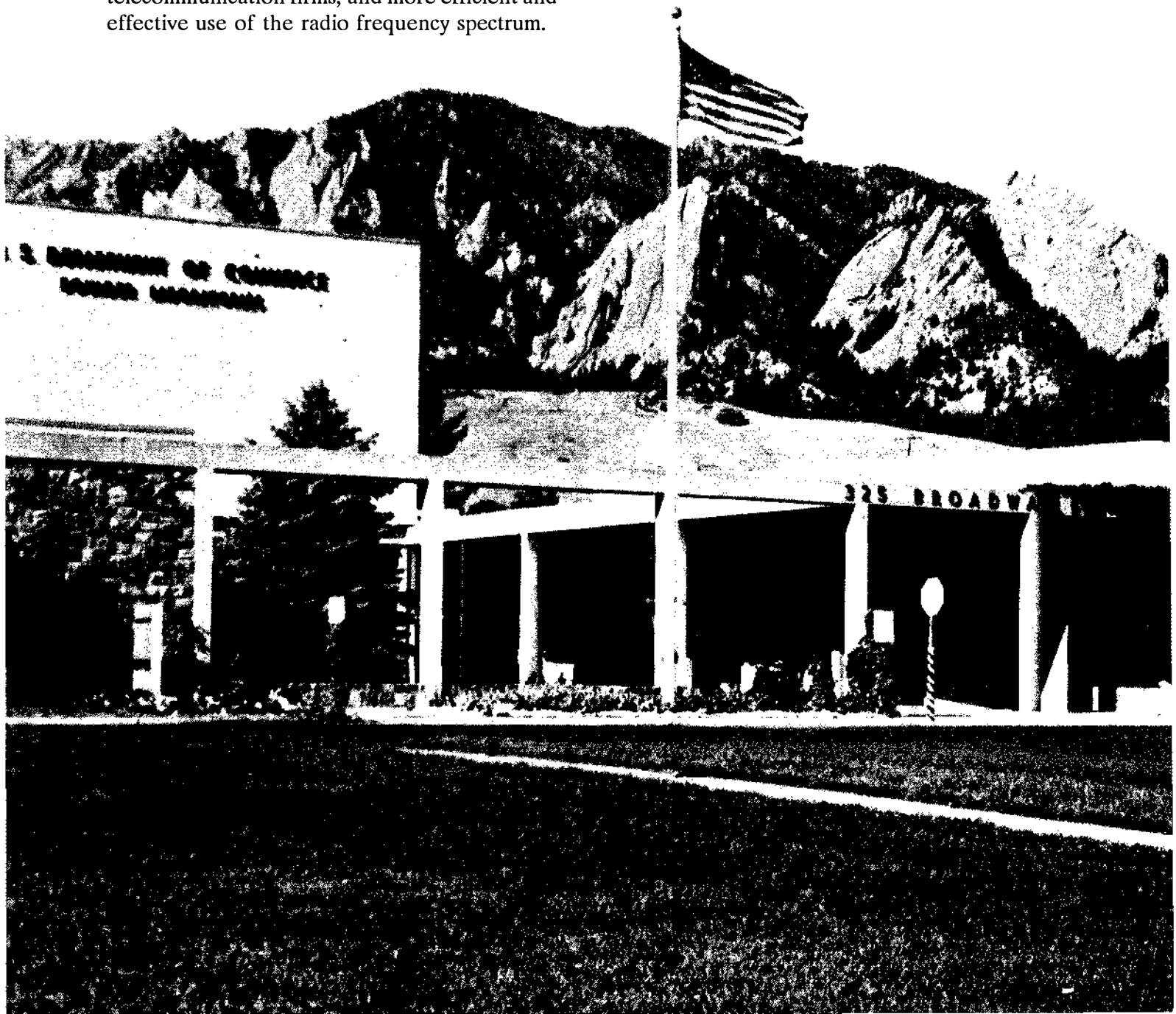

**U.S. DEPARTMENT OF COMMERCE**
**Robert A. Mosbacher, Secretary**

Janice Obuchowski, Assistant Secretary
for Communications and Information

# THE ITS MISSION

As the chief research and engineering arm of the National Telecommunications and Information Administration, the Institute for Telecommunication Sciences (ITS) supports Administration telecommunication objectives such as enhanced domestic competition, improved foreign trade opportunities for U.S. telecommunication firms, and more efficient and effective use of the radio frequency spectrum.

ITS also serves as a principal Federal resource for assistance in solving telecommunication problems of other Federal agencies, state and local governments, private corporations and associations, and international organizations.



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# OVERVIEW

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce. ITS employs approximately 100 permanent program staff. Many of these employees bring substantial engineering and scientific backgrounds and skills to our technically oriented programs. Indeed, 48% of our employees are electronics engineers, 9% are mathematicians, 4% are physicists, 5% are computer scientists, and 4% are computer programers. During FY 1989, ITS support consisted of $3.2 M of direct funding from Commerce and $6.7 M in work sponsored by other Federal agencies.

## ACTIVITIES

In achieving its mission, the Institute performs state-of-the-art telecommunication research, planning, and engineering in each of the following functional areas:

- **Spectrum Use Analysis**
  Performing technical analysis of radio usage in selected frequency bands and preparing U.S. technical positions for use at international spectrum allocation conferences

- **Telecommunication Standards Development**
  Contributing to and developing Federal national and international telecommunication standards

- **Telecommunication Systems Performance**
  Forecasting how individual communication elements will perform together and then testing them in a laboratory or operational environment

- **Telecommunication Systems Planning**
  Relating needs of end users to the capabilities of a planned network

- **Applied Research**
  Modeling the way radio waves travel from point to point in various frequency bands and evaluating the way information is carried by radio signals, including modulation and coding

## BENEFITS

The Institute's work significantly benefits both the public and private sectors in several areas including

- **Spectrum utilization**
  Optimizing Federal spectrum allocation methods, identifying available frequencies and potential interference through field measurements, and promoting technology advances aid in more efficient and effective use of the scarce spectrum resource

- **Telecommunication negotiations**
  Developing negotiation support tools such as interference prediction programs and providing expert technical leadership improve the preparation for, and conduct of, telecommunication negotiations at various international conferences

- **International trade**
  Promulgating broadly based, nonrestrictive international telecommunication standards helps to remove technical barriers to U.S. export of telecommunication equipment and services

- **Domestic competition**
  Developing user-oriented, technology-dependent methods of specifying and measuring telecommunication performance gives users a practical way of comparing competing equipment and services

- **National defense**
  Improving defense network operation and management, enhancing survivability, expanding network interconnection and interoperation, and improving planning for emergency communications restoral contribute to the strength and cost effectiveness of U.S. national defense forces

- **Technology transfer**
  Making available Institute technology evaluations and application studies hastens and expands the beneficial use of research results for industry in meeting specific user telecommunication needs

## OUTPUTS

Major outputs of the Institute's research and engineering activities include

- **Engineering tools and analysis**
  Predictions of transmission media conditions and equipment performance; test design and data analysis computer programs; complete laboratory and field tests of experimental and operational equipment, systems, or networks

- **Standards, guidelines, and procedures**
  Contributions to and development of national and international standards in such areas as network interconnection and interoperation, performance evaluation, and information protection

- **Research results**
  Models for electromagnetic wave propagation, noise, and interference characterization

- **Expert services**
  Training courses and workshops to communicate technology advances and applications to industry and Government users

## ORGANIZATION

To carry out its activities, ITS is divided organizationally into two main program divisions--Spectrum Research and Analysis, and Systems and Networks Research and Analysis--and an Executive Office to handle administrative matters. Each of the program divisions is further divided into functionally oriented groups.

Work performed by the Spectrum Division involves analyses directed toward understanding radio wave behavior at various frequencies and determining methods to enhance spectrum utilization. The Systems and Networks Division focuses on assessing and improving the performance of Government and private sector telecommunication networks, developing domestic and international telecommunication standards for telecommunication networks, and evaluating new technologies for application to future needs. Activities carried out within the two divisions are complementary and often synergistic.

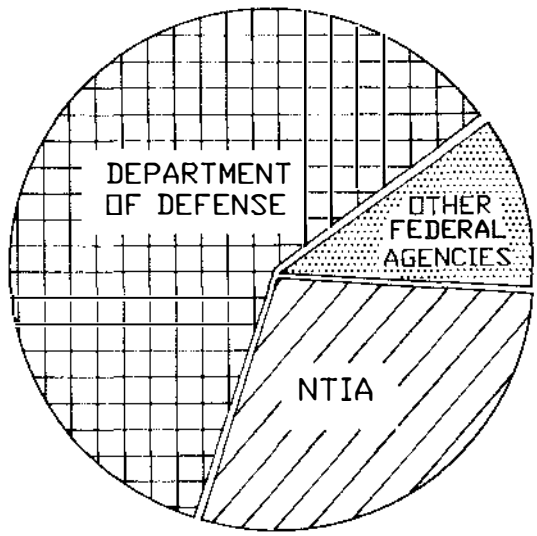
The Executive Office handles the Institute's budget and program planning functions as well as interacts with various administrative offices within other parts of Commerce to achieve its payroll, procurement, personnel, facilities management, civil affairs, and publications requirements.

## HISTORY

ITS had its organizational beginning during the 1940's as, first, the Interservice Radio Propagation Laboratory and then later as the Central Radio Propagation Laboratory (CRPL), each located within the Commerce Department's National Bureau of Standards. In 1965, CRPL was transferred to the Environmental Science Services Administration and given a new name---Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, ITS and the "A" organization were split. ITS was transferred into the newly formed Office of Telecommunications (OT). Finally, under the President's Reorganization Act #1 of 1977, OT and the Office of Telecommunications Policy merged to form NTIA. Since that time, ITS has been responsible for performing telecommunication research programs within NTIA and for providing technical engineering support to other elements of NTIA as well as to other agencies on a reimbursable basis.

## SPONSORS

The activities of the Institute are undertaken through a combination of Commerce-sponsored and other-agency-sponsored programs. NTIA/ITS policy provides that other-agency-sponsored work results in contributions to and reinforcement of NTIA's overall program and is directed toward supporting Commerce goals. Various Army, Air Force, Navy, and other Department of Defense (DoD) components provide the majority of ITS' other-agency funding. Non-DoD sponsors typically include the Department of Transportation, the U.S. Information Agency, and the Department of Agriculture. Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that does not require duplication throughout many Federal agencies.




ITS Funding Sources

Scientific research and engineering are critical to continued U.S. leadership in the provision of telecommunications and information equipment and services. In the pages that follow, this annual technical progress report summarizes specific FY 1989 technical contributions made by ITS that have significance for the public and private sectors.

## DISCLAIMER

Certain commercial equipment and software products are identified in this report to adequately describe the design and conduct of the research or experiment. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.


O'Day


Matheson


Utlaut


Seitz


Salaman


Cahoon


Bachinski

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# SPECTRUM USE ANALYSIS

The National Telecommunications and Information Administration (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, ITS conducts a variety of studies and field measurement activities directed toward ensuring efficient, effective, and equitable use of the radio spectrum resource. A prime objective of these analyses is to increase spectrum usefulness by developing ways for using presently congested portions of the spectrum more efficiently and for opening up new portions of the spectrum for productive use.

In conjunction with these spectrum analyses, ITS supports NTIA's active role of developing and advocating the United States' position at various international spectrum allocation conferences. Decisions taken at these conferences significantly affect the amount of the spectrum resource, and the methods of using it, available to the United States.

Through a variety of its project activities, ITS uses its scientific and engineering research expertise to develop computer programs to assist the Federal Government in the most productive methods of utilizing this available spectrum. These methods are useful for the private sector as well and, therefore, ITS has established a computerized method of transferring this technology to all interested parties on a reimbursable basis.

## Areas of Emphasis

### International Radio Conference Support

Includes projects funded by the National Telecommunications and Information Administration and the U.S. Information Agency

### CCIR Activities

Includes projects funded by the National Telecommunications and Information Administration

### Domestic Spectrum Analysis

Includes projects funded by the National Telecommunications and Information Administration

### Spectrum Usage Measurements

Includes projects funded by the Department of Defense, the National Telecommunications and Information Administration, the National Weather Service, and the U.S. Air Force

### Telecommunications Analysis Services

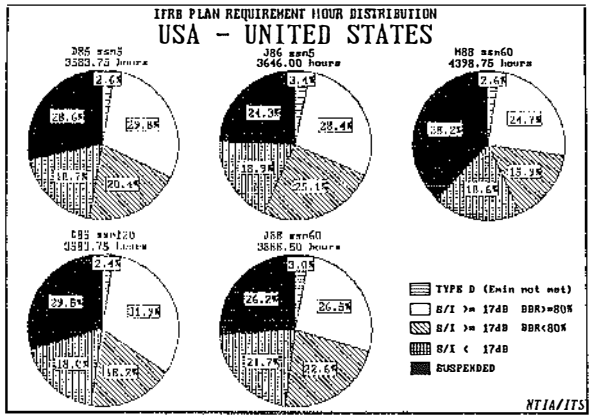
Includes a project funded by reimbursement from subscribers

# International Radio Conference Support

## Outputs

- Development of U.S. positions and defense at radio conferences
- Techniques and methods to assist the ITU in preparation for radio conferences
- Models to be used by the United States to determine positions at radio conferences

Institute personnel have actively participated in the preparation and defense of U.S. positions at international and regional radio conferences. Institute personnel have assessed the decisions of the Second Session of the High Frequency Broadcasting Conference (HFBC). Using a high frequency spectrum utilization model (HFSUM) developed by ITS to predict how these decisions impact U.S. broadcasting objectives guides the United States in its preparations for a Reallocation Conference in 1992 and a third session of the HF Broadcast Conference in 1993. The Institute is actively testing these decisions under various scenarios to determine their detailed impact on U.S. broadcasting objectives. The Institute is also working closely with U.S. broadcasters to determine the optimum manner for the United States to submit their broadcasting requirements to the International Frequency Registration Board (IFRB), who will also perform detailed tests. The following figure shows summary results of the planning process.

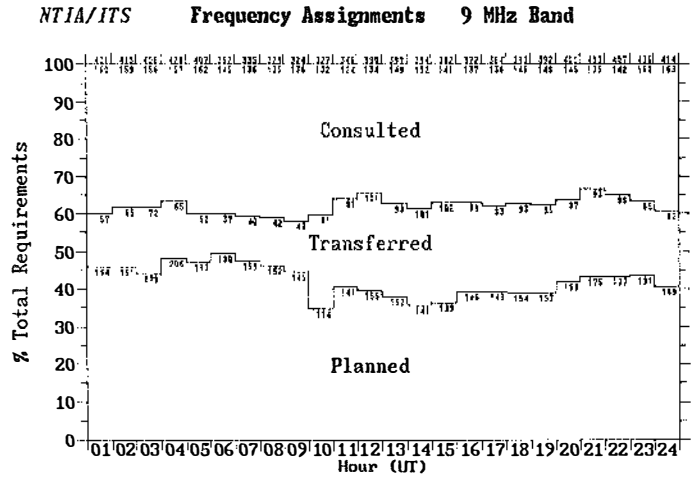



Results of all U.S. Broadcast Requirements for HFBC(87).

HFSUM determines the effect of a priori planning of HF broadcasting requirements on U.S. broadcasting objectives. This model has been expanded to meet the decisions taken at the 1987 HFBC--the most noteworthy being changes to assure, to the

Project personnel (from left) Les Berry, Jeanne Wakefield, Frank Stewart and Greg Hand

extent possible, frequency continuity of broadcasts and the division of the HF bands into "planned" and "consulted" portions with all requirements being satisfied. The planned portion of the bands has more stringent protections against interference and noise and may require some requirements to be transferred to the consulted portions on a least-interfering basis. The following figure demonstrates this concept using the IFRB's June 1988 requirements for the 9 MHz band. Note requirements for all 24 hours are represented here and the "transferred" requirements were transferred from the planned portion to the consulted portion of the band.




Distribution of all HF Requirements in the Planned and Consulted Portions of the 9-MHz Band for June 1988.

In addition to the technical studies related to planning, the Institute is a primary force in providing data to the IFRB for identifying locations of jammers of western HF broadcasts. These data result from a world wide data collection effort coordinated by the Institute. These monitoring campaigns are called for in the Final Acts of WARC-HFBC(87).

Another effort involved ITS modifying the medium frequency (MF) analysis program that is used by the IFRB to determine the coverage and interference limits of MF broadcast stations for Region 2 frequency allocation. The modifications allow the use of the ITS tilted curtain antenna model, which calculates the gain of the type of antenna used at Voice of America's (VOA's) Belize MF broadcast station. The modified IFRB program was installed on VOA's VAX computer, and the antenna model was installed on the IFRB's Siemens computer in Geneva. The antenna is a rectangular array of evenly spaced, horizontally polarized dipole elements. The user defines the number of broadside and end-fire elements (rows), the interelement spacing, and the electrical phasing. The model calculates the power gain of the antenna including the effects of a curved Earth and the coupling between elements. The Belize antenna consists of two rows of four dipole elements spaced 74 m between rows. The element feeds are spaced 97.45 m apart in each row and are 55 m above ground. The power pattern calculated for this antenna is shown in the following figure.

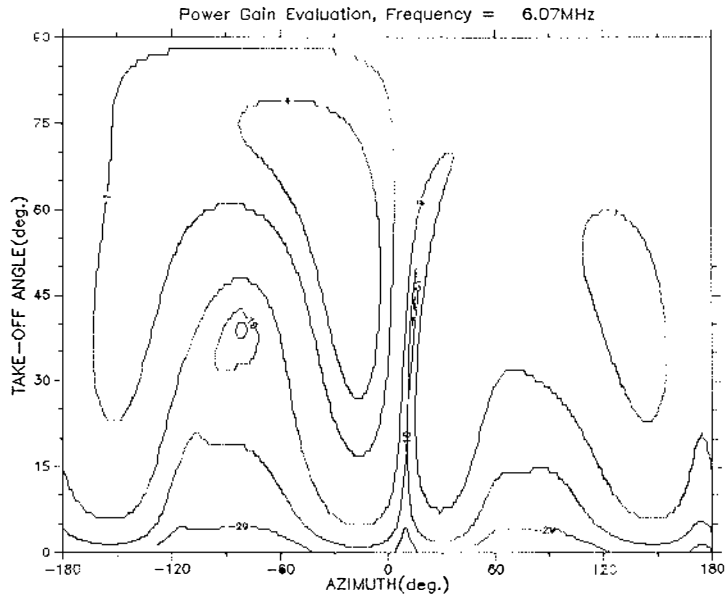
Recent ITS Publications

A High-Frequency Spectrum Utilization Model (by Rush, Washburn, and Berry)

The Results of WARC-HFBC(87): Technical Implications (by Rush, Jacobs, and Richards)

Monitoring of Harmful Interference to the HF Broadcast Service: IV. Results of the July 1988 Coordinated Monitoring Period (by Sowers, Hand, and Rush)

Recommendations for the VOA Monitoring Service (by Washburn and Rush)




New MF antenna pattern at VOA's Belize site.

# CCIR Activities

## Outputs

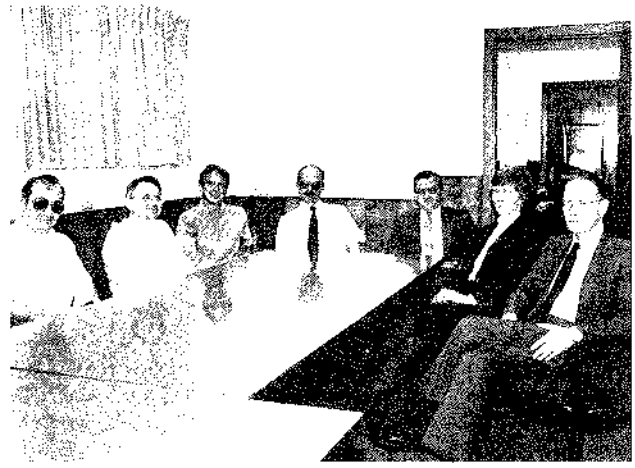
- Technical standards to support U.S. positions at radio conferences
- Leadership of U.S. participation in key CCIR Study Groups
- Coordination of U.S. positions on all issues related to CCIR reports and recommendations

The International Radio Consultative Committee (CCIR) is one of the two consultative committees of the International Telecommunication Union (ITU), the International Telegraph and Telephone Consultative Committee (CCITT) being the other. Both of these committees are permanent organs of the ITU.

All the member countries of the ITU as well as certain private organizations can participate in the work of the CCIR. The work of the CCIR provides the basis for decisions that lead to efficient use of the spectrum for telecommunication applications. The reports and recommendations of the CCIR are used by radio conferences to establish technical criteria that form the basis for spectrum allocation decisions and spectrum use on a global and a regional scale. The material contained within the documentation of the CCIR must be consistent with U.S. positions at these conferences if the United States is to be successful in defending its positions on purely technical grounds. It is to this end that much of the CCIR work undertaken by the Institute is directed.

The CCIR is organized into Study Groups, each Study Group addressing a specific area of radio system technology. There are 13 Study Groups in the CCIR ranging from such applied areas as fixed satellite service (Study Group 4) and mobile service operations (Study Group 8) to more scientifically oriented work of Study Group 5 and Study Group 6 dealing with propagation in nonionized and ionized media, respectively.

The CCIR cycle of activity results in approved modifications to its texts about every 4 years. These modifications are approved at the Plenary Assembly. In preparation for the Plenary Assembly, the CCIR meets at an Interim Meeting followed by a Final Meeting roughly in 2-year intervals. At times, the work the CCIR must undertake is of such a pressing nature that it cannot



Project personnel (from left) Jean Adams, Les Berry, Eldon Haakinson, Don Spaulding, Ray Jennings, Marcie Geissinger, and Bill Utlaut

be delayed until an Interim or Final Meeting. In this instance, the CCIR creates an Interim Working Party (IWP) to address the issue and generate a report or other approved document that is forwarded for consideration either by correspondence or at the next meeting of the Study Group under whose auspices the IWP falls.

Within the United States, the organization of work in support of CCIR activities is under the purview of the Department of State (DOS). A National Committee chaired by DOS personnel oversees the U.S. contributions to the CCIR. Because of its preeminent position in the field of telecommunication research and development, members of the Institute participate very actively in the work of the CCIR at the national and international levels.

An Institute member serves as the International Vice Chairman of Study Group 3. Institute members serve as U.S. chairpersons of Study Group 1 and Study Group 6. Other Institute personnel play prominent roles in and serve as U.S. delegates to Study Groups 1, 4, 5, and 6. These efforts address issues related to spectrum efficiency and use, satellite fixed-service operations, modification of the texts of Study Groups 5 and 6, and development of methods to improve on the global representation of

ionospheric parameters and natural and man-made noise.

Efforts at ITS that are directed to U.S. CCIR concerns in the past year have emphasized participation at the Final Meetings. Two Institute engineers participated in preparations for, and will be delegates to, the Final Meeting of Study Group 1, to be held in November 1989. A major issue will be establishment of criteria for shared use of the VHF and UHF bands allocated to the broadcasting and land mobile radio services. Another major concern is reorganizing the work of the Study Group to better carry out its mission. A Planning Document with priorities and implementation procedures will be adopted.

The Institute hosted a meeting of the Study Group 3 IWP that determined a number of new protection ratios for HF systems spectrum sharing. This meeting was held in Boulder, CO, in June and chaired by ITS personnel. In addition, ITS provided the U.S. head of the delegation to the Final Meetings of Study Group 3 in September. The International Vice-Chairman of Study Group 3 is also from ITS and in the Final Meetings served as Chairman of the subworking group on protection ratios, adaptive antenna systems, and meteor-burst systems.

Emphasis in the Institute's work this year, pertaining to Study Group 4, was directed primarily to concerns about the earth-station antenna reference and design objective patterns and the extent these patterns influenced calculations of estimated intersystem interference. Institute staff also addressed concerns that arose in development of the Allotment Plan during the Second Session of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of Space Services Utilizing It (WARC ORB-88) and that needed to be resolved, if possible, prior to revision of the Green Books for the 1986-1990 study period. Some study was given to an assessment of the Allotment Plan adopted at the Conference, but the more important work was concerned with the preparation of technical material that proposed modifications of the CCIR Recommendations concerned with earth-station antenna sidelobe characteristics and the presentation of that material at national and international meetings. The final International Study Group 4 meeting for the 1986-1990 Study Period was held in Geneva September 20 to October 6, 1988. The technical material prepared by ITS was presented at this meeting and was the basis for modifications, which will be forwarded to the XVIIth Plenary Assembly, for both Recommendations. An Institute representative was one of the U.S. delegates to the Study Group 4 meeting and served as Rapporteur for the Study Group 4 Plenary Sessions.

In the area of support to Study Group 5, the Institute concentrated its efforts at the Final Meeting on the improvement of the CCIR report dealing with millimeter-wave propagation and propagation effects in the land mobile and broadcast bands in the VHF/UHF parts of the spectrum.

The activities undertaken by Institute personnel to support Study Group 6 work are primarily to assure a sound technical basis for U.S. high-frequency broadcasting interests as well as reviewing and updating the texts of Study Group 6 and producing new reports and recommendations where appropriate. Engineers at the Institute also undertook the major revision of texts of Study Group 6 dealing with ionospheric properties and natural and man-made noise and interference. These documents are of fundamental importance to Study Group 6 and, along with the reports on HF propagation and fading, are very relevant to the upcoming (1992) World Administrative Radio Conference (WARC) on frequency allocations and the 1993 WARC on HF broadcasting. Three Institute members served as delegates to the Final Meeting of Study Group 6 held September 5-19, 1989 with one serving as Rapporteur for the Plenary Sessions.

Following is a list of CCIR Study Groups by number and title.

1 Spectrum Utilization & Monitoring
2 Space Research & Radioastronomy
3 Fixed Service at Frequencies Below About 30 MHz
4 Fixed-Satellite Service
5 Propagation in Non-Ionized Media
6 Propagation in Ionized Media
7 Standard Frequencies and Time-Signal
8 Mobile Services
9 Fixed Service Using Radio-Relay Systems
10 Broadcasting Service (Sound)
11 Broadcasting Service (Television)

CMTT (joint with CCITT) Transmission of Sound Broadcasting and Television Signals Over Long Distances
CMV (joint with CCITT) Vocabulary

# Domestic Spectrum Analysis

## Outputs

- Measurements of characteristics of unlicensed devices:
  - garage door opener
  - nursery monitor
  - auto security alarm
  - video distribution system
  - cordless telephone
  - cordless microphone
- Benefits of relaxing UHF TV taboos for HDTV supplementary channels
- Frequency selection section of NTIA Handbook: Introduction to Spectrum Management
- Draft CCIR Report on a measure of aggregate spectrum use

Project personnel Les Berry (left) and Ken Steele

The National Telecommunications and Information Administration (NTIA), in its role as manager of the Federal Government's use of the radio frequency spectrum, undertakes a number of studies each year dealing with spectrum utilization, congested areas of the spectrum, and potential compatibility problems between systems of various departments and agencies. These studies, called Spectrum Resource Assessments (SRA), provide recommendations for resolving any compatibility conflicts, recommend changes to improve spectrum management procedures, and recommend changes to promote efficient use of the spectrum. One SRA conducted this year by the Institute concerned the electromagnetic compatibility (EMC) characteristics of unlicensed devices.

Recently, the Federal Communications Commission has revised Part 15 of its regulations governing the operation of unlicensed radio frequency devices. These are devices that radiate so little power that users are not required to obtain licenses. Examples of such devices are garage door openers, cordless telephones, and nursery monitors. The rules were changed to, among other things, allow the devices to radiate increased power in some areas and to allow their operation in some new frequency bands. Because of the proliferation of such devices and because of recent reports of interference between authorized Government systems and unlicensed devices, NTIA decided to determine the electromagnetic compatibility characteristics of the devices.

The Institute developed test methods for measuring the relevant emission and reception characteristics of Part 15 devices using calibrated test equipment capable of precise electromagnetic measurements. We measured a number of unlicensed devices and drafted an SRA containing the results. This is an ongoing effort aimed at building up a data base containing the characteristics of Part 15 devices that can be used to analyze possible interference situations.

The EMC characteristics measured included the field intensity at specified distances, the emission spectra, receiver threshold, receiver saturation level, and interference bandwidth. Besides contributing to the data base, the data lend credence to anecdotal reports of garage door receiver lock-up in certain areas near large authorized Government transmitters.

Residential garage door opener units were reported to fail under the influence of a 310 MHz Government transmitter in a populous region. To investigate the reported failures, the Institute laboratory tested a garage door opener unit of the type known to fail. It was found that the unit could not be activated by its own transmitter when there was a strong competing continuous wave signal in the vicinity. The figure on the following page shows the strength of the competing signal, relative to the control signal required to saturate the receiver in the frequency range from 302 to 316 MHz.

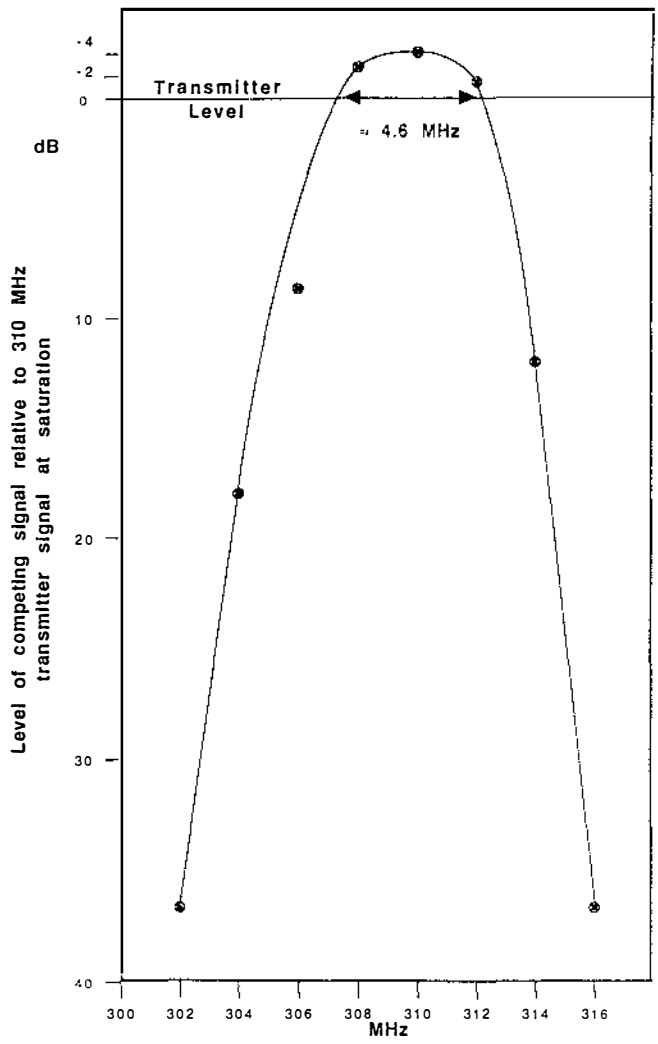
The Institute will continue to build up the data base containing the EMC characteristics of

unlicensed devices by measuring the devices supplied by other agencies or recommended by NTIA's Office of Spectrum Management.

The recent interest in high-definition television (HDTV) results in additional demand for television broadcasting spectrum because HDTV (together with a standard television signal compatible with present TV receivers) will require more than one channel to broadcast. The "UHF taboos" are rules controlling the allotment of television channels. They require transmitters within a given number of channels of each other to be separated by a specified distance. They were developed more than 30 years ago when there was little demand for UHF TV to protect inexpensive UHF receivers from interference. Modern technology could produce receivers less susceptible to interference, and the need for additional channels for HDTV makes it worthwhile to determine the benefits of relaxing or eliminating at least some of the UHF taboos.

Such a study was conducted using computer simulation and the UHF TV station sites in the eastern half of the United States. The scenarios were somewhat simplified because of time and computer program limitations, but the results give a reliable indication of the possible benefits. The scenarios did not consider the smaller station separations that might be possible if the HDTV signals are digital and are received by "smart" receivers. Such considerations could be included in future studies.

The most relevant result is that even if no VHF stations are assigned supplementary channels, and if only co-channel and adjacent-channel taboos are retained, 12 percent of the UHF stations in the northeast and upper midwest could not be assigned supplementary channels to broadcast HDTV signals. The denied stations are almost all in major markets. Obviously, a larger percentage would be denied supplements if the VHF stations were included in the scenarios.




Interference Bandwidth of Garage Opener Receiver

# Spectrum Usage Measurements

## Outputs

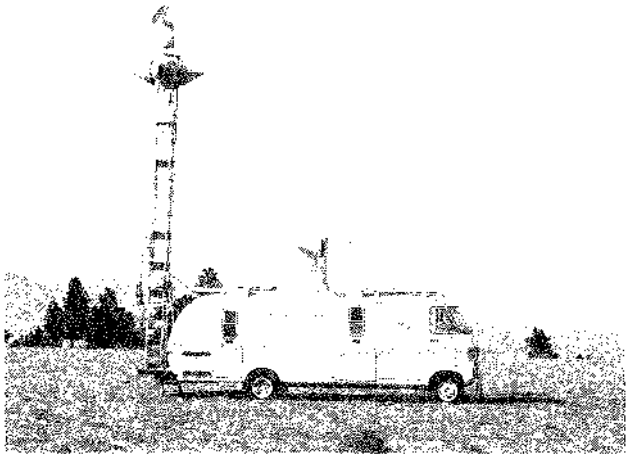
- NTIA spectrum surveys at
  Washington, DC
  Dallas, TX
- Radar emission spectra
- Common carrier interference studies
  Norfolk and Volens, VA
  Beckley, WV; Tulsa, OK
- Special radar study NEXRAD
  Norman, OK
- Site surveys at
  Adak and Anchorage, AK
- Local assignment data bases
- Air Force monitoring vans
- Low frequency measurements

NTIA manages Federal Government use of the radio spectrum, a function similar to the FCC's responsibility for the use of radio frequencies for state, private, and commercial purposes. In support of the NTIA frequency management effort, ITS operates the Radio Spectrum Measurement System (RSMS). The RSMS provides the following:

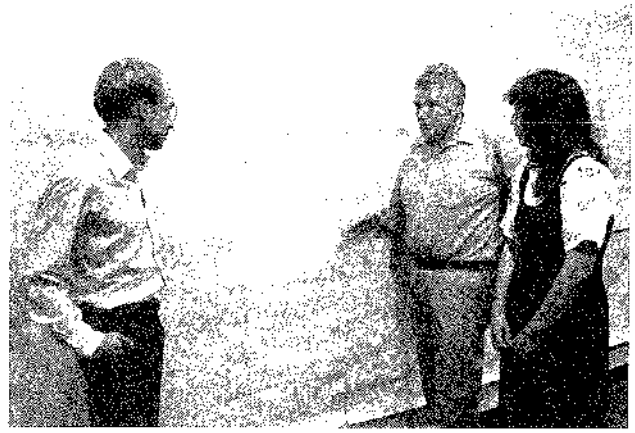
**Occupancy** measurements to show how much of the time a particular frequency is occupied by radio signals.

**Compliance** measurements to show whether observed signals are properly authorized and meet applicable technical standards.

**Compatibility** measurements to show whether signals will cause interference to each other.



Radio Spectrum Measurement System

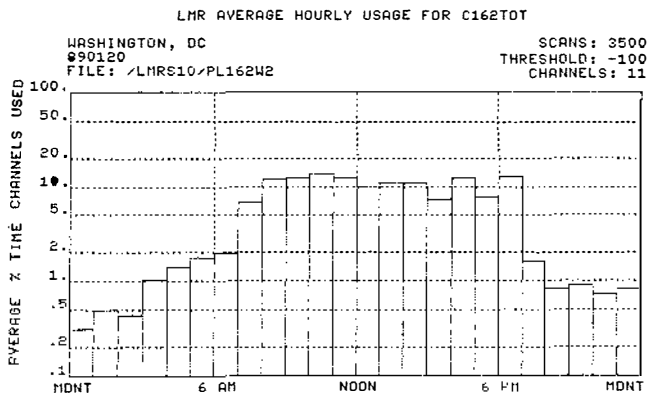


Project personnel (from left) Frank Sanders, John Smilley, Patricia Rausch

These measurements help form a technical basis for policy decisions in frequency management. Although we occasionally note signals that do not match the Government frequency listings--and we take appropriate action in these instances--the RSMS continues to be used mainly as a research tool for improved spectrum management.

The RSMS consists of two independent computer controlled receiving systems: the land mobile radio (LMR) system, optimized for narrowband voice channels, and the radar measurement system (RMS), a multipurpose system used for site surveys, general occupancy, and transmitter characteristics measurements such as emission spectra, antenna patterns, and radar pulse shape characteristics. Both measurement systems can simultaneously and continuously measure frequency bands selected from a preset schedule. This allows efficient sampling of frequency usage over a period of a week or more, giving good statistical information on signals encountered at each frequency in many frequency bands.

Both the Washington, DC, and Dallas, TX, LMR usage measurements were made by interleaving 3 LMR bands such that 20 minutes of each hour were used to measure each band. The Washington measurements were timed to overlap the 1989 presidential inauguration so that the usage of channels dedicated to the inauguration could be analyzed for the before, during, and after inauguration day periods. For example, average occupancy versus time of day for a group of these channels on inauguration day is given in the graph at right.




Average Occupancy versus Time of Day

Local assignment data base capabilities have been developed for both RMS and LMR. These allow computerized access to local (e.g., within 100 miles of an RSMS measurement site) Government Master File (GMF) assignment information by the RSMS staff so that information applicable to specific transmitters is readily available. For example, the LMR data base provides the distance and bearing of transmitters from the RSMS along with an estimate of the expected received signal levels. Statistics for GMF parameters are also obtained. For example, about half of the assignments in an LMR band will not have a call sign associated with them; about a quarter will not specify fixed transmitter locations with coordinates that include seconds.

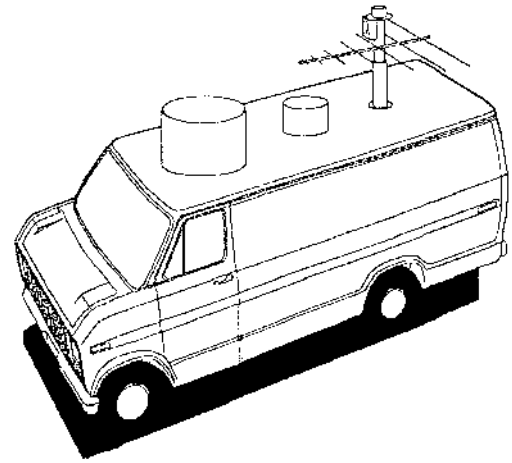
A system is being developed at ITS that will augment the measurement capability of the RSMS. A "suitcase" measurement system consisting of a spectrum analyzer, digital oscilloscope, and a microcomputer-based automatic control system will provide additional capability for situations that require portability without the full capabilities of the RSMS system.

### Air Force Van Design

This year has seen the culmination of the design of two special purpose measurement vans for the Air Force as shown in the figure to the right. These vans will comprise a measurement system to be deployed on a test range for the purpose of monitoring the radio/radar spectrum to assure that tests proceed without interference from outside signals. A third van, designated a Ground Emitter Monitoring System (GEMS) will watch the emitters directly involved in the test to assure that the signals do not fail.

The computer operating systems require advanced techniques to utilize the modern computer technology to accomplish high-speed data collection and processing. The operating system software requires flexibility and ease of learning for the untrained operator. Concepts learned with the RSMS will apply to the design of this system. Conversely, the computer operating system used in the Air Force systems shows promise for application in the RSMS for the RMS and LMR measurement systems.

As part of this development, the Air Force requires a remote, unattended antenna subsystem that can be placed in a danger zone as a normal part of the Air Force testing process. The remote system will be coupled to the attended system using fiber optic techniques. Remote data transfer is also being designed for integration into these systems to allow monitoring at a central data processing center in near real time.



Frequency Control and Analysis Van

### Low-Frequency Signal Processing

A measurement system is being developed for measurement of ELF and LF signals. This is a fully automated, highly accurate, portable system using as its nucleus a digital audio tape recorder. This device uses 16-bit digitizing to provide 96 dB of dynamic range with the capacity for storing up to 2 Megabytes of audio data. The system antenna is an 800-turn active loop specially designed for this frequency range.

The system is to be placed in office areas of various buildings to record magnetic noise data such as computer noise (digital processor noise and cathode ray tube noise) and electric motors (elevators etc.). The tapes are then analyzed using fast Fourier transforms covering the frequency range of 5 Hz to 10 KHz. The processed data are then grouped in full spectrum displays or in amplitude probability distribution Rayleigh plots. Data will also be sorted by time of day for diurnal plots.

# Telecommunications Analysis Services

## Outputs

- Easy access for U.S. industry and other Government agencies to the latest in ITS research results and to ITS engineering models and data bases
- Broad applications in telecommunication system design and evaluation of broadcast, mobile, link, and radar systems
- Standard method of system analysis for comparison between competing designs or proposed telecommunication services

Telecommunications Analysis Service (TAS) is a service provided by the Institute to all of the telecommunications community that allows industry, and Government agencies access to the latest Institute research and engineering on a cost basis. It is built around a series of computer programs that have been designed to be user friendly and intelligent, so that the user can access the required information and data with a minimum of computer expertise or in-depth knowledge of radio propagation. These programs and data bases are updated as new data and methodologies are developed at the Institute's Boulder Laboratories in its many engineering and research programs.

The following is a brief description of the current programs in the TAS that do the calculations that the user requests on-line, and immediately send the output to the user's terminal.

INFO - This gives an up-to-date listing of the services available, and any new or changed operating procedures.

MORE-INFO - This program gives more general system news, programs to be made available in the near future, etc.

PATH PARAMTRS - This program calculates the great circle distances and bearings between the user specified locations, and also provides "delta H" and average terrain heights for those locations.

RAPIT - This program gives the user on-line access to the latest in VHF/UHF propagation models. It can calculate basic transmission loss and other engineering information such as received signal levels over irregular terrain for the design or analysis of broadcast and mobile radio systems. The program has a broad range of options that allows the user to easily look at the affects on the received signal from changes in the input parameters such as antenna height.

FMFIND - This program lists the user selected FM station engineering parameters from the Federal Communications Commission (FCC) assignment data base according to user specified search parameters of location and search distance.

TVFIND, AMFIND, TOWERFIND, and LMFIND are all similar to FMFIND in that they return the parameters for the respective TV, AM, Tower, or Land Mobile station assignments/data according to the user specified search locations and distances.

RAIN - This program calculates the increased attenuation of microwave and millimeter wave signals due to the precipitation along the path. It is used in the design and analysis of point-to-point telecommunication systems.

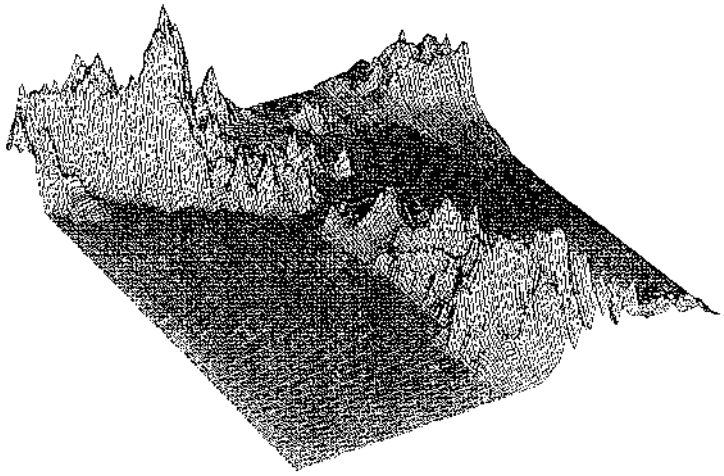
BURST - This program calculates the waiting times for a message to be successfully received over a meteor burst communication system or network. The user specifies the locations and engineering characteristics of the equipments, and the program determines the probabilities of successful communications for the transmission of various length messages that are propagated from reflections of ionized meteor trails.

LFMF - This program uses the latest Institute methodology for propagation of surface wave signals. It calculates the user's system performance or basic propagation path loss for systems that use the ground wave between 10 KHz and 30 MHz as the primary means of propagation, and it will also calculate the skywave for MF systems if requested.

The following set of programs do the calculations that the user requests, and sends the response either immediately to the user's terminal, or else the calculations are completed off-line and the output mailed or expressed over night to the user.

INMOD - This is a comprehensive intermodulation calculation program that will calculate and list to the user intermodulation products in the user's specified receiver bandpass from up to 40 transmitters, 40 receivers, up to seventh order, and with up to 5 concurrently operating transmitters.

PROFILE - The Institute maintains a digitized topographic data base of elevations of the terrain in various parts of the world. A sample of the topography around the San Francisco Bay area is shown in the figure below. The data varies in density from 3 to 30 second increments, but is generally derived from 1:250,000 scale maps of the Defense Mapping Agency. Using this program the path profiles are extracted according to user specified input parameters of location, bearing, etc. The data are extracted and then either the individual elevations along the profile are sent to the user's terminal or optionally they are averaged and the average sent to the user's terminal. Another option allows the user to have the Institute plot the profiles adjusted for various K factors depending upon the intended use of the path. For microwave links, Fresnel zone clearance can be easily determined from the plots so that poor paths can be eliminated from a planned circuit or network.



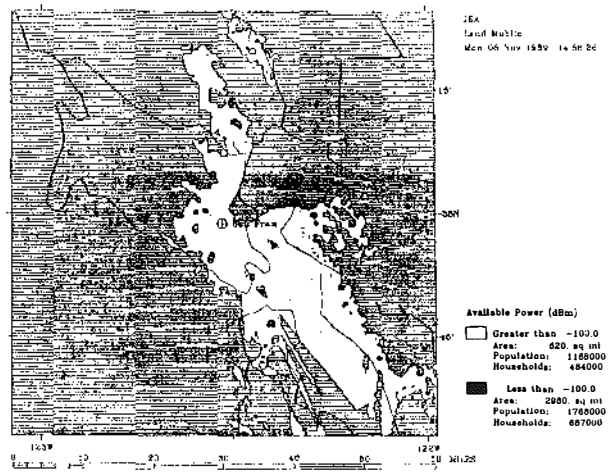
In the following programs, the user inputs the required system details on-line, then the calculations are performed off-line, and the output tables and or plots are either mailed to the user the following day (usually) or sent by overnight express.

HORIZON - This program plots the radio horizon around a specified location in the United States using the digitized topographic data. It is generally used for siting of satellite terminals so that the terrain shielding effects can be determined as well as the limits on the elevations visible from the site.

SHADOW - This program will plot the radio line-of-sight regions around a specified location in the United States using the digitized topographic data. It shows clear areas that are line-of-sight to the base of the antenna, grey to areas that are line--of-sight to the top of the antenna, and black to areas that are beyond line-of-sight to the antenna.

COVERAGE - This program calculates the receive signal levels along radials that are spaced at 15° increments of bearing around the transmitter. It plots the contours of signal coverage of the transmitter, and then includes the population coverage estimates based on the latest census data. The user can specify that either the FCC Broadcast rules or the Institute's irregular terrain propagation model be used in the calculations.

CSPM - Communication System Performance Model is a program that determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity as shown in the following figure. This program has an option that allows the user to have the output plotted on clear plastic to a specified scale, and in brilliant colors for overlaying on top of widely available geopolitical maps. This program is the most detailed of the signal calculation programs available, and uses the Institute's irregular terrain model in point-to-point mode. It is capable of combining coverage from several transmitters to show the coverage from a network of stations. Another option allows the plotting of interference regions to determine potential interference from a user specified transmitter within the area of interest. It shows the population, households, and areas covered within each of the user defined signal ranges. The most ambitious use of CSPM to date involved plotting the coverage by all of the educational TV stations in the United States and determining the population covered by at least one of these stations.




SKYWAVE - This program provides predictions of the performance of radio systems that use the frequencies ranging from 3 to 30 MHz and that propagate over ionospheric paths. It uses the Institute's ionospheric prediction program IONCAP and provides table of reliability or other user requested performance measures.

# TELECOMMUNICATION STANDARDS DEVELOPMENT

Much effort within ITS is focused on the development and application of national and international telecommunication standards. These standards promote interoperability and facilitate competition in the provision of enhanced telecommunication products and services and promote trade opportunities for U.S. telecommunications providers.

The Institute's national standards efforts address 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 Institute has spearheaded the development of technical standards for specifying and measuring performance of data communication systems and services as seen by end users. Major end products are Federal and American National Standards Institute (ANSI), respectively.

The Institute's international standards effort addresses the need for technically strong, broadly-based U.S. contributions to international telecommunication standards organizations. Institute staff members lead and contribute to several international standards groups functioning under the aegis of the International Telecommunication Union's International Telegraph and Telephone Consultative Committee (CCITT) and International Radio Consultative Committee (CCIR). Recommendations developed by these organizations significantly influence United States trade in telecommunication products and services. During FY 89, special emphasis was placed on the development of technical standards for Integrated Services Digital Networks (ISDNs). The Institute has provided strong leadership and support to ISDN standards development activities in both domestic and international forums.

## Areas of Emphasis

### CCITT Activities

Includes projects funded by the National Telecommunications and Information Administration

### Digital Network Performance Standards Development

Includes projects funded by the National Telecommunications and Information Administration

### Voice Quality Standards Development

Includes projects funded by the National Communications System and the National Telecommunications and Information Administration

### Video Quality Standards Development

Includes projects funded by the National Telecommunications and Information Administration

### Radio System Interoperability Standards Development

Includes projects funded by the National Communications System

### Building Cabling and Telecommunication Terminology Standards Development

Includes projects funded by the National Communications System

# CCITT ACTIVITIES

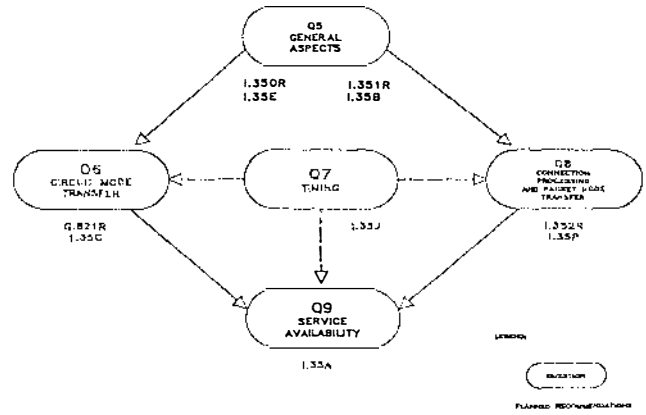
## Outputs

- U.S. CCITT leadership
- International standards planning
- Technical contributions

Telecommunications has become an essential infrastructure for our Nation's economy and a major component of international trade. The planning of future telecommunication services and facilities has been internationalized and increasingly, is centered in the International Telegraph and Telephone Consultative Committee (CCITT). The work of the CCITT has thus assumed substantial importance to U.S. economic development and trade objectives. The Institute supports U.S. involvement in CCITT activities by leading U.S. CCITT preparatory committees, preparing technical contributions on CCITT standards development issues, and drafting new CCITT Recommendations on topics of particular importance to U.S. interests and goals.

The Institute supports NTIA's domestic telecommunications infrastructure and international trade objectives by assisting the U.S. Department of State in leadership of U.S. participation in the CCITT. During FY 89, Institute personnel served on the U.S. CCITT National Committee, which guides overall U.S. involvement in the CCITT; participated in the quadrennial CCITT Plenary Assembly, at which several hundred Recommendations developed or revised during the 1985-1988 CCITT Study Period were approved; chaired U.S. CCITT Study Group B, which coordinates and approves U.S. Contributions to CCITT on ISDNs; and headed the U.S. Delegations to several meetings of CCITT Study Group XVIII (ISDN). The latter activities contributed strongly to the achievement of a major U.S. objective: Study Group XVIII agreement on key technical characteristics of the Asynchronous Transfer Mode (ATM), a fast packet switching technology that is expected to be widely implemented in future Broadband Integrated Services Digital Networks (B-ISDNs). This landmark agreement will greatly facilitate the development of multi-media telecommunication services and will ensure efficient interoperation of B-ISDNs with evolving Metropolitan Area Networks (MANs). The CCITT's B-ISDN Recommendations are expected to influence hundreds of billions of dollars in telecommunications investments over the next decade.

The Institute also provides leadership in CCITT Study Groups and ANSI-accredited standards committees that contribute to CCITT activities. During FY 89, the Institute assumed leadership of the CCITT Study Group XVIII Special Rapporteurs Group on Question 5, and continued its leadership of two key standards groups within the ANSI-accredited T1 (Telecommunications) Standards Committee: Subcommittee T1S1 and Working Group T1Q1.3. The Question 5 Rapporteurs Group is responsible for developing the general technical approach to be used in ISDN performance description. Subcommittee T1S1 has overall responsibility for developing American National Standards on ISDN services, architectures, and signalling and is the principal source of U.S. contributions to CCITT on these subjects. Working Group T1Q1.3 develops national standards and contributes to CCITT Recommendations dealing with the performance of packet-switched networks and ISDNs.



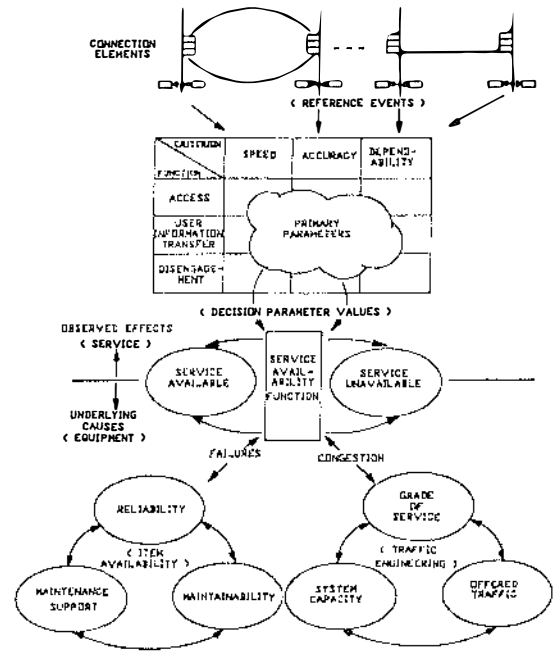

Relationship of ISDN Performance Questions and Recommendations

During FY 89, the Institute's technical contributions to CCITT were focused on organizing the development of ISDN performance Recommendations within CCITT Study Group XVIII. In cooperation with other participants, Institute staff members developed five new ISDN performance "Questions" and a detailed work plan which will direct the

activities of Working Party XVIII/6 (Performance) during the 1989-1992 CCITT Study Period. The new performance Questions address, respectively, the framework and general principles for ISDN performance description (Q5), user information transfer in ISDN circuit-mode services (Q6), network timing and synchronization (Q7), ISDN connection processing and packet-mode services (Q8), and ISDN service availibility (Q9). These Questions are complementary and collectively address all major aspects of ISDN performance from a network planning and service evaluation point of view. The work plan describes relationships among the Questions and identifies 10 ISDN performance Recommendations which will be developed or substantially revised during the Study Period. Four of the planned Recommendations are associated with Question 5 and will be developed under the leadership of a Special Rapporteur from the Institute. These bellwether Recommendations will provide a basis for the more specialized studies to follow, and will define initial performance measures for broadband ISDNs.

In another planning contribution, the Institute examined the relationships among ongoing CCITT studies in three areas: service availability, item availability, and traffic engineering. Service availability studies characterize the frequency and duration of service outages perceived by users. They provide a basis for defining user availability requirements and relating network capabilities to them. Item availability studies define reliability, maintainability, and maintenance support objectives for particular equipment items (e.g., switches, lines, and trunks) and identify means of employing redundancy to maintain connectivity between users when item failures occur. Traffic engineering studies relate two fundamental service characteristics--the offered traffic and the grade of service--to the capacity of the underlying network resources. They provide a means of optimizing the dimensioning and configuration of transmission and switching equipment. The ITS contribution clarifies the complementary nature of these studies and points out that in a comprehensive availability performance analysis, all three aspects of availability must be considered. Institute staff members have initiated the development of a comprehensive availability performance model in which these interactions and dependencies will be accurately represented.

The Institute also began the study of B-ISDN asynchronous transfer mode performance issues during FY 89. The ATM concept is an enhancement of packet switching in which user information is communicated through ultra-high-speed transmission and switching facilities in fixed-length packets called cells. The ATM cells




Relationships Among Service Availability, Item Availability, and Traffic Engineering Studies

are routed between switches on the basis of information contained in a cell header. The ATM switches interpret cell headers "on the fly," so that each switch delays a cell's transmission by only a few bytes. The network capacity is assigned dynamically on the basis of the users' instantaneous transmission needs. In comparision with conventional circuit-switched and packet-switched networks, ATM networks are expected to be more efficient in communicating bursty traffic, more flexible in multiplexing services with different information transfer rates, and more easily adapted to long-term changes in the service requirements. However, they will be extremely sensitive to network congestion and transmission errors. In its ATM performance studies, the Institute examined these performance effects with two objectives: to clarify the need for performance-enhancing protocol mechanisms such as priority selection and header error control, and to provide a basis for the definition of ATM network performance parameters. Initial results were presented in technical contributions to Working Group T1Q1.3 and CCITT Study Group XVIII.

## Recent Publications and Standards Contributions


Performance Standards for Packet-Switched Services (by Seitz)

Broadband ISDN - Asynchronous Transfer Mode Performance Issues (by Seitz)

# Digital Network Performance Standards Development

## Outputs

- Standard performance parameters and measurement methods
- Performance measurement software
- ISDN laboratory capabilities

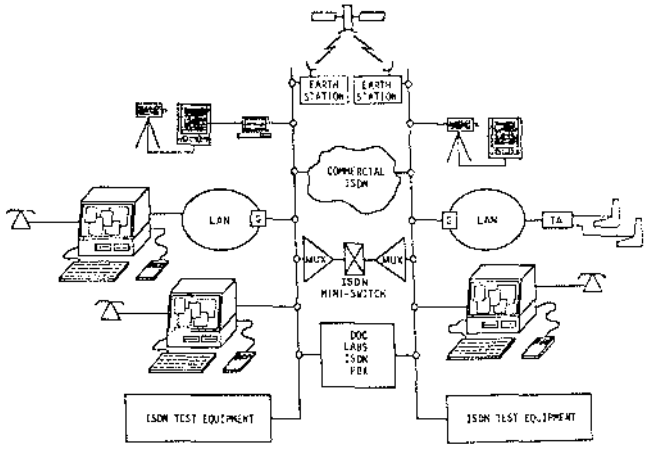
The Institute has been involved in digital network performance standards development for a number of years. In prior work, Institute staff members have defined comprehensive methods of specifying and measuring the performance of data communication systems and services from an end user perspective; coordinated the adoption of these methods in national and international standards; implemented the specified measurement methods in prototype microcomputer-based test equipment; and demonstrated application of the prototype test equipment in assessing the performance of private and competing public data communication networks. The ITS-developed performance specification and measurement standards are now mandatory for use by Federal departments and agencies in the procurement of data communication systems and services. In FY 89, the Institute assisted users and providers in applying these standards in several data communication procurements and developed measurement software documentation, performance standards contributions, and laboratory capabilities focused on particular performance assessment needs.

Performance Measurement Software Documentation. Among the major results of the Institute's digital network performance program are two American National Standards, ANS X3.102 and ANS X3.141, which define user-oriented performance parameters and measurement methods for data communication services. In prior work, Institute staff members have developed a software system which provides an efficient, automated means of measuring data communication performance in accordance with these standards. The software system can be implemented on a wide variety of general-purpose computers, including microcomputers commonly used in portable test equipment, and is available to other Federal agencies and the public. During FY 89, Institute personnel developed a six-volume report which describes the X3.102/X3.141 measurement software system in detail and provides step-by-step instructions on its installation and use. The 6 volumes include a general overview of the software system and a separate volume describing each of its five component programs: Experiment Design, Data Extraction, Data Reduction, Data Analysis, and Data Display. The flow of performance information among these component programs is illustrated in the figure at the upper right.

Packet-Switched Network Performance Measurement Standard. The Institute contributes to the development of performance standards for packet-switched public data networks through its leadership of the ANSI-accredited T1 (Telecommunications) Standards Committee's Working Group T1Q1.3. During FY 89, the Working Group completed the development and coordination of a new American National Standard, T1.504, which defines a comprehensive set of packet-switched service performance parameters. The T1.504 parameters are technology-specific counterparts to the user-oriented, technology-independent parameters defined in ANS X3.102. The Working Group also developed the first draft of a companion T1 standard, consistent with ANS X3.141, which defines packet-switched service performance measurement methods. The figure at the lower right illustrates a simple, approximate method of measuring one particular parameter defined in the T1.504 standard: residual error ratio (RER). That parameter is defined in T1.504 as the ratio of total incorrect, lost, and extra user data bits to the total user data bits either transmitted or received in a packet network connection. In measuring RER, a sample consisting of $n_T$ user data bits is transmitted. A corresponding sample consisting of $n_R$ user data bits is received. If $n_T = n_R$, the transmitted and received user data bits are compared bit for bit, and the number of incorrect data bits in the sample is estimated by $m_E$, the number of corresponding transmitted and received bits that do not match. If $n_T > n_R$, the number of lost data bits in the sample is estimated by $m_L = (n_T - n_R)$. If $n_T < n_R$, the number of extra data bits is estimated by $m_X = (n_R - n_T)$. The residual error ratio (RER) is then calculated from these quantities as indicated in the figure.

ISDN Performance Measurement Laboratory. A major objective of the Institute's digital network performance program is to develop and demonstrate practical methods of measuring the

performance of Integrated Services Digital Networks (ISDNs). This work provides an experimental foundation for NTIA's contributions to the development of ISDN performance standards and ultimately will facilitate the evaluation and use of ISDN services. FY 89 activities included the specification and procurement of laboratory equipment and the conduct of initial ISDN service demonstrations and performance measurement experiments. The ISDN performance laboratory concept is illustrated in the figure below. Desk-top computers equipped with special ISDN interface cards function as ISDN Terminal Equipment (TE), and provide ISDN telephone connectivity. Commercial ISDN test equipment monitors the ISDN "D" and "B" channels and provides a record of performance-significant events. An ISDN mini-switch, specified and ordered during FY 89, will provide a stand-alone ISDN network simulation capability. The mini-switch will be supplemented by operational ISDN network capabilities, including an ISDN PBX, one or more commercial ISDN services, and a satellite-based ISDN transmission and switching facility. The ISDN terminal and measurement equipment will be supplemented to include local area networks and video capabilities. Ultimately, the laboratory will be upgraded to provide full broadband ISDN capabilities.



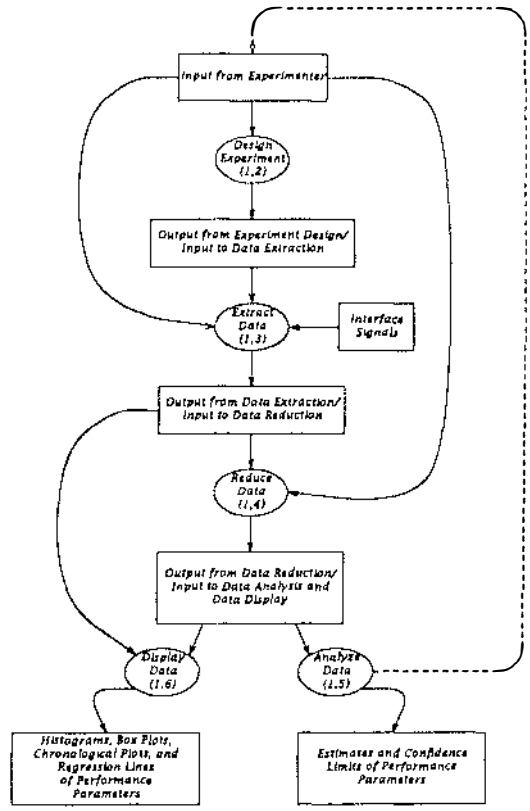

ISDN Performance Laboratory Concept

## Recent ITS Publications

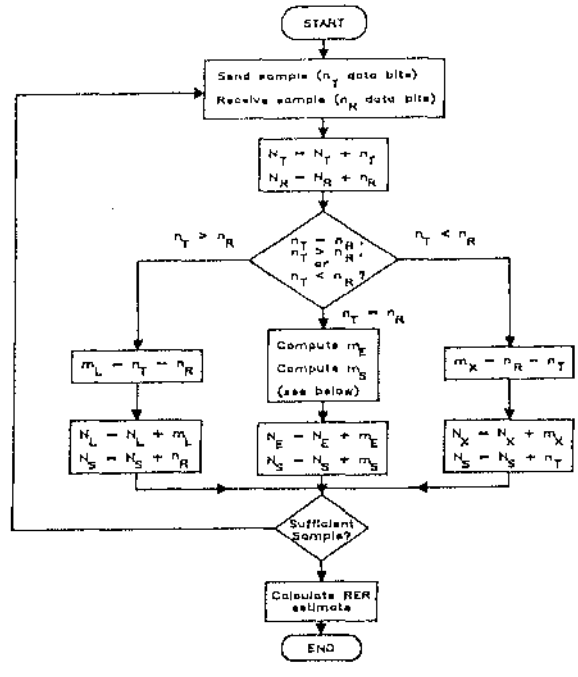
User-Oriented Performance Evaluation of Data Communication Services: Measurement Design (by Bloomfield and Spies)

User-Oriented Performance Evaluation of Data Communication Services: Measurement Results (by Bloomfield and Spies)

NTIA/ITS Implementation of ANS X3.141: Data Communication System and Services-Measurement Methods for User-Oriented Performance Evaluation (by Bloomfield)




Structured Flow of ITS Performance Assessment Software




$$m_E = \sum_{i=1}^{n_T} b_i^T \oplus b_i^R \qquad i = \text{bit position}$$

$$m_S = n_T - m_E$$

$$RER = \frac{N_E + N_L + N_X}{N}$$

$$N = N_L + N_S + N_E + N_X$$

An Approximate Method of Calculating Residual Error

# Voice Quality Standards Development

## Outputs

- Contributions to standards organizations
- Operational voice quality assessment software
- Techniques for analyzing voice parameters

Assessing transmission speech quality is a primary means of gauging performance of voice communication services and equipment. Organizations that depend on voice quality assessment include providers and developers of voice products, purchasers, end-users, and standards organizations. Assessment technology is equally important to network operators for managing telecommunication networks to maintain the highest possible level of performance. Finally, government organizations have a deep interest in assuring interoperability of public and private networks during times of crisis or national emergency, and require measures of overall network performance.

In response to these needs, the Institute is developing a tool for automatic measurement of voice quality. Although human listeners provide the most dependable ground truth assessment, the time and dollar costs of listener panels often make them prohibitive. Network performance models developed to estimate quality on older public telephone networks have existed for many years but can't handle impairments generated by newer transmission modes such as low bit rate codecs and ISDN ATM communications.

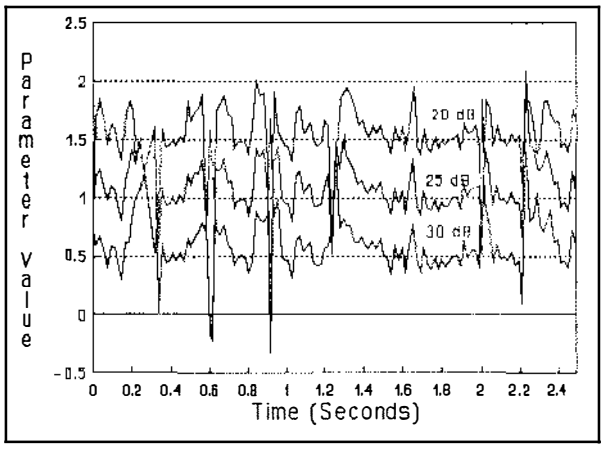
The Institute is also strongly supporting national and international standards development in this area. During FY 89, Institute personnel continued to lead a Study Project, within the ANSI-accredited T1Y1 committee, to determine the feasibility of a national standard objective assessment technique. On the international level, ITS is participating in a CCITT SG XV subjective and objective test of 16 kbit/s coding techniques. Included in the codec test is an evaluation of the four objective assessment methods being considered by CCITT. Techniques include the ITS pattern recognition based system, as well as submissions from France, Japan, and Canada. Results of the test will determine future CCITT goals regarding establishment of an international standard assessment method.

Project personnel (from left) Kevin Kiser, Bob Kubichek, and D.J. Atkinson

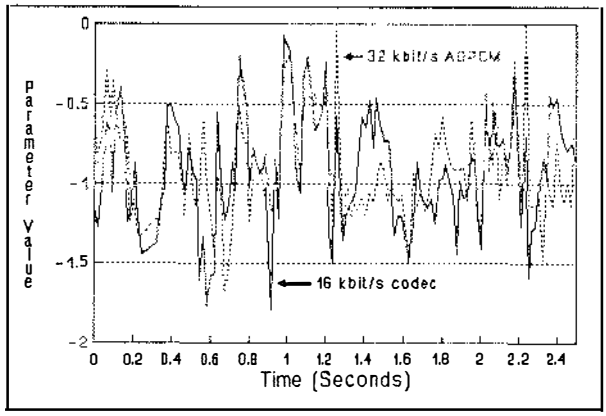
Developing an automatic "objective" measure depends on identifying parameters derived from the speech signal that correlate with "subjective" listener scores. A significant portion of ITS research involves the development of a set of parameters that provide accurate prediction of subjective listener panel scores for a broad range of impairments. Nearly 250 parameters have been implemented and are being studied for use in the system. Identification of an effective set of parameters is a formidable task considering the massive number of possible parameter combinations to be evaluated.

The first two figures at right illustrate behavior typical of many parameters being studied. In the top diagram, parameter values (based on a measure of frequency coherence) are graphed for a single spoken sentence. Curves for three types of impairment are shown, namely, 20, 25, and 30 dB speech to correlated noise. The speech has been subjectively tested to provide listener Mean-Opinion-Scores (MOS) of 2.54, 3.21, and 3.87 respectively. The curves are well separated providing strong evidence that the parameter is sensitive to subjective quality.

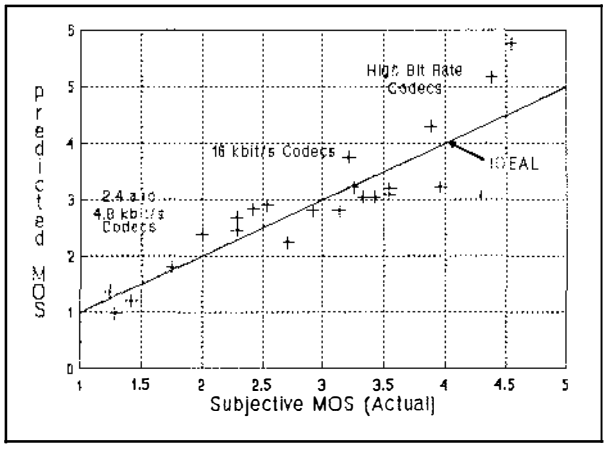
The next graph demonstrates the difficulty of finding a single parameter effective for many types of impairments. Here, the two curves represent compressed speech at 16 and 32 kbit/s with MOS of 1.42 and 3.54. Though the




Parameter Values for Noisy Speech




Parameter Values for Coded Speech




Quality Assessment Using ITS System

subjective quality of the two records is quite different, the overlap of the curves implies little sensitivity to quality for these types of distortion. Thus, a combination of two or more parameters is necessary to achieve acceptable accuracy for real world impairments.

The final graph shows application of the ITS voice quality assessment system to 23 different distorted speech records including 2.4, 4.8, 16, 32, and 64 kbit/s voice coding. A combination of three voice parameters was used. Predicted MOS values are graphed against subjective listener scores and indicate good correspondence. Current efforts are focused on increasing system accuracy and verifying effectiveness for a realistic range of network impairments.

Recent Publications and Contributions

Draft Outline of Final Technical Report: Technology-Independent, User-Oriented, Objective Classification of Voice Transmission Quality (by Kubichek)

Some Results on Evaluation of Objective Parameters for Automatic Assessment of Voice Quality (by Kubichek and Atkinson)

Voice-Quality Assessment for Transmission Delay using Expert System Techniques (by Kiser, Kubichek, and Quincy)

Speech Quality Assessment Using Expert Pattern Recognition Techniques (by Kubichek, Quincy, and Kiser)

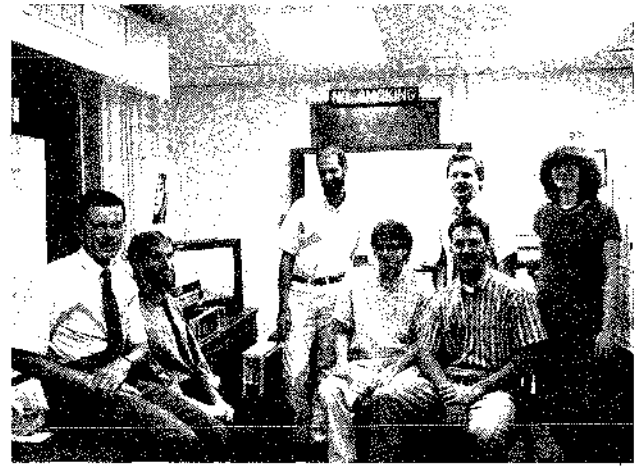
# Video Quality Standards Development

## Outputs

- Contributions to standards committees
- Video quality measurement software including image processing, pattern recognition, and expert system development
- Video expertise provided to NTIA and Department of Commerce for establishing U.S. policy on advanced video technologies

As the world prepares to enter the age of compressed and digitally transmitted video services such as video teleconferencing/video telephony, digital television, wideband ISDN, high resolution graphics transmission, and high definition television (HDTV), new quality assessment techniques are needed. Traditional techniques for estimating video quality are based on analog measures of the transmission signal. Such measures include waveform tests and chrominance/luminance gain and phase factors. These parameters are not adequate in assessing video quality when images are impaired by the many new types of distortions introduced by the modern digital transmission systems given above. In such cases, the video transmission quality is often a function of the type of imagery being transmitted (line drawings, natural scenes, etc.). Since the information has been compressed, small transmission errors can have large effects on the received video quality. As a result, viewing panels have been used to subjectively evaluate these modern distortion effects on video quality. Unfortunately, this approach is time consuming and expensive, and requires special care to prevent wide variations between tests.

New, objective measures of video transmission quality are urgently needed by standards organizations, end users, and providers of advanced video services. ITS is developing a method for objective measurement of video quality based on parameter extraction from sampled video imagery and expert systems techniques. The ITS computer-based approach extracts objective video quality measurements directly from the captured video images. Video quality parameters extracted from the sampled imagery are sensitive to user applications and the effects of modern transmission channel impairments. The objectively measured

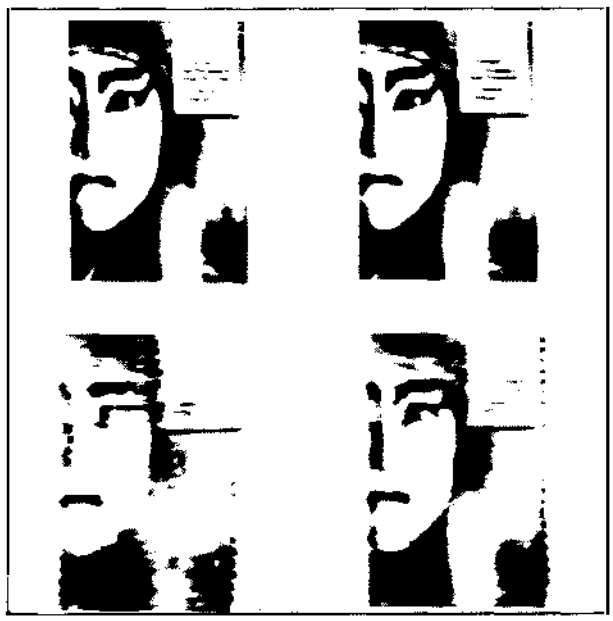


Project personnel (standing from left) Dara Parsavand, Steve Wolf, Margaret Morris, and (seated from left) Ed Quincy, Kevin Kiser, Tim Butler, and Keith Junker

parameters can then be interpreted and mapped to an overall quality rating using expert system or knowledge based techniques. The ITS approach removes unwanted human variability while implementing the essentials of user oriented subjective evaluation. The ITS approach will allow users to obtain impartial, reliable, repeatable, and cost effective measures of video and image transmission system performance. Other benefits include increased competition among providers as well as better capability of procurers and standards organizations to specify and evaluate new systems.

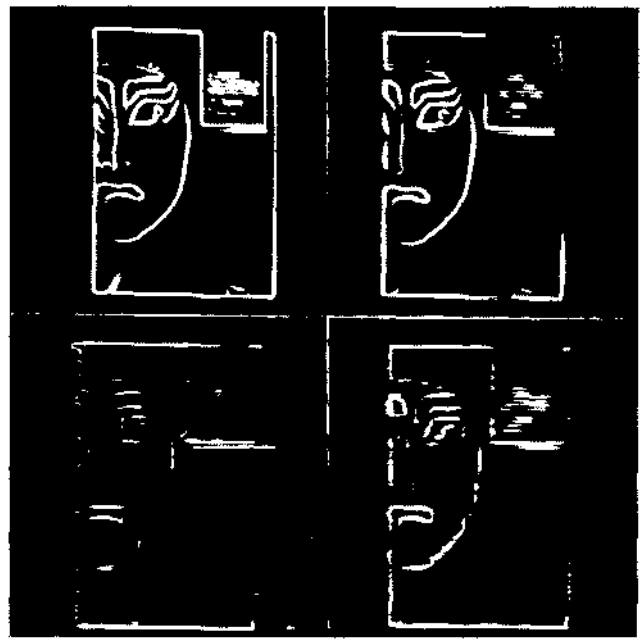
The American National Standards Institute, Committee T1Q1.5 is drafting interface performance specifications for digital video teleconferencing/video telephony (VTC/VT), digital television, and advanced television. The VTC/VT working group of T1Q1.5 is developing a catalogue of video motion artifacts associated with video compression and the resultant effects on video quality. The artifacts which are most noticeable to the viewer and whose parameters show the most potential for measurement are being considered for inclusion into the draft standard for VTC/VT. ITS has actively participated in the development of this catalogue of artifacts and has developed measurement techniques and parameters for the different artifacts.

One of the most prevalent VTC/VT artifacts is blurring/smearing, defined as the deterioration of a video picture in which the received image has lost edges and detail of the original imagery. The ITS developed parameter for this artifact is illustrated in the figures. The figure below shows 4 images captured by the image processing system which contain different amount of blurring. The top left image was captured from an NTSC camera with no motion present in the video scene (this image can be used as a reference). The top right image was captured from an NTSC camera when translational (right to left) motion was present. The bottom right image was captured from the output of a codec running at rate T1 (1.536 Mbps) when translation motion was present (here the input imagery to the codec came from the camera). The bottom left image was captured from the output of the same codec running at rate 1/4 T1 (384 kbps). The figure at right shows the corresponding sampled imagery after edge enhancement filtering performed by the ITS image processing system. Note the well-defined edges for the image captured from an NTSC camera with no motion present (top left) and the successive worsening of the edge blur for camera with motion (top right), camera with motion and T1 compression (bottom right), and camera with motion and 1/4 T1 compression (bottom left). The figure at the lower right shows the histograms of the edge enhanced sampled imagery. Note the percentage of picture elements (pixel) values at the maximum intensity of 255 (255 is the maximum image pixel value for the 8 bit image processing system which was used to generate these results). The percentage of high intensity pixels decreases as the input imagery suffers increased degradation of spatial resolution.

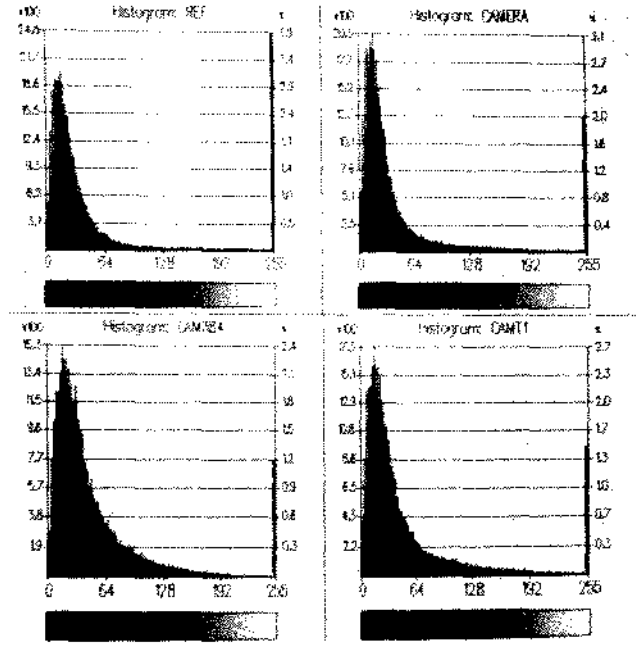


Motion Distortion and Compression Effects on Digital Video Imagery

The edge sharpness parameter just described is applicable to many types of video imagery, including natural scenes. This parameter, in addition to many others being developed, forms a set of measures which can be used to evaluate the performance of modern digital compression and transmission systems.



Edge Enhanced Imagery



Histograms of the Edge Enhanced Imagery

# Radio System Interoperability Standards Development

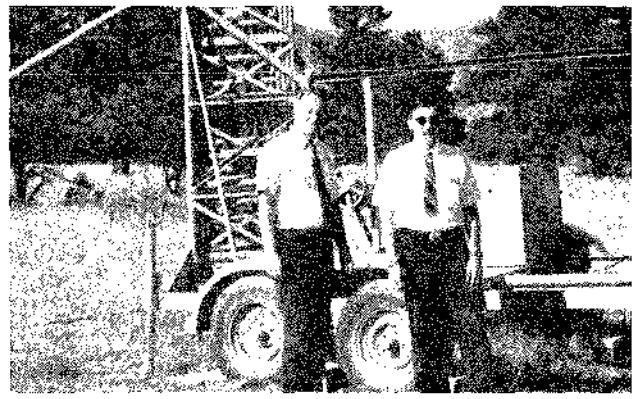
## Outputs

- FTSC subcommittee leadership and technical support
- Federal interoperability standards for radio systems
- Standards impact assessments
- Radio system interoperability evaluations

The Federal Government has many missions, including national defense, drug enforcement, and disaster recovery, that require cooperation among different Federal agencies. The ability to successfully carry out these missions is significantly strengthened when interoperable communications equipment is used. The Federal Telecommunications Standards Committee (FTSC) has responsibility for development of Federal interoperability standards for radio systems, including high frequency (HF) and land mobile radio equipment. The Institute supports FTSC radio standards activities through leadership of technical subcommittees and through a variety of standards development, implementation, and evaluation projects.

HF Radio Interoperability Standards. The FTSC, under direction of the National Communications System (NCS), has assigned its HF Radio Subcommittee the responsibility for developing a family of HF radio interoperability standards: Federal Standards 1045 through 1054. The HF Radio Subcommittee is chaired by an ITS staff member. FED-STDs-1045 through 1049 will provide interoperability for automated HF radios. The first standard, FED-STD-1045 (HF Radio Automatic Link Establishment) was approved by the FTSC and forwarded to the General Service Administration for publication during FY 89. FED-STD-1046 (HF Radio Automatic Networking) and FED-STD-1049, Section 1 (Automated HF Radio Operation in Stressed Environments, Link Protection) are currently under development.

The HF radio standards are being written in a progression that conforms to the Open Systems Interconnection (OSI) architecture. The features necessary to automate an HF radio system are illustrated in the upper diagram on the facing page. These features will be implemented in the sequence shown to achieve increasingly higher levels of automation.



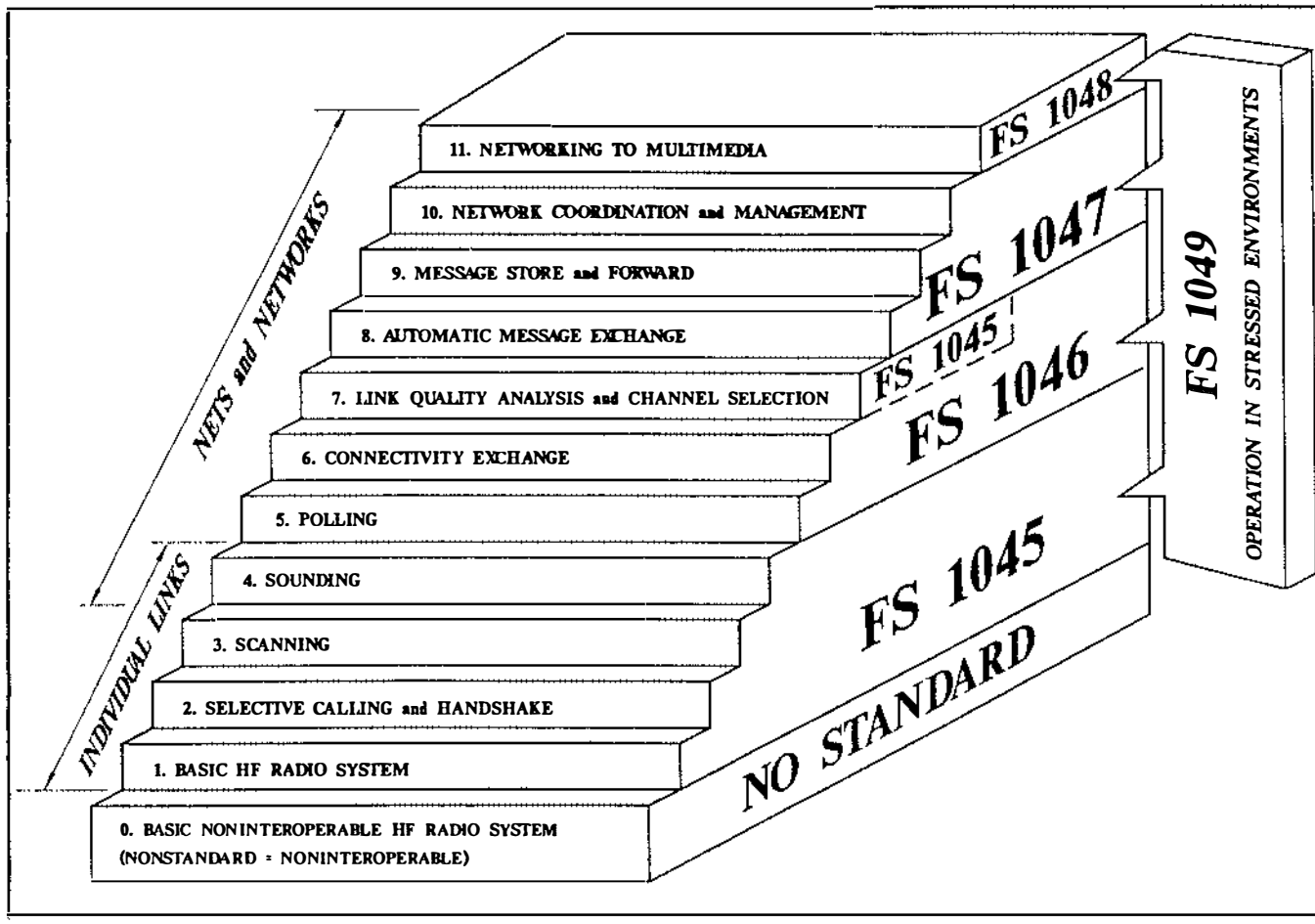
Project personnel (from left) Dave Peach and Bob Adair

Land Mobile Radio Interoperability Standards. ITS serves as Secretariat and provides strong technical support to the FTSC Land Mobile Radio Subcommittee. Federal Standard 1023 (encrypted digital voice radio for 25 kHz channels) was approved in FY 89. Federal Standard 1024 (narrowband digitized voice radio) and Federal Standard 1044 (trunked radio system for 25 kHz channels) are currently under development. Federal Standard 1024 will considerably enhance the spectral efficiency of land mobile radio voice communications.

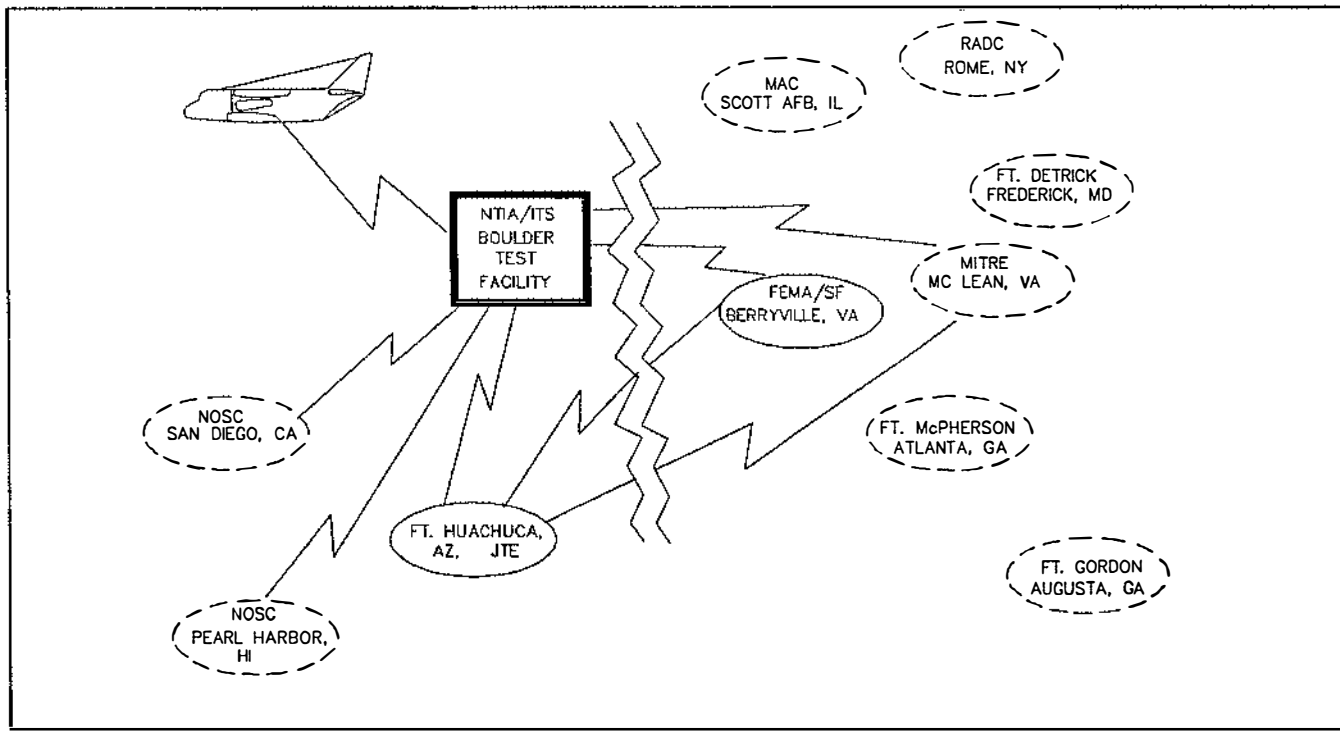
HF Radio Interoperability Assessment Facility. During FY 89, NCS funded the start-up of an HF interoperability facility at the Institute. The purpose of the new facility is to assess the degree of interoperability of HF radio systems within the 1045-1049 standards family. An initial implementation of the facility became operational in August 1989. A sample configuration of typical stations that will be networked in demonstrating HF radio interoperability is shown in the lower diagram on the facing page.

Recent ITS Publications

A Federal Standard for HF Radio Automatic Link Establishment (by Adair and Peach)
An HF Automatic Link Establishment Standard for Automated Digital HF Radios (by Adair)
Digital Comes to Narrowband (by Jones)




Implementation of HF Radio Standards Within the OSI Environment




Typical HF Radio Test Network

# Building Cabling and Telecommunication Terminology Standards Development

## Outputs

- Fiber optic standards
- Building telecommunications wiring standards
- Telecommunications terminology standards

Cooperative Efforts in Developing Industry Standards. The Federal Telecommunication Standards Committee (FTSC), administered by the National Communications System (NCS), provides a forum for developing and coordinating Federal Standards to assure end-to-end interoperability of telecommunication systems owned or leased by the Federal Government. The FTSC adopts industry-developed voluntary standards as FED-STDs wherever the industry-developed standards are perceived to meet Government user needs. To ensure that Government user needs are addressed during industry standards development in areas pertinent to NCS missions, ITS staff members participate actively in several Electronic Industries Association/Telecommunications Industry Association (EIA/TIA) committees and working groups on behalf of NCS. During FY 89, this work has resulted in Proposed Federal Standards (pFS) as indicated below:

Proposed FED-STD-1070. Significant progress was made during FY 89 on the development and approval of FED-STD-1070, which specifies a 62.5-$\mu$m core diameter, a 125-$\mu$m cladding diameter, and other technical characteristics for fiber optic cables used in on-premises applications. This effort was coordinated very closely with the development of related EIA standards. FED-STD-1070 was adopted by the FTSC in September 1989. The optical fiber specification, which was adopted as an American National Standard in January 1989, was also authored by the Institute. Designated ANSI/EIA/TIA-492AAAA, it is the first EIA/TIA Detail Specification (procurement document) in the optical fiber field.

Some examples of the widespread impact of this work follow. 1) One of the major manufacturers of multimode optical fiber has proposed that the 62.5/125 $\mu$m standard be adopted as a CCITT Recommendation. That action would afford U.S. providers new opportunities in international trade. 2) Continuing ITS liaison, the National Institute for Standards and Technology (NIST)f has included FS-1070 in the ANSI Fiber Distributed Data Interface (FDDI) standard. 3) One of the major private sector implementers of fiber optic systems has adopted the ANSI Detailed Specification as a company-wide standard.

Proposed FED-STD-1090. Another industry standards committee of importance to the FTSC is the TIA, Technical Committee on Telephone Terminals, TR-41.8. One of its subordinate committees, Working Group TR-41.8.1, was formed by terminal manufacturers to address standardization of building telecommunications wiring. The industry's objective was to alleviate chronic problems with the inadequacy of much installed wiring for proper operation of state-of-the-art data terminals and systems such as local area networks. The ITS participation has resulted in the standard's specification of several key components, e.g., copper transmission line characteristics, wall outlets and wiring formats for work areas, and an EIA Detail Specification for multimode optical fibers, to optimize terminal portability and interoperability. The EIA/TIA work was approved for ballot in FY 89 as EIA SP-1907. The corresponding Federal document, entitled "Commercial Building Wiring Standard," has been accepted by the FTSC as pFS 1090.

Proposed FED-STD-1091. The Institute has also supported TIA Working Group TR-41.8.3 in developing an EIA/TIA standard, on building Telecommunications Pathways and Spaces. This standard specifies minimum technical requirements for building wiring pathways and enclosures, e.g., telecommunication closets, conduits, and raceways. This industry standard was completed and voted out of committee for formal letter ballot as EIA SP-2072 near the end of FY 89.

Proposed FED-STD-1092. Working Group TR-41.7.2 was organized in September 1989, with good industry support, to develop a grounding, bonding, and protection standard for commercial buildings. This proposed new standard will complement the above commercial building wiring standards. An ad hoc working group of expert representatives from the participating agencies of the FTSC has been formed under ITS leadership to develop

Government requirements and recommendations for the EIA/TIA TR-41.7.2 group. Assuming that the completed TR-41.7.2 standard meets the requirements of the Government agencies, it will be recommended by ITS for adoption as pFS 1092.

The diagram below illustrates the various components of a modern building telecommunications wiring system, to which proposed Federal Standards 1070, 1090, 1091, and 1092 will be applied.

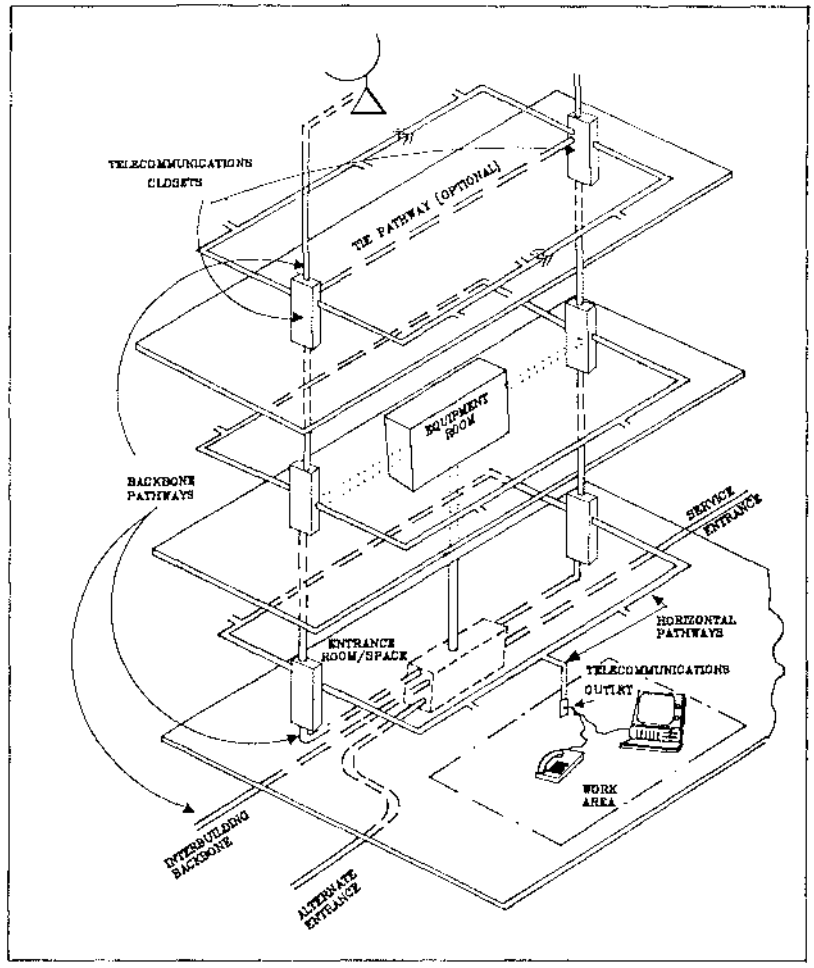
Telecommunication Terminology Definition. A commonly agreed upon definition of telecommunication terms is vital to assure an unambiguous language for use within the Federal Government and between the Government and the private sector. A primary example is the technological and legal requirement for mutually understood vocabulary in procurement of telecommunication equipment, systems, and services. Other needs include the standardization of terminology for preparation of Federal standards, military standards, and military handbooks, engineering and scientific writing and editing, and technical training.

"Glossary of Telecommunication Terms" (FED-STD-1037A), generally considered to be the most widely used Federal Standard, fulfills these and many other similar needs for both the Federal civil sector and the U.S. Department of Defense. In accordance with FTSC 5-year review requirements, the ITS began revision of FED-STD-1037A in FY 89, with completion scheduled for the end of FY 90.

The rapid evolution of numerous telecommunication technologies has mandated a major updating of the glossary in areas such as optical fiber communication, HF radio, data transmission, and secure communication. This updating comprises both the inclusion of many new entries and the rewriting of some previous definitions to map state-of-the-art usage.

Recent ITS Publications

Proposed Federal Standard 1070 (by Hull)
Telecommunications Building Grounding Standards: A Status Report (by Hull)




Building Telecommunications System Wiring

# TELECOMMUNICATION SYSTEMS PERFORMANCE

The Institute conducts a variety of programs in which the results of more basic studies are applied in improving the performance of particular telecommunication systems. The Institute develops practical methods of predicting and evaluating telecommunication system performance; applies these methods in system design; and conducts laboratory and field measurements to optimize the performance of recommended systems and their components.

## Areas of Emphasis

### High Definition Television Evaluation

Includes projects funded by the National Telecommunications and Information Administration

### Computer Aided Design and Video Teleconferencing Network Development

Includes projects funded by the Naval Sea Systems Command

### HF Systems Assessment

Includes projects funded by the Air Force Geophysics Laboratory, the Army Communications-Electronic Command, the Army Information Systems Engineering Command, the Department of Defense, and the U.S. Information Agency

### Transmission System Performance, Monitoring, Evaluation, and Control

Includes projects funded by the Air Force Electronic Systems Division, the Army Information Systems Engineering Command, and the Defense Communications Agency

### Network and Link Performance Characterization

Includes projects funded by the Air Force Electronic Systems Division and the Naval Air Test Center

### Transmission System Modeling

Includes projects funded by the Army Information Systems Engineering Command and the Department of Defense

# High Definition Television Evaluation

## Outputs

- Analysis of HDTV signal compression
- Analysis of propagation effects on split-band HDTV signals

Propagation Study. The Institute is studying the spectrum needs for High Definition Television (HDTV). Compared with the 6 MHz spectrum currently allocated for NTSC (National Television Systems Committee) television channels, HDTV will probably require additional spectrum. Although an HDTV system has not been selected, a 12 MHz bandwidth is needed by many of the candidate systems that have been proposed. In many areas of the country, current TV stations are densely packed within the available spectrum. The assignment of a second 6 MHz channel adjacent to the original signal channel could potentially cause interference to many of the current television viewers. To allow for the additional 6 MHz required by many of the proposed systems, a possibility of using non-contiguous channels has been suggested.

This raises concerns that differences in the characteristics of propagation at widely spaced frequencies will cause significant synchronization problems for the simultaneously transmitted, widely spaced HDTV channels. Some of the problems that may exist in widely spaced systems are

**Differential delay** - the difference in the time of arrival between the signals in the lower frequency channel and the signals in the higher frequency channel. This delay would affect the synchronization between the two channel's signals particularly if the differential delay varies significantly with time.

**Differential fading or crossband fading** - the difference in the frequency selective fading (resulting in frequency nulls within a single channel) between the two channels. This would affect how well the augmentation channel could track the master TV channel.

**Echoes** - the difference in the multipath characteristics between the two channels. In order to produce adaptive echo equalizers to eliminate ghosts in analog systems or determine error rates in digital systems, the multipath characteristics must be known.

In order to determine the differential time delay and echo characteristics that exist in television channels, a measurement system that transmitted very narrow pulses could be used to measure the time of arrival of the pulses and measure the pulse spreading due to multipath. However, this measurement would require a very wide bandwidth with high peak powers. An alternative measurement system uses a pseudorandom noise (PN) code to modulate the transmitted signal and to demodulate the received signal. This produces a wide transmission bandwidth as well but the power required is relatively low. The measurement receiver uses the same PN code to mix with the received signal. When the receiver's PN code and the received signal are in perfect time alignment, the receiver produces a large voltage at its output. At any other moment the output is a small voltage. Thus, the PN code measurement system operates as if it were transmitting and receiving narrow pulses.

The Institute used a Wideband Propagation Measurement System (WPMS) to simultaneously measure complex time varying impulse response (TVIR) data for both a VHF (or low frequency UHF channel) and a UHF frequency channel. The WPMS design limits the low frequency channel's center frequency to between 200 MHz (approximately Channel 12) and 700 MHz (Channel 55) and the high frequency channel's center frequency to between 701 MHz (Channel 55) and 1050 MHz. The WPMS system was designed to determine multipath signal characteristics with a resolution on the order of 20 ns with compensations for specific equipment variability (such as the antennas) using the 50 MHz wide spread spectrum signals.

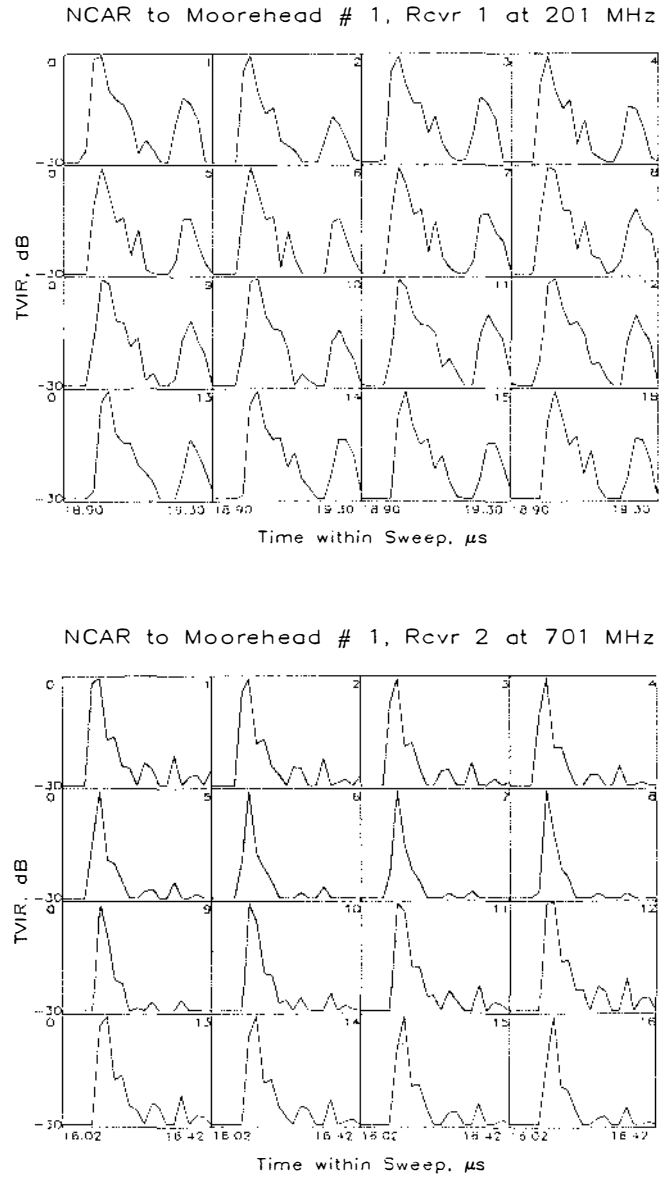
The transmitter is a computer-controlled system that simultaneously generates two spread spectrum signals. The spread spectrum signal for each band is generated by digital phase modulating a local oscillator (the center frequency for the spread spectrum signal) with a PN code sequence. The spread spectrum signal from each band is amplified, low-pass filtered, and then combined to produce up to a 100 W output signal in each band. A horizontally polarized log periodic antenna mounted on a tower above the van was used to transmit the signal. The receiver van contains two identical computer-controlled correlation receivers to allow simultaneous data collection on two frequencies. In the configuration used in these

measurements, a 1023 bit PN sequence at a chip rate of 50 MHz is correlated with the incoming rf signal. The corresponding chip duration is 20 ns (duration equals 1/[chip rate] ). After a complete correlation (which takes 1023 times 20 ns or 20.46 $\mu$s) the output of the integrator is digitized and stored, the PN sequence is shifted by 1 bit, and the process is repeated. The impulse response consists of 1023 of these digitized values and is called a sweep. The total time for one sweep is then 1023 correlations times 1023 chips/correlation times 20 ns/chip or 20.93058 ms. The receiver takes 128 sweeps during each measurement episode and in post-processing, 8 consecutive sweeps are averaged to reduce noise. The theoretical dynamic range of the receivers is approximately 30 dB.

A sample of the correlation receivers' output is shown in the accompanying figure. The top set of measurements shows 20 chips (out of a total of 1023 chips) around the correlation peak for the receiver centered at 201 MHz, and the bottom set shows measurements at 701 MHz. Both the low and high band signals show one large peak, which for this path is the direct line-of-sight signal. Roughly 240 ns beyond the peak is a stationary multipath that is detected by both receivers, although the multipath amplitude is greater for the 201 MHz receiver.

The 240 ns time difference translates to a path difference between the direct path and the multipath of 73 m (240 ft.). The measurements show multipath that was created by a reflector moving as shown by the trailing edge of the direct signal. The multipath signal blends in with the direct signal on some frames (e.g., 1, 10, and 11 for Receiver 1) and then becomes distinct from the direct signal on other frames (e.g., 2, 4, and 16 for Receiver 1). The time duration between frames is about 168 ms. The cause of the multipath is probably due to vehicles as the receiver was located near a busy intersection. A car traveling at 65 m (40 mph) would move about 3 m (10 ft) in 168 ms which corresponds to 10 ns or one-half of the chip width in these measurements. This is of the order of the multipath position changes shown in the figures.

Compression Study. Using the Advanced Television Systems Committee (ATSC) recommendations to CCIR for defining a worldwide HDTV studio standard, studies were performed to estimate the compression required to transmit HDTV over the 6 MHz channel required by FCC. These recommendations are to use 750 progressively scanned lines and 60 frames (1 field/frame) per second. In addition, the typical proposed HDTV digital parameters of 750 picture elements (pels) per line and 16 bits per pel (8 luminance, 8 chrominance) were used. This 9 Mbit/frame digitally encoded video signal requires a 540 Mbit/second digital channel without compression. If it were to be analog transmitted over 6 MHz, a compression factor of 45 would be required. This compression would reduce the digital channel requirements to 12 Mbits/second. Many clever schemes for HDTV transmission have been proposed that may produce acceptably compressed HDTV. They take advantage of spatial redundancies in each frame, temporal redundancies from frame to frame, unused spectrum, and perceptual limitations of the human.



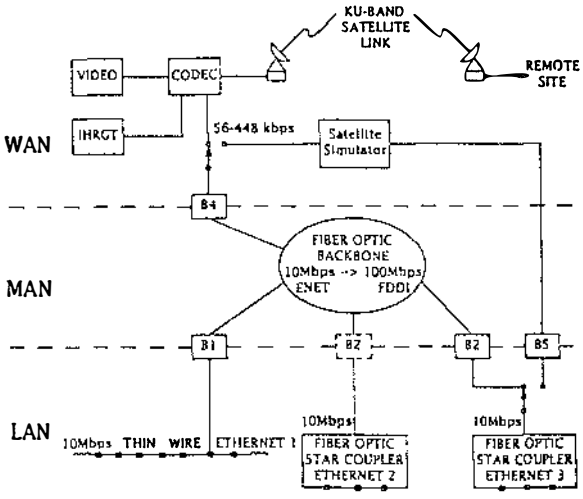

**Time Varying Impulse Response Measurements in a Multipath Environment**

# Computer Aided Design and Video Teleconferencing Network Development

## Outputs

- Navy shipbuilding telecommunication network models
- Fiber optic Ethernets
- Ku-band satellite earthstation
- Measurements of dial-up networks at 9.6 and 19.2 kbps
- Objective measures of VTC quality

Modeling and Development of Shipbuilding Integrated Services Networks. The Institute has developed prototype networks and a test-bed to demonstrate and evaluate the integration of a variety of services for fulfilling Navy shipbuilding requirements. Fundamental shipbuilding services supported on the networks are Computer Aided Design (CAD) and Computer Aided Logistics Support (CALS) for paperless contracting. Video Teleconferencing (VTC) and Interactive High Resolution Graphics Teleconferencing (IHRGT) for joint review and interactive editing of documents or images is also supported on the Wide Area Network (WAN).




ITS CAD/CALS/VTC/IHRGT Network Development and Test-Bed

The series of interconnected networks implemented at ITS include coaxial cable and three fiber optic Ethernets operating as 10 Mbps

Project personnel processing VTC images (from left) Tim Butler, Keith Junker, Ed Quincy, and Dave Wortendyke

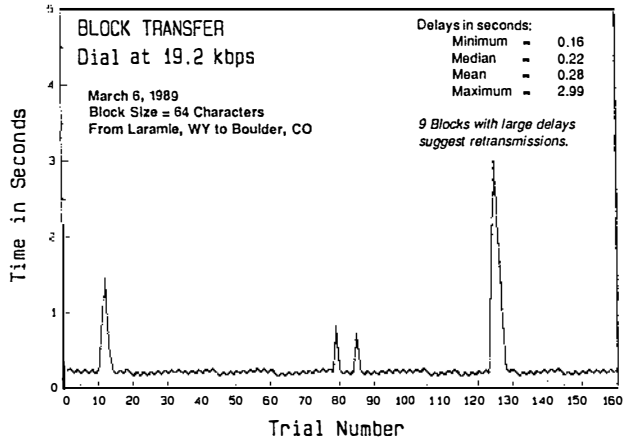
Local Area Networks (LANs) and a fiber optic Ethernet backbone operating as an interim 10 Mbps Metropolitan Area Network (MAN) or Campus Network. The MAN will be migrated to a 100 Mbps Fiber Data Distributed Interface (FDDI) network as appropriate components become available. It is connected to a transmit/receive (14/12 GHz) satellite earthstation operating as the interface to the T1 (1.536 Mbps) WAN pipe interconnecting Navy sites.

A codec operating at 384 kbps-1.536 Mbps is employed to digitize video and also integrate VTC/CAD/CALS/IHRGT data using subchannels. Multiple Ethernets and a satellite WAN simulator permit loopback evaluation of multivendor workstations, protocol suites, and performance of the interconnected networks in the laboratory. Similar multi-site evaluations will be performed subsequently.

Performance Testing of Dial-up Networks. Data exchange over a wide geographical area may be costly and unreliable if the performance of the network being used is questionable. For infrequent and low traffic volume data exchange, the new dial-up error correcting modems have presented an alternative at 9.6 and 19.2 kbps. Use of the American National Standard user-oriented performance parameters

to evaluate the performance of a modem/carrier combination was demonstrated as a part of this project.

Two personal computers were used with the ANS X3.141 performance measurement software to originate and answer calls between cities in two different states.




Chronological Block Delay

One such test was conducted between Laramie, WY and the ITS Laboratory, investigating block delay as data is sent into a non-loaded channel at 19.2 kbps. The delay of 64-character blocks was typically around 0.22 seconds, but due to phone line noise, several times during the test the delay jumped to as much as 2.99 seconds with no errors in the delivered data. Another test was conducted at 9.6 kbps where a large data file was sent continuously, but divided into 64-character block sizes. The throughput was found to be 79% of the signalling rate. Access times over the dial-up network (including computer to computer log-in) were as large as 43 seconds. Typically the Public Switched Telephone Network took 14 seconds longer for access than the in-house PBX.

Objective Assessment of Video Teleconferencing Quality. Video teleconferencing has evolved into a high priority service for the Navy network to support intersite communication and review of shipbuilding progress. The transmission bit rate for the WAN may be restricted to 786 kbps (1/2 T1) in order to provide a cost competitive channel. The bit rate and the four services competing simultaneously for this channel reduce the video quality. Objective assessment of video quality will enable tradeoffs of the requirements for each of the four services and selection of an appropriate channel bit rate to support these services.

Efforts for the Navy have been directed toward developing objective measures that can be applied directly to typical live VTC scenarios where spatial and motion resolution are high priorities. A useful measure was developed that focuses on the loss of edge energy in scenes with detail and motion.

Demonstration of Motion Distortion
in Compressed Video Images
(upper left: NTSC-none, upper right: T1,
lower right: 1/2T1, lower left: 1/4T1)

A standard NTSC source recording of live VTC data was played through a typical codec at T1, 1/2 T1, and 1/4 T1 compression rates demonstrating motion distortion and loss of detail as rates were reduced. Next, the edge energy in each image was determined by processing the image with a type of Laplacian edge detection operator where brightness in the image represents sharp edges. Then the edge energy for each image was computed as the square of the number of pixels at the brightest 255 level. Comparing compressed edge energy with original NTSC image shows a monotonic decrease in this measure as the compression rate is decreased and agrees with subjective evaluation of the same images. The final goal in objective assessment is to combine several such measurements and provide automated classification of VTC quality that correlates well with subjective evaluations.

Recent Publications

Performance Testing of Wide Area Networks (by Wortendyke, Morris, and Atkinson)

CAD and Video Teleconferencing Network Development (by Quincy and Ralston)

# HF Systems Assessment

## Outputs

- Improved techniques to predict HF system performance
- Analytical techniques for Government agencies' HF operational use
- Interactive HF sky-wave models

The Institute for Telecommunication Sciences has provided support to other Government agencies in various areas pertaining to high-frequency (HF) propagation system performance. Many of the efforts undertaken involve the Ionospheric Communication Analysis and Prediction Program (IONCAP). The IONCAP program is an integrated system of models designed to predict HF sky-wave system performance and analyze ionospheric parameters.

There has been an increased interest in the representation of ionospheric propagation predictions in the form of a communication network. Predictions such as the maximum usable frequency (MUF), circuit reliability, signal-to-noise ratio, and median field strength could assist communication engineers, designers, and others if presented in a form that specifies the value of the ionospheric parameter for each possible link of each pair of nodes in a network. The modeling effort presented here is the initial stage of development in establishing such a network capability with IONCAP.

The task consists of development of a procedure to generate a network representation of ionospheric characteristics. The network is identified by specifying a set of node numbers and descriptors for the nodes and a connection table for the nodes to define the actual network. The ionospheric propagation predictions are computed for every pair of connected nodes and represented in a tabular output. The network capability is, therefore, a representation of all point-to-point communication paths that constitute the network.

There are three specific aspects of the IONCAP network capability. These include (1) an input processor to generate the standard IONCAP input from the nodal information and connection table, (2) an interface to the IONCAP program to generate the propagation predictions, and (3) an output processor to represent the propagation predictions as a network. Collectively these three parts of the network capability are called IONNET.

There are distinct advantages to this design. The IONCAP program is a point-to-point communications model and does not directly allow network representation. The input processor portion of IONNET generates all of the possible links between two nodes in the network and represents these as a set of point-to-point communication paths that IONCAP can use without a significant modification to the IONCAP program. The interface portion of IONNET allows for the efficient computation of the ionospheric predictions. The IONCAP program, for instance, is utilized more efficiently if the propagation predictions for an individual path are generated for all necessary hours and frequencies. The network representation might require that all the links be available for a specific hour and frequency. The interface portion allows that the predictions be calculated and saved for a representation not available with IONCAP. The output processor of IONNET provides the network representation of the ionospheric parameters.

There are several other tasks that have been initiated or completed that use the IONCAP program. The development of a simplified digital model has been initiated for IONCAP. The methodology of this effort consists of the identification of a specific digital system and bit error rate. The model will predict the relationship between the specified bit error rate and the signal-to-noise ratio for an impulsive noise environment. This signal-to-noise ratio will then be considered as the required signal-to-noise ratio for IONCAP. Therefore, the digital model consists of determining a required signal-to-noise input value for the IONCAP program.

There has been an effort, using IONCAP, to improve the predicted structure of the polar ionosphere. The polar ionosphere is a highly variable medium characterized by dynamic processes of ionospheric and magnetospheric origin. Many of the features of the polar ionosphere--ionization troughs, electron density enhancements, and irregularities in ionospheric structure--are associated with the auroral oval. Changes in the ionospheric representation given in IONCAP were made to include the auroral oval-related features. This has enabled the results of IONCAP to be used to assess changes to

propagation conditions that are likely to be associated with the passage of radio waves through the polar ionosphere.

Another study involved the development of an interactive input processor called IONPUT that can be used to generate input for the IONCAP program. This processor allows the user to generate input for IONCAP by (1) specifying freeform card images that are then translated to the standard IONCAP input, (2) answering questions from the input processor corresponding to the specific analysis to be performed, or (3) a combination of these where the user specifies the input card image name and then responds to questions from the input processor. This input processor has been implemented on mainframe and micro computers and is now intended for release for public distribution.

It is often useful to have ionospheric propagation predictions presented in a form to assist in the estimation of geographic coverage of a given frequency at a given time and with a specific antenna. Predictions such as the MUF, circuit reliability, signal-to-noise ratio, and median field strength could aid HF broadcasters and others if presented in a geographic latitude-longitude display or a distance azimuth display for specified areas of the world. A procedure has been developed to generate a geographic area coverage representation of ionospheric characteristics for a specified area. The area is identified by specification of the latitude and longitude boundaries of the area or by specifying distances from the transmitter location and a set of azimuths. The ionospheric predictions are computed at the boundary locations of the grid and at incremental locations within the grid. The area coverage representation consists of these predictions represented on a matrix grid for each frequency and each hour the user requests and for each specified month and antenna. The area coverage representation, therefore, consists of the propagation predictions of several point-to-point communication paths that characterize the grid specified by the user.

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

IONCAP is used to generate the propagation predictions presented in the area coverage representation. The procedure consists of an input processor that generates the input to the IONCAP program based on the user-specified area coverage requirements. The input generated by this processor consists of the many point-to-point communication paths that represent the area to be covered. The second step in the area coverage procedure consists of the interface to the IONCAP program and the generation of the propagation predictions. The final step in this procedure is the geographic representation of the propagation predictions. This representation is currently in the form of a numerical representation but could be modified to constitute a graphical representation of the predictions. This graphical representation would allow, for instance, coverage maps to be produced that display the predicted field strength in a given service area. This area coverage model has been implemented on large mainframe computers and also micro computers. The area coverage model developed has been given the name QUILT.

The IONCAP program has also been structured to allow IONCAP to evolve into the "next generation" propagation model. Consideration has been given to the restructured version that should allow the program to become the center of an IONCAP system that would include the existing analysis capabilities and other new models and capabilities. The new IONCAP system could become an integrated procedure that is highly interactive and user friendly, but also could allow batch processing capability and ease of transport from one computer to another.

# Transmission System Performance, Monitoring, Evaluation, and Control

## Outputs

- Transmission monitor and control software
- Consultative services on transmission network management
- Network monitor hardware and software architectural design
- Field support for pilot system implementation

The Institute has developed a set of functional requirements for a network management system for a global data communication network managed by the U.S. Army Information Systems Command. The network consists of a mix of point-to-point microwave, Defense Satellite Services, and leased commercial services that include satellite and foreign PTT services. The upper figure on the facing page displays possible user-to-user data connectivities.

The ITS study has considered several alternative architectures that are capable of meeting the requirements. The general configuration consists of a single master monitor facility, polled remote acquisition systems, and remote display facilities. One of the more desirable options is an independent connection, different than the data circuits, between the master terminal and the remote facilities. The basic architecture is shown in the lower figure on the facing page.

Functional requirements of the network management system include the ability for failure detection, fault isolation, remote switching of redundant elements, confirmation of restored service, circuit data quality measures, and interface with the Defense Communications System (DCS) monitor systems. Final output of this effort includes technical solutions to the requirements and an implementation and acquisition strategy.

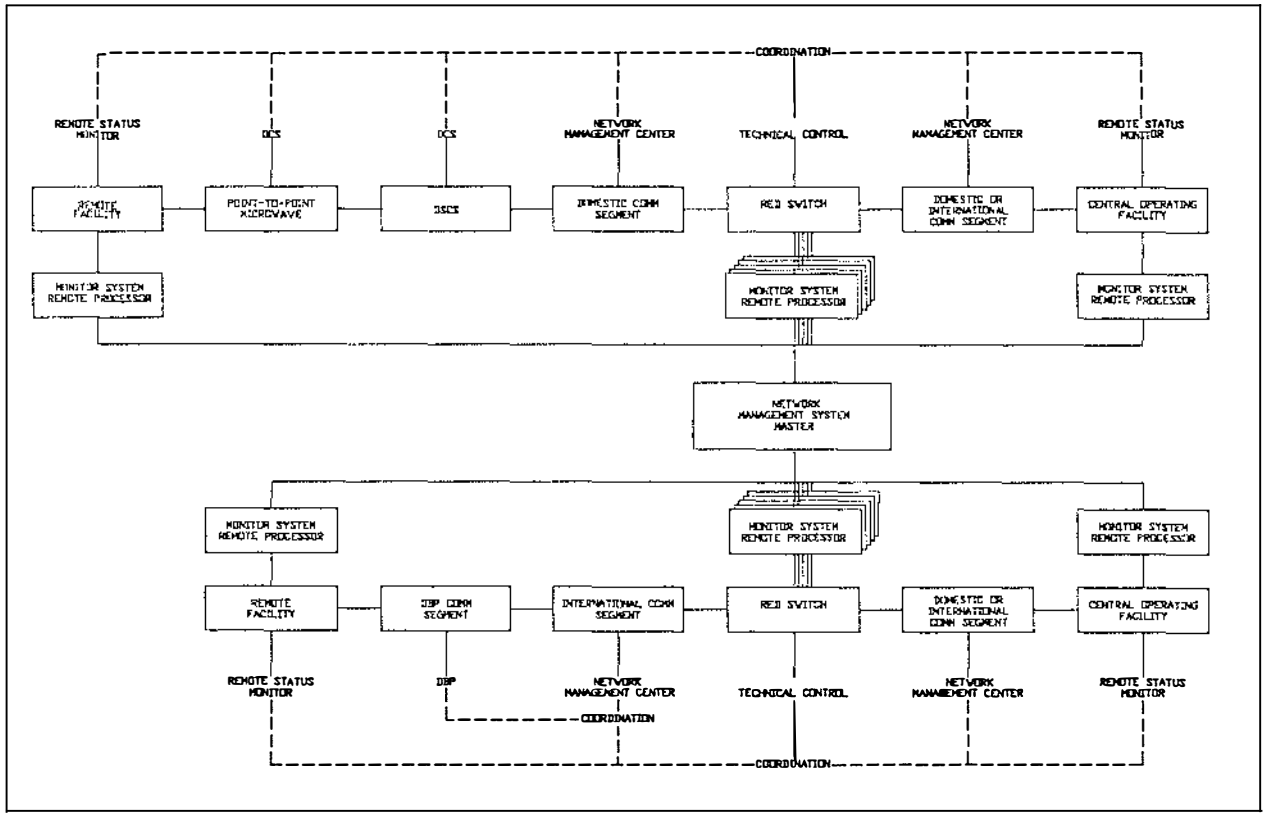
The U.S. Department of Defense is in the process of installing a microwave communications network in Europe. This network, known as the Digital European Backbone (DEB), is now partially operational. The Institute has played a major role in the successful design, development and testing of this network over the last several years. A current example of the Institute's contributions to this critical communications network are the Transmission Monitor and Control (TRAMCON) software development project.

The Institute has developed the software for the TRAMCON system which is used to 1) monitor the status of DEB transmission assets, and 2) provide the means for remotely controlling system configuration and for switching in redundant equipment in the event of failure. The TRAMCON system will eventually consist of 20 minicomputers that monitor transmission equipment at over 250 communication sites in Europe.

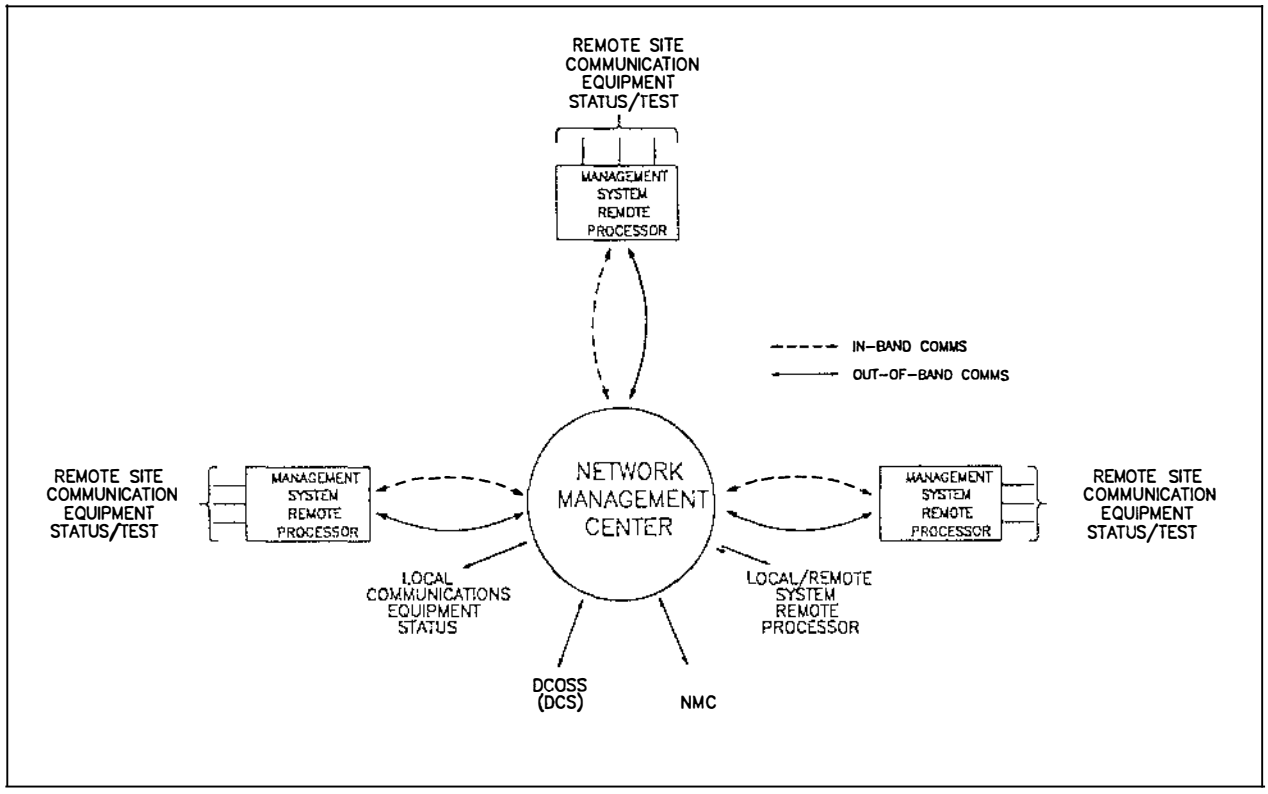
During FY 89, the Institute completed new versions of both the TRAMCON on-line software and network configuration data base software. The TRAMCON on-line software is a real time system for remotely monitoring the status of transmission facilities throughout the DEB. The off-line TRAMCON network configuration software is a large program that organizes a complex set of physical, geographical, and electrical data items that describe the actual implementation and connectivity of transmission components. The software revisions implemented during FY 89 incorporated new user requirements and substantially improved the ability of European DCS technical controllers to monitor DEB network status.

The TRAMCON system has reduced the number of Air Force and Army personnel required to operate and maintain the Digital European Backbone. This has resulted in significant cost savings to the Government.

As an extension to the TRAMCON effort, the Institute is supporting the fielding of the TRAMCON system. Field support is being made available on location in Europe for TRAMCON installation, testing, training, and data base management. Operational support during the initial phases of implementation is an efficient means to obtain user feedback for the critical man-machine interfaces. This information can be used to improve the displays and the type of data to be displayed.




Network Management System Connectivities




Network Management System Architecture

# Network and Link Performance Characterization

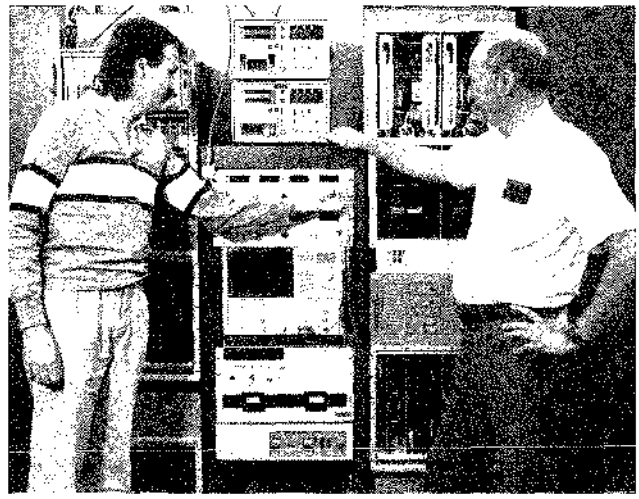
## Outputs

- Digital link and network performance measurement hardware and software
- Radio and propagation data analysis software
- Long-term radio performance and propagation statistics applicable to CCITT, CCIR, and military standards

During FY 89, the Institute completed an 18-month line-of-sight (LOS) microwave radio performance and propagation measurement program. The objectives of this program were to 1) verify radio link design methods, models and criteria, 2) compare measured radio performance with both military and CCITT communications performance standards, 3) obtain long-term digital transmission performance statistics for tandem microwave links, 4) obtain propagation data needed for digital radio outage prediction, and 5) investigate alternative space diversity switching algorithms.

The network and link performance characterization measurements were made on the Frankfurt North Segment of the Digital European Backbone (DEB), illustrated on the facing page (above). The DEB is a U.S. owned and operated digital transmission network that stretches from the United Kingdom across Western Europe to the Mediterranean Sea. The network consists of 250 microwave radio sites. The measured data were required to compare measured network performance with that specified in military communication standards.

During the course of this project, the Institute developed a specialized hardware/software performance measurement system and applied it in collecting performance data on end-to-end channels from Berlin to Feldberg and from Linderhofe to Feldberg. Each of these end-to-end channels is comprised of 5 tandem digital radio links. The Institute also collected more detailed performance and propagation data on two individual links: the LOS link from Schwarzenborn to Feldberg and the troposcatter link from Berlin to Bocksberg. More than 6 gigabytes of data were recorded during the measurement period, which ended in September 1989.



Project personnel Tim Riley and Lauren Pratt with DEB equipment

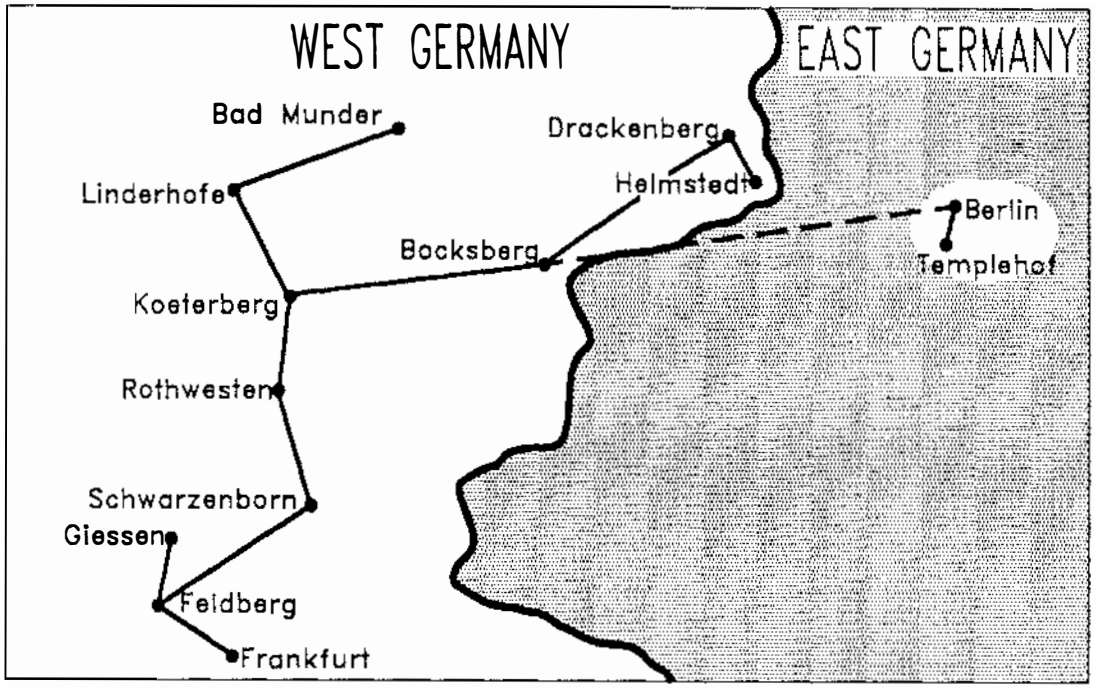
Although designed specifically for DEB application, the real-time data acquisition and off-line data analysis systems used in this measurement project could be easily adapted for use in other propagation and digital radio performance measurements. The photo above shows typical digital transmission equipment tested during this program.

The graph on the facing page (below) is an example of the 123 charts produced monthly during the 18-month program. The graph illustrates a least squares regression relationship between two commonly-used digital transmission performance parameters: bit error ratio (BER) and the fraction of errored seconds. The BER data are widely dispersed about the regression line, indicating that the degree of error clustering is highly variable among samples. This demonstrates the complexity of the error-generating processes and suggests that at least two parameters would be required to represent them in a mathematical model.

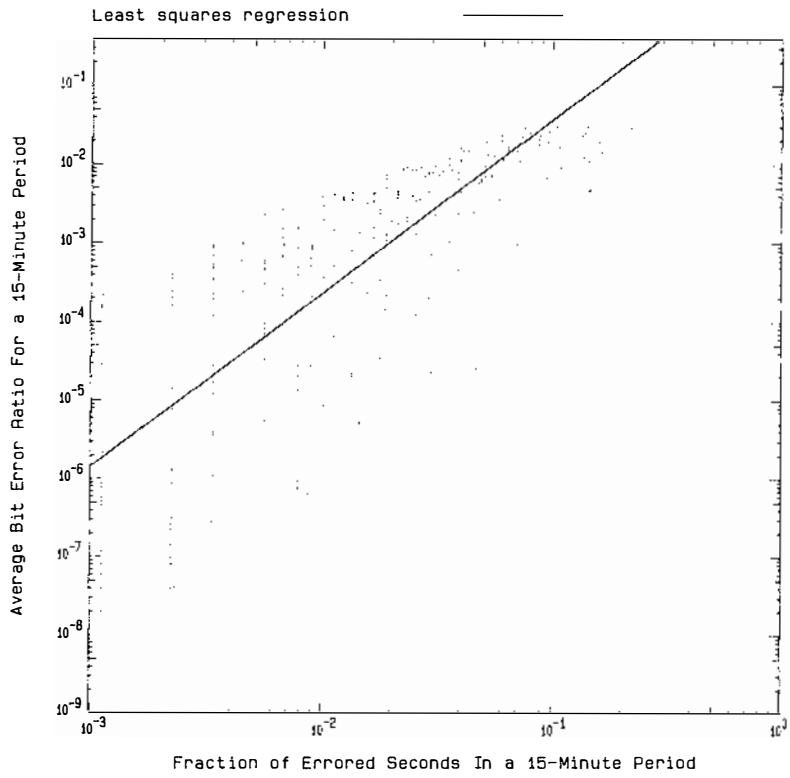
Recent ITS Publications

Digital European Backbone Performance: A 12-Month Summary for the Frankfurt North Segment (by Hoffmeyer and Riley)

Summary of Propagation Conditions and Digital Radio Performance Across the English Channel (by Hubbard and Riley)




**Frankfurt North Segment of DEB**



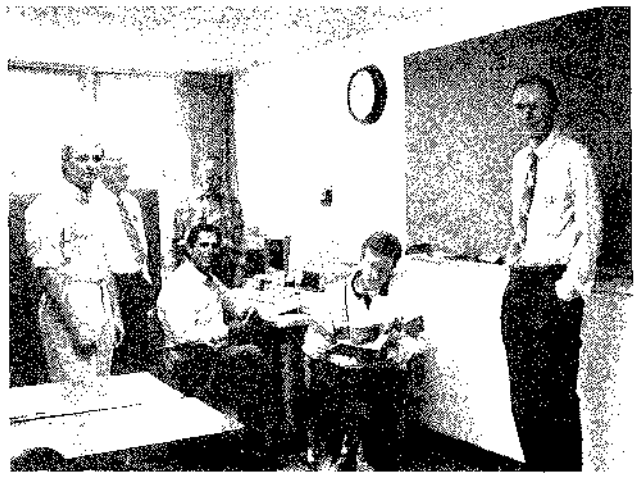

**Example of Data Collected on the DEB Network/Link Performance Characterization Project**

# Transmission System Modeling

## Outputs

- Enhanced microwave common carrier antenna pattern
- Model for the symbol error rate performance
- Set of Digital Line-of-Site (DLOS) programs

Atmospheric and terrain propagation effects at microwave frequencies affect the various terrestrial systems developed, or being developed, in that region of the spectrum. Continued model development and computer implementation of these models has become more sophisticated as the systems themselves are required to operate in varying environments, with ever increasing sensitivity to those environments. This effort involves several microwave propagation models and data bases to meet these requirements.



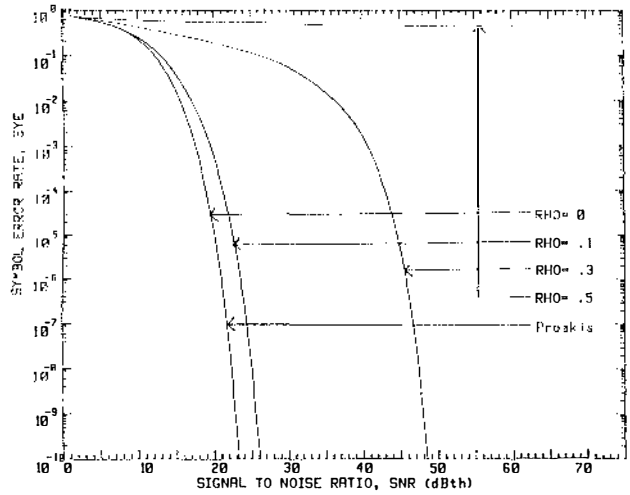
Project personnel (standing from left) Mike Province, Ray Thompson, Duane Hyovalti, Evan Dutton and (seated from left) Charles Samora, Don Dalton

Wide Area Propagation Model. One of the major efforts that has been undertaken is an update of a common carrier azimuthal antenna gain pattern data base. This file has not been updated since 1981. Since that time, the number of antenna types that are currently in use at 2, 4, 6, and 11 GHz has almost doubled. This has necessitated a relatively large effort to establish the most contemporaneous list possible, which has involved extensive contact with antenna manufacturers and the Federal Communications Commission (FCC). Not only was it necessary to obtain the new information, it was necessary to digitize all (old and new) information so that individual antenna characteristics could be readily accessed. When the 1981 data were collected, the antennas were lumped into groups with "similar" gain characteristics. With this lumping process came a compromising of the individual antenna characteristics, acerbated by the fact that the group antenna pattern was approximated with only a 10-point segmentation. The new approach provides a 30-point approximation to the antenna gain pattern. It also approximates in this manner each individual antenna pattern so that the earlier grouping of antenna patterns is avoided. This greatly simplifies the process of obtaining individual antenna information, and avoids the need to convert from antenna nomenclature to the old group designations.

Another major effort was examination in depth of the error rates of several digital modulation techniques. The FCC has strict bandwidth allocations in the nominal 2, 4, 6, and 11 GHz bands. This has required that sophisticated modulation schemes be employed to have the effect of minimizing the bandwidth requirements.

The sophisticated schemes are designed to achieve maximum bandwidth efficiency. For example, 16-QAM achieves 4 bits/Hz, 64-QAM achieves 6 bits/Hz, and 256-QAM achieves 8 bits/Hz. When quadrature partial response is used, 9-QPR achieves 2 bits/Hz and 49-QPR achieves 4 bits/Hz. All of these schemes required investigation to determine the impact of terrain multipath thereon. Generally the higher the bandwidth efficiency, the more devastating the effect of terrain multipath. The figure on the next page shows a 16-QAM example of the modeled effects on terrain multipath, in comparison with the interference-free, Gaussian-noise only error probability theory in "Digital Communications," by John A. Proukis (McGraw-Hill Book Co., New York, NY, 1983, pg. 187).

Some relatively new models of diffraction have appeared in the literature. Thus, it was necessary to evaluate these new approaches for the Wide Area Propagation Model. This resulted in reviewing five models: Epstein-Peterson (EP), Giovaneli (GV), Degout (DG), Bullington (BL), and the model currently included in the Wide Area Propagation Model--the modified Epstein-Peterson model (EMP). After a review




Modeled probability of error, as a function of relative received power, SNR, 16-QAM modulation in the presence of various values of terrain reflection coefficient, RHO

and evaluation, it was decided to retain the EMP model for the microwave diffraction function to be incorporated into the Wide Area Propagation Model. This EMP model provides a conservative estimate of the microwave signal power that could be received and can be readily incorporated into the Wide Area Propagation Model.

Wide Area Prediction. Extensive analysis is required of the radiosonde data for the various regions within the United States. From the pressure, temperature, and humidity readings of the radiosonde, one can determine the refractive index, and its surface gradient (i.e., the rate of decrease of the Earth's surface refractive index, say, 100 m above the Earth's surface). This is necessary to upgrade existing information and expand the coverage to include more of the United States. The information needed is contained in the 5-years of radiosonde observations from specially selected sites. The data were collected twice daily. It requires very extensive data analysis to establish a cumulative distribution of the resultant index of refraction's vertical gradient for each selected site. This information from each site provides the criteria for establishing "zones" of climatologically similar gradient characteristics. Each zone then is represented by the same refractive gradient distribution. When significant variations can be determined, there is a basis for establishing new zones. The gradient information is used to predict the effects of the lower atmosphere on microwave terrestrial link propagation.

Radio Link Integrated Performance Prediction. ITS has completed the development of a set of digital line-of-site (DLOS) programs that run on a desk-top personal computer and automate the calculations involved in design of line-of-sight microwave radio relay paths. This program set automates one of the most tedious and personnel intensive aspects of radio link design, namely, that of drawing the profile and assembling the system particular information about a given type of radio equipment. These programs were developed for the U.S. Army Information Systems Engineering Command at Ft. Huachuca, AZ.

DLOS provides a series of link design modules for running in sequence to provide a complete link prediction or running singly to investigate some aspects of expected link performance. The computer hardware and software configurations are designed to be convenient to operate and to give the design engineer immediate access to calculated results corresponding to changes in design parameters. It provides graphic output of the path profile module and text output of the user inputs and calculation results for the other modules. It incorporates a friendly user interface that advises the operator about the correct range of values for the required inputs to the programs and lets the user know when sufficient information has been entered and the calculations can be performed.

ITS is currently developing the Radio Analysis and Integrated Design for Engineering Requirements (RAIDER) program set, which will run on the HP9826 personal computer with a UNIX operating system. These programs also emphasize a friendly user interface and incorporate a menu system to assist the operator in entering, editing, and processing link design data. The programs will guide the operator to run them in the proper sequence while allowing the flexibility of running them in a different order for special cases.

The RAIDER program set is being developed for three major types of paths: line-of-site, marginal line-of-site, and beyond-the-horizon. Because of updating of standards, conversion from analog to digital systems, and other evolving communication requirements of the U.S. Army, it is essential that the DLOS programs be enhanced and new programs added to address special cases for problem paths, especially long, marginal-clearance line-of-site paths experiencing frequent and severe atmospheric fading. Two sets of programs are being developed, one for typical paths and one for problem paths.

The program set for typical paths is similar to DLOS but is enhanced to take advantage of speed, memory capacity, and multiuser systems. Additional algorithms are being added for the problem paths to help identify problem links in the design states.

# TELECOMMUNICATION SYSTEMS PLANNING

The Institute serves as a central Federal resource to assist other Federal agencies in planning new telecommunication systems to meet emerging needs. Specific ITS activities include user requirements analysis, technology assessment, network architecture development, and detailed system and equipment design. The Institute's efforts are directed toward effectively relating the needs of end users to the capabilities of a planned network, taking into consideration a variety of environments and conditions.

## Areas of Emphasis

### Satellite Studies

Includes projects funded by the National Communications System and the National Telecommunications and Information Administration

### Planning for Special Communication Environments

Includes projects funded by the Army Signal Center, the National Communications System, and the National Institute of Standards and Technology

### Advanced Systems Planning

Includes projects funded by the Defense Communications Agency, the National Telecommunications and Information Administration, and the U.S. Department of Agriculture/Forest Service

# Satellite Studies

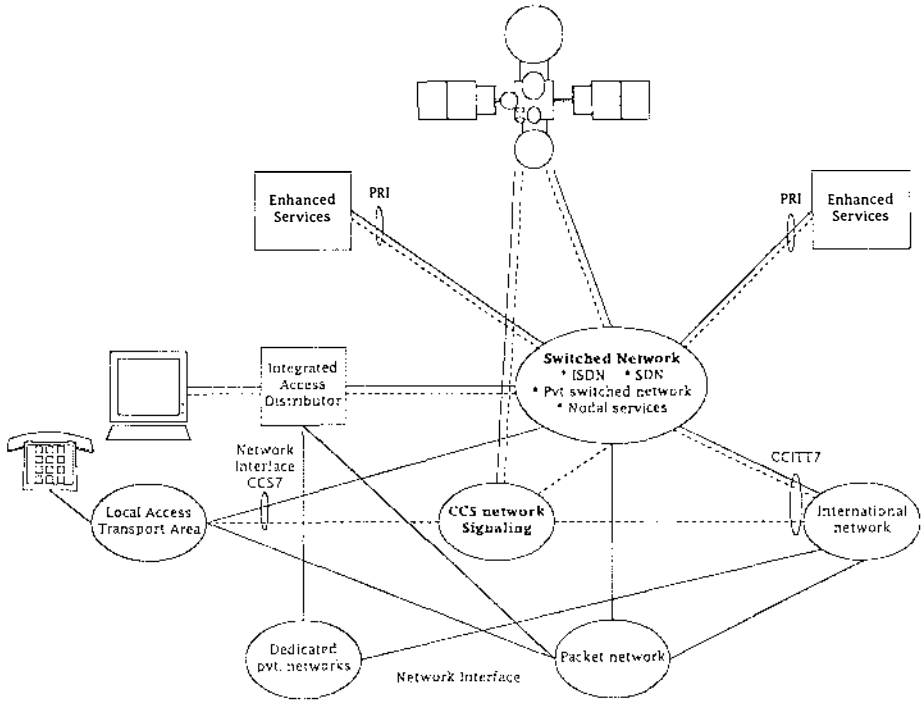
## Outputs

- Advanced satellite communication technology studies
- Technical guidance on the PEACESAT network

Advanced Satellite Communication Technology Studies. The evolution of communication satellites is being driven by the need for increased service capacity and reliability, lower service costs, and integration with advancing communication system technologies such as optical fiber transmission and Integrated Services Digital Networks (ISDN). A new generation of advanced, "smart," communication satellite systems will respond to these requirements through the application of on-board switching and digital signal processing techniques. These advanced satellites will also incorporate sophisticated antenna systems to facilitate the instantaneous establishment of high-volume circuits on demand and "hub-less" very small aperture terminal (VSAT) operation. These features will help alleviate orbit and spectrum congestion and, through the use of 30/20 GHz (Ka-band) frequencies, will provide greater channel capacities.

Project personnel (from left) Ray Jennings and Rob Cass

There is a need for a broad range of empirical and analytical studies to characterize the performance




Proposed Interoperable Broadband Satellite and Terrestrial Network

of this new class of communication satellites. The National Aeronautics and Space Administration (NASA) is developing and will launch in 1992 an experimental satellite, the Advanced Communications Technology Satellite (ACTS), as a test bed for these and other advanced satellite studies. Government agencies, universities, and commercial organizations are being invited and encouraged to plan and conduct experiments using ACTS.

The Institute is designing a unique set of end-to-end system performance experiments using the framework of American National Standard (ANS), X3.141-1987, "Measurement Methods for User-oriented Performance Evaluation." Included in these performance measurements is an experiment to characterize the system transfer function using techniques similar to the NTIA-developed impulse response measurement methods.

Satellites and ISDN. Integrated Services Digital Network (ISDN) technology will play an important role in future telecommunication networks. The Institute has expanded its satellite program to examine how ISDNs might interoperate with advanced satellite communications networks. This project will develop and promulgate network interface, management, and performance specifications for advanced satellite/ISDN interoperation. A proposed, interoperable, broadband network is illustrated in the figure on the preceding page.

ITS personnel have completed an initial assessment of the current stand-alone terrestrial and satellite broadband networks. A continuation of this study will focus on the nationwide interoperation of broadband networks including ISDNs.

ITS personnel have also continued active participation in the CCIR (as noted in the section concerning CCIR activities). ITS has most recently contributed to questions of earth-station antenna reference and design-objective patterns. The Institute's satellite/ISDN studies will enable it to play a more active role in CCIR studies concerned with the integration of advanced satellite systems and terrestrial (digital) transmission networks.

Reduced Vulnerability to Telecommunication Outages. The Nation's vulnerability to telecommunication outages has increased greatly as a consequence of the development of new applications of telecommunications and an increasing dependence of business and Government activities on them. Telecommunication systems have become indispensable to national defense, and to many other Government functions. For example, the Departments of the Treasury and Health and Human Services are among the world's largest telecommunications users.

ITS has begun technical studies of the use of advanced satellite system technology to enhance rapid restoration of services provided by the public switched network following a natural or "man-made" disaster. These studies include a survey and assessment of existing network restoration techniques and the development of network architectures that incorporate advanced satellite networks to enhance the continuity of public network services. This work will contribute to the development of network control and interface standards to facilitate the integration of advanced satellite networks with broadband terrestrial networks.

PEACESAT. ITS is continuing to provide consultative support to the Pan-Pacific Education and Communication Experiment by Satellite (PEACESAT) program, a University of Hawaii effort largely funded by a Public Telecommunication Facilities Program grant. The original PEACESAT Network was established in the early 1970s as an educational, cultural, and emergency medical communication satellite network using NASA's Application Technology Satellite 1 (ATS-1). In 1985 ATS-1 ran out of station-keeping fuel and started to drift, resulting in the abandonment of the network. In 1988 Congress funded a grant to re-establish the network.

The Geostationary Operational Environmental Satellite-3, operating in the 2 GHz band, has been identified as a potential interim replacement satellite. This necessitates new earth terminal equipment since the original PEACESAT Network operated in the VHF band. Investigation of a suitable permanent replacement satellite is also continuing, with the most likely candidates operating in the 2.5 to 2.7 GHz Fixed-Satellite Service band.

The ITS consultative role in the PEACESAT program includes providing continued technical guidance for the identification and evaluation of suitable long term replacement satellite candidates and associated earth terminal equipment.

Recent ITS Publications

Earth Station Antenna Reference or Design Objective Radiation Pattern (Frequency Range From 2 to about 30 GHz) (by Jennings)

# Planning for Special Communication Environments

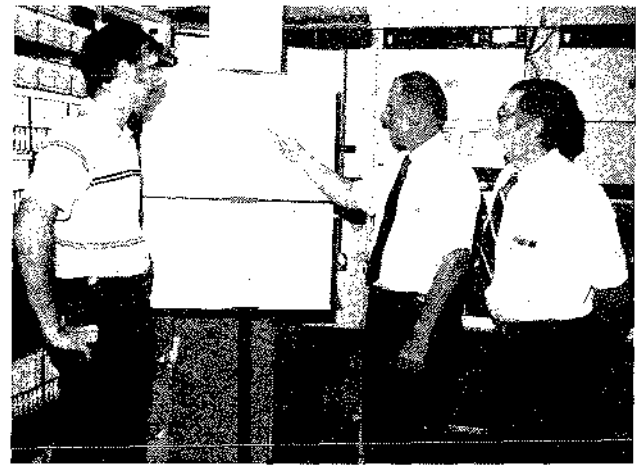
## Outputs

- Adaptive antenna design technology
- Industry/government workshops on fiber optic system survivability
- Trunked radio system analysis

Automated Steerable Nulling Antenna Processor (SNAP) Model. The Institute recently completed a project that developed a model for assessing the spectrum conservation potential of a steerable nulling antenna processor (SNAP). Spectrum congestion and performance inadequacies present serious technical and operational support compromises for tactical and theater communication, command, control, and intelligence functions and systems. The spectrum conservation potential for multilevel SNAP implementation was evaluated for a segment of an Army tactical communication network supporting a moderate and high stress dynamic operation environment.

An adaptive-antenna mathematical model was developed to simulate the SNAP. The mathematical model was then implemented in FORTRAN computer code. The model can be used to demonstrate the application of antennas with the SNAP for obtaining increased spectrum utilization or improved performance in an interference or jamming environment. Multiple point-to-point communication links with conventional antenna systems must operate on separate radio frequencies to avoid interfering with each other. Each of the links containing an antenna with a SNAP will be permitted to operate on the same radio frequency by virtue of the multiple nulls formed by the SNAP in the directions of interference.

A SNAP antenna system consists of an array of radiating elements and a real-time adaptive receiver processor. When given a beam-steering command, the system will simultaneously sample the current environment for interference and jamming. The system then proceeds to adjust the element control weights in phase and amplitude to attain one form of optimum condition such as maximum signal-to-(interference-plus-noise) ratio using a particular adaptive algorithm. The optimum weighting condition produced via this algorithm usually forms some degree of nulling in the directions of interference. This is termed adaptive interference nulling. The complete operation of the adaptive-antenna array is equivalent to a spatial filter. A SNAP antenna radiation pattern response to a single interference source appears in the figure at right. The SNAP requires a finite time to respond to the interference source. After 1050 adaptation cycles the desired signal amplitude is maximized and the interference signal amplitude is minimized.

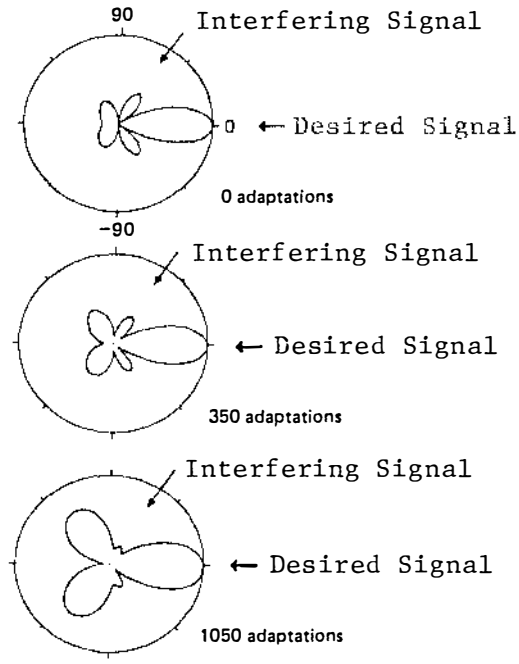


Project personnel (from left) Tom Jones, Dave Peach, and Bob Adair

The adaptive weight adjustment is determined by sensing the correlation between the total composite antenna element signals that contain the actual signal, noise, and interference environment. The SNAP implementation of the adaptive array is capable of forming N-1 nulls where N is the number of array elements of the antenna. It is possible to null more than N-1 interferers when either multiple interferers are located at the same angular direction or the interferers possess symmetries in angle.

The U.S. Army Signal Center at Fort Gordon, Georgia provided the funding for the development of the SNAP adaptive antenna model and the computer program. There are also many non-military applications for adaptive antenna systems.

NS/EP Fiber Optic Research. The installed base of fiber optic cable has continued to increase




**SNAP Antenna Radiation Pattern Response to One Interference Source**

dramatically. Most fiber optic telecommunication backbones in and around larger metropolitan areas are complete, and the installation of fiber-to-the-home facilities has progressed faster than expected. Fiber-to-the-home projects are currently in progress in nearly all of the Regional Bell Operating Companies. These developments offer users the promise of vastly increased transmission capability and an array of new services including ultra-high speed data transfer, video teleconferencing, video telephony, and high-quality audio and video distribution. At the same time, the consolidation of the nation's transmission plant in fewer and fewer high-capacity fiber optic cables is substantially increasing our society's vulnerability to telecommunications outages. The Institute's national security/emergency preparedness (NS/EP) fiber optic research is intended to provide practical means of mitigating this growing vulnerability.

During FY 89, the Institute developed and presented several workshops to acquaint telecommunication planners and design engineers with the need for survivable fiber optic facilities to carry national security/emergency preparedness (NS/EP) traffic. The message conveyed at these workshops was that if certain specific enhancements were used in designing and installing fiber optic links, the resulting systems would be less costly to maintain and at the same time, would be more durable, to yield a more survivable telecommunications network. The feedback from participating fiber optic system providers was that such enhancements would be feasible if a Federal Standard were written to mandate that all providers should implement them. The participants felt that a standard was necessary to ensure that the providers that implement survivability enhancements would not be economically disadvantaged in competing for Government business.

Performance and Application of Trunked Land Mobile Radio. During FY 89, ITS provided assistance to the National Institute of Standards and Technology's Law Enforcement Standards Laboratory (LESL) in a project entitled Performance and Applications of Trunked Land Mobile Systems. In this project, ITS investigated the relative advantages and disadvantages of trunked radio systems compared to conventional (nontrunked) radio systems. Two reports to the sponsor detailed the results of the ITS analysis. The first report described trunked radio systems architecture and models and provided information particularly relevant to public safety entities considering the purchase of a trunked radio system. The second report enumerated important trunked radio system parameters and how these parameters should be measured.

Recent ITS Publications

Multitier Specification Applied to Modify the Hardness of an Essential NS/EP Fiber Optic Link (by Peach and Adair)

NS/EP Enhancement of Fiber Optic Long-Haul Links (by Peach and Hull)

Automated Steerable Nulling Antenna Processor (SNAP) Model (by DeMinco)

# Advanced Systems Planning

## Outputs

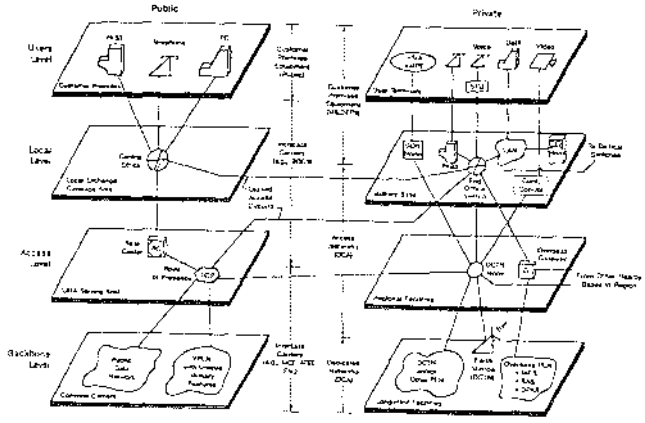
- Advanced system concepts and specifications
- Telecommunications policy development support

The Institute contributes to the planning of advanced telecommunications and information systems in two ways: first, by providing system requirements analysis and planning services to other Federal agencies, and second, by providing technical support to other NTIA offices involved in developing telecommunications and information policies. Examples of specific FY 89 activities follow.

Access Node Architectures for the DSN. Military communications have traditionally been provided by service-dedicated private networks, including AUTOVON, AUTODIN, AUTOSEVOCOM, and a large number of very special networks designed for small user groups with distinctive applications. The private-network approach can be effective in meeting particular user needs, but sacrifices survivability benefits and economies of scale that can be realized in public common-user networks. The trade-off between service-dedicated private and public common-user networks has become much more complex with the advent of ISDN, Open Network Architecture, and the proliferation of Local Area Networks and other customer premises equipment options. During FY 89, the Institute completed a 3-year study in which these and other long-range military communications planning issues were addressed. This study was conducted for the Communications Division in the Center for Command and Control and Communications Systems ($C^4S$) of the Defense Communications Agency (DCA). The $C^4S$ is responsible for developing a western hemisphere (WESTHEM) architecture relative to its strategic and National Communications System (NCS) roles and capabilities. The final report, submitted in September 1989, summarized efforts directed toward defining nodal architectures for the Defense Switched Network (DSN) access areas in the WESTHEM. The focus is on the post-1995 era, into the early 21st century.

As considered in this study, the concept of an access node extends beyond a single node to include collections of network elements (physical and functional) and protocols that together allow remote end users to communicate and to access distributed telecommunication services. An access node architecture, in general, may consist of network elements within both a military base and a long haul network. Therefore, the access node architecture stands only in relation to specific local and long haul telecommunication architectures. Because of this, the ITS access node architecture study required making assumptions about future "bounding" architectures, (i.e., "local" and "long haul" architectures) and establishing representative designs for these architectures.

A multi-level structural approach was developed to show the physical and functional architectural characteristics. This included the users, local access, and backbone levels in both public and private domains. A multi-level structured diagram of one DSN configuration is illustrated here. This diagram also indicates principal areas of responsibility for the public and private network domains.




**Multilevel Structured Diagram of an Example DSN Configuration**

Forest Service Telecommunications Planning. Sponsored by the Wallowa-Whitman National Forest, this project began in FY 88. The Institute performed a requirements assessment and a study culminating with the development and evaluation of telecommunication network alternatives. The requirements assessment included an identification of primary and peripheral needs articulated by Forest telecommunication users and managers, a review of existing public and private voice and data

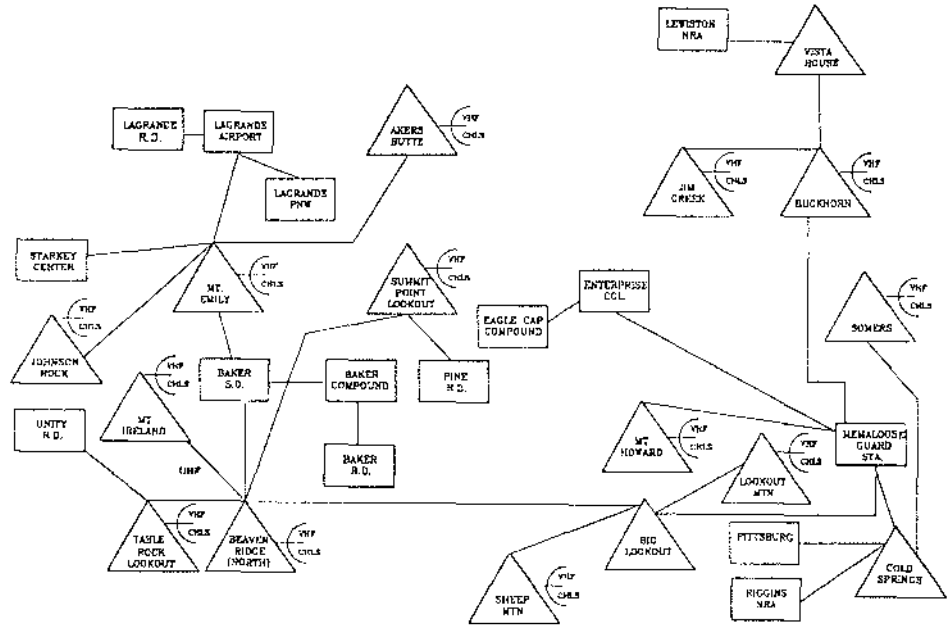
systems serving the Forest including mobile radio components, consideration of technical and non-technical constraints to the design process imposed by the Forest, Region, Forest Service, and Department of Agriculture, and the establishment of the degrees of service integration which would be appropriate for study. In a follow-on system design study, the Institute used the requirements assessment in deriving 9 viable architectural alternatives for satisfying the requirements. Voice telephone systems and data communication systems were joined with radio systems to form "full-service" telecommunication networks. Technical ramifications (functional capability, ease of operation, etc.) were defined for each alternative. Detailed cost estimates were provided for the 9 different designs, including initial investment (procurement) costs and continuing costs over the life cycle (operation and maintenance). One alternative was chosen as the focus for the Forest's Telecommunications Plan.

In FY 89, the long-range telecommunications plan for the Forest was completed. A comprehensive report was provided to Wallowa-Whitman, documenting the proposed system design and operation and a recommended schedule for implementation of major network element upgrades. The report identified specific system components and priced the network down to the component level.

The network design recommended to the Forest is depicted in the figure below. Voice and data traffic for Forest personnel will be served by a very flexible and highly expandable multichannel microwave backbone network tied to low-density UHF and (low-band) VHF tail circuits. Besides access via the fixed facilities, personnel with portable and mobile equipment can access the network, and "talk around" locally, via mountain-top radios.

Microwave radio links require line-of-sight paths between the two termination points. In order to assess whether specific microwave paths were practical for a Forest configuration, about 150 path profiles were constructed between mountain tops, between mountain tops and Forest facilities, and between Forest facilities using computer simulation programs and (3 second) U.S. Geological Survey topographical data. The effects of various atmospheric conditions and terrain irregularities on radio propagation were considered in path profiles and link budget calculations for the links in the final architecture.

NTIA Policy Support. The Institute's policy support activity has two objectives: (1) to identify telecommunications and information technology trends (and specific technology advances) whose manifestation in products and services is likely to require changes in regulation or other government policies, and (2) to provide specific technical contributions to NTIA policy development in such areas as domestic competition, international trade, and radio spectrum management. During FY 89, the Institute assisted NTIA in evaluating the policy implications of emerging technologies including Integrated Services Digital Networks (ISDNs), fiber optics, mobile communication systems, and advanced high-resolution television.




Recommended VHF/UHF/Microwave Radio Topology

# APPLIED RESEARCH

The use of the electromagnetic spectrum, in telecommunications, has grown dramatically in the last four decades. This growth stems from population increases, 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, ITS continues an historic program to better understand and use higher frequencies.

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. A prime purpose of the Institute's applied research effort is to study conditions in the transmission medium and provide models and prediction methods for cost-effective and spectrum-efficient radio system design. This research includes both terrestrial systems as well as satellite-based systems.

The Institute has a long history of radio-wave research and propagation prediction development that provides a substantial knowledge base from which state-of-the-art methods for developing, testing, and utilizing telecommunication systems is made possible. Transferring this technology to the user community, both public and private, to enhance spectrum use is the Institute's ultimate aim.

## Areas of Emphasis

### Millimeter-Wave Propagation Modeling

Includes projects funded by the Department of Defense, the Naval Ocean Systems Center, and the U.S. Air Force

### Propagation Measurements

Includes projects funded by the Army Communications-Electronics Command, the Army Missile Command, the Department of Defense, the National Institute of Standards and Technology, and the National Telecommunications and Information Administration

### Radio Environment Simulation

Includes projects funded by the Army Information Systems Engineering Command, the Defense Communications Agency, the Joint Tactical Command, Control, Communications Agency, and the Rome Air Development Center

# Millimeter-Wave Propagation Modeling

## Outputs

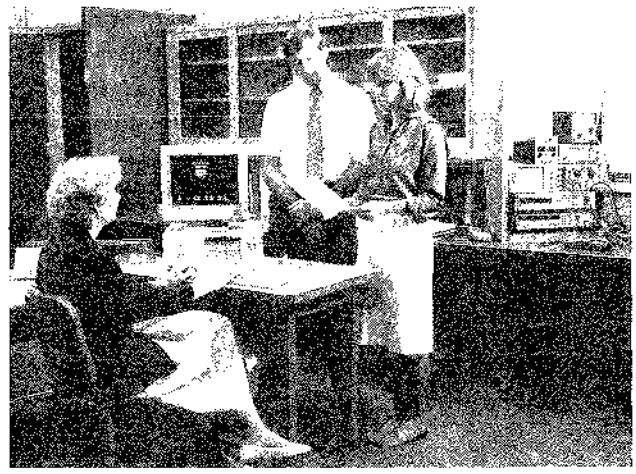
- Updated AMOS, MPM, and MZM models
- Additional scenarios added to AMOS model
- Improved meteorological data base added to AMOS

The millimeter-wave program at ITS continues to be a comprehensive program for telecommunication research and applications. This program consists of laboratory measurements, field measurements, and model development. The ITS field and laboratory measurement programs are discussed in the following section entitled "Propagation Measurements." The results of ITS research in both the field measurement program and laboratory studies are used to develop, enhance, and verify computer-based, user-friendly programs that serve as development and analysis tools for Government and private industry.

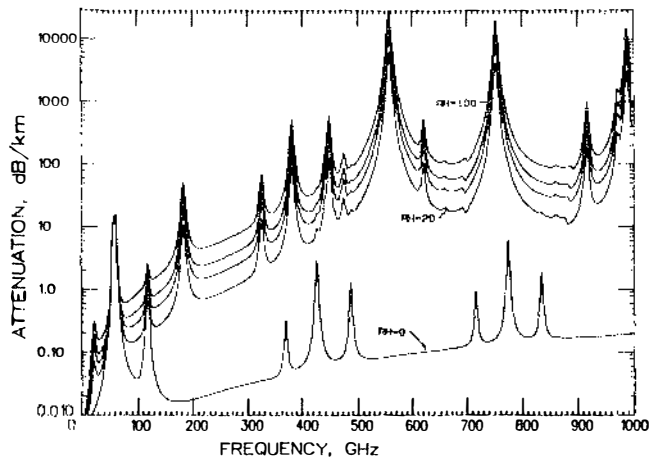
The ITS millimeter-wave propagation modeling effort has resulted in four software packages that combine state-of-the-art propagation models with user-friendly, high-level languages to provide users with effective means for developing and analyzing millimeter-wave telecommunication systems. These computer programs are ETSEM, MPM, MZM, and AMOS. Each is briefly discussed below.

ETSEM (EHF Telecommunication System Engineering Model) was developed in previous years to predict the performance of terrestrial links. It is an aid to engineers in the determination of cost-effective design trade offs while maintaining required link availability. Prediction of performance accounting for attenuation due to rain, clear air, and multipath effects are provided for any interval of months for the year. ETSEM has been expanded to include earth-satellite and aircraft-satellite links. The major drawback of the ETSEM model has been that it requires the user to know a great deal about the system equipment and geographic information for every case. The AMOS model described below significantly improves the user interface by modularizing much of this information.

MPM (Millimeter-wave Prediction Model) predicts, at frequencies up to 1000 GHz, loss and delay effects for a nonprecipitating, isotropic atmosphere. Contributions from dry air and water vapor are included as well as suspended water droplets that simulate fog or cloud conditions. For clear air, a local absorption line base is employed (44 oxygen and 30 water vapor lines) complemented by an empirical water vapor continuum. Suspended water droplet obscuration is treated with the approximate Rayleigh scattering theory. Input variables are barometric pressure, temperature, relative humidity, and droplet concentration.



Project personnel (from left) Nancy Kuester, Rob DeBolt, and Janet Geikas




An example for sea level conditions with a varying relative humidity from 0 to 100 percent is illustrated above. Across the spectrum one notices

more or less transparent window ranges separated by molecular resonance peaks.

The MZM model has been developed as an aid in understanding propagation effects in the mesosphere. The mesosphere lies between the stratosphere and the thermosphere from above 30 km to about 100 km in altitude. In this region, the air is dry so that the parameters of interest are pressure (from 1.2 to 3x10-5 kPa) and temperature (from -2 to -87°C). In this region, oxygen line absorption is strong enough to affect radio propagation. Because the pressure is low, the lines are very sharp, and new phenomena appear due to the Zeeman effect. The Earth's geomagnetic field splits each line into a number of sublines that react to an electromagnetic field in a way dependent on the polarization state of that field. Over a few megahertz around the line centers, the medium is anisotropic, making radio waves subject to polarization discrimination and Faraday rotation. The reasons for this behavior and applications are discussed in the reference cited below.

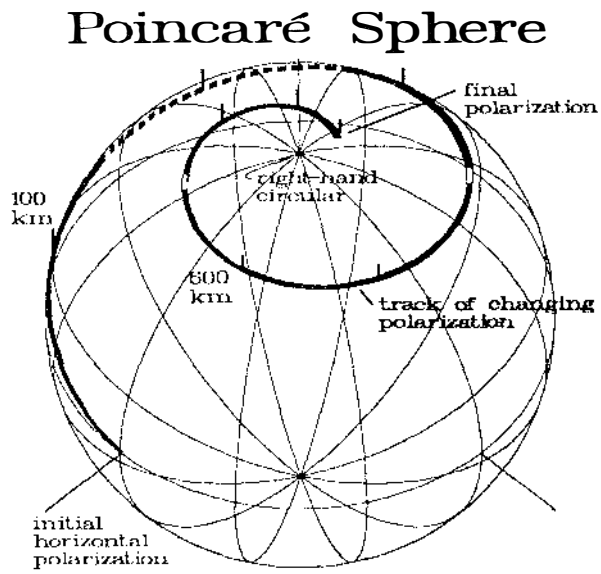
The MZM program models an anisotropic refractive index in three dimensions as a function of frequency about each oxygen line. For a given propagation direction with respect to the geomagnetic field, a transmission matrix is derived the eigenvectors of which define the characteristic waves' polarizations. The eigenvalues of this matrix define the phase delay and attenuation rate for each characteristic wave.

As a wave propagates through the mesosphere, its polarization approaches that of the characteristic wave with the lower attenuation rate. The polarizations of the characteristic waves are linear when the propagation direction is perpendicular to the magnetic field lines and circular when parallel to the lines.

The illustration to the right shows the change in polarization of a 59.592 GHz wave propagating for a distance of 1000 km at an altitude of 80 km and an angle of 27.5 degrees with respect to a magnetic field of 31 $\mu$T. The wave is initially horizontally polarized but approaches right-hand circular polarization.

ITS has continued to develop a new software model for the Analysis of Millimeter wave Operational Scenarios (AMOS). This model is highly structured and modular in design, which allows for greater flexibility and expansion.

The major components of AMOS are a user created catalog of equipment, ground stations, aircraft and satellite platforms, and the software for creating and maintaining this catalog; a climatological data base for the world; a library of propagation




subroutines; and the analysis software. Current scenario types that can be analyzed are ground-to-ground, ground-to-satellite, ground-to-aircraft, aircraft-to-satellite and a generic MODEL EXERCISER option that allows the user to run programs that are not part of AMOS such as ETSEM, MPM, MZM, from the AMOS environment.

Typically, users would run AMOS by choosing a scenario type, selecting an existing scenario or creating a new scenario. For example, for a ground-to-aircraft scenario type, the user would specify the ground and aircraft station names and the flight path of the aircraft. The ground and aircraft stations already contain all the information about the equipment at that site such as transmitter specifications, and antenna information.

After defining the scenario, the user chooses from a list of analyses available for each scenario type. For example, the user may wish to calculate the received signal level as a function of an aircraft's flight position. After examining the output results, the user can modify the scenario by entering different equipment names, frequencies, or stations and rerun the scenario, or the user may choose an entirely different scenario.

Recent ITS Publications

Mesospheric Radio-Wave Propagation in the 60 GHz Band Affected by Zeeman-split Oxygen Lines (by Liebe, Hufford, and Katz)

# Propagation Measurements

## Outputs

- New millimeter-wave laboratory instrumentation
- Polarimetric measurements at 28.8 GHz on a slant path in Hawaii
- Testing with measured data of methods for adaptively boosting power on satellite links to mitigate fading due to rain
- Report on measurements of millimeter-wave system performance on an AT&T path
- Final report on urban/suburban millimeter-wave propagation measurements
- Report on measurements of millimeter-wave propagation through conifer forests
- Meteor scatter measurements near 100 MHz on a path from Israel to Greece

The Institute has maintained a premier millimeter-wave laboratory measurement program for many years. Measurements of clear-air absorption and phase delay have been made using a Fabry-Perot cavity within an environmentally controlled chamber. Previous measurements have addressed the effects of molecular oxygen and water vapor up to 140 GHz for pressures ranging from 10 to 1000 Mb.

A computer-controlled vector network analyzer has been added to the laboratory system to enable the rapid production of accurate measurements. The system is available to support telecommunication and remote sensing requirements.

Millimeter-wave staff have also been consulting with the National Institute of Standards and Technology to assist in the development of similar measurement systems to study the electromagnetic properties of materials.

In addition to laboratory measurements, ITS has placed a major emphasis on field measurements. They help identify areas where further modeling work is needed and are the ultimate test of the validity of models. In fiscal year 1989, instrumentation was deployed in the field to add new polarization capabilities.

The most common technique for measuring the elements of the transmission matrix is to switch between combinations of polarizations at the transmitter and receiver. However, with such a method the measurements are not simultaneous and

Project personnel Hans Liebe (left) and Rob DeBolt by the Millimeter-Wave Laboratory Measurement System

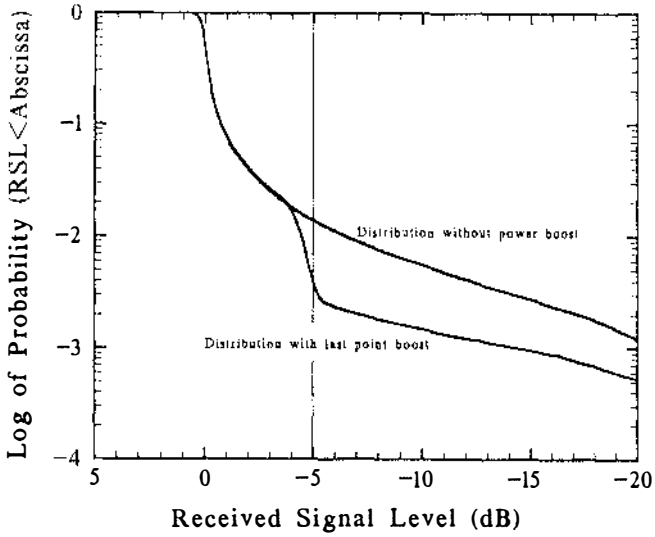
are limited in time resolution by the time required for switching and settling. The technique used in the ITS instrumentation is to transmit one polarization at 28.8 GHz and the other simultaneously at 28.815 GHz. A dual polarization receiver is used in which each received polarization results in two intermediate frequencies (IFs), one for the copolarized wave and one for the cross-polarized wave. All signals are coherently received, and the amplitude of each component is measured. Thus, all the elements of the transmission matrix are measured simultaneously and the time resolution of the measurements is limited only by the IF bandwidth and system noise. The same technique is used simultaneously at 9.6 and 9.605 GHz and at 96.1 and 96.150 GHz.

The use of the 20/30 GHz band for earth-satellite communications is approaching because of spectrum crowding at lower frequencies. In order to measure the effects of the lower atmosphere on satellite signals, the 28.8 GHz polarimetric system was installed on a simulated earth-space path. The slant path from near sea level in Hilo, Hawaii to the top of Mauna Kea at 4.176 km (13,700 ft) in altitude is 45.6 km long with an elevation angle of 5 degrees. This path was selected because rainfall is a major propagation factor, and the 7 m annual rainfall on portions of the path assure an adequate sample. Since most weather occurs at

lower elevations, the slant path attenuation may be representative of the attenuation of a whole earth-space path.

During preparations for the slant path measurements, measurements were completed on a short path at the bottom end of the slant path (Hilo, Hawaii) to characterize the rain in Hawaii (and more generally in a tropical climate). Attenuation (vertical polarization) at 9.6, 28.8, 57.6, and 96.1 GHz on a 1-km path and rain rate were measured from February through September 1988. These data were added to the ITS data base of other short-path measurements made in California, Colorado, and Alabama. Together, these data form the largest data base on the climatic and geographical variability of millimeter-wave attenuation rates in rain.

The short-path 28.8 GHz data were used to test the performance of several methods of adaptively boosting transmitter power on earth-satellite links as has been proposed for the Advanced Communication Technology Satellite being developed by NASA. The data indicate that fading is approximately a first-order Markov process and that the most recent measured value of received signal level should be an adequate predictor of the future received signal level. These data provide adequate information on which to base the decision to boost power. An example of the results is shown in the figure below.




Cumulative Distributions of Received Signal Level for a 30-GHz Satellite Uplink without Power Boosting and with Boosting in 1-dB Steps up to 13 dB Based on the Received Signal Level 1 Second Earlier

In order to study the performance of millimeter-waves under multipath conditions, measurements were made in 1988 on an AT&T operational path (Salton to Brawley) known to suffer almost every day from multipath fading. This gave the opportunity to compare the relative performance of links at 4 and 6 GHz to links at 11.4, 28.8, and 30.3 GHz, where the use of narrower beam antennas might result in improved performance under multipath conditions. A report on the results of these measurements was published this year.

Over a period of several years, ITS made measurements of millimeter-wave propagation in urban and suburban environments. A "ray" model for propagation in urban environments was developed, which agrees well with the measurements. A final report containing all of the results was published this year.

In addition to urban propagation measurements, ITS has measured millimeter-wave propagation through various vegetation over several years. Last year measurements were made in a conifer forest in Washington. A report on these measurements was published this year.

An evaporation duct for millimeter-waves is known to form a few meters above the surface of the ocean. We completed plans to make measurements in fiscal year 1990 to characterize propagation within the duct, including the selection of a 52.8 km path between the islands of Maui and Hawaii. The polarimetric measurement system was modified to use independent local oscillators at the transmitters and receivers, stable to within 1 part in $10^{10}$ per day.

In addition to millimeter-wave measurements, a system to measure meteor scatter at VHF on a link between Israel and Greece was deployed. Measurements are currently being made and will be reported in the future.

## Recent ITS Publications


Millimeter-Wave Propagation Characteristics and Channel Performance for Urban-Suburban Environments (by Violette, Espeland, and Allen)

A Comparison of Millimeter-Wave and Microwave Link Performance in the Presence of Multipath Fading (by Jones, Allen, and DeBolt)

Pattern Recognition Techniques Applied to the NASA-ACTS Order-Wire Problem (by Allen)

Vegetation Loss Measurements at 9.6, 28.8, 57.6, and 96.1 GHz through a Conifer Ochard in Washington State (by Jones, Espeland, and Violette)

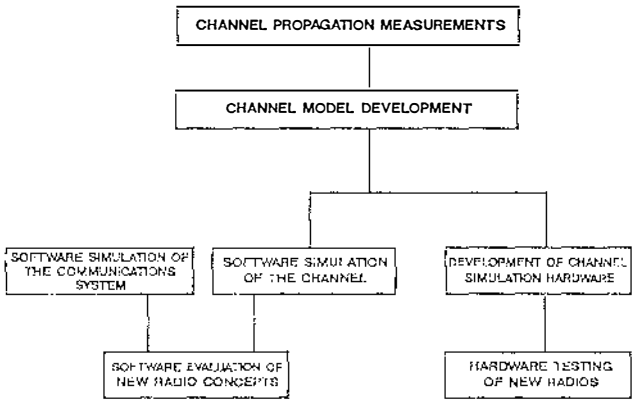
# Radio Environment Simulation

## Outputs

- Line-of-sight channel simulator hardware
- Enhanced HF channel model
- Model of wideband HF noise and interference

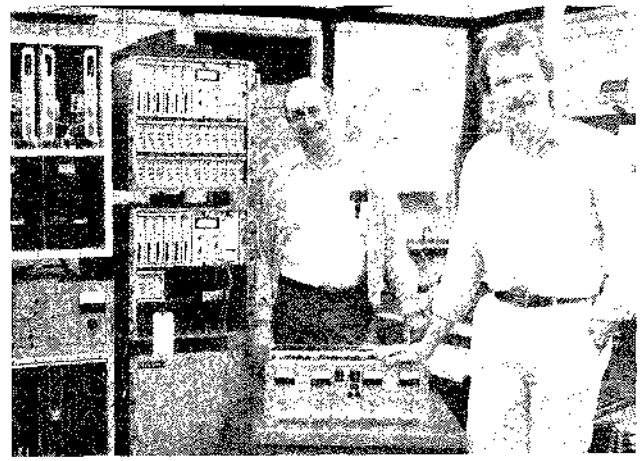
Radio performance evaluation typically consists of both field testing and laboratory testing. Laboratory testing using channel simulators has proven to be a cost-effective means for assessing and comparing the performance of two or more radio systems under controlled conditions. The advantages of channel simulators include repeatability, accuracy, comprehensiveness, and reduced testing cost in comparison with field testing. These general advantages are equally applicable to the performance evaluation of both line-of-sight (LOS) and high frequency (HF) radios.

These channel simulators must be based on accurate models of the propagation channel and the noise and interference in that channel. The relationships between the channel measurements, the development of the model and the use of the model are depicted in the figure below.




Relationships of Channel Measurements, Modeling, and Simulation

In the HF portion of the radio spectrum, the Institute has been working on the development of both a new HF channel model and a wideband HF noise and interference model. The channel model is much more general than existing models. It is not restricted to the modeling of stable propagation conditions, and can model wideband as well as narrowband channels.



Project personnel (from left) Lauren Pratt and Tim Riley

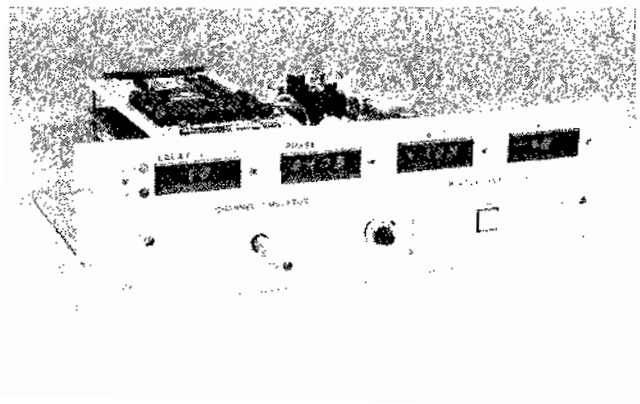
All channel and noise/interference models must be based on measured data. Other Federal agencies had previously developed the instrumentation necessary to obtain the necessary data, and had conducted field measurements to obtain representative samples of both propagation and noise/interference data. Rather than duplicate effort, the Institute has worked cooperatively with these agencies in the analysis of the existing data. Results of the analysis have been incorporated in the HF channel model and are currently being incorporated in the noise/interference model.

The computer-generated plots shown at the right provide a comparison of an HF scatter function plotted from measured data with a scatter function generated by the Institute's HF channel model. Scatter functions have been found by many researchers to be an excellent tool for characterizing the fading on HF channels. As can be seen, the new channel model can accurately represent the measured data. The Institute expects to begin hardware construction on a simulator which implements the new HF channel model during FY 90.

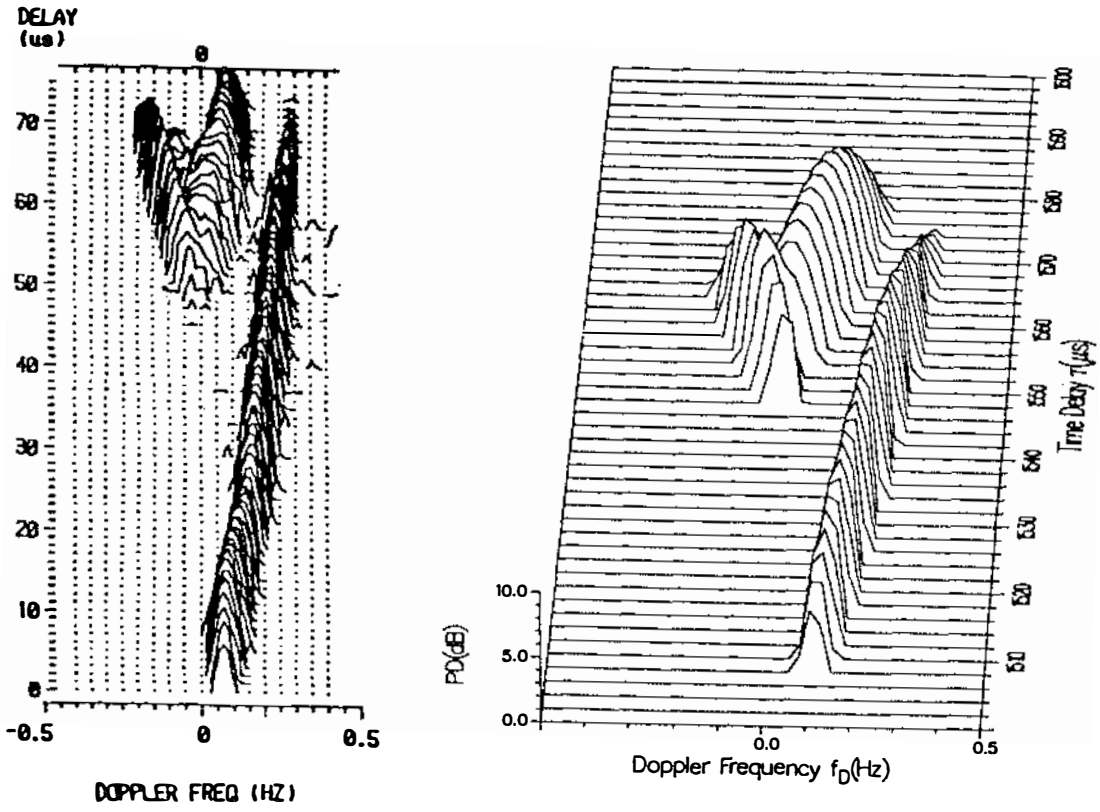
The Institute has also developed a line-of-sight (LOS) channel simulator, pictured at the upper right. During FY 89, this simulator was used to provide fading data useful in the development of software for analyzing data obtained from the Institute's LOS channel probe.

Recent ITS Publications

A New Approach to HF Channel Modeling and Simulation (by Vogler and Hoffmeyer)
Wideband HF Noise and Interference Modeling (by Lemmon)
Measurement, Modeling and Simulation of Line-of-Sight Microwave Channels (by Hoffmeyer and Vogler)
Performance Evaluation of LOS Microwave Radios (by Hoffmeyer, Pratt, and Riley)



LOS Microwave Channel Simulator




a) measured scattering function for a 126-km midlatitude HF path

b) scattering function generated by new HF channel model

Comparison of Measured and Model Scattering Functions

# ITS Tools and Facilities

**Data Communication Laboratory Test Bed** • This ITS test facility is used as a tool for

- Verifying the validity of new and developing Federal and ANSI data communication standards. It provides realistic data and suggestions for refinements and improvements of a developing standard to the working standards committees.
- Building a representative data base of user-oriented performance parameter values for real-world data communication systems such as the ARPANET, several public data networks, and in the future local area networks, gateways, and alternate services (since deregulation).
- Evaluating the performance of alternative data communication technologies, systems, and services in terms of specified user needs.

Three computers, including a transportable desk-top UNIX system, comprise a portion of the equipment used in the testing. Normally, one of the computers serves as the local host to one or more networks, and the transportable machine is taken to a distant city to function as the user of the network under test. This test facility is available for use by private parties on a reimbursable basis.

**ISDN Laboratory** • To support ITS leadership in developing national and international telecommunication performance standards and to facilitate the transfer of telecommunications technology to industry and Government, the Institute has recently established an Integrated Services Digital Network Performance Laboratory. In FY 89, the Systems and Networks Division focused on establishing in-house capabilities for testing prototype ISDN services. The equipment includes personal computer ISDN coprocessor boards, ISDN network emulation software, and a sophisticated ISDN protocol test system. Functionally, the equipment allows ISDN basic rate (2B+D) bearer service to be emulated and the protocols monitored between two ISDN workstations. ISDN performance measurement software developed by ITS is used to send voice, video, and data information between the workstations to measure the performance parameters under study.

**Laboratory Atmospheric Simulator** • ITS has a unique laboratory atmospheric simulator facility to measure the radio refractive index of moist air. A computer-controlled environmental chamber, resonator, and millimeter-wave vector network analyzer provide highly accurate measurements of attenuation and phase delay in the frequency range 10 to 220 GHz. The simulator permits the pressure to be varied over six orders of magnitude ($10^{-3}$ to $10^{3}$ millibars), the relative humidity to be varied between 0 and 100 percent, and the temperature to be varied between 270 and 320 degrees Kelvin. The simulator provides a means to conduct millimeter-wave propagation experiments in a controlled environment that can represent atmospheric heights from the Earth's surface to 120 km. This latter height provides a realistic basis to conduct experiments that are representative of satellite heights for most applications. This tool is available for use by private parties on a reimbursable basis.

**Local Area Network Laboratory** • The ITS Network Laboratory is used to develop and study a variety of networks for interoperability and performance under many conditions. This facility can be used to simulate Local Area Networks, Metropolitan Area Networks, and Wide Area Networks. Specific objectives include the development of user-oriented performance measures for applications involving CAD, CAM, and both video and high-resolution graphics teleconferencing.

Equipment available for this laboratory is quite varied. Two micro-minicomputers with high-resolution displays and two 80386-based computers are available as workstations. These units are connected together by an IEEE 802.3 coaxial Ethernet (10 Mbps). Test equipment consists of two Ethernet analyzers and one 64-Kbps protocol analyzer. ITS plans to add six 80386-based workstations, an additional protocol analyzer, an optical fiber Ethernet, a Fiber Distributed Data Interface (FDDI) network, a 14/12-GHz transmit/receive earth station (Ku Band), and a video teleconferencing system.

**Microwave Line-of-Sight (LOS) and Troposcatter Channel Probes** • ITS has developed a unique capability for measuring the amount of multipath on either line-of-sight or troposcatter communication links. Multipath is the result of atmospheric refraction of the signal as it propagates from the transmitter to the receiver. Multipath causes a deterioration of radio performance. Channel probes are used to measure the amount of the dynamically changing multipath

during the period in which radio performance is being measured. This permits a correlation of the amount of multipath with the performance level of the radio.

**Microwave Line-of-Sight (LOS) Channel Simulator** • ITS has developed this tool to simulate channel fading conditions in a controlled environment in order to evaluate the performance of different radios under identical conditions. ITS developed the simulator to perform evaluations for the Department of Defense; however, it could also be used for testing microwave radios used in the private sector.

**Mobile Millimeter-Wave Measurement Facility** • ITS has a highly sophisticated, fully computerized 10 to 100 GHz channel probe for determining the performance of potential communication paths. Each terminal (transmit and receive) can be fixed or mounted on a van, which provides a means to perform path measurements in environments ranging from urban to isolated locations. Measurements and analysis from remote terminals (via wire or telephone) can be conducted to determine occurrence of signal fades and identification of fade mechanism (such as rain attenuation, multipath phase interference, antenna beam decoupling, and ray defocusing) as well as channel distortion across a 1.5 GHz bandwidth. Instrumentation to measure meteorological parameters such as rain rate, refractive index, and water vapor content is also available for simultaneous observation. This facility is available for use by private parties on a reimbursable basis.

**Network Laboratory Test Bed** The ITS Network Laboratory is used to develop, demonstrate, and evaluate interoperability, and measure performance of prototype wideband, high-data rate networks under a variety of conditions. The Laboratory was developed to support Navy shipbuilding telecommunication. The networks consist of interconnected Local Area Networks (LANs) and a Metropolitan Area Network (MAN) and an interface to Wide Area Networks (WANs) via an ITS 14/12 GHz (Ku-band) transmit/receive satellite earth station. This is complemented with a satellite network simulator. The networks are capable of integrating and transferring data for Computer Aided Design (CAD), Computer Aided Logistics Support (CALS), digitized Video Teleconferencing (VTC), and Interactive High Resolution Graphics Teleconferencing (IHRGT).

**Propagation Measurement Van** • ITS uses this mobile facility to measure the performance of radio systems throughout the spectrum. The receiver is placed on a mobile van and the system makes continuous measurements of the received signal level as the van moves along a planned measurement path. The measurement system is capable of taking samples at many different wavelengths. ITS makes measurements using this facility to improve and validate computer models that provide system designers and users with performance prediction capabilities.

**Radio Spectrum Measurement System** • This van-deployed measurement system is used by ITS to support NTIA frequency management programs. The RSMS contains two independent, computer-controlled measurement systems--one general-purpose system and one optimized for land mobile radio channel usage measurements. A wide range of capabilities includes automated site surveys over the 2 MHz to 18 GHz range, radar pulse sorting and measurement, emission spectra, and band occupancy studies. Specialized software and hardware have been developed for many customers, taking the RSMS to locations ranging from the Aleutian Islands to Florida. Lightweight, portable systems can be used when the full RSMS capabilities are not needed.

**TASERVICES** • This is a service providing the latest engineering models and research data developed by ITS to industry and other Government agencies. It is an interactive, computer-based service designed to be both user friendly and efficient. The services offer a broad range of programs that allow the user to design or analyze the performance of telecommunication systems. The services cover terrestrial, ionospheric, and space systems and include built-in data bases that allow the consideration of terrain, atmospheric, and precipitation affects on the systems. TASERVICES have been used in the solution of interference problems, design of cellular radio systems, and FCC applications for licenses.

**The Table Mountain Radio Quiet Zone** • This unique facility (one of only two in the Nation) is controlled by public law to keep the lowest possible levels of unwanted radio frequency energy from impinging on the area. This situation allows research concerned with low signal levels (such as from deep space, extraterrestrial low-signal satellites, or very sensitive receiver techniques) to be carried out without the ever-present interference found in most areas of the Nation. As the use of electronic systems (i.e., garage door openers, computers, citizen band radios, arc welders, and appliances) increases and the number of radio and

TV stations increases along with many new uses for the radio frequency spectrum, the average level of electromagnetic energy across the spectrum increases. This occurrence is important to companies involved in developing very sensitive receivers and radio signal processing equipment since front ends of these receivers are often saturated by the background signal level. This facility is available for use by private parties on a reimbursable basis.

**Video Quality Laboratory** • The ITS Video Quality Laboratory is used to develop automated techniques for assessing the quality of video and image data. This computer-based system will allow users to obtain reliable, repeatable, and cost-effective measures of video and image transmission system performance. The system also provides a means of implementing a large set of video and image parameters and evaluating their usefulness in quality assessment.

Laboratory hardware consists of an 80386 computer-based image-processing workstation and peripheral image store/capture equipment. The workstation is capable of capturing 512 x 512 color images from video cameras, video tape recorders, or broadcast television signals. Once captured, images are digitized and stored and may be analyzed and processed using standard and ITS-developed methods. Other equipment includes an electronic-shutter, solid-state color camera and a still-frame VHS video cassette recorder.

**Voice Quality Laboratory** • This laboratory is used to study the effects of transmission impairments on perceived voice quality. ITS is using the facility to develop a method for automatically assessing voice quality as perceived by human listeners without the need for costly subjective scoring. The system will satisfy an urgent need of providers, users, and standards organizations for fast, inexpensive, accurate, and reliable quality-assessment methods. The laboratory consists of high-fidelity audio equipment attached to a computer workstation used to process and analyze the speech data. Two extensive data bases of distorted speech are also available. These represent a wide variety of real-world impairments and have been tested by human listeners.

# ITS Projects for Fiscal Year 1989 Organized by Department and Agency

## AGRICULTURE, DEPARTMENT OF

### Forest Service

**Wallowa-Whitman Telecommunications Plan** • Val J. Pietrasiewicz (497-5132) • Develop a long-range telecommunications plan for the Wallowa-Whitman National Forest

## BOARD OF INTERNATIONAL BROADCASTING (BIB)

**BIB/CCIR Monitoring** • John R. Godwin (497-5191) • Provide receiving equipment to support a CCIR-proposed HF propagation experiment

## COMMERCE, DEPARTMENT OF

### National Telecommunications and Information Administration (NTIA)

**Advanced Satellite Communication Technology Studies** • Robert D. Cass (497-5478) • Develop end-to-end system performance experiments applicable to the class of advanced communication satellite systems that use a baseband processor (switch) in the space craft. Investigate the various roles these advanced communication satellites should play in ISDNs

**Analysis Services (TASERVICES)** • Jean E. Adams (497-5301) • Make available to the public, through user-friendly computer programs, a large menu of engineering models, scientific and informative data bases, and other useful communication tools

**Broadcasting and Related Propagation Studies** • Eldon J. Haakinson (497-5304) • Provide support to NTIA's Office of Policy Analysis and Development for high-definition television studies

**Common Carrier Technical/TELECOM 2000** • Roger K. Salaman (497-5397) • Perform assessments to support common carrier and information industry deregulation and competitive thrusts including studying the technical and policy implications of the convergence of the telecommunications, computer, and information industry segments resulting from the interdependence of electronic technology and systems

**Digital Network Performance** • Randall S. Bloomfield (497-5489) • Promulgate and demonstrate compatible Federal and American National Standards and international standards for specifying and measuring data communication performance, and provide emphasis on application of these standards to, or integration with, voice and video performance in ISDNs

**HF Broadcasting WARC Planning** • James S. Washburn (497-3109) • Provide the United States with the capability to assess the impact of decisions taken at WARC-HFBC(2) on U.S. high-frequency broadcasting interests and provide the United States with the technical leadership necessary to successfully defend U.S. positions

**International Standards** • Neal B. Seitz (497-3106) • Provide leadership to T1 and U.S. CCITT preparatory committees and lead and contribute technically to international efforts for development of functionally oriented, implementation-independent performance standards for packet-switched public data networks and ISDNs

**Video Quality Standards** • Stephen Wolf (497-3771) • Develop video quality assessment techniques and standards contributions in support of ISDN standards within T1 and CCITT, focusing on applications in video teleconferencing, high-definition television, and video communications over broadband ISDN

**Voice Quality Standards** • Robert F. Kubichek (497-3594) • Develop voice quality assessment techniques and standards contributions in support of ISDN standards within CCITT

**Millimeter-Wave Modeling** • Kenneth C. Allen (497-3412) • Perform studies and experiments necessary to develop a user-oriented, millimeter-wave propagation model applicable to frequencies up to 300 GHz that will be useful in assessing millimeter-wave telecommunication system performance

Note: Commercial telephone users dial 303 + number shown in parentheses. FTS users dial 8-320 + last four digits shown.

**PEACESAT** • Raymond D. Jennings (497-3233) • Provide technical support to identify a satellite replacement system for the ATS-1 satellite and develop the technical specifications to acquire a space segment to replace ATS-1

**RSMS Engineering Enhancements** • Robert J. Matheson (497-3293) • Improve the measurement capabilities of the Radio Spectrum Measurement System as needed to provide improved measurement data

**RSMS Operations** • Robert J. Matheson (497-3293) • Provide measurements of spectrum usage and other technical parameters of radio systems

**Satellite/ISDN** • Raymond D. Jennings (497-3233) • Study the role of advanced satellite systems in a future broadband Integrated Services Digital Network

**Spectrum Efficiency Studies** • Leslie A. Berry (497-5474) • Develop the general principles for efficient use and management of the spectrum, and resolve specific current issues related to spectrum efficiency

**Spectrum Engineering Models** • Leslie A. Berry (497-5474) • Develop and implement spectrum engineering models necessary to effectively manage the Government's use of the radio spectrum

**Spectrum Resource Assessments** • Leslie A. Berry (497-5474) • Perform assessments that support the development of spectrum standards for digital land mobile radios, measure emissions from nonlicensed devices, and investigate optimum sequential frequency assignment strategies

National Institute of Standards and Technology

**Boulder Switching System** • Val J. Pietrasiewicz (497-5132) • Perform technical consulting services regarding the acquisition of a new digital voice/data switching system at the Boulder Laboratories

**EM Properties of Materials** • Hans J. Liebe (497-3310) • Assist in developing accurate measurement techniques for the dielectric properties of solid materials at microwave and millimeter-wave frequencies

**Performance and Application of Trunked Land Mobile Radio Systems** • L. Thomas Jones (497-5953) • Assess the usefulness of trunked radio systems and their enhancements to law enforcement radio licensees, and identify the important performance aspects of a trunked radio system and make measurements to assess the performance of available systems

National Oceanic and Atmospheric Administration

**Profiler Communication Procurement** Support • James A. Hoffmeyer (497-3140) • Provide assistance in the technical evaluation of proposals for the NOAA Profiler Communications System

National Weather Service

**Beckley WSR-74C Measurements** • John D. Smilley (497-5218) • Perform radio frequency emission spectrum measurements on WSR-74C radar at Beckley, WV

## DEFENSE, DEPARTMENT OF (DOD)

**Alaska Site Survey** • John D. Smilley (497-5218) • Perform a radio frequency site survey at three sites in Alaska

**AMOS Model Development** • Robert O. DeBolt (497-5324) • Continue the development of the millimeter-wave prediction model for tactical scenarios known as Analysis of Microwave Operational Scenarios (AMOS) with the addition of new propagation models and outputs

**DOD Consulting** • A. Donald Spaulding (497-5201) • Provide consultation and advisory services on such things as optimum system design and performance determination, detection algorithms, and interference modeling

**DOD Site Survey** • John D. Smilley (497-5218) • Perform a radio frequency site survey in several point-to-point microwave frequency bands

**HF Polar** • Frank G. Stewart (497-3336) • Implement a polar model in IONCAP to correct inconsistent predictions of polar paths

**LF Signal and Noise Measurement** • Donald H. Layton (497-5496) • Study the signal and noise environment in the 0 to 10 kHz range in a typical office/business environment

**Millimeter-Wave Mesospheric Propagation Model** • Hans J. Liebe (497-3310) • Develop a computer model running on the IBM PC and compatibles that describes the propagation effects in the mesosphere for arbitrary polarization

**Millimeter-Wave Prediction Model for Tactical Scenarios** • Kenneth C. Allen (497-3412) • Develop a highly structured computer model to predict the performance of millimeter-wave systems in a wide variety of tactical scenarios

**Millimeter-Wave Propagation in the Ocean Surface Evaporation Duct** • David N. Haupt (497-3330) • Enhance the polarimetric millimeter-wave probe and perform propagation measurements in the ocean evaporation duct with the updated probe

**Technology Transfer Methodology Implementation** • Ernest L. Morrison (497-5888) • Provide guidance to selected Federal agencies in the application of strategic defense initiative organization developed telecommunications, AI/ES, and supercomputer technologies

**VHF Experiment** • Jean E. Adams (497-5301) • Design, install, and conduct a VHF propagation experiment to determine and model radio propagation in the Mediterranean region over meteor-burst paths

**Digital Propagation Model** • Evan J. Dutton (497-3646) • Investigate, assess, and model the effects of terrain multipath on digital common carrier links operating at the nominal carrier frequencies of 2, 4, 6, 11, and 18 GHz

**Wide Area Prediction** • Evan J. Dutton (497-3646) • Refine computer programs that analyze the receivability of common carrier links to allow the analysis of an entire metropolitan area, or any wide area in the United States, in a single program run

Air Force (USAF)

**54 to 66 GHz Laboratory Study** • Hans J. Liebe (497-3310) • Provide propagation data for the frequency interval from 54 to 66 GHz at simulated atmospheric conditions over the height range from 5 to 30 km

**Hill AFB FCA Van** • Donald H. Layton (497-5496) • Design, procure, and integrate radio-frequency control and analysis vans for Hill Air Force Base

**Hill AFB Remote Antenna** • Donald H. Layton (497-5496) • Design and construct a remote antenna system for Hill Air Force Base

**MOTES-R** • Donald H. Layton (497-5496) • Assist the USAF in resolving problems and improving the operation of the MObile Test and Evaluation System-Radar (MOTES-R) tracking system to enable performance of slave tracking with a new system

Air Force--Electronic Systems Division (ESD)

**European TRAMCON Support** • Robert A. McLean (497-3262) • Support the TRAMCON operation in Europe for a period of 30 months including problem isolation, training, testing support, and configuration management

**Feldberg-Schwarzenborn Performance Measurements** • James A. Hoffmeyer (497-3140) • Conduct measurement program on the Feldberg-Schwarzenborn link of the Digital European Backbone

**Swingate-Houtem LOS Channel Measurements** • James A. Hoffmeyer (497-3140) • Perform measurements on the Swingate-Houtem link of the Digital European Backbone using the LOS channel probe

**TRAMCON 87/89** • Richard E. Skerjanec (497-3157) • Develop, test, and support the TRAnsmission Monitor and CONtrol program (TRAMCON), which is being developed to monitor and control the digital transmission system for the Defense Communication System in Europe

**TRAMCON 87 Software** • Richard E. Skerjanec (497-3157) • Continue development, testing, and support for the TRAnsmission Monitor and CONtrol program (TRAMCON)

Air Force Geophysics Laboratory (AFGL)

**TEC Variability** • Mary W. Sowers (497-3820) • Determine and characterize the total variability in the total electron content of the ionosphere

Air Force--Rome Air Development Center (RADC)

**Wideband HF Study** • James A. Hoffmeyer (497-3140) • Study the wideband HF medium leading to its characterization and modeling

Army Communications-Electronics Command (CECOM)

**Ionospheric Variability Study** • Mary W. Sowers (497-3820) • Conduct studies that will model on a global scale the effects of variability in the critical frequencies of the F2 region of the ionosphere

**MMW Studies of Propagation Through Deciduous Vegetation** • David L. Jones (497-6295) • Modify the wideband millimeter-wave propagation measurement system for enhanced sensitivity and accuracy and make propagation measurements through deciduous vegetation

Army Information Systems Engineering Command (ISEC)

**Army HF Propagation Study** • Larry R. Teters (497-5410) • Assist Army in the development and implementation of analytic techniques for tactical operation use

**DRAMA Radio Performance** • James A. Hoffmeyer (497-3140) • Conduct tests on the DRAMA system, seeking methods to improve performance in a multipath channel

**IONCAP Model Development** • Larry R. Teters (497-5410) • Undertake a specific HF propagation study to assist the Army in the development and implementation of analytic techniques for tactical operation use

**Radio Link Integrated Performance Predictions** • Joseph E. Farrow (497-3607) • Update and enhance the interactive computer programs developed to predict the performance of line-of-sight, marginal line-of-sight, and beyond-the-horizon radio links

**TROJAN Communications Network Management System** • William J. Pomper (497-3730) • Design a TROJAN communication network system

Army Missile Command

**Millimeter-Wave Polarimetric Studies** • Kenneth C. Allen (497-3412) • Provide information on time-dependent polarimetric effects of rain on millimeter waves that may affect specific polarimetric sensors

Army Signal Center

**Spectrum Management Analysis** • Ernest L. Morrison (497-5888) • Evaluate the spectrum conservation potential for three implementation levels in a segment of an Army tactical network supporting a moderate and high-stress dynamic operation

Defense Communications Agency (DCA)

**DCS Integrated Node Architecture** • Randall S. Bloomfield (497-5489) • Develop a DCS/DSN integrated access node architecture for the 1995 time frame

**DEB Performance Measurement** • James A. Hoffmeyer (497-3140) • Obtain long-term (12-month), user-to-user performance data on a 64-kb/s channel

**HF Radio Interoperability Testing Facility** • Paul C. Smith (497-3677) • Design, implement, and demonstrate a test facility capable of evaluating the interoperability of automated HF radio systems

**NCS Voice Quality** • Robert F. Kubichek (497-3594) • Develop an expert pattern recognition system and specify Federal standards for technology-independent assessment of voice transmission quality

**NSEP/FOCS** • David F. Peach (497-5309) • Make available to system designers and users the knowledge necessary to understand what is required to protect a fiber optic system from stress

**R&D/O&M Engineering Services for NCS** • Joseph A. Hull (497-5726) • Provide technical support to NCS in areas relating to performance and interoperation of Government telecommunication assets for National Security Emergency Preparedness purposes

**Reduced Vulnerability to Telecommunication Outages** • Raymond D. Jennings (497-3233) • Provide technical investigations of the potential for using advanced satellite system technology to enhance rapid restoration of services provided by the public switched network following a natural or "manmade" disaster

**Revision of FED-STD-1037A** • A. Glenn Hanson (497-5449) • Develop, edit, and maintain a data base for the revision of FED-STD-1037A, Glossary of Telecommunication Terms, and correlate this data base with relevant international standards

**Wideband HF Channel Modeling and Simulation** • James A. Hoffmeyer (497-3140) • Develop validated models for the wideband HF channel, HF noise and interference, and HF jamming signals and implement those models in simulator hardware

Joint Tactical Command, Control, Communications Agency

**HF Simulator/HF Test Bed Procurement Consultation** • James A. Hoffmeyer (497-3140) • Provide technical consultation in the procurement of a narrowband HF channel simulator and the HF distributed test bed

Naval Air Test Center

**Navy Air Systems Command Consulting** • Joseph E. Farrow (497-3607) • Provide consulting services to assist with the activation of the Charleston Tactical Aircrew Combat Training System communication links

Naval Ocean Systems Center (NOSC)

**Millimeter-Wave Propagation Model** • Hans J. Liebe (497-3310) • Develop a reliable propagation model for the atmospheric transmission window centered around 94 GHz

Naval Sea Systems Command

**Aegis CAD/VTC Satellite Networks** • Edmund A. Quincy (497-5472) • Design, develop, and measure performance of a prototype wideband high-data-rate satellite telecommunication network consisting of a series of interconnected Local, Metropolitan, and Wide Area Networks. The networks are optimized to integrate and transfer Computer Aided Design, Computer Aided Logistics Support, digitized Video Teleconferencing, and Interactive High Resolution Graphics Teleconferencing data between the Navy's principal shipbuilders and weapons manufactures and headquarters.

U.S. INFORMATION AGENCY (USIA)

**IFRB MF Modification** • Jean E. Adams (497-5301) • Provide Voice of America with an MF analysis capability that allows the use of VOA-generated antenna patterns

**VOA Predictions** • A. Donald Spaulding (497-5201) • Provide Voice of America with ionospheric predictions that are used in frequency planning and coordination

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## AVAILABILITY OF PUBLICATIONS

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

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