Institute for Telecommunication Sciences

1998
Technical Progress Report

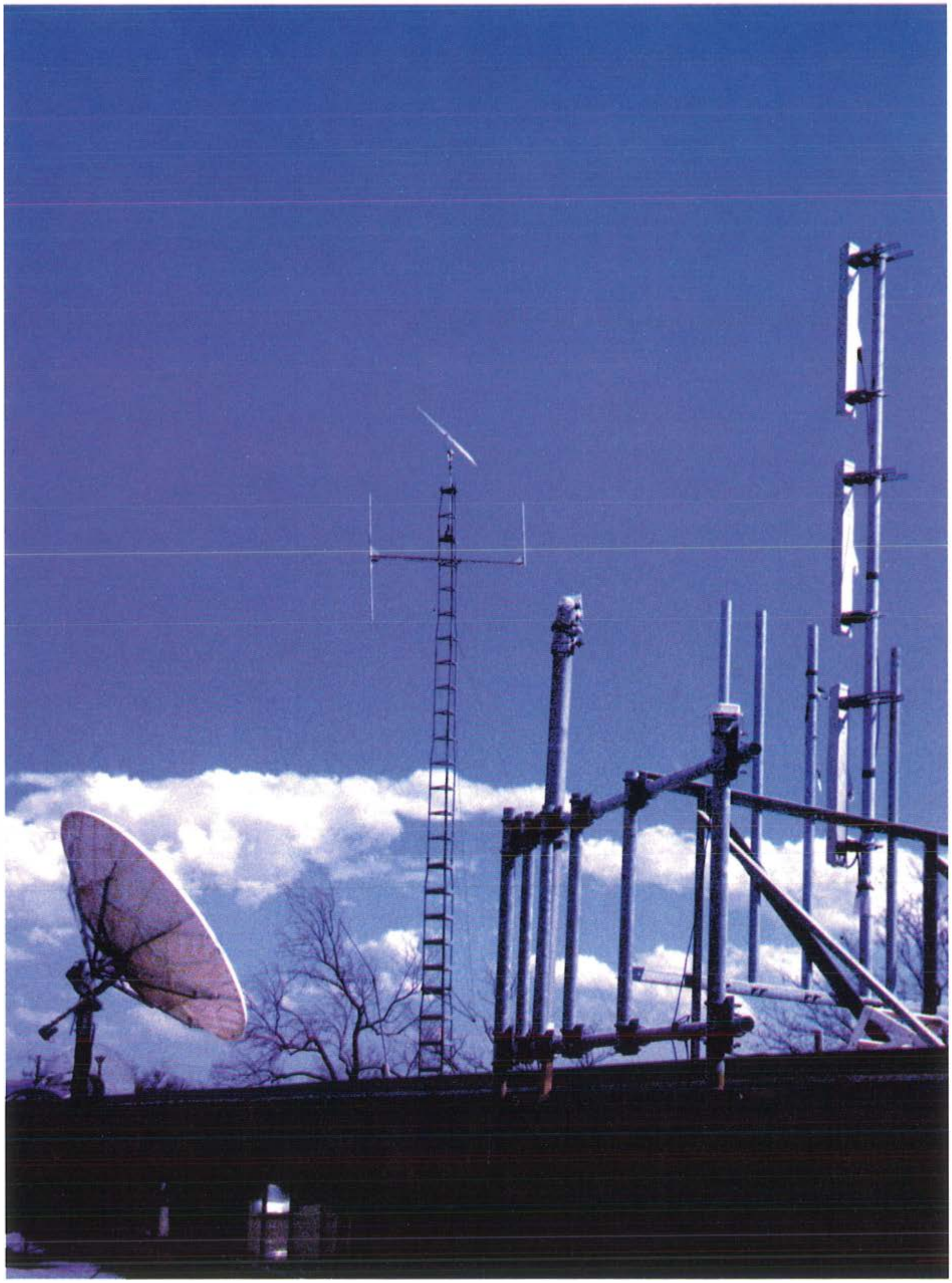
Institute for Telecommunication Sciences

1998 Technical Progress Report

U.S. Department of Commerce
William M. Daley, Secretary
Larry Irving, Assistant Secretary for Communications and Information

Certain commercial equipment, components, and software are identified in this report to adequately describe the design and conduct of the research and experiments at ITS. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the equipment, components, or software identified is necessarily the best available for the particular applications or uses.

Contents



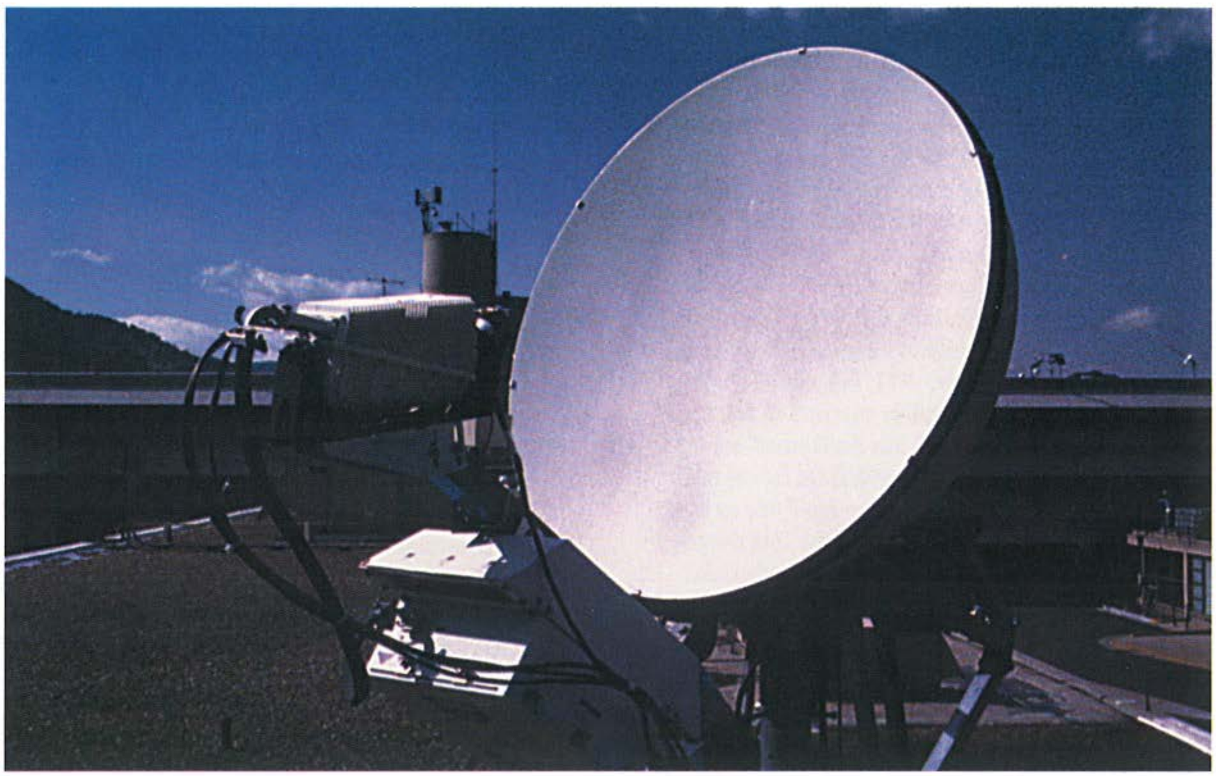
ITS antennas on the roof of the Department of Commerce Boulder Laboratories (photograph by F.H. Sanders).

The ITS Mission

The Institute for Telecommunication Sciences (ITS) is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA). ITS supports such NTIA telecommunications objectives as promotion of advanced telecommunications and information infrastructure development in the United States, enhancement of domestic competitiveness, improvement of foreign trade opportunities for U.S. telecommunications firms, and facilitation of more efficient and effective use of the radio spectrum.

ITS also serves as a principal Federal resource for solving the telecommunications concerns of other Federal agencies, state and local Governments, private corporations and associations, and international organizations.

Cooperative research agreements based upon the Federal Technology Transfer Act of 1986 are the principal means of aiding the private sector. This Act provides the legal basis for and encourages shared use of Government facilities and resources with the private sector in advanced telecommunications technologies. These partnerships aid in the commercialization of new products and services.



Advanced Communications Technology Satellite (ACTS) antenna (photograph by F.H. Sanders).

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) of the U.S. Department of Commerce. ITS employs individuals with substantial engineering and scientific skills and experience to support our technical programs. The majority of our employees are electronics engineers, with a complement of mathematicians, physicists, computer scientists, and computer programmers. ITS' support during the 1998 fiscal year consisted of $4.4 million of direct funding from the Department of Commerce and approximately $5.2 million for work sponsored by other Federal Government agencies and U.S. industry.

History

ITS began in the 1940s as the Interservice Radio Propagation Laboratory, which later became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards of the Department of Commerce. In 1965, CRPL became part of the Environmental Science Services Administration and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the telecommunications function of ITSA 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 performed telecommunications research and provided technical engineering support to NTIA and to other Federal agencies on a reimbursable basis. Over the last decade, ITS has pursued cooperative research with U.S. industry under the provisions of the Federal Technology Transfer Act of 1986.

Activities

The Institute performs telecommunications research, planning, and engineering in the following areas:

- ***Spectrum Planning and Assessment:*** The Institute analyzes spectrum use in selected frequency bands and prepares U.S. technical positions for international spectrum allocation conferences.
- ***Telecommunication Systems Planning***: The Institute relates the needs of users with present and future telecommunication technologies to assist in the development of organizational plans for the effective use of telecommunications.
- ***Telecommunication System Performance Assessment:*** The Institute forecasts the performance of individual communication elements in a system, and tests and measures systems in a laboratory or operational environment.
- ***Telecommunications Standards Development:*** The Institute contributes to and develops Federal, national, and international telecommunications standards.
- ***Applied Research:*** The Institute models radio wave travel from point to point in various frequency bands and evaluates the way information is carried by radio signals.

Benefits

The Institute's research significantly benefits both the public and private sectors in several areas:

- Spectrum Utilization: Optimization of Federal spectrum allocation methods, identification of unused frequencies and potential interference through field measurements, and promotion of technology advances to aid in efficient use of the spectrum.
- Telecommunications Negotiations: Expert technical leadership at international conferences and development of negotiation support tools such as interference prediction programs.
- International Trade: Promulgation of nonrestrictive international telecommunications standards to remove technical barriers to U.S. export of telecommunications equipment and services.
- Domestic Competition: Development of user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services.

- National Defense: Improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of emergency communications that contribute to the strength and cost-effectiveness of the U.S. Armed Forces.

- Technology Transfer: Direct transfer of research results and measurements to U.S. industry and Governments to support national and international competitiveness, hasten the advent of new technology to users, and expand the capabilities of national and global telecommunications infrastructures.

Outputs

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

- Engineering Tools and Analyses: Predictions of transmission media conditions and equipment performance; test design and data analysis of computer programs; and laboratory and field tests of experimental and operational equipment, systems, and 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: Mathematical 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

ITS is organized into two program divisions: Spectrum Research and Analysis, and Systems and Networks Research and Analysis. The Spectrum Division concentrates on analyses directed toward understanding radio wave behavior at various frequencies, determining methods to enhance spectrum use, and predicting and improving the performance of existing and emerging technologies. The Systems and Networks Division focuses on assessing and improving the performance of Federal and private telecommunication networks, developing domestic and international telecommunications standards for networks, and evaluating new technologies for future needs.

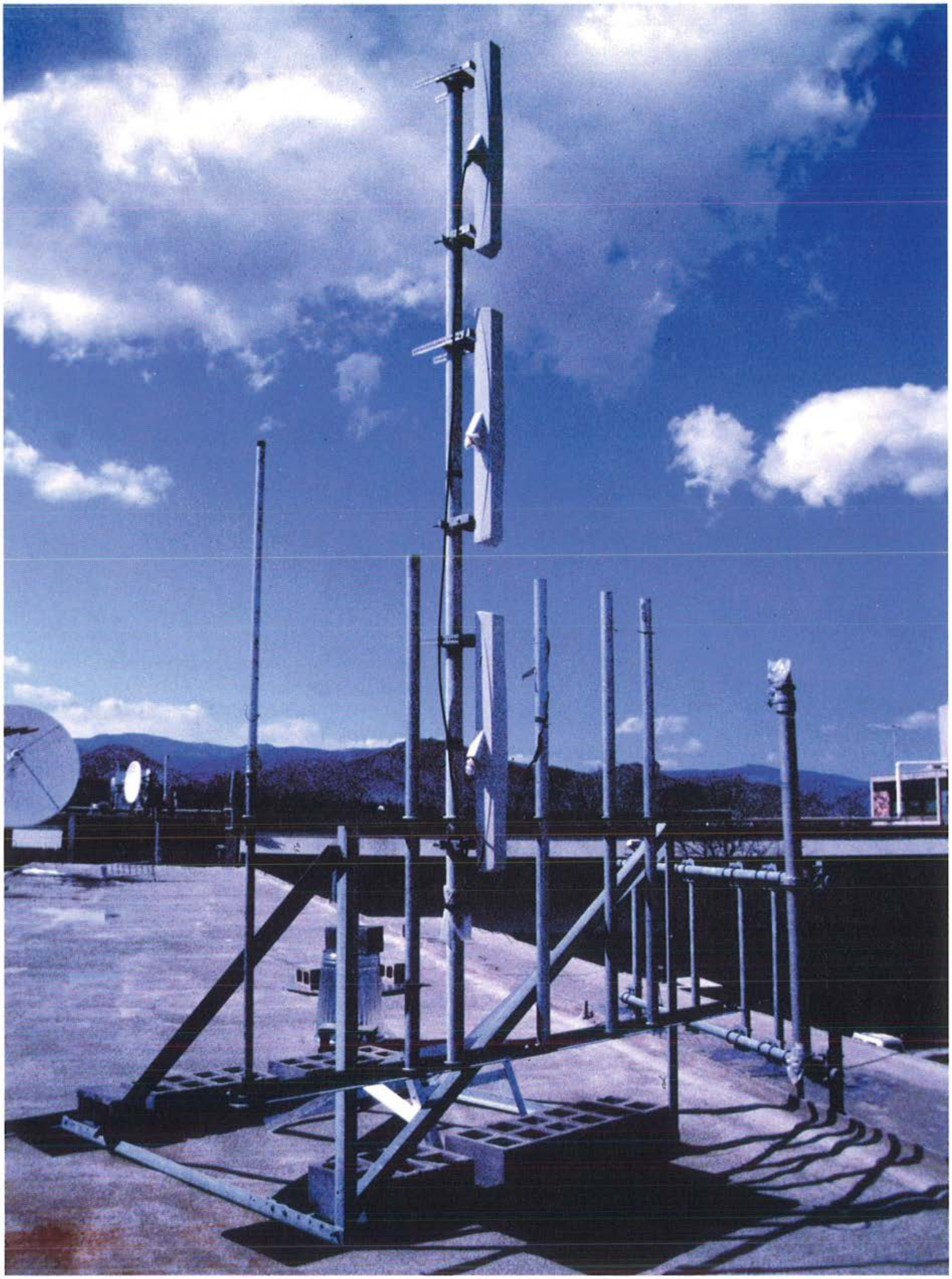
The ITS Executive Office manages administrative matters. The Executive Office also manages the Institute's budget and program-planning functions and interacts with various administrative offices within other parts of the Department of Commerce to meet its payroll, procurement, personnel, facilities management, civil affairs, and publications needs.

Sponsors

Activities at the Institute are undertaken through a combination of programs sponsored by the Department of Commerce and other Government agencies, and through cooperative research agreements with the private sector. The Institute's policy provides that research sponsored by other agencies result in contributions to and reinforcement of NTIA's overall program and must be directed toward supporting the goals of the Department of Commerce. Various agencies within the Department of Defense provide the majority of the Institute's funding from other agencies. Other sponsors include the Department of Transportation, the Federal Aviation Administration, and the National Institute of Standards and Technology.

Cooperative research agreements with telecommunication-operating companies and manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the Department of Commerce. ITS has cooperative research agreements with large established companies as well as small, start-up companies. Partnerships such as these enhance synergies between entrepreneurial ventures and broad national goals.

Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides scientific research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 1998 to both the public and private sectors.



Vertical antenna array used by ITS adaptive antenna testbed (photograph by F.H. Sanders).

Spectrum Planning and Assessment

NTIA is responsible for managing the Federal Government's use of the radio spectrum and is the President's advisor on telecommunications. NTIA's responsibilities include establishing policies on spectrum use — directed toward ensuring that the spectrum provides the maximum benefit to all users, while continuing to accommodate new users and new services.

ITS supports these activities by performing theoretical studies and spectrum measurements directed toward assessing present spectrum use and predicting future spectrum requirements; identifying existing and potential electromagnetic compatibility (EMC) problems among radio systems; recommending effective EMC mitigation techniques and efficient long term solutions; and helping to develop improved spectrum management tools that promote spectrum efficiency and maximize the usefulness of spectrum-based systems. ITS provides technical support for NTIA in the development and advocacy of the United State's position at international spectrum conferences. Decisions made at these bodies significantly affect spectrum use in the United States and worldwide. Major impacts occur in U.S. export markets and interoperability of global communication systems. ITS develops software and hardware to support Federal spectrum management. Many of these products are also useful to the private sector and are available on a reimbursable basis.

Areas of Emphasis

Domestic Spectrum Analysis

The Institute assists in the development of national radio policies by assessing current spectrum use and predicting the impact of new technologies and policies. Projects are funded by the Department of Transportation (DOT) and NTIA.

Spectrum Compatibility Testing

The Institute helps to prevent interference in new and existing spectrum applications through measurement and analysis of potential interferers and potential victim systems. Projects are funded by AAMA and NTIA.

Spectrum Occupancy Measurements

The Institute performs usage measurements across a wide range of spectrum services and environments to understand trends in spectrum crowding and opportunities to support new services. Projects are funded by FAA and NTIA.

Spectral Assessment of Government Systems

The Institute performs emission measurements on radio systems as required to verify proper operation or to identify and mitigate interference in operational and planned systems. Projects are funded by NTIA.

Radio Frequency Interference Monitoring Systems

The Institute provides expertise in the design and development of radio monitoring systems to Federal agencies that use such systems. Projects are funded by FAA and NTIA.

Modulation Bandwidth Requirements

The Institute develops improved mathematical models to examine digital modulation techniques from the perspectives of spectrum efficiency and adjacent channel interference. Projects are funded by NTIA.

ITU-R Activities

The Institute assists in the development of international regulations, tools and techniques, and policies for using the radio spectrum through participation and chairmanships in the working groups of the International Telecommunications Union–Radiocommunications Sector. Projects are funded by NTIA.

Domestic Spectrum Analysis

Outputs

- Fixed Services report progress.
- Participation in 706 Petition and broadband alternatives studies.
- Spectrum Use Rights report draft.
- Television coverage studies.
- Study of use of higher wireless frequencies.

During FY 1998 ITS provided technical inputs to NTIA in numerous areas related to domestic spectrum policies and actions. In many cases, the Institute's intended role was to add a solid technical engineering perspective to issues that often require being examined from many angles.

Work continued on a revision to a 1993 report on the Fixed Services, which historically have consisted mainly of the traditional point-to-point microwave links. However, recent developments are rapidly adding new categories of services, many of which operate in new frequency bands. New services like Teligent's wireless local loop (WLL) at 24 GHz, the recently auctioned cellular cable (LMDS) at 28 GHz, and Winstar's "wireless fiber" at 38 GHz are among the more visible recent entries.

These new services differ from existing services in several ways. First, they all operate in frequency bands that were until recently considered to be much too high for widespread consumer applications. Second, although these services each originally started out to provide various individual traditional services (e.g., consumer TV, individual telephone service, wideband digital telephone trunks), they all appear to be morphing into a single generalized broadband digital service (the great digital convergence). Third, they are all trying to become successful competitors of the local telephone companies and cable TV companies, a development with great implications for the entire telecommunications regulatory environment. And, finally, this is all happening in the Fixed Services, which many observers believed were becoming obsolete because of competition from optical fiber.

Up-to-date information on the Fixed Services is important to government spectrum regulators like NTIA, because some of these Fixed Service bands are considered possible candidates for reallocation to new wireless services. Even when such drastic reallocations are not contemplated, many bands must contend with proposed new sharing arrangements with various new satellite services. The updated ITS study of 30 Fixed Service bands is expected to be published in FY 99.

Based largely on research aimed at understanding developments in the Fixed Services, the Institute was able to supply NTIA with information on alternative means to deliver broadband access, which was an important issue in the FCC "706 petition" concerning regulation of local exchange carriers (LECs). The existing ITS knowledge of broadband digital wireless technologies was extended to include wireline access such as power line carriers, various digital subscriber line (xDSL) systems from the telephone companies, digital cable techniques, and various optical fiber configurations.

Institute staff participated with NTIA staff in extended discussions aimed at developing improved spectrum management techniques and policies. As a partial outgrowth of this effort, Institute staff have prepared a draft document proposing a series of spectrum use rights, as related to interference issues. The major goal of this paper is to help formulate joint FCC/NTIA policies on interference. More detailed and explicit interference policies are needed to help spectrum users make full use of the extra flexibility that has been allowed in most of the bands where licenses have been recently auctioned.

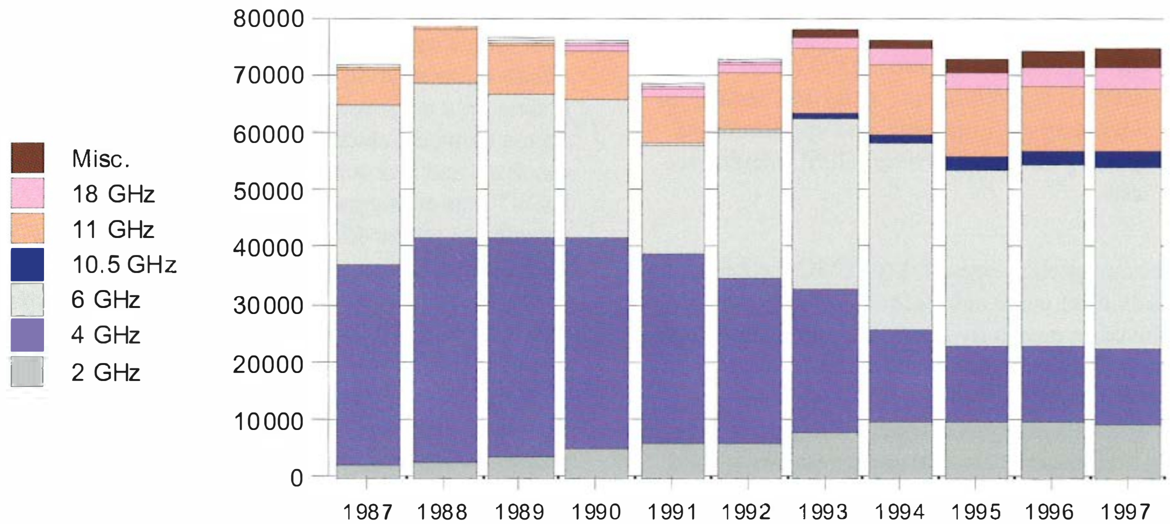
ITS staff have continued to provide technical assistance to NTIA and the FCC on numerous issues related to broadcast TV. For example, the Institute provided more accurate terrestrial broadcast TV coverage maps to show regions of adequate signal coverage from broadcast TV stations. These maps were needed, because the present FCC regulations state that direct broadcast satellite (DBS) companies cannot provide network TV programming to any viewers who can adequately receive the same networks directly over-the-air from the local TV stations. The TA Services facility (see pp. 44-45 and pp. 87-88) provided 200+ detailed terrain-based

(Longley-Rice) coverage maps for selected TV stations in all U.S. TV markets. These coverage maps have been placed on the ITS website at

http://flattop.its.bldrdoc.gov/gifs_ntia/gifsindex.htm

providing an independent technical means for potential satellite customers to document whether they can receive the local TV broadcasting stations. Though the FCC has scheduled extensive future hearings on these regulations, this ITS capability has provided useful information while the difficult policy issues are debated.

ITS staff completed work on a report that described why higher frequency bands are suitable for many types of wireless systems. This tutorial paper was written to dispel a widespread (but often false) belief that modern wireless services must be located at-frequencies below 3 GHz. A major premise of the paper is that systems using higher frequencies need to be engineered differently from traditional systems implemented at lower frequencies. The key is to recognize the differences and to design the system to exploit the unique advantages available at higher frequencies.



Common carrier licenses, showing the migration from the 4 GHz band to the 6 GHz band, caused by incompatibility with 4 GHz satellite downlinks.

Recent Publication

J.M.Vanderau, R.J. Matheson, and E.J. Haakinson, "A technological rationale to use higher wireless frequencies," NTIA Report 98-349, April 1998.

For more information, contact:
Robert J. Matheson
(303) 497-3293
e-mail matheson@its.bldrdoc.gov

Spectrum Compatibility Testing

Outputs

- Development of the NTIA Broadband Arbitrary Waveform Transmitter (BAWT) for electromagnetic compatibility (EMC) testing at field sites.
- Development of a radar signal simulation capability for EMC testing at field sites, and used in tests with a fixed wireless access system.
- Development of the Broadband Noise Generator (BBNG) for interference and EMC testing in laboratory environments, and application to global positioning system (GPS) interference tests.

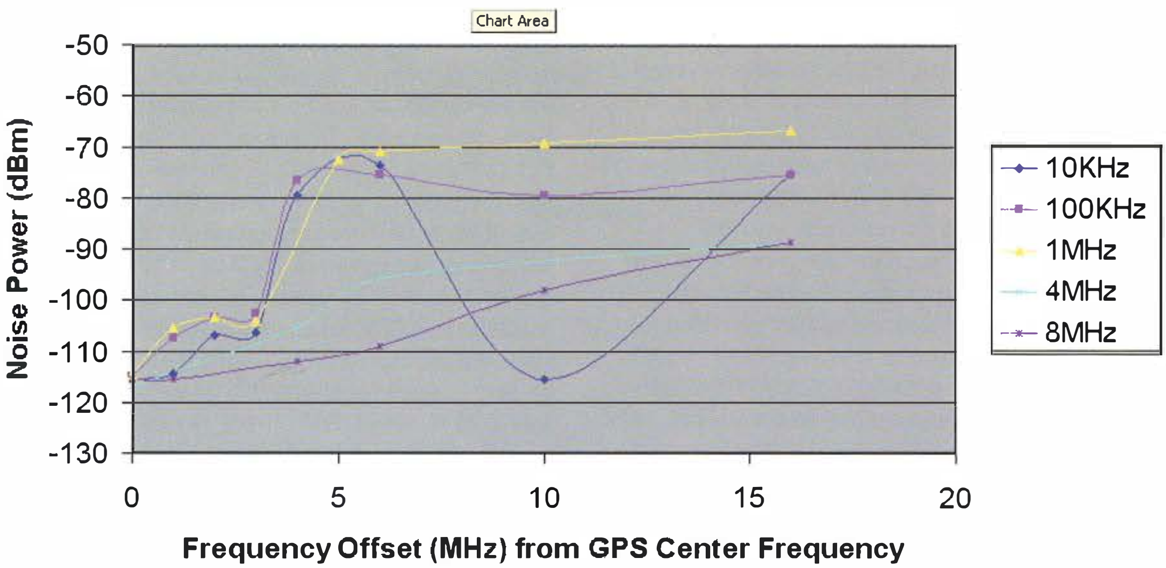
Electromagnetic compatibility (EMC) problems frequently arise when new-technology systems are deployed in proximity to existing ones. In the past, these problems have often been dealt with more reactively than proactively. But large investments in new and existing systems make it desirable to perform preliminary tests and measurements at field sites with transmitters that replicate the signal emissions of new and proposed transmitter systems. For cases involving Government transmitters and receivers, ITS has developed two types of general-purpose interference transmitters that can produce radiated waveforms identical to those produced by radars and other radio transmitter systems. Use of these transmitters in such tests is necessary in cases in which a potential interferer may be unavailable for use (such as transmitters on ships or aircraft), or may still be in the early stages of development, or may be too expensive to install unless assurances can be provided in advance that such an installation will not be the cause or the victim of EMC problems with other systems.

The first system is known as the Broadband Arbitrary Waveform Transmitter (BAWT) and can be used to simulate the spectral output of a wide variety of radar and communication systems. BAWT signals can be coupled directly into a system under test, or can be transmitted into the target system's antenna to more accurately gauge its response to a real interference situation. In cases where the exact form and characteristics of the proposed interferer are poorly known, the second type of generator may be used. This device, the Broadband Noise Generator (BBNG) produces a noise-like signal at the frequency of interest with a bandwidth determined by the investigator. This signal is typically directly coupled into the target system for measurement purposes.

Using the BAWT, ITS personnel participated in a cooperative project with engineers of the Joint Spectrum Center in Arlington, Virginia to test the effects of an existing frequency agile naval radar system on a proposed commercial fixed wireless access network which utilized a portion of the same spectrum and was scheduled for deployment. The BAWT was configured to simulate the complex waveforms produced by the naval radar including such characteristics as frequency hopping, pulse width modulation and phase shift keying. This signal was fed into the receivers of the system under test along with the desired signal, and the degree of signal degradation versus interference was measured. The results of these tests will provide valuable guidelines to designers of similar systems in the future.

The BAWT was also used in a slightly different configuration to evaluate the effects of interference between a sophisticated communications system currently in use by U.S Armed Forces and Personal Communications Services (PCS) telephones of several different types. In this research the BAWT was used to simulate signals from the Joint Tactical Information Distribution System (JTIDS) which were radiated into various types of cellular phones to assess their vulnerability to interference from this source. Using the BAWT allowed the generation of signals at carrier frequencies significantly different from those normally used by JTIDS but within the bands in current use for cellular phone transmissions. This project was done in support of a study by the NTIA Office of Spectrum Management (OSM) to determine the feasibility of allocating new spectrum space for PCS usage in bands currently occupied by military users. Results from these tests, which were accomplished within less than a four week period from the project's conception, led to a reevaluation in the spectrum allocation scheme.

Another quick reaction measurement was accomplished by ITS engineers in concert with NTIA Spectrum Engineering and Analysis Division (SEAD) personnel using the BBNG to test Global Positioning System (GPS) receivers. The spectrum band from 1559 MHz to 1610 MHz has been allocated by international agreement for satellite to earth radionavigation transmissions. In the past the GPS was the only user of this spectrum. However, new satellite radionavigation systems which would share this band have recently been proposed. Because the parameters of these systems are largely unspecified at this time, and because the GPS uses a spread-spectrum signal which has similar spectral characteristics to band-limited noise, it was determined that testing with a band-limited noise-like interference source at frequencies offset from the GPS L1 frequency of 1575.42 MHz would most closely simulate worst case interference conditions from these spectrally collocated systems. These tests were performed in Portsmouth, Virginia using a GPS simulator located at the United States Coast Guard Command and Control Engineering Center (C2CEN). The BBNG provided Gaussian distributed white noise at different bandwidths and at carrier frequencies near 1575.42 MHz. The results of these tests are currently under evaluation, and more such tests are expected.



Noise power required to cause loss of acquisition in GPS receivers versus offset from center frequency for different noise bandwidths.

For more information, contact:
Frank Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Spectrum Occupancy Measurements

Outputs

- Measurements of spectrum occupancy generated by new-technology ultrawideband (UWB) radar and communication systems.
- Measurements of digital television (DTV) spectrum occupancy, and comparison to analog television spectrum occupancy.
- Broadband spectrum surveys at the Department of Commerce Table Mountain Radio Quiet Zone and at the National Institute for Standards and Technology (NIST) outdoor antenna range facilities at Boulder, CO.

To accomplish the NTIA Federal spectrum management mission, including assessment of current and future trends in spectrum use, ITS performs broadband spectrum measurements at selected locations and on selected wideband devices. Measurements are performed on both Government and non-Government devices, as either category may potentially cause interference to Government systems. The results of these measurements are provided to the NTIA Office of Spectrum Management (OSM), to spectrum management offices in other Federal agencies, and to the public in the form of NTIA Reports. Spectrum surveys and emission measurements on individual devices can be performed for Other Agency sponsors and private industry on a reimbursable basis.

In fiscal year 1998, ITS, OSM, and the Federal Communications Commission (FCC) embarked on a joint technical effort to quantify spectrum emissions from new-technology ultrawideband (UWB) transmitters. Designed to be used as both short-range radars and as communication devices, these systems produce intentional emissions which are typically several gigahertz wide. They represent a new challenge to U.S. spectrum managers because their emissions cannot be confined within a single band allocation. These devices are being developed commercially, but may eventually be procured by both the private sector and by Government agencies. The joint measurements were performed by NTIA and FCC personnel at the FCC Columbia, MD laboratories, and utilized an ITS suitcase measurement system. Results of these measurements on a UWB transmitter are shown in Figure 1. The measurements quantified the spectrum occupancy impact of these devices. The results are being used to determine the conditions under which these devices may be able to share spectrum with other systems and services.

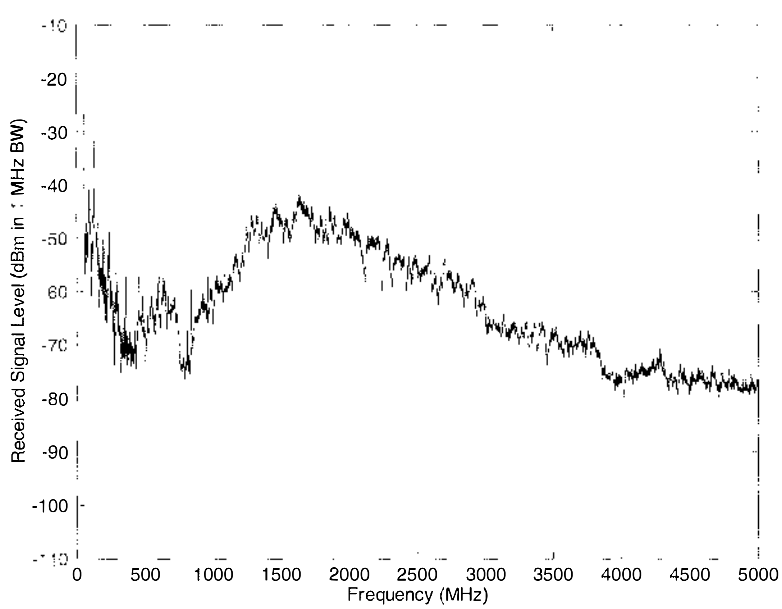


Figure 1. Spectrum of a UWB device emission.

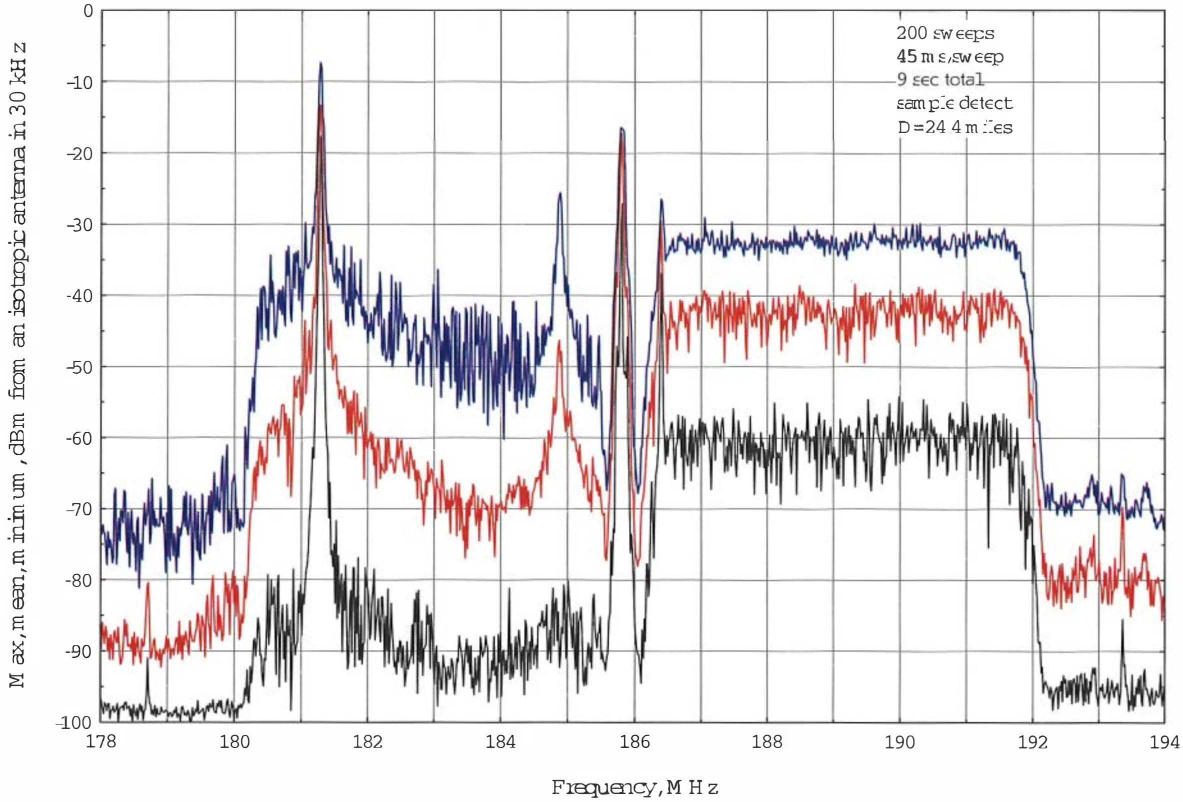


Figure 2. Spectra of analog TV (180-186 MHz) and DTV (186-192 MHz) transmissions side-by-side.

Digital television (DTV) represents another newly developed technology whose deployment is presenting new challenges for spectrum management. To determine the relative impact of DTV transmissions and existing analog television transmissions (which are gradually being phased out as DTV is introduced), the ITS Radio Spectrum Measurement System (RSMS, see p. 86) was deployed to Dallas, TX to measure simultaneous emissions from a DTV transmitter and an adjacent-channel analog transmitter to determine relative impact of the two types of signal in the spectrum. The two signals were being transmitted from the same tower and were covering the same broadcast area. Therefore, all emission factors were controlled except the signal modulation. Figure 2 shows the measurement results. This measurement demonstrates that for narrow receiver bandwidths, DTV signals may produce less impact than analog television signals, but that for wider receiver bandwidths, it is possible for DTV signals to couple more energy into receivers than do conventional analog television signals. The RSMS measurements quantified this effect as a function of bandwidth.

Finally, the ambient radio noise environment at the Dept. of Commerce Radio Quiet Zone near Boulder, CO was quantified by an RSMS standard broadband spectrum survey between 30 MHz to 19.7 GHz. A similar survey was performed at the NIST outdoor antenna range at the Boulder laboratories. The results of these surveys are being used to plan for future development and use of these facilities.

For more information, contact:
Frank H. Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Spectral Assessment of Government Systems

Outputs

- Spectrum emission measurements on prototype dedicated short-range communication systems for the Federal Highway Administration.
- Performance measurements on maritime mobile radio receivers.
- Measurements of Coast Guard maritime radio channel availability along the lower Mississippi River.

Growing numbers of spectrum users and new communication technologies are placing increasing demands upon the national spectrum. New spectrum demands often generate electromagnetic compatibility (EMC) problems that threaten Government radio operations, and it is necessary to proactively analyze and resolve such EMC problems for new systems. Further, in the event that new or existing Government systems do experience EMC problems at field locations, it is necessary to resolve these problems promptly and efficiently. ITS provides extensive EMC measurement and analysis capabilities for the solution of EMC problems.

In 1998, ITS resolved existing and potential EMC problems with the following organizations: NTIA Office of Spectrum Management (OSM), Federal Highway Administration (FHWA), U.S. Coast Guard (USCG), and the Radio Technical Commission for Maritime Services (RTCM).

As part of a study for FHWA to determine technical requirements for Intelligent Transportation Systems (see Intelligent Transportation Systems Planning, pp. 40-41), ITS measured spectrum emissions from prototype dedicated short-range communication (DSRC) systems such as may be used for automated toll collection stations. The emissions from one such device are shown in Figure 1. This measurement determined the feasibility of spectrum sharing between this type of system and other systems in the same band.

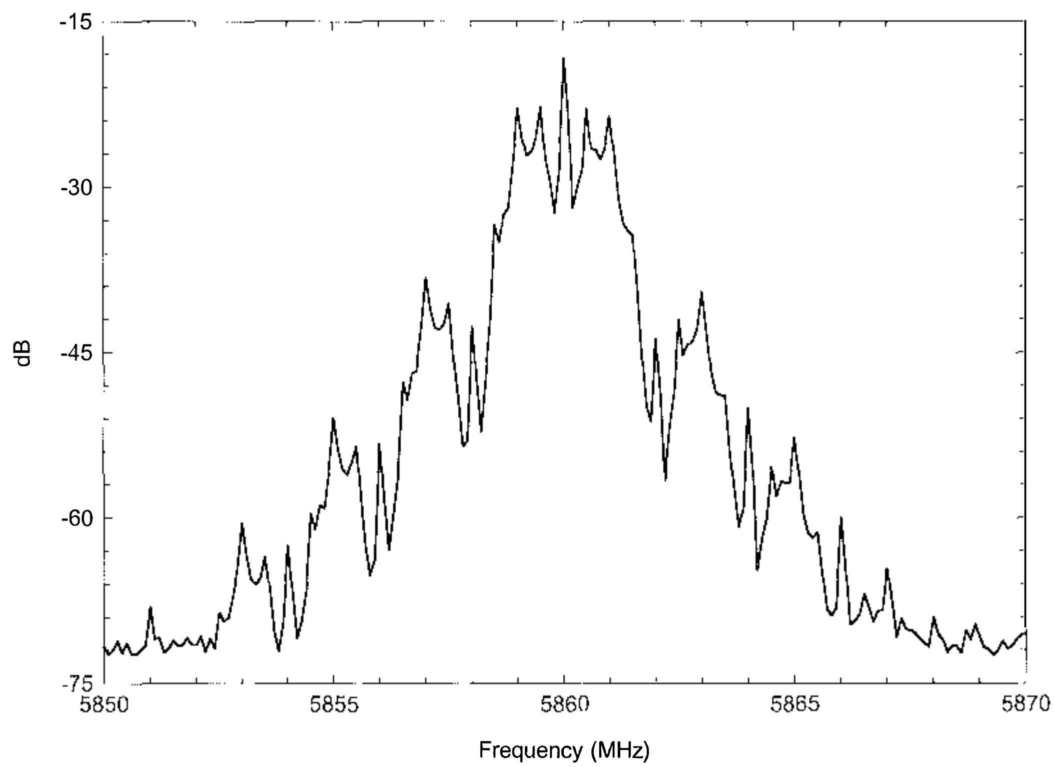


Figure 1. Spectrum of a DSRC device emission for FHWA study. Note separate emissions from the base station and the vehicular beacon.

Another concern of spectrum managers is the performance of mobile radio receivers in crowded spectrum when strong signals occur on frequencies other than the desired frequency. This problem has become acute in many areas for maritime mobile radios. ITS, along with OSM, USCG, and RTCM, therefore performed a series of measurements of a parameter called the intermodulation rejection ratio for several maritime radio types. In these tests, desired and off-frequency (potentially interfering) signals were combined and fed into the test radios. The test results were used to determine the susceptibility of the radios to this type of interference, and also to determine the signal levels that would be needed for USCG Vessel Traffic Service (VTS) transmitters in metropolitan environments. An interference problem in Savannah, GA was solved by this work.

A related problem is the limited availability of clear channels for VTS communications. Availability of clear channels is critical to the success of VTS. To measure channel availability, ITS personnel transported a suitcase measurement system (see Radio Spectrum Measurement Systems, p. 86) to the lower Mississippi River and operated it aboard a boat, in a land vehicle, and at a series of VTS base stations. As the system moved along the river (and while installed at each base station), the quality of VTS radio channels was continuously assessed and recorded. For each measurement, a desired signal was fed into a marine radio receiver in combination with ambient signals from an outdoor antenna. Outputs from a computerized signal to interference noise and distortion (SINAD) meter were recorded along with time and position data from a global positioning system (GPS) receiver. SINAD values indicated the quality of the channel for use by VTS as a function of both time and position along the river. A resulting graph is shown in Figure 2. This task has been critical to the successful deployment of this portion of VTS.

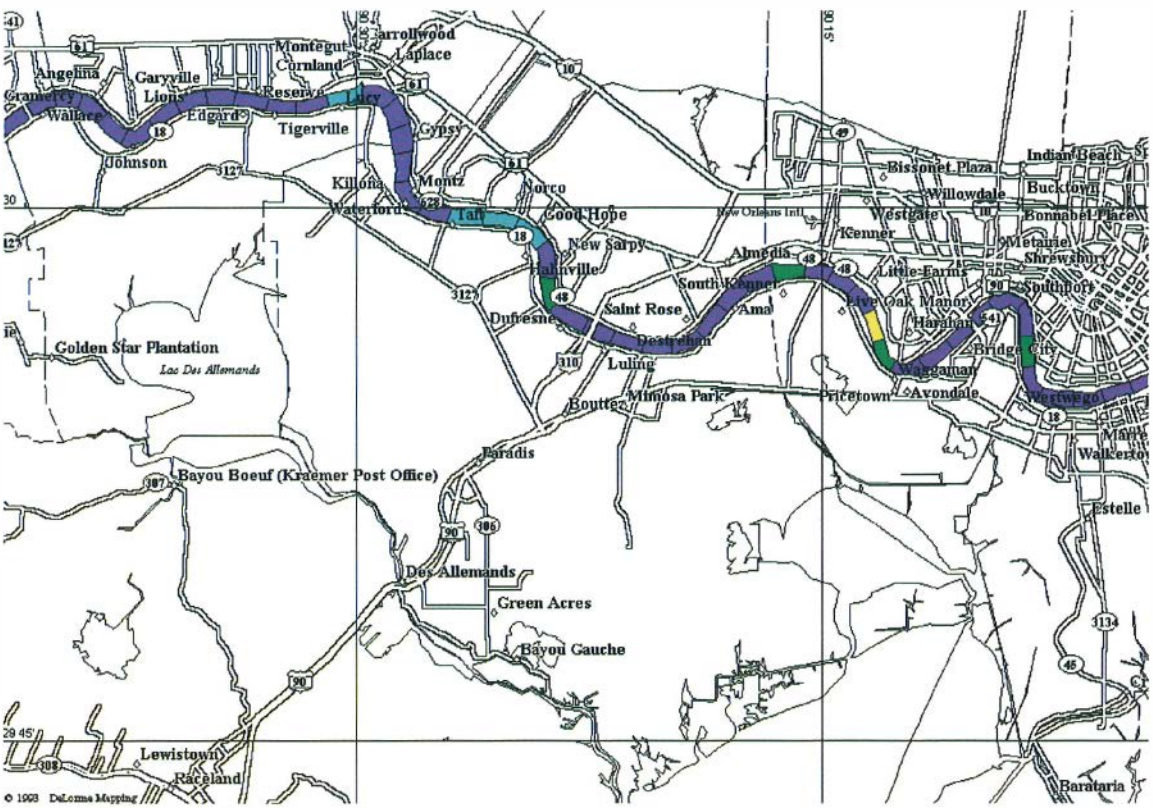


Figure 2. Mississippi river coverage map for Coast Guard VTS study.

Yellow = 04 - 07.9 dB
Green = 08 - 11.9 dB
Blue = 12 - 15.9 dB
Violet = 16 - > dB

For more information, contact:
Frank H. Sanders
(303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Radio Frequency Interference Monitoring System

Outputs

- Initial (prototype) Radio Frequency Interference Monitoring System (RFIMS) unit designed, developed, tested, and delivered to Federal Aviation Administration (FAA).
- Two production RFIMS units delivered to FAA.
- Patent obtained for automated measurement of air traffic control radar beacon system (ATCRBS) antenna patterns.

ITS offers expertise in custom measurement system design to other Federal agencies and industry. One such design effort is the Federal Aviation Administration (FAA) Radio Interference Monitoring System (RFIMS), with units to be provided nationwide to every FAA region. Under the RFIMS program, ITS personnel analyzed FAA requirements and developed an automated, custom-designed radio spectrum measurement system; integrated and tested a prototype mobile system; and have now integrated and tested two (of eleven total) production systems. ITS also plans and manages associated support requirements including documentation, training, and operation of the RFIMS Development Lab located in Boulder.

The RFIMS managerial effort was divided into three tasks. Task I included assessment of requirements, option evaluations, and development of a measurement system specification. Task II included system acquisition and testing of a prototype RFIMS, delivered in February 1998 to Western Pacific Headquarters (Figure 1). In Task III, ITS is continuing integration, testing, delivery, and training required for the remaining eight of the total eleven systems. Software management, development, and documentation have played and continue to play a critical role in all three RFIMS Program Tasks.

The RFIMS technical program was organized by ITS into three major sub-systems: the vehicle, the Integrated Electronic Package (IEP) hardware, and the measurement control system (MCS) software. The vehicular platform is a Ford Econoline outfitted with three six-foot equipment racks. The IEP is primarily commercial off-the-shelf measurement equipment, but includes two pieces of equipment developed and assembled at ITS. These are a unique mast-top signal preamplifier and preselector system, and an automated antenna controller. The MCS (written in LabView©) controls the measurement system, and records and documents every measurement. Information automatically recorded in every scan includes data, correction factors for antennas, measurement system gains and losses, and equipment parameter settings.

The MCS incorporates a suite of custom measurement routines specified by the FAA. These automated capabilities allow the FAA to perform standardized computer-controlled measurements that would be impractical to perform manually. This includes measurements that require highly repetitive tasks during measurements and extensive post processing. Such measurements would theoretically require weeks to perform by hand, and would

Figure 1. Prototype RFIMS at Los Angeles International Airport (photograph by P. Raush).

produce unreliable results. An example of an MCS automated measurement is the Air Traffic Control Radar Beacon System (ATCRBS) antenna pattern assessment. This measurement utilizes a unique algorithm that resulted in a patent for novel use of software and hardware to determine directional and omni-directional antenna patterns without interrupting beacon operations. Figure 2 shows the ATCRBS measurement panel.

The algorithm collects multiple frames of radar pulse data. Each data frame is sorted into directional and omni-directional pulse sets, normalized, and then plotted on a polar graph. Previous techniques for creating ATCRBS antenna patterns used either expensive pulse sorting hardware or required an interruption of the ATCRBS to make the measurement. Since ATCRBS is a primary air control tool, such operational interruptions are a safety concern, and development of this algorithm for the FAA was a breakthrough in this type of measurement.

The RFIMS Program is an excellent example of how ITS can assist other Federal agencies with their spectrum measurement needs. The combination of hardware and software engineering expertise and knowledge of spectrum monitoring and measurement techniques allows ITS engineers to assist other agencies with their automated spectrum measurement design and development needs.

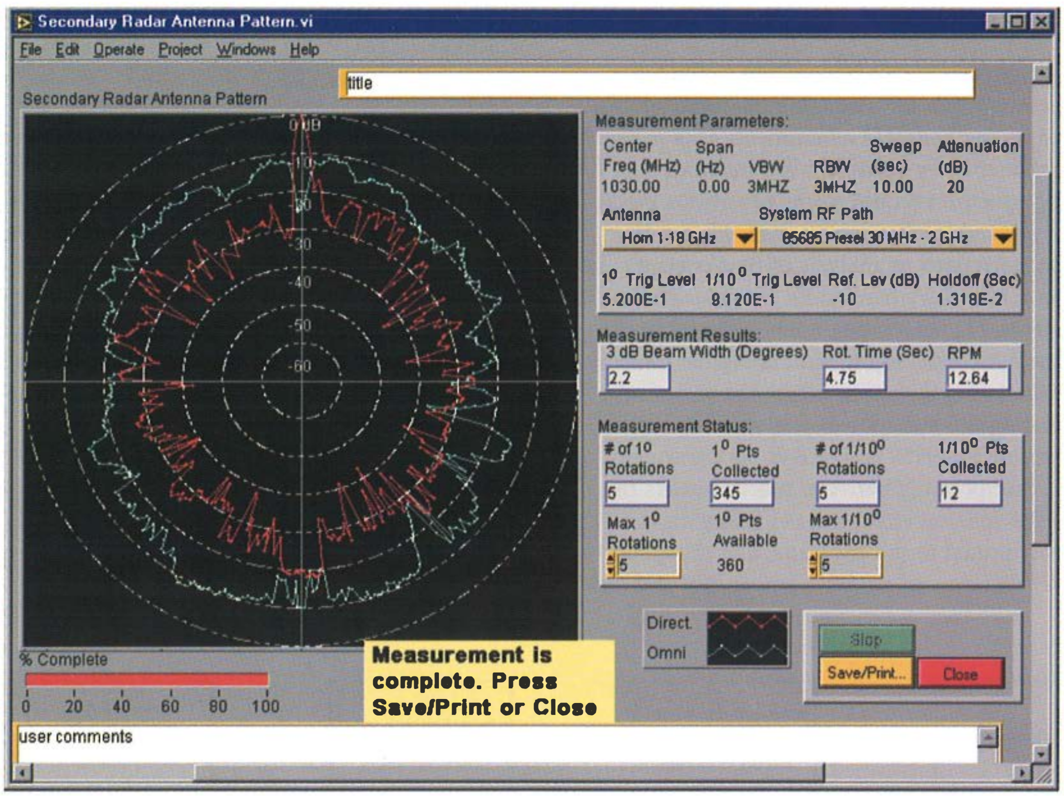


Figure 2. The ATCRBS measurement panel.

Recent Publication

P. Raush, J. Kub, B. Bedford, T. Sparkman, S. Davidson, and E. Gray, "The radio frequency interference monitoring system (RFIMS)," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998

For more information, contact:
Patricia J. Raush
(303) 497-3568
e-mail praush@its.bldrdoc.gov

Modulation Bandwidth Requirements

Outputs

- Power spectral density for signal parameters and percent power within a bandwidth.
- Spectral peak locations with spline interpolation between peaks for envelope.
- Nth degree polynomial fit to envelope using mean-square-error (MSE) criterion.
- Spectral envelope rolloff as a function of bandwidth (BW).

The Office of Spectrum Management (OSM) in NTIA is responsible for managing the radio spectrum used by the Federal Government. This research supports the OSM by establishing a methodology for specifying spectrum requirements of various modulations employed by the Government. Figure 1 shows the steps used in analysis of the spectrum and establishing necessary bandwidth formulas (NBWF). This includes: (1) calculating a modulation spectra from an analytic equation or simulating the transmitter and calculating the spectra from the waveform, (2) calculating the total power contained in a BW and specifying the 99% power BW parametrically, (3) spline interpolating between spectral peaks to establish the spectral envelope, (4) fitting an nth degree polynomial to the envelope, and (5) specifying NBWF in terms of the 99% power BW and the polynomial describing the spectral envelope. With these results, the NBWF can be specified in terms of: (1) meeting the 99% power BW and (2) an efficient spectrum requirement of keeping a proposed modulation rolloff within the spectral envelope (or a specified deviation). This analysis was applied to orthogonal frequency division multiplexing (OFDM), also referred to as multicarrier modulation (MCM), and minimum-shift-keying (MSK) that provides an analytically tractable baseline for comparison with other modulations. Additional modulations under investigation include: (1) Gaussian minimum-shift-keying (GMSK), (2) Feher quadrature phase shift keying (FQPSK), and (3) Multi-h continuous phase modulation.

Analysis results for OFDM are shown in Figures 2-5. Figure 2 describes the major blocks of the transmitter where T, the data block length, is used in normalizing the analysis results. The spacing of the multi-carriers is 1/T in Figure 3 and frequency axes are normalized to T. The one-sided power spectrum is shown in Figure 3 along with spectral peaks (triangles) and the resulting envelope fitted with a 15th degree polynomial. Lower order polynomials can be used to specify the envelope with a resulting increase in the MSE. The spectral envelope rolloff BW is specified by another 15th degree polynomial in Figure 4 and the percentage of total power contained in a BW is given in Figure 5.

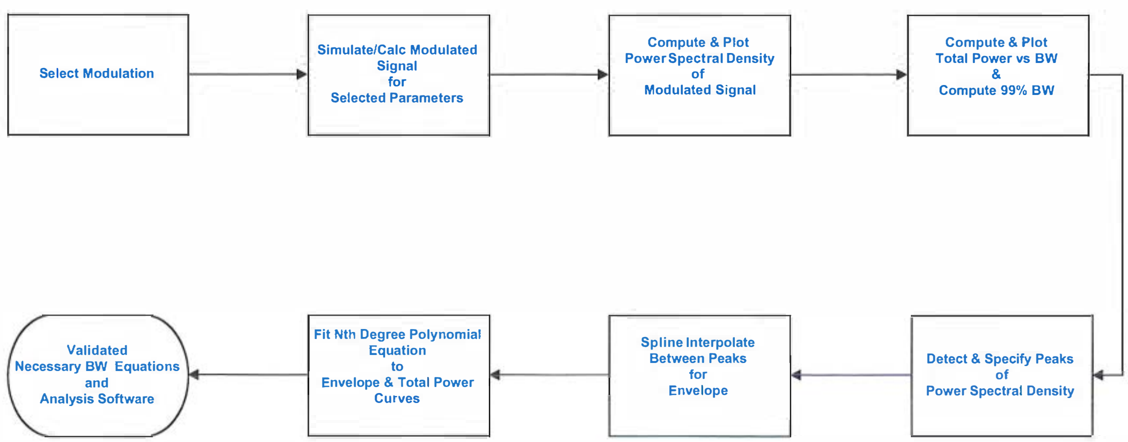


Figure 1. Spectral analysis of modulations flowchart.

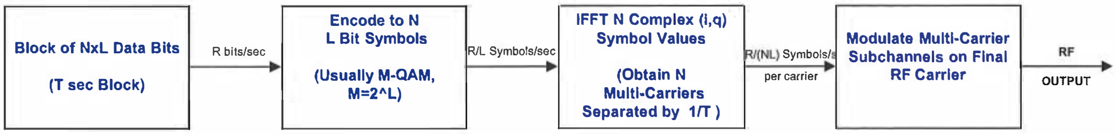


Figure 2. OFDM transmitter.

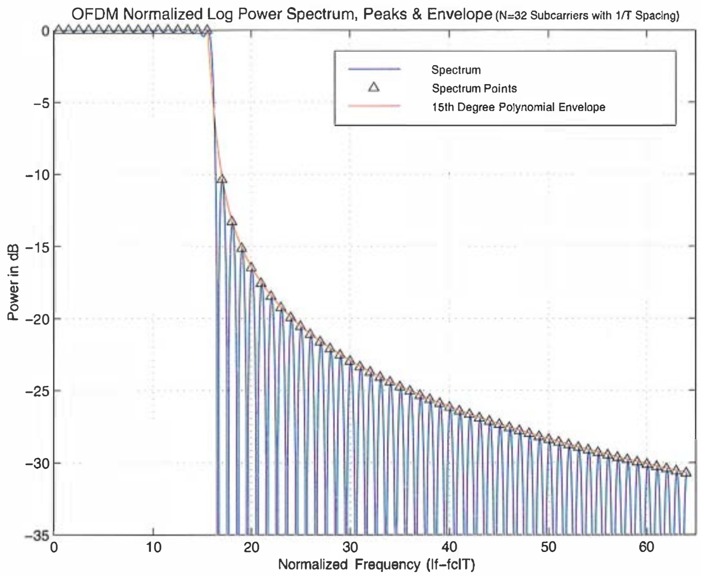


Figure 3. OFDM power spectrum and envelope.

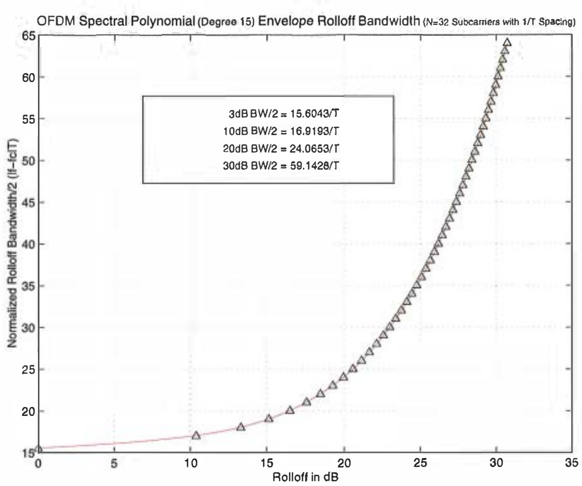


Figure 4. OFDM spectral envelope rolloff BW.

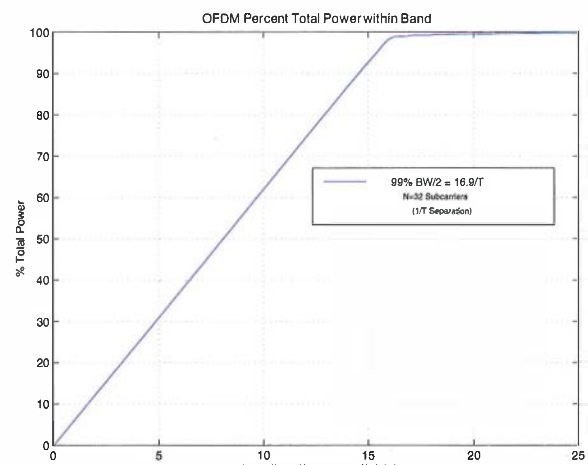


Figure 5. OFDM percent power within a bandwidth.

For more information, contact:
Edmund A. Quincy
(303) 497-5472
e-mail equincy@its.bldrdoc.gov

ITU-R Activities

Outputs

- Preparation of technical standards and recommendations supporting U.S. positions at radio conferences.
- Leadership of U.S. participation in key ITU-R study groups.
- Coordination of U.S. positions on issues related to ITU-R recommendations.

The International Telecommunication Union - Radiocommunication Sector (ITU-R) is the ITU body responsible for developing international standards (ITU-R Recommendations) for radio systems. The United States supports the efforts of the ITU-R to ensure compatibility between radio systems operating in this country and those operating in neighboring countries and to promote commerce by providing telecommunication system standards that U.S. companies can use to develop products for international markets. The Institute provides leadership and expertise in the development of the recommendations, both to support U.S. interests and to ensure high-quality, worthwhile international radio system standards.

The international growth in telecommunications technology and the demand for communication services has compelled the ITU to provide more timely information and standards. In the past, the introduction of new telecommunication services would take years of research and development; now faster development and implementation is required. Communication service providers are anxious to develop new services, provide alternative forms of competition, and let the marketplace determine the fate of new services.

To meet the demand for international standards, the ITU-R has divided its work program into study groups that develop recommendations. As study groups meet infrequently (with some only meeting every 2 to 4 years), each study group is subdivided into working parties and task groups that provide a continuous forum for the development of recommendations on particular issues for the study group. The ITU-R is comprised of eight study groups; the first two consider spectrum utilization and propagation issues and the latter study groups manage service-oriented issues (see the Table).

ITU Study Groups & Associated Areas of Concern

Study Group	Area of Concentration
1	Spectrum management
3	Radiowave propagation
4	Fixed-satellite service
7	Science services
8	Mobile, radiodetermination, amateur, and related satellite services
9	Fixed service
10	Broadcasting service - sound
11	Broadcasting service - television

Just as international study groups of the ITU-R address specific radio system technologies, the United States has a corresponding set of national committees that prepare U.S. documents for consideration by the international committees. The particular topics treated by each study group vary to meet current needs and to reflect the topics that will be discussed at forthcoming radio conferences. The recommendations of the ITU-R are used to establish technical criteria that are the basis for spectrum allocation decisions and spectrum use, both globally and regionally. In addition, the agreements reached at the World Administrative Radio Conferences become international treaties for the United States. Therefore, it is important to the United States that ITU-R documents accurately reflect the U.S. position on important spectrum policy matters.

While the ITU-R Recommendations describe the radiocommunication propagation methods and models, the Recommendations do not give guidance on how to use the Recommendations nor which Recommendations should be used in various situations. The ITU has started the process of providing handbooks that give advice on use of the Recommendations. During the past study session, the U.S. has proposed a draft new Handbook, intended to guide the user with practical advice on the application and interpretation of propagation calculations in the Land Mobile Radio Service. The proposed Handbook will cover the following areas:

- General Path, Propagation Loss Models
- Propagation Loss Models for Terrain Obstructed Paths
- Propagation Effects due to Ground Clutter
- Propagation Loss Models for Within Building and Underground Paths
- Characteristics of Environmental Noise
- Characteristics of Signal Variation
- Characteristics of Delay Spread

The Handbook will provide the user with the appropriate Recommendations that should be used for a particular situation, and provide references to other material in the literature that the user can access.

An example of how the U.S. contributes to the development of models, consider the problem of characterizing propagation loss into a forested region. The Figure below shows a transmitter T outside an area of woodland or vegetation and a receiver R inside the vegetation at a distance d from the point P where the direct ray from T to R enters the vegetation. The vegetation excess loss L is defined as the basic transmission loss between T and R minus the smaller transmission loss which would exist were the vegetation absent but with all other conditions the same. The Figure also shows the variation of L with d according to the expression:

$$L = A\,(1 - k\text{-}d) \qquad (1)$$

where

d = distance in meters

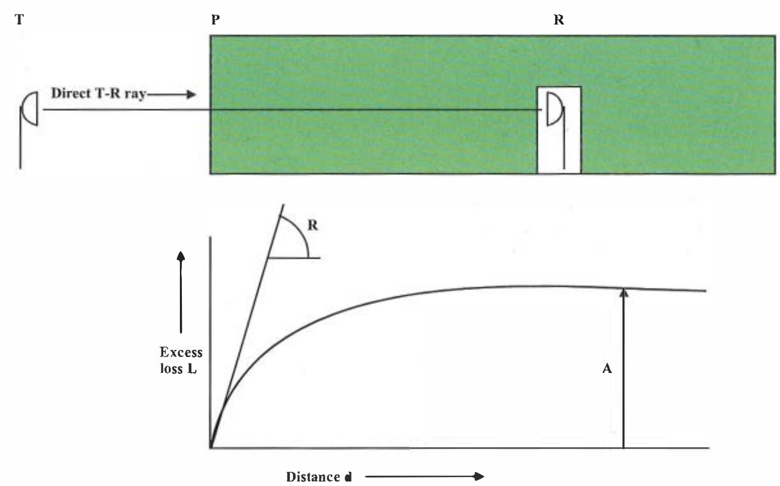
$$k = \exp\,(R/A) \qquad (2)$$

and

R = initial specific attenuation rate in dB/m

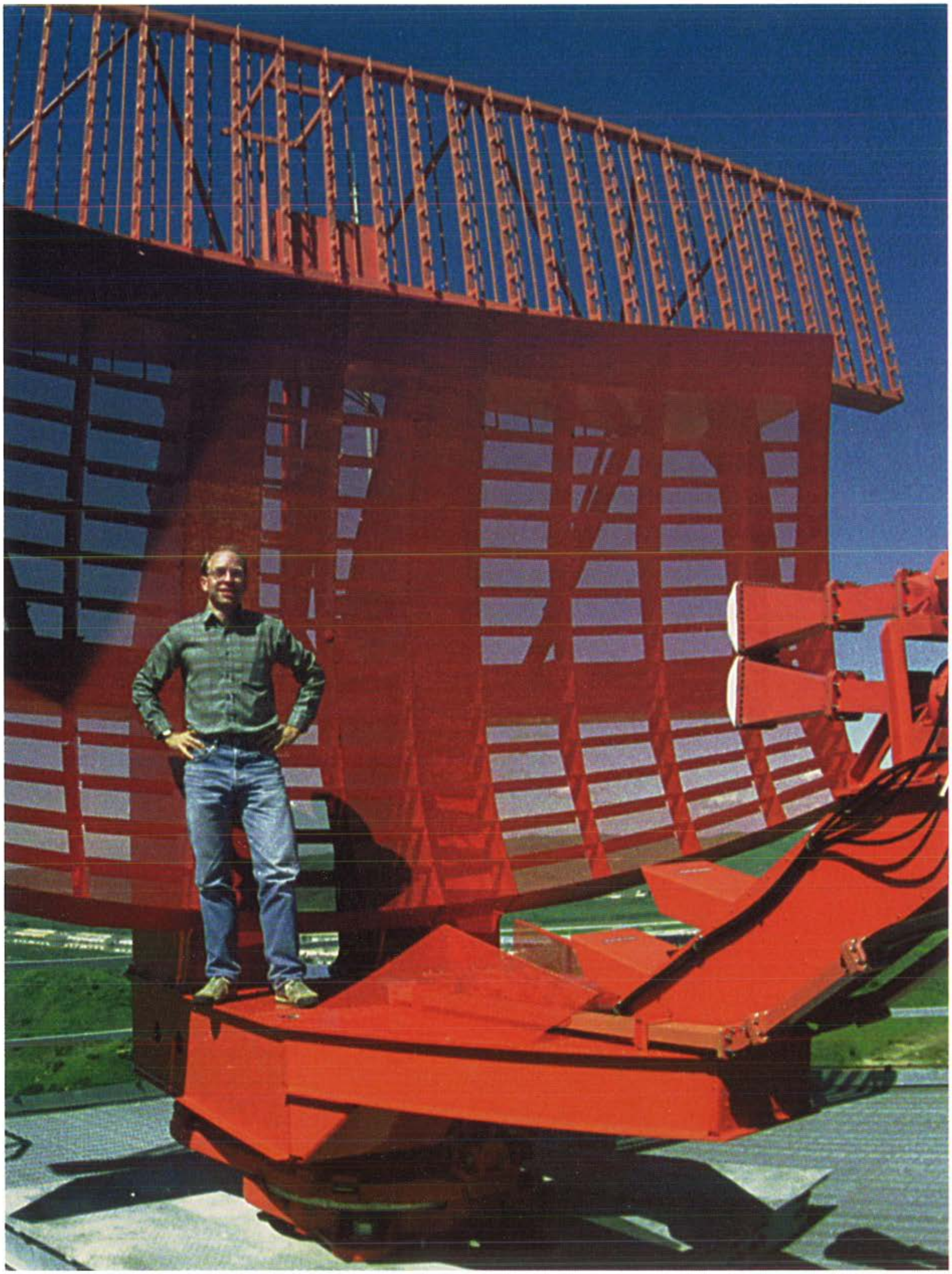
A = maximum vegetative excess loss for one terminal within vegetation.

The initial specific attenuation rate R is due to absorption or scattering from the direct ray from T to R. It is a function of the type, density and condition of the vegetative cover. The maximum excess loss A is the value to which L becomes asymptotic with a sufficient increase in d. It is a function of vegetation type, density, condition and geometry (e.g. canopy height), as well as antenna height in relation to canopy height, and probably of antenna beamwidth. The physical basis for A is that above a certain attenuation of the direct T-R ray, energy will reach R primarily via other paths, such as over the top of the vegetative cover, reaching R by surface-wave mechanisms at the air-vegetation interface in a manner analogous to ground-wave losses over imperfectly-conducting terrain. The objective by the U.S. and other Administrations of the ITU-R is to facilitate experimental work leading to a table of parameters on vegetation losses, which would be useful in radio system planning.



A transmitter T outside an area of vegetation, and a receiver R inside the vegetation.

For more information, contact:
Eldon J. Haakinson
(303) 497-5304
e-mail eldon@its.bldrdoc.gov



ITS engineers routinely assess emissions from high-power radars. Pictured is a radar measured at Camp Pendleton, California. The ITS engineer is standing on the antenna during a lull in the measurements, when the radar was not radiating (photograph by F.H. Sanders).

Telecommunication Standards Development

The Institute contributes significantly to the development and application of national and international telecommunications standards. These standards provide a technological framework for evolving U.S. and global information infrastructures, promote innovation and competition in telecommunications products and services, and enhance international trade opportunities for U.S. telecommunications firms. Institute staff members provide leadership and technical contributions to key national and international standards committees, including the American National Standards Institute-accredited Committee T1, the Telecommunications Industry Association (TIA), the Federal Telecommunications Standards Committee (FTSC), the International Telecommunication Union's Telecommunication Standardization and Radiocommunication Sectors (ITU-T and ITU-R), and others. The technical standards and recommendations developed in these forums are blueprints for technology evolution and can influence billions of dollars in telecommunications research and development investments worldwide.

Areas of Emphasis

Video Quality Standards Development

The Institute develops and implements perception-based, technology-independent video quality measures and promotes their adoption in national and international standards. Projects are funded by NTIA and by the National Communications System (NCS).

Audio Quality Standards Development

The Institute conducts research and development leading to standardization and industry implementation of perception-based, technology-independent quality measures for voice and other audio communication systems. Projects are funded by NTIA and NCS.

Broadband Networks

The Institute contributes to the development and effective use of Asynchronous Transfer Mode (ATM) and advanced Internet technologies through laboratory measurements and technical contributions to national and international performance standards committees. Projects are funded by NTIA and NCS.

Telecommunication Terminology Standards

The Institute leads the development of telecommunication terminology standards in Federal, national, and international fora and contributes to their dissemination in Internet-accessible hypertext and other innovative publication media. Projects are funded by NCS.

Wireless Standards Support

The Institute contributes to the development of industry standards for personal communications services and provides objective testing and evaluation of the associated technologies. Projects are funded by NTIA, the Federal Highway Administration, the Federal Railroad Administration, and NCS.

Law Enforcement Telecommunication Standards

The Institute provides engineering support, scientific analysis, technical liaison, and testing to assist NIST's Office of Law Enforcement Standards (OLES) in the development and validation of criminal justice communications standards and other communication system products supporting law enforcement and corrections needs. Projects are funded by OLES.

ITU-T Standardization Activities

The Institute leads U.S. ITU-T preparatory committees and related international work groups, provides technical contributions to ITU-T standardization activities, and drafts proposed ITU-T recommendations and compatible national standards. Projects are funded by NTIA.

Video Quality Standards Development

Outputs

- Contributions to national and international video quality measurement standards.
- Automated video quality measurement techniques and prototype instrumentation.
- Technical input to development of U.S. policies on advanced video technologies.

Digital video compression and transmission techniques offer an economical means of implementing video communication services in emerging national and global information infrastructures. However, these techniques cause received video quality to change dynamically depending upon scene complexity (e.g., spatial detail, motion) and transmission channel operating characteristics (e.g., bit rate, dropped packets). Hence, to accurately measure the received quality experienced by the end-user, performance measurements must be made in service (i.e., using the same program material the end user sees). ITS engineers have addressed this problem through the development and standardization of a fundamentally new methodology for video quality assessment. The patented, ITS-developed methodology can efficiently make in-service measurements that are highly correlated with the subjective assessments of human viewer panels.

The ITS-developed video quality assessment methodology was adopted as a national standard by the American National Standards Institute (ANSI) in 1996 (ANSI T1.801.03). During FY 97 and FY 98, ITS engineers made significant enhancements to the flexibility and accuracy of the original measurement techniques. These enhancements were submitted in FY 98 to the International Telecommunications Union (ITU) Video Quality Experts Group (VQEG) to be considered for international standardization.

The enhanced methodology adds fine spatial impairment measurements to the techniques described in ANSI T1.801.03, while maintaining flexible provisions for in-service measurement. Quality parameters are computed from features that are extracted from spatial-temporal (S-T) regions of input and output video scenes, as shown in Figure 1. This figure illustrates two S-T region sizes, 8 pixels x 8 lines x 1 frame and 2 pixels x 2 lines x 6 frames. Since the features extracted from these S-T regions require only a small transmission bandwidth in comparison with the bandwidth required to send the 270 Mbit/s ITU-R Recommendation BT.601 digital video streams, they can be readily transmitted and/or stored as ancillary information. The S-T region size determines the ancillary information bandwidth required. In-service methods based on this approach are anticipated to have the widest possible application, since the measurement resolution can be

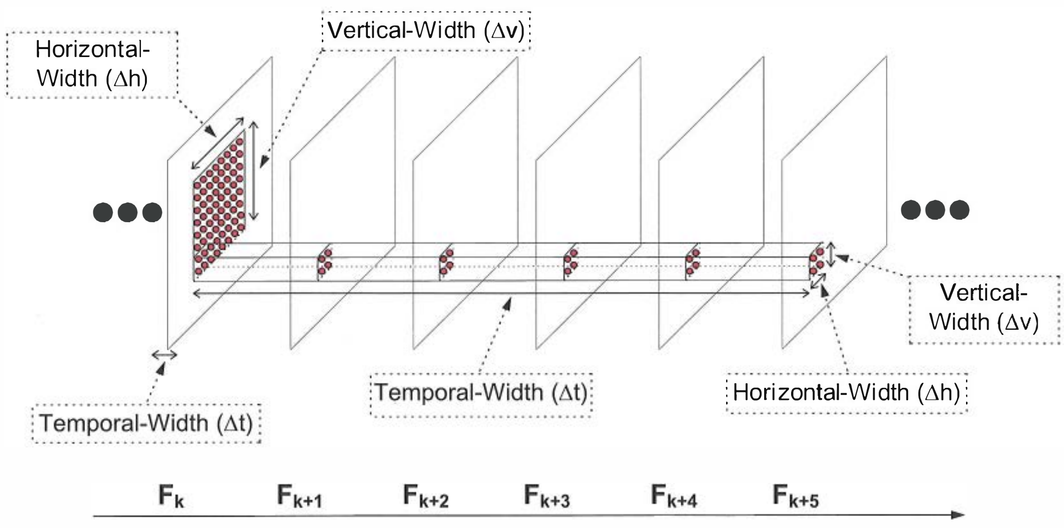


Figure 1. Illustration of spatial-temporal (S-T) regions for a video scene.

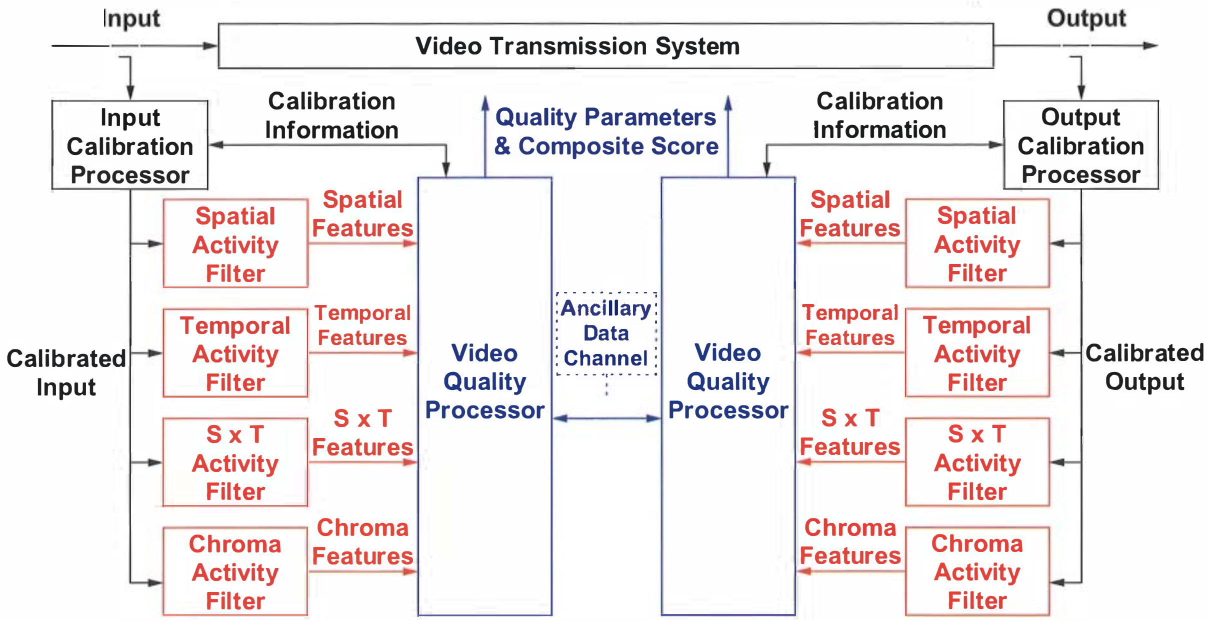


Figure 2. Measurement system overview.

adapted to accommodate the available ancillary information bandwidth. In some applications, such as network control and fault monitoring, the available ancillary information bandwidth might be quite low, while in other applications, such as laboratory testing of a video codec, the available ancillary information bandwidth might be quite large. In the latter application, smaller S-T region sizes can be used to achieve greater measurement accuracy.

Figure 2 illustrates a non-intrusive in-service video quality monitoring system based on this approach.

Recent Publications

G.W. Cermak, S. Wolf, E.P. Tweedy, M.H. Pinson, and A.A. Webster, "Validating objective measures of MPEG video quality," *SMPTE Journal*, vol. 107, no. 4, pp. 226-235, Apr. 1998.

C. Fenimore, J. Libert, and S. Wolf, "Perceptual effects of noise in digital video compression," in *Proc. 140th SMPTE Technical Conference*, Pasadena, CA, Oct. 1998.

S. Wolf and M. Pinson, "In-service performance metrics for MPEG-2 video systems," in *Proc. Made to Measure 98 — Measurement Techniques of the Digital Age Technical Seminar*, International Academy of Broadcasting, ITU, and Technical University of Braunschweig, Montreux, Switzerland, Nov. 1998.

The system can measure the video delay, spatial shift, gain, and level offset of the video transmission system, as well as parameters that indicate perceptual distortions in four aspects of video quality: spatial, temporal, chrominance (i.e., color), and spatial x temporal (spatial-temporal cross product). Spatial features characterize the activity of image edges. A digital video system can add edges (e.g., edge noise) or reduce edges (e.g., blurring). Temporal features characterize the activity of temporal differences (motion) between successive frames. A digital video system can add motion (e.g., error blocks) or reduce motion (e.g., frame repeats). Chrominance features characterize the activity of color information. A digital video system can add color information (e.g., cross color — black edges on white backgrounds that produce color artifacts) or reduce color information (e.g., color sub-sampling). A cross product of spatial features and temporal features allows one to account for relative impairment masking (i.e., reduced visibility of impairments) in areas of high spatial-temporal activity. The measurement system also produces a composite score that is representative of the overall subjective video quality. For more information, see http://its.bldrdoc.gov/n3/video/

For more information, contact:
Stephen Wolf
(303) 497-3771
e-mail swolf@its.bldrdoc.gov

Audio Quality Standards Development

Outputs

- Objective audio quality assessment and optimization algorithms.
- Reports on relationships between signal processing parameters and perceived audio quality.
- Related telecommunications standards and recommendations.

Technology advances have greatly expanded the available options for encoding and transmitting audio signals — and created an urgent need for technology-independent audio quality assessment techniques. Toll-quality speech can now be transmitted or stored at bit rates as low as 8 kbit/s. Fully intelligible, lower quality speech can be transmitted or stored at bit rates down to about 1.6 kbit/s. These advances have enhanced the capacity and efficiency of both wired and wireless telecommunications systems. High-quality audio signals, such as music and entertainment soundtracks, can now be encoded at rates as low as 32 or 64 kbit/s per channel, enabling the efficient storage and dissemination of those signals.

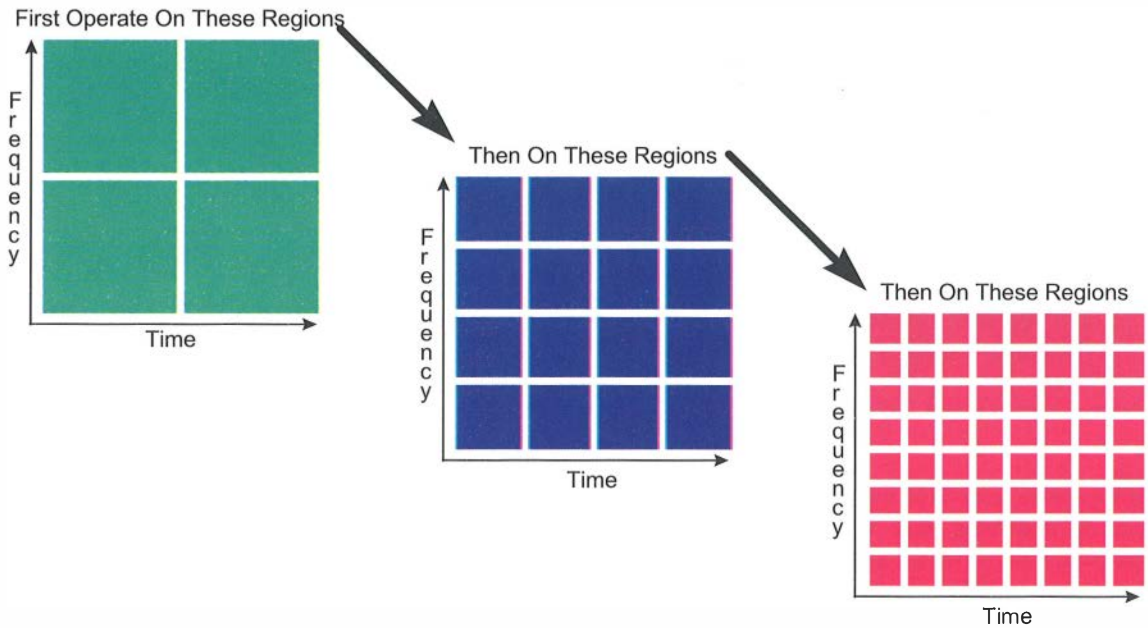
The transmission of audio signals is also being changed fundamentally as new technologies are introduced. Encoded audio signals can be carried as data packets through networks, sharing capacity with other data streams in teleconferencing, distance learning, and multimedia services.

These technology advances and the associated economic trade-offs have created important new measurement issues. Equipment manufacturers, service providers, and users all need audio quality assessment methods that work no matter how a signal has been encoded and transmitted. Increasingly complex, time-varying interactions among audio signal content, source coding, channel coding, and channel conditions have made it impossible to determine end-to-end quality from individual component specifications. Not surprisingly, traditional waveform reproduction measures developed for wired 4-kHz analog telephony are ineffective in assessing the listener-perceived quality of today's digital speech and audio systems. The most fundamental and correct measures of audio quality are the subjective responses of users. These responses can be obtained by conducting subjective listening experiments, but the time and cost of such experiments is often difficult to justify.

In its Audio Quality Standards Development program, the Institute is developing practical alternatives to controlled subjective listening experiments: digital signal-processing algorithms that objectively estimate perceived audio quality as determined in subjective listening experiments. Quality estimates generated by these algorithms are compared with listening experiment results to ensure that the selected algorithms accurately reflect human perception over a wide range of encoding techniques and channel conditions.

The ITS approach to the development of objective audio quality assessment algorithms is *perception based*. Recent ITS work has produced a family of fundamentally new algorithms called the Measuring Normalizing Block (MNB) algorithms. These algorithms work because they model both human hearing and human judgement. A psychoacoustic frequency scale and a model for nonlinear loudness growth are included in the hearing model. The judgement model involves measuring and normalizing spectral deviations at multiple time and frequency scales. In order to best emulate listeners' patterns of adaptation and reaction to spectral deviations, the measuring normalizing blocks are combined so that analysis proceeds from larger scales to smaller scales, as illustrated in the Figure. ITS has applied for a patent on these innovative audio quality estimation algorithms.

During FY 98, project staff members worked through American National Standards Institute (ANSI)-accredited standards Working Group T1A1.7 (Signal Processing and Network Performance for Voiceband Services) to develop and gain approval for the ANSI telecommunications standard T1.518-1998. This standard defines an MNB algorithm and describes how it can be used to objectively estimate perceived speech quality of 4-kHz bandwidth telecommunication systems. The Institute is also contributing to the work of the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) Study Group 12. A project staff member serves as Associate Rapporteur



Example time-frequency analysis regions for MNB algorithms.

for Question 13/12, which addresses methods of modeling and measuring nonlinear distortion processes in voice transmission. In FY 98, approval was gained for ITU-T Recommendation P.861, Appendix II, providing an MNB algorithm to the international telecommunications community.

Project staff applied the MNB algorithms to many different telecommunications devices in FY 98. Digital and analog radios, software speech codecs, and voice-over-Internet systems were all evaluated by the MNB algorithms. Objective estimates of perceived speech quality were generally found to be in good agreement with subjective listening test results. These objective-subjective comparisons provide valuable information for the future refinement and extension of the MNB algorithms.

Project staff also designed, conducted and analyzed a subjective conversation test for an industry partner under a cooperative research and development agreement. Other subjective listening tests were performed to gather more information to extend the MNB algorithms to address conditions outside their present scope. Analysis of other, less effective objective estimators was completed, and an MNB algorithm was used to optimize a speech coder.

Project staff members disseminated objective audio quality assessment results to industry, Government, and academia through numerous technical publications and presentations and laboratory demonstrations during FY 98. Laboratory demonstrations focused on prototype audio quality test instruments that implement MNB algorithms in near real time.

Recent Publications

S. Voran, "Perception-based bit-allocation algorithms for audio coding," in *Proc. 1997 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, New Paltz, NY, Oct. 1997.

S. Voran, "Objective estimation of perceived speech quality using measuring normalizing blocks," NTIA Report 98-347, Washington, D.C., Apr. 1998.

S. Voran, "A simplified version of the ITU algorithm for objective measurement of speech codec quality," in *Proc. 1998 IEEE International Conference on Acoustics, Speech and Signal Processing*, Seattle, WA, May 1998.

S. Voran, "Observations on frequency domain companding for audio coding," in *Proc. 8th IEEE Digital Signal Processing Workshop*, Bryce Canyon, UT, Aug. 1998.

For more information, contact:
Stephen D. Voran
(303) 497-3839
e-mail sv@its.bldrdoc.gov

Broadband Network Standards

Outputs

- Network emulation and performance measurement tools.
- Contributions to national and international performance standards committees.
- Draft national and international standards.

The explosive growth of Internet usage and the evolution of "streaming" and other real-time Internet applications have created an urgent need for uniform, user-oriented performance parameters to characterize Internet Protocol (IP) -based data communication services. During FY 98, the Institute motivated and contributed strongly to the successful development of a new international standard, ITU-T Recommendation I.380, that defines such parameters. The Recommendation I.380 parameters characterize IP-based services with respect to four general performance attributes: speed, accuracy, dependability, and availability. They are intended to be used by service providers in the planning, development, and assessment of IP services that meet user performance needs; by IP network and terminal equipment manufacturers as performance information that will affect equipment design; and by users in evaluating end-to-end IP service performance.

An ITS staff member presented a baseline text for Recommendation I.380 at the September, 1997 meeting of the ITU-T Study Group 13 Rapporteurs Group on Question 13. During FY 98, ITS staff members made strong technical and editorial contributions to the completion of that new Recommendation. The completed document was "determined" at the June, 1998 ITU-T Study Group 13 meeting and is expected to be approved at the February, 1999 meeting of that group.

The Figure, from Recommendation I.380, illustrates the layered nature of IP service performance. The end-to-end performance provided to IP service users depends on the performance of several nested protocol layers:

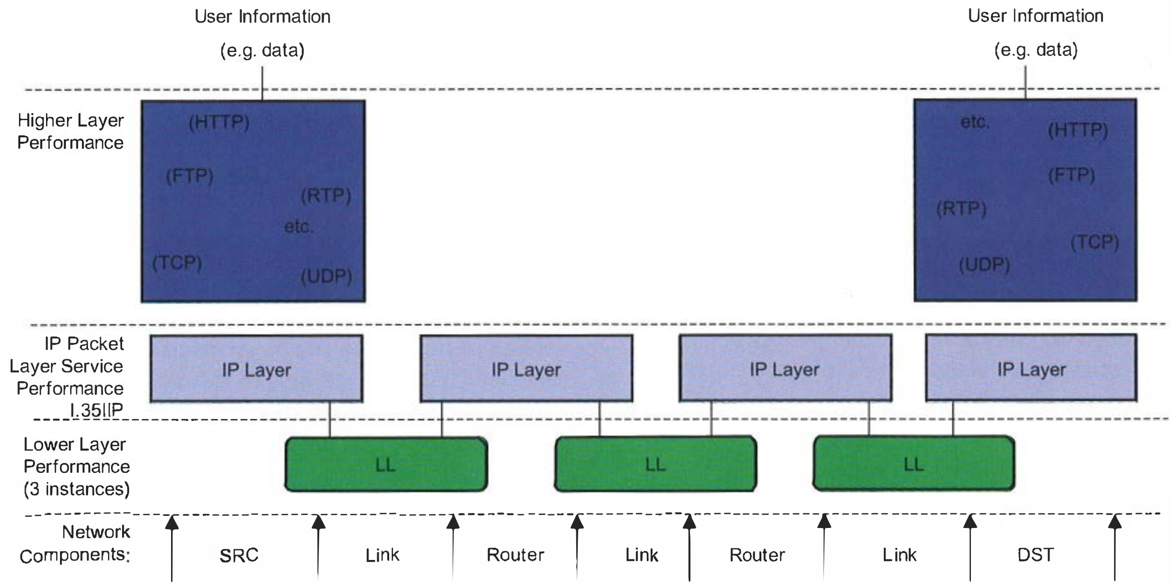
- *Lower layers* (LL), implemented in *links* that provide connection-oriented or connectionless data transport between IP layer entities. Links can be implemented using a variety of technologies — for example, Asynchronous Transfer Mode (ATM), Frame Relay, Synchronous Digital Hierarchy (SDH), Plesiochronous Digital Hierarchy (PDH), Integrated Services Digital Network (ISDN), and leased lines. Several layers of transmission protocols and services can be embedded in a link.

- The *IP layer*, implemented in source (SRC), destination (DST), and intermediate *routers* that perform Internet addressing, packet fragmentation/reassembly, and packet forwarding functions. The IP layer has end-to-end significance for a given pair of source and destination IP addresses.

- *Higher layers*, implemented in source and destination *hosts* that provide additional communication functions supporting particular Internet applications. The higher layer protocols may include, for example, Transmission Control Protocol (TCP), User Datagram Protocol (UDP), File Transfer Protocol (FTP), Real Time Protocol (RTP), and Hyper Text Transfer Protocol (HTTP). These protocols modify (and may enhance) the end-to-end performance provided by the IP layer.

In developing Recommendation I.380, the Question 13 Rapporteurs group was able to make use of the performance description framework and principles evolved (under ITS leadership) in earlier network performance standardization efforts. The characterization of IP network performance nevertheless required that the group address several new technical problems.

- The connectionless nature of IP packet transfer complicates IP network performance description by obscuring the population (e.g., set of transmitted packets) to which the defined parameters apply. The group addressed this problem by defining a *population of interest* in terms of specified source and destination hosts and associated complete IP addresses.



Layered model of performance for IP service - example.

- The diverse routing of IP packets complicates IP network performance description by requiring consideration of packet transfer reference events at multiple ingress and egress points, in multiple transit networks, in determining packet transfer outcomes. The group addressed this problem by defining concepts of *permissible* ingress and egress points and *corresponding packets* for a population of interest. The permissible ingress and egress points are defined with reference to the restrictions established by global routing information.

- Packet fragmentation complicates IP network performance description by multiplying the number of reference events that must be observed in determining the outcome of an individual packet transfer attempt. The group addressed this problem by defining separate reference events for each packet fragment and associating them through the definition of corresponding ingress and egress events.

Six IP packet transfer performance parameters are standardized in Recommendation I.380: IP packet transfer delay, IP packet error ratio, IP packet loss ratio, spurious IP packets rate, and two measures of IP service availability. The Recommendation also provides provisional definitions for throughput and packet delay variation. In ongoing work, ITS is assisting Study Group 13 in considering the specification of IP network service classes and associated numerical performance objectives. This work is being coordinated with the specification of "Differentiated Services" in the Internet Engineering Task Force (IETF).

During FY 98, ITS also spearheaded the development of a national counterpart to I.380, proposed American National Standard T1.5IP, in American National Standards Institute (ANSI) accredited Working Group T1A1.3. This national standard is expected to be published as a "delta document" to I.380 in 1999.

For more information, contact:
William R. Hughes
(303) 497-3728
e-mail whughes@its.bldrdoc.gov

Telecommunication Terminology Standards

Outputs

- Search engine for Federal Standard 1037C online.
- Technical reports and journal publications describing the standard's development and electronic implementation.

Common understanding of technical terminology is essential in a wide range of telecommunications planning functions, including the development of product and procurement specifications. The Institute has spearheaded the development of telecommunications terminology standards for many years through its leadership and technical contributions in the Federal Telecommunications Standards Committee (FTSC) Telecommunications Glossary Subcommittee.

The Subcommittee's most recent product is Federal Standard 1037C, Glossary of Telecommunications Terms. This 5800-entry glossary was published in hard copy form in 1996, and was made available in HTML form on CD-ROM and the World Wide Web (at http://glossary.its.bldrdoc.gov/fs-1037) in 1997.

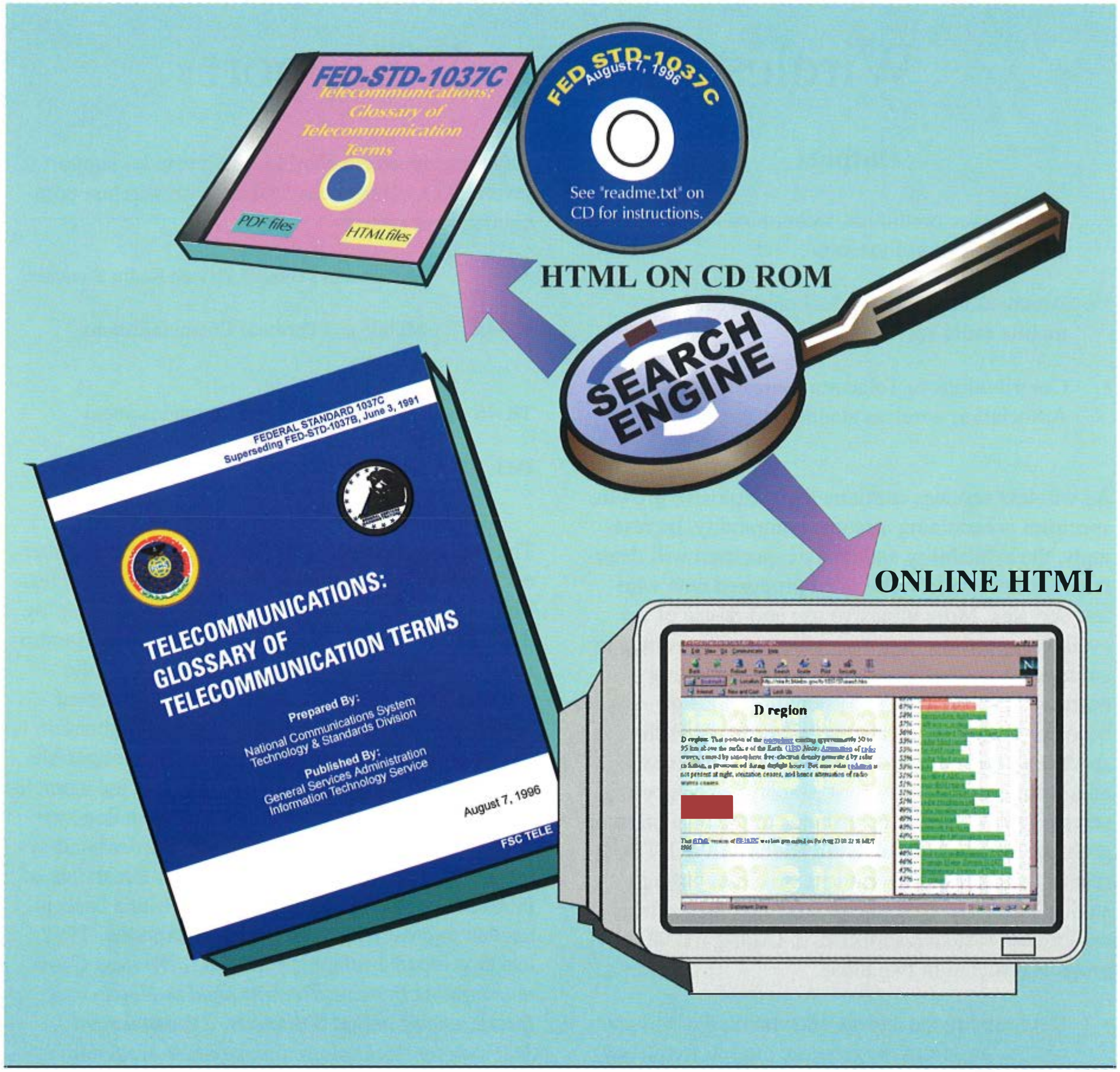
During FY 98, ITS staff members enhanced the CD-ROM and WWW versions of the glossary by equipping each version with a custom-designed search engine. In response to user requests, input as character strings, each search engine examines the complete 5800-entry text for related definitions and displays a relevance-ordered list of results. The search process takes 7 to 40 seconds, depending on the length of the input character string. The Figure illustrates a typical on-screen result, produced by searching the online HTML glossary for terms and definitions relevant to the phrase "D region." A major advantage of the search engine is its ability to speed a user's access to particular entries in the glossary. The search engine also promotes more organized and systematic use of the glossary by giving users access to groups of related terms.

Earlier versions of Federal Standard 1037 were available in hard copy only, with revisions issued at 5-year intervals. Translation of the document to an on-line, searchable form has made it much more usable — and greatly expanded its use. The WWW version of FED-STD-1037C received over 120,000 accesses ("hits") in the first 18 months of its on-line availability. Over 75% of current on-line users employ its search engine feature. The document's on-line availability has also made possible a more efficient, and more timely, approach to its revision. ITS has developed an electronic template for soliciting proposed new terms and definitions to be used in future revisions of the glossary. The template will be made accessible on the 1037C Web page to allow e-mail submissions of new or revised definitions. An e-mail exploder could be used to circulate, discuss, and conduct ballots of reviewer comments enabling the draft of a proposed revision to FED-STD-1037C to be developed more quickly and more economically on-line.

The conversion of the glossary to HTML, its posting on the Web, the addition of the search engine, and the facility for submitting e-mail proposals for updates have significantly increased the availability, usability, and value of FED-STD-1037C. These enhancements should enable the standard to contribute strongly to the clear understanding and effective use of telecommunications terminology for many years to come. They may also motivate improvements in the processes used to develop and maintain other telecommunication standards.

Hard copy and a CD-ROM of the glossary may be obtained at no cost from

National Communications System
Attn: Ms. J. Orndorff
701 South Court House Road
Arlington, VA 22204-2198
Phone: (703) 607-6204



ITS has developed a customized search engine that searches the HTML files of FED-STD-1037C, Glossary of Telecommunication Terms *— either online or on the CD-ROM.*

Recent Publications

W. Ingram and E. Gray, "A federal standard on electronic media," NTIA Report 98-350, Aug. 1998.

E. Gray, W. Ingram, and D. Bodson, "The ABCs of writing a technical glossary," *Technical Communication*, vol. 45, no. 1, pp. 23-32, First Quarter 1998.

For more information, contact:
Evelyn M. Gray
(303) 497-3307
e-mail egray@its.bldrdoc.gov

Wireless Standards Support

Outputs

- Interference prediction techniques for Personal Communication Systems.
- Attenuation prediction techniques for land mobile radio service.
- Contributions to Telecommunications Industry Association wireless standards.

As wireless services continue their explosive growth, spectrum is becoming a scarce commodity. Increasingly, the availability and cost of spectrum will determine the economic viability of proposed new wireless services. More intensive use and re-use of the available spectrum improves efficiency but results in an increase in interference and a corresponding decrease in performance. System optimization becomes a challenge since systems that share the spectrum employ different technologies and are administered by independent, sometimes competing, service providers. ITS contributes to the resolution of problems in commercial applications and to NTIA's role as manager of government spectrum through studies of interference phenomena and their effects on wireless system performance. During FY 98, projects centered in two areas:

- Determining the excess attenuation due to local clutter (buildings, vegetation, etc.) in frequency coordination of digital land mobile radio (LMR) systems conforming to Association of Public Safety Communications Officials (APCO) Project 25 standards.
- Determining the performance effects of intra-system and inter-system interference in personal communication services (PCS).

The results of ITS's work have been submitted to the Telecommunications Industry Association (TIA) and American National Standards Institute (ANSI) in support of standards for wireless communications. TIA is accredited by ANSI to develop voluntary industry standards for a variety of telecommunications products. The various TIA committees produce Technical Service Bulletins (TSBs) used by industry and frequency administrators as guidelines for managing spectrum sharing. ITS provides support to several TIA committees dealing with wireless communications issues:

TR-8	Mobile and Personal Private Radio Standards
TR-45	Mobile and Personal Communications Systems
TR-46	Mobile and Personal Communications
IMT 2000	International Mobile Telecommunications Standards

The standards progress in TR-8 is of particular interest to federal, state and local public safety agencies. This committee has the responsibility of developing the industry standard for the APCO Project 25 radio system. After the new narrowband, digital radio standard (TSB-102) is adopted and implemented, these agencies will need to pay particular attention to the coordination process used to ensure compatible operations of the radio systems. While some agencies will continue to use existing wideband analog systems, others will migrate to the new narrowband systems. Since the systems have different thresholds of interference, coordination on a one-on-one basis is needed to ensure non-interfering operations. TR-8 has developed a reference standard, *Wireless Communications Systems, Performance in Noise- and Interference-Limited Situations, Recommended Methods for Technology-Independent Modeling, Simulation, and Verification* (TSB-88) which defines the coordination process.

The standard propagation model used in many LMR situations is an empirical model developed by Hata based on measurements by Okumura et al., commonly called the Okumura-Hata model. The user selects from a variety of environments: urban, suburban, quasi-open, and open, and chooses the base station antenna height (which is usually above local clutter heights) and the mobile antenna height (which is usually below). These parameters define the amount of clutter attenuation that will be added to the propagation loss.

In the coordination process, the user selects the open environment when using the Okumura-Hata model. A clutter factor, which is a function of the particular band used by the LMR system and the mobile station's environment, is added. ITS and industry have developed values of excess loss due to clutter based upon measurements from a number of sources. Figure 1 shows how the clutter attenuation varies for the LMR bands of interest and a variety of environments.

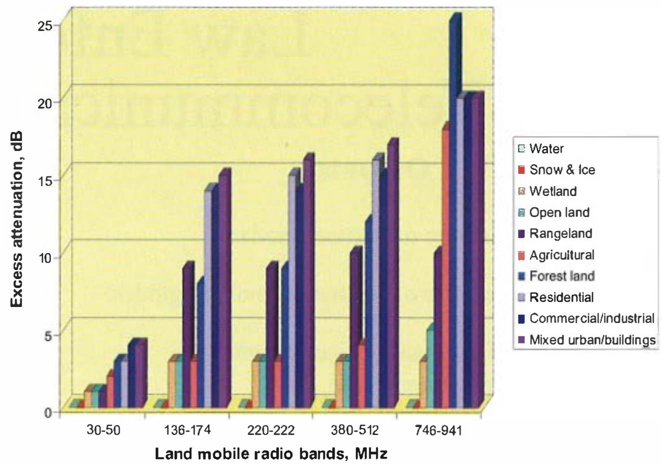


Figure 1. Excess attenuation due to local clutter as a function of land mobile radio band and land use classification.

The FCC recently suggested that clutter losses could be added to broadcast service predictions and encouraged the development of such models. ITS is working to establish good excess loss values for various bands and environments. One important component of the process is the land use or land cover classification that surrounds the mobile station, but the information provided by digital data bases available from agencies such as the U.S. Geological Survey is coarse and needs to be updated constantly. ITS is researching improved land use/ land cover data bases appropriate for these models.

Another limitation to wireless system performance is due to the co-location of base station transmitters, receivers, and antennas. Figure 2 shows that third-order intermodulation (IM) products between two systems operating in different bands can affect themselves, systems operating in other PCS bands, as well as systems operating outside of the PCS bands, such as the military band located from 1755 to 1850 megahertz. Service providers should cooperate to alleviate these problems, but cooperation may not be possible during the chaotic situation following a

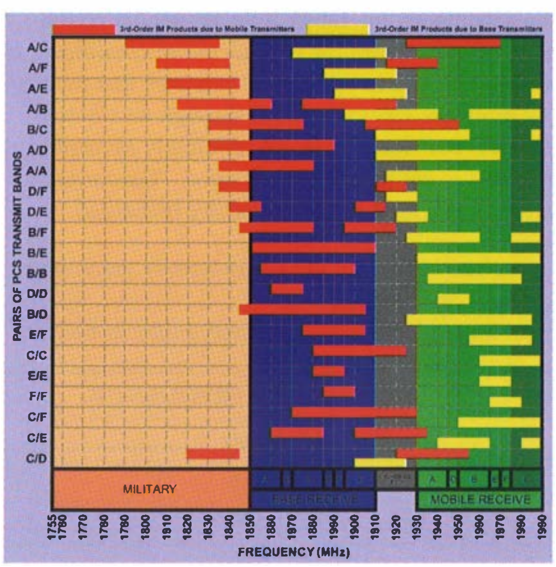


Figure 2. Coverage of third-order intermodulation products produced by co-located PCS systems.

natural disaster or emergency situation, when damaged cell sites are repaired or replaced, and traffic loads rise due to increased dependency on wireless communication. To understand the interaction between co-located PCS systems and the nature of inter-PCS interference, ITS developed an interference model based on two PCS technologies: the Global System for Mobile (GSM) based PCS1900, and the IS-95 based code division multiple access (CDMA) system. As discussed in an NTIA report (Ferranto, 1997; see Publications Cited, p. 106), the model can be expanded to cover the remaining PCS technologies and can be used to predict the effect that co-located systems can have on each other, in terms of performance, capacity, and reliability. The model produces a waveform that is an aggregate of the transmitted waveforms from all base stations and mobile stations of a particular system, and can be used with mathematical models to predict system response to less than ideal conditions, or can be implemented in hardware to test existing equipment.

ITS' expertise in interference modeling has been of value in the development of the TIA handbook *Licensed PCS to PCS Interference* (TSB-84A) which is intended to help equipment manufacturers, service providers, and field personnel minimize interference through the design and implementation phases of PCS systems.

For more information, contact:
Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov
Eldon Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Law Enforcement Telecommunication Standards

Outputs

- National Institute of Justice standards.
- National Institute of Justice technology guides.
- Analysis of criminal justice community telecommunications needs.

The Institute provides engineering support, scientific analysis, technical liaison, and testing to assist NIST's Office of Law Enforcement Standards (OLES) in the development and validation of criminal justice communications standards and other communication system products supporting law enforcement and corrections needs. As an integral component of the National Institute of Justice's (NIJ's) *National Law Enforcement and Corrections Technology Center System*, OLES is tasked to apply science and technology to the needs of the criminal justice community. ITS supports the OLES Communications Program by determining customer needs, recommending program initiatives to address those needs, and developing NIJ standards, guides, handbooks, and other forms of documentation that are used by thousands of agencies across the country.

The Institute conducted a number of projects supporting OLES and NIJ during FY 98. ITS staff members updated NIJ Standards for Fixed/Base Station and Mobile Antennas, and delivered the updated standards to OLES for publication. A *New Technology Batteries Guide* was developed and published. ITS progressed with work on an *Antenna Guide for Land Mobile Radio*, and began updating a *Video Surveillance Equipment Guide* developed earlier. ITS also developed an NIJ tactical plan for the standardization of the Advanced Law Enforcement Response Technology (ALERT) system, and prepared a magazine article describing the ALERT system and the benefits of its standardization. To facilitate the development of ALERT NIJ standards, ITS established liaison with developers of data bus standards at the Society of Automotive Engineers. More information about the *New Technology Batteries Guide* and *Video Surveillance Equipment Guide* is provided below.

New Technology Batteries Guide (NIJ Guide 200-98)

This guide reviews the fundamentals of battery technology and describes several different battery types (e.g., Zinc-Carbon (Zn-C), Nickel-Cadmium (Ni-Cad), Nickel-Metal Hydride (Ni-MH), Lithium, Lithium Ion, rechargeable alkaline) used in law enforcement applications. Battery performance, battery economics, and the trade-offs between them, are discussed. For example, voltage profiles and memory effects are explained, as well as self-discharge rates and cycle life. Data tables and curves illustrate the differences among batteries. The buyer/user is assisted in selecting the proper battery for particular applications and operating environments and is advised on how to handle and maintain batteries. Battery chargers and adapters are addressed both in general and in the context of certain battery types (e.g., Ni-Cad). The guide provides a glossary of battery terms, a bibliography to facilitate further study, and a list of typical products and suppliers.

The accompanying Table, from the guide, recommends battery types for various usage conditions. In the Table, the term "primary" indicates that the battery produces electric current through an electrochemical reaction that is not efficiently reversible. Hence, it is not normally recharged. "Secondary" battery types may be economically recharged.

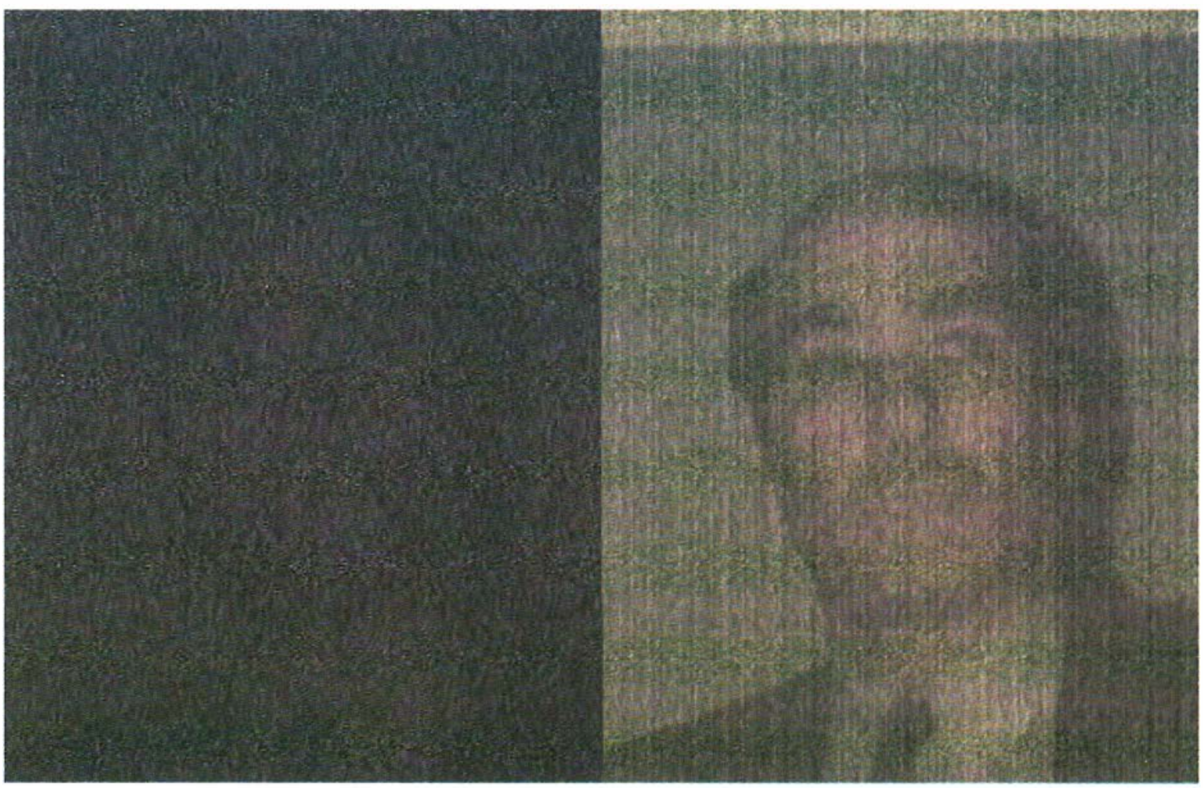
An on-line version of the entire battery guide may be found on the Internet at http://www.nlectc.org/oles/batteryguide/ba-m.htm.

BATTERY TYPE	DEVICE DRAIN RATE	DEVICE USE FREQUENCY
Primary Alkaline	High	Moderate
Secondary Alkaline	Moderate	Moderate
Primary Lithium	High	Frequent
Secondary Ni-Cd	High	Frequent
Primary Zn-C ("Heavy Duty")	Moderate	Regular
Primary Zn-C ("Standard")	Low	Occasional

Video Surveillance Equipment Guide

This guide assists law enforcement and corrections agencies in selecting video surveillance systems for use in collecting evidence, promoting officer safety, and other applications. The guide addresses both general-use video equipment (e.g., separate video cameras, self-contained camcorders, video recorders/ players, monitors) and special-purpose video equipment (e.g., surveillance systems for police cars, retractable and portable units). The guide begins with a description of typical video surveillance assignments — the basic user requirements for police video applications. These requirements serve as a context and reference for all subsequent evaluations. The guide provides an extensive description of video surveillance components and systems, including a review of the available video technology for each equipment category (cameras, camcorders, etc.), as well as common and special features and accessories.

The guide defines the technical parameters that most strongly influence operational performance in a section called, "Quality Parameters and the User — Interpreting Manufacturers' Specifications." These parameters include image resolution, signal-to-noise ratio, minimum illumination, and color accuracy. The ergonomic aspects of equipment are discussed in detail. The document provides guidelines for applying video equipment to meet specific functional requirements. For example, an appendix addresses surveillance work in low-light situations — a particular need of the law enforcement and corrections community. The guide presents results of laboratory experiments conducted at ITS to compare camera performance. It describes PC-based image enhancement techniques that can dramatically improve the clarity of faces and other images recorded in near darkness. The Figures shown here represent an image before and after such image enhancement processing.



An example of image enhancement from a low-light scene.

For more information, contact:
Val Pietrasiewicz
(303) 497-5132
e-mail valp@its.bldrdoc.gov

ITU-T Standardization Activities

Outputs

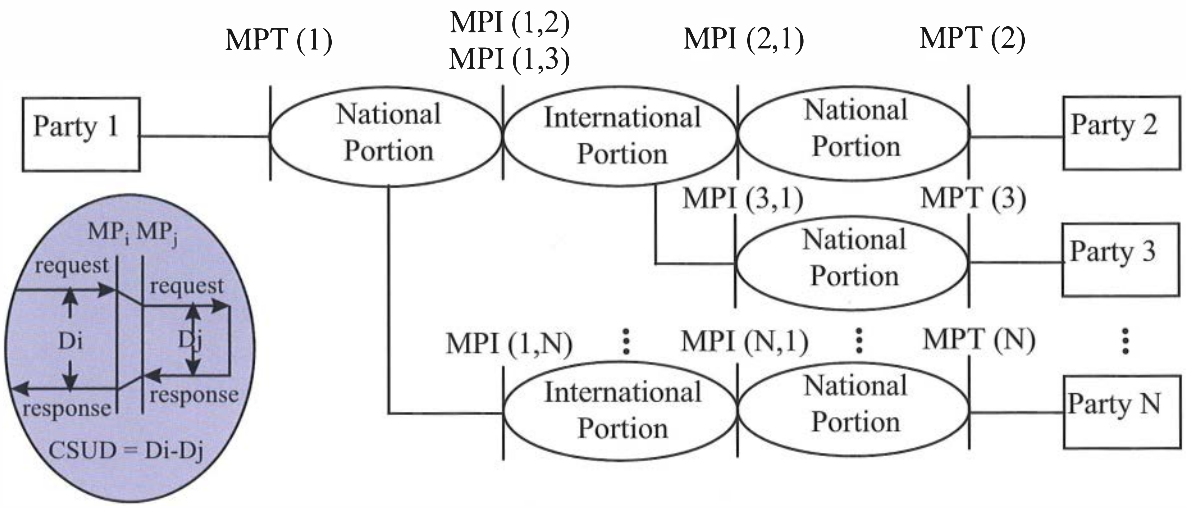
- U.S. and international ITU-T standards leadership.
- Technical standards contributions.
- Proposed ITU-T Recommendations.

The International Telecommunication Union - Telecommunications Standardization Sector (ITU-T) plays a vital role in the cooperative planning of public telecommunication systems and services worldwide. The technical standards (Recommendations) developed in the ITU-T impact both the evolution of the U.S. telecommunications infrastructure and the competitiveness of U.S. telecommunications products and services in international trade. The Institute supports ITU-T activities by leading U.S. preparatory committees and international work groups, preparing technical contributions to ITU-T standardization activities, and drafting proposed new ITU-T Recommendations in technology areas important to U.S. Government and industry organizations.

The Institute provides strong support to the U.S. Department of State in leading the U.S. Organization for the ITU-T. During FY 98, Institute personnel served on the U.S. International Telecommunications Advisory Committee (ITAC), provided technical leadership and administration for U.S. ITU-T Study Group B, and headed the U.S. Delegation to an international meeting of ITU-T Study Group 13. The U.S. ITAC guides overall U.S. participation in ITU-T activities. U.S. Study Group B approves and presents U.S. contributions to ITU-T Study Groups 4 (Telecommunications Management Networks and Network Maintenance), 6 (Outside Plant), 10 (Languages and General Software Aspects for Telecommunications Systems), 11 (Signaling Requirements and Protocols), 13 (General Network Aspects), and 15 (Transport Networks, Systems, and Equipment). Study Group 13 develops Recommendations for advanced telecommunication networks using high-speed synchronous digital hierarchy (SDH), broadband integrated services digital network (B-ISDN), asynchronous transfer mode (ATM), and Internet Protocol (IP)-based technologies, and is leading ITU-T efforts to define the Global Information Infrastructure (GII) envisioned by government leaders and network planners worldwide.

The Institute also provides direct leadership in the ITU-T, and in American National Standards Institute (ANSI) accredited standards committees whose work supports ITU-T goals. During FY 98, Institute representatives continued technical leadership of ITU-T Working Party 4/13, and the ITU-T Rapporteur groups for Questions 11, 13, and 22/12; and assumed a new (elected) position as Chair of ANSI-accredited Technical Subcommittee T1A1. Working Party 4/13 develops performance specifications and measurement methods for B-ISDN/ATM and IP-based network services and the GII. The three Study Group 12 Rapporteur groups headed by ITS staff members develop international standards that define subjective and perception-based objective quality-of-service measures for speech transmission, audio/visual, and multimedia communication systems. Technical Subcommittee T1A1 develops national standards (and U.S. contributions to ITU-T) in the areas of network performance and signal processing. During FY 98, an ITS staff member was presented the Committee T1 Outstanding Contributor Award for his contributions to the work of T1A1.

The Institute's FY 98 activities in Study Group 13 contributed strongly to the completion of a proposed new ITU-T Recommendation I.380, that defines parameters for specifying and assessing the speed, accuracy, dependability, and availability of IP-based networks. ITS participants also developed the text for a corresponding American National Standard, T1.5IP, and spearheaded national and international efforts to coordinate the IP performance standards work with related activities in the Internet Engineering Task Force (IETF), the Cross-Industry Working Team (XIWT), and other Internet-related organizations. In related ITU-T work, ITS staff members contributed to the advancement of proposed new Recommendation Y.Perf, which will establish general principles and a framework for GII performance description. This new Recommendation is expected to be important in providing a common understanding of performance concepts among the several industries (e.g., telephone, computer, cable television, wireless, satellite, and broadcasting) whose technologies will comprise the GII.



MPT = Measurement Point Terminal - Q.2971 (DSS-2) Signalling
MPI = Measurement Point International - Q.2761 (B-ISUP) Signalling
CSUD = Call Setup Delay

Reference configuration for B-ISDN call processing performance.

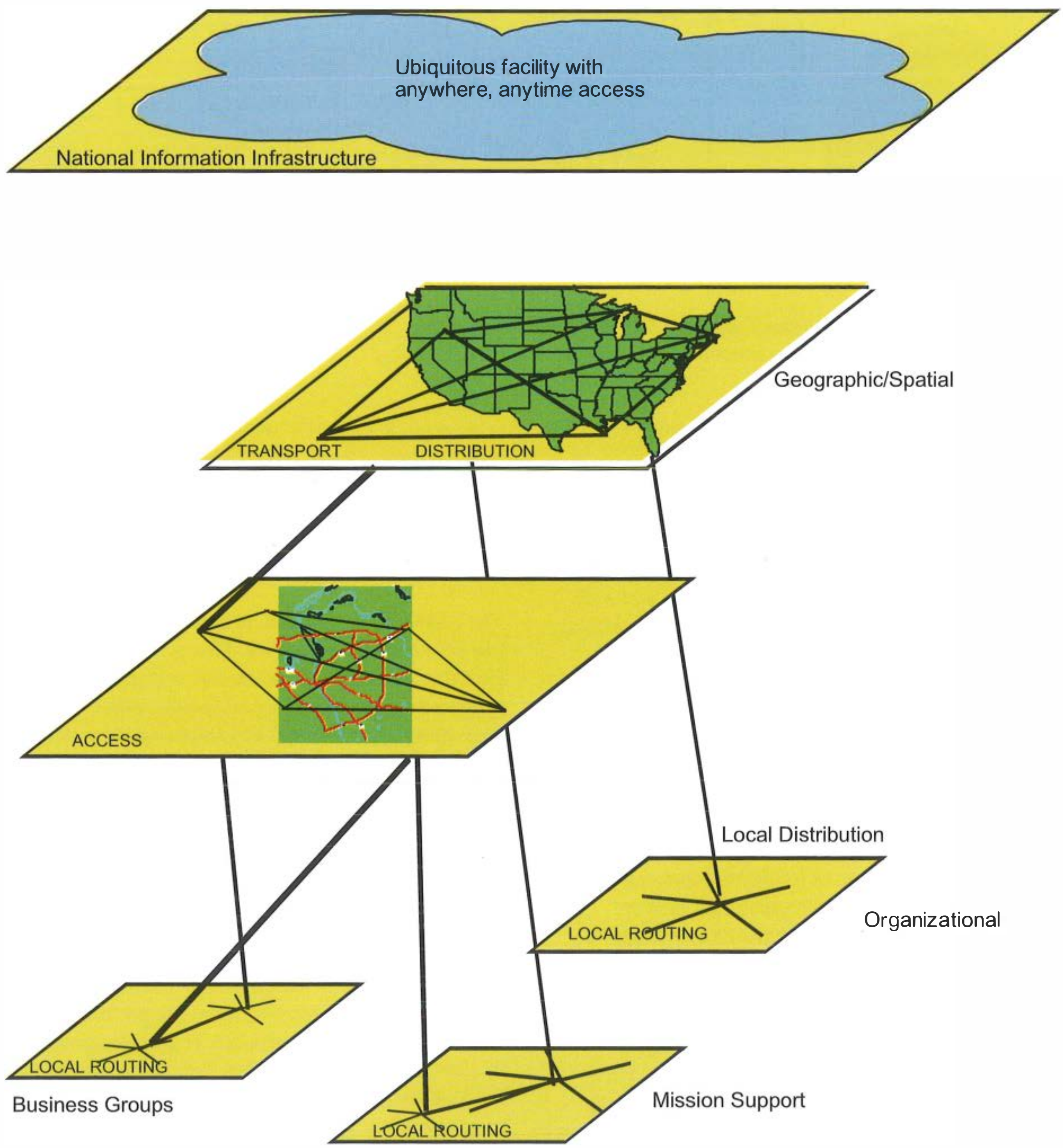
ITS also directed and contributed technically to the development of a new ITU-T Recommendation, I.358, that specifies call processing performance for B-ISDNs. This work required the specification of a reference configuration, reference events, and a set of performance parameters capable of characterizing a number of new call processing functions more powerful (and more complex) than those implemented in traditional telephony networks. The planned functions include the establishment of multipoint connections and multiconnection calls and modification of the topologies, capacities, and performance of established connections. The Figure illustrates the defined reference configuration in a simplified form. A hypothetical multipoint B-ISDN connection is divided into national and international portions delimited by measurement points (MPs) at which call processing reference events, defined on the basis of ITU-T standardized signalling messages, can be observed. Measurement Point T (MPT) occurs at user (terminal) interfaces; Measurement Point I (MPI) occurs at interfaces that terminate an ATM transmission system at an international switching center. The indexed notation illustrated in the Figure is useful in identifying related events and parameters in cases where an MPI supports a multipoint connection segment that branches to several different parties. A third index can be added to permit characterization of multi-connection cells.

The I.358 parameters can be applied between any pair of measurement points. This generality facilitates the allocation of end-to-end performance objectives to the branches of a multipoint connection and their component national and international portions. For example, the connection setup delay attributable to the connection portion between any specified pair of MPs (Mpi, MPj) is defined as the delay (Di) between connection request and response events (e.g., setup, connect) at the first MP minus the corresponding delay (Dj) at the second MP. This definition makes the delays of concatenated portions directly additive, and ensures that delays attributable to called users (and "downstream" connection portions) are excluded from the network performance values specified for a particular connection portion. In addition to call setup delay, Recommendation I.358 defines call setup accuracy and dependability parameters and a corresponding set of speed, accuracy, and dependability parameters for the connection release, add party, and drop party functions.

Recent Publication

N. B. Seitz and K. C. Glossbrenner, "Performance Standards for the GII," *IEEE Communications Magazine*, Vol. 36, No. 8, Aug. 1998, pp. 116-121.

For more information, contact:
Neal B. Seitz
(303) 497-3106
e-mail nseitz@its.bldrdoc.gov



Schematic view of the telecommunications infrastructure.

Telecommunication System Planning

The ultimate goal of the telecommunication planning process is to ensure that systems or networks satisfy user requirements at an appropriate cost. The process involves a set of related, but independent, steps that consider all aspects of the telecommunications environment. For example, these steps identify current and projected user requirements, evaluate existing infrastructure and associated assets, identify regulatory or policy restraints, investigate relevant standards, assess existing and emerging technologies, develop alternative architectures and modes of operation, and select the best approaches based on a derived set of evaluation criteria. Classical analysis, computer models and simulations, laboratory experiments, and prototype testing are often used to validate system designs and network architectures at various stages of development. The Institute has the resources to assist with any or all facets of telecommunications system planning.

Areas of Emphasis

Department of Commerce Telecommunications Planning

The Institute performs Department-wide telecommunications assessment by characterizing the efficiency and effectiveness of existing resources within a strategic planning context. Projects are funded by the Office of Systems and Telecommunications Management, U.S. Department of Commerce.

Intelligent Transportation Systems Planning

The Institute characterizes the electromagnetic spectrum environment, develops propagation models, analyzes electromagnetic compatibility, and examines new telecommunication technologies to support the development of intelligent transportation systems. Projects are funded by the Federal Highway Administration (FHWA).

Railroad Telecommunication Planning

The Institute performs engineering analyses, including objective voice quality assessments, of radio system designs being considered for use in the railroad industry. Projects are funded by the Federal Railroad Administration.

Telecommunications Analysis Services

The Institute provides network-based public access to the latest ITS research results, engineering models, and databases supporting broad applications in wireless telecommunications system design and the evaluation of broadcast, mobile, and radar systems. The telecommunication system planning tools are funded by fee-for-use charges paid by the users of the services and by fee-for-development charges for new software/model tools. Both funding methods are available through Cooperative Research and Development Agreements (CRADAs) between the users of the services and the Institute.

Augmented Global Positioning System

The Institute supports the design and optimization of a nationwide navigation and positioning service by assessing the needs of system users, and determining the most desirable locations and operating parameters for differential global positioning system reference stations. Projects are funded by the FHWA.

Low-Cost HF Automatic Link Establishment (ALE)

The Institute implements ALE functionality in personal computer (PC) software to enable users of inexpensive commercial HF radios (e.g., amateur radio operators) to participate in ALE networks supporting emergency communication needs. The project is funded by the National Communications System (NCS).

DOC Telecommunications Planning

Outputs

- Assessment of U.S. Department of Commerce telecommunications infrastructure.
- Recommendations for infrastructure optimization and cost savings.

During Fiscal Year 1998, ITS assisted the Department of Commerce's Office of Systems and Telecommunications Management (OSTM) in long-range planning for a Department-wide enterprise network by conducting a detailed assessment of the Department's existing telecommunications assets. In this study, ITS and OSTM determined what telecommunications equipment and services are presently available within the various Commerce agencies and examined how well these existing resources satisfy current and projected needs. The study results achieved economies in specific service-dedicated networks and provided a framework for cooperative planning of future infrastructure capabilities.

The study team first collected facility and traffic data from the various Commerce agencies using a structured survey. The survey results were voluminous and useful, but nevertheless incomplete. Individual agency responses varied greatly in level of detail and were not easy to integrate. Information needed to assess agency use of existing assets was not always available. Accordingly, ITS identified and obtained supplementary information from other sources, such as the Federal Telecommunications System (FTS) billing databases, local exchange carrier records, human resource databases, Internet Web sites, and direct contacts with agency representatives. The survey results and this supplementary information were integrated with software analysis and graphical presentation tools that enabled the project team to view the Commerce infrastructure from various perspectives and levels of detail.

These data and the associated telecommunications assessment results were valuable from several perspectives. First, they provided, perhaps for the first time, a relatively complete (and understandable) picture of the Department's overall telecommunications assets. Second, they enabled cost analyses that revealed several instances where billing errors existed or savings could be achieved immediately without any change in service levels or performance. Finally, and most importantly, they provided a basis and incentive for information sharing and cooperative planning among agencies. Following are a few general observations derived from the Assessment results:

- The Department's 33,000 employees are widely dispersed geographically across the United States and beyond. The Department receives communications services at over 5,100 Service Delivery Points in over 1,600 different geographical locations.
- Commerce Department agencies use a substantial number of independently-procured commercial communication services in addition to FTS services in meeting their mission needs. Figure 1 illustrates the non-FTS dedicated circuits used by one Commerce agency, the National Weather Service.

Figure 1. National Weather Service non-FTS dedicated circuits.

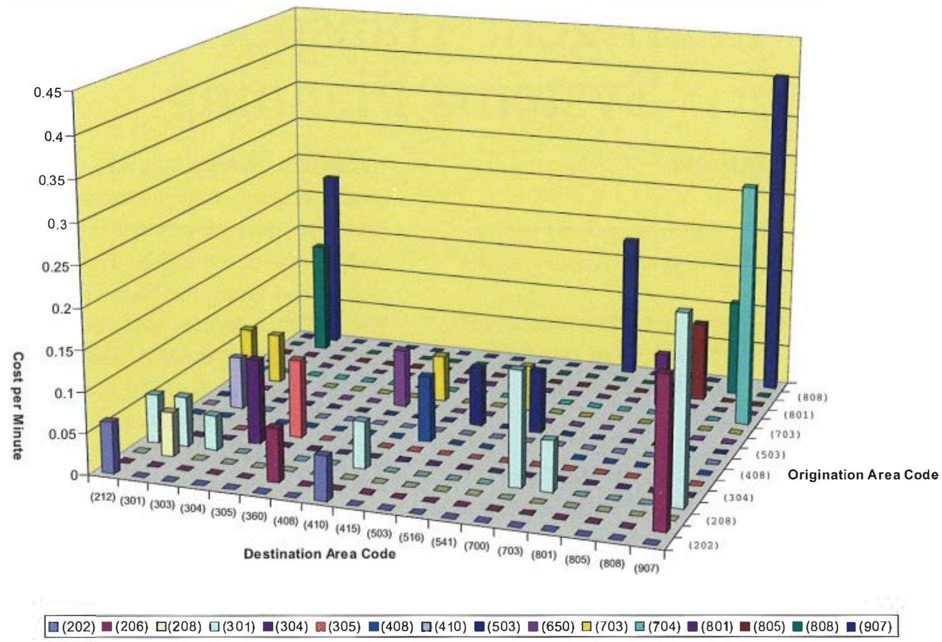


Figure 2. Average cost per minute for area code pairs where monthly bills exceed $1000/mo.

- Even within FTS switched voice service, the average cost per minute of a telephone call varies widely for different area code pairs. See Figure 2.

- There are numerous opportunities to optimize telecommunication arrangements at Commerce locations to achieve economies of scale. The study's identification of the collective assets at some locations has already prompted consolidation actions, supported by the user agencies, that have netted substantial cost savings.

- No comprehensive plan for a Department-wide enterprise network exists today. A number of the Department's largest networks operate independently with little interaction or coordinated network management.

- Network plans being developed in several Commerce agencies could serve as valuable templates for similar planning in other agencies — or for cooperative planning of more integrated, multi-agency solutions. As examples, the National Weather Service's Advanced Weather Interactive Processing system (AWIPS) telecommunication network architecture could provide a useful planning model for other Commerce services involving significant geographic dispersion. The Patent and Trademark Office's campus network evolution plan could be applied in a similar way in situations where an agency's work is concentrated in a limited geographic area.

ITS is currently working with OSTM to develop the Department's Strategic Telecommunications Plan — a structured methodology for evolving Commerce's telecommunications infrastructure into the 21st century. The detailed information obtained in the telecommunications assessment project will enable the Department to make maximum use of current assets in this evolution, thereby reducing costs. The Strategic Plan will provide a framework from which Department officials can make decisions regarding both normal and emergency telecommunication operations. It will also facilitate the establishment of regulations and guidelines pertaining to the procurement, implementations, ownership, management, maintenance, and upgrading of telecommunication system elements across all agencies. Major tenets guiding the plan are mission effectiveness, flexibility to accommodate evolving needs, reliability, and minimum life cycle cost. The plan will enable the various agencies to implement mission-specific capabilities in the context of a broader commerce enterprise network.

For more information, contact:
Val J. Pietrasiewicz
(303) 497-5132
e-mail valp@its.bldrdoc.gov

Intelligent Transportation Systems Planning

Outputs

- Electromagnetic compatibility analysis of the intelligent transportation system & subsystems.
- Low and medium frequency propagation model development for differential global positioning system and advanced traffic information systems analysis.
- Electromagnetic compatibility analysis and testing of dedicated short-range communication systems for intelligent transportation systems.

Vehicle traffic congestion is on the increase in the United States. Unless it can be checked, the continued increase will result in productivity loss, accidents, wasted energy, and increased vehicle emissions. The conventional approach to this problem is to build more roads or expand the number of lanes on existing highways. But financial and environmental constraints are making these techniques less and less feasible. The approach of intelligent transportation systems (ITS) is to utilize computer and telecommunications technology to provide information to travelers about road and transit travel conditions and to monitor, guide, and control the operation of vehicles. ITS can improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy, and promote economic productivity on the Nation's transportation system. ITS will allow travelers to plan their mode of transportation ahead of time, and to make more informed choices about routes, time, and modes of travel. In addition, authorities will be able to manage transportation systems and control traffic more efficiently in a dynamically changing traffic environment.

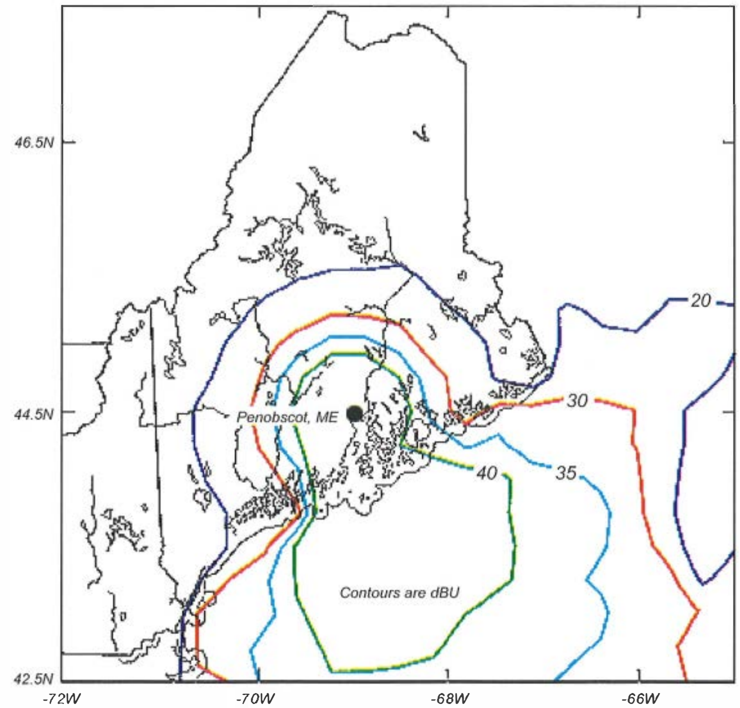
Another area of development for ITS is electronic toll collection to reduce traffic delays and congestion at toll booths on bridges and highways. Related to this area is automated in-transit commercial vehicle weigh-in for trailer truck traffic. Truckers traveling across the United States must weigh in frequently as they pass through different states so that interstate trucking fees and taxes can be properly assessed. Conventional weigh-in procedures require the truck to pull up onto a large off-road scale to determine the vehicle and cargo weight. This causes significant delays in delivery and scheduling for the trucking industry with resultant loss of productivity and profit, wasted energy, increased emissions, and possible spoilage of perishable cargo. Automated weigh-in is accomplished as the truck drives at highway speed along the highways which have been outfitted with a special scale and electronic identification and tolling system. This procedure has none of the disadvantages of the conventional weigh-in system. Toll collection is one function for which dedicated short-range communication (DSRC) systems are used.

The Institute has been working to ensure electromagnetic compatiblity (EMC) between ITS electronic systems and the electrical/electronic environment. EMC is the ability of electronic equipment to achieve a specified level of operability when operating in an uncontrolled environment. EMC involves the orchestration and integration of system components to control interference coupling. It is a primary factor in the performance, safety, and effective operation of ITS systems, and thus a primary consideration in ITS system design. The electronic devices and equipment used for ITS, and the coupling of external signals and interference from external sources represent a complex interactive electromagnetic environment with emitters and receptors. Interference problems may arise when radio communications equipment and other electronic devices are operated around ITS-equipped vehicles. This could cause interference among ITS equipment, the resident automotive electronic systems and the electronic equipment in the rest of the environment. EMC must be achieved to prevent interference problems.

Recent activities and accomplishments by the Institute to address the EMC of ITS include:

1. Analysis and testing of two DSRC Systems that determine the potential EMC problems with radars in the 5850 to 5925 MHz band. One system conforms to the European Standard and the other to the Japanese Standard. Both systems are in the development phase and have been proposed for use in electronic toll collection.

2. Measurements of radar characteristics in the 5850 to 5925 MHz band to assist in characterizing emissions in that frequency band in order to assess interference potential to the DSRC Systems.



Radio coverage for an AM broadcast subcarrier system generated by the low and medium frequency propagation model developed by the Institute (illustration by A. Romero).

3. Measurement of satellite uplink interference levels in the 5850 to 5925 MHz band to characterize the emission spectrum specifically for interference analysis to the DSRC systems.

4. Development of a low and medium frequency propagation model to be used for analysis of the Differential Global Positioning System (DGPS) signal for refinement of position accuracy and the AM subcarrier advanced traveler information system (ATIS). This ATIS system would be used to disseminate information to travelers in the rural roadway environment. This analysis will support the design and field operational testing of the AM subcarrier evaluation effort for ATIS.

Future activities of the Institute include but are not limited to: characterization and measurement of the electromagnetic environment, spectrum planning, propagation model development, determination of suitable new and emerging communications technology for ITS, prediction of radio coverage for communication systems, and selection/establishment of an EMC requirement standard for ITS.

The Figure is an actual output of the low and medium frequency propagation model developed by the Institute. It shows the coverage for an AM radio station that would be used to disseminate traffic and weather information for an AM subcarrier traveler information system of the ITS.

Recent Publications

N. DeMinco and C.L. Holloway, "Propagation modeling for ITS applications in the roadway environment," *Intelligent Transporation Systems Journal*, Vol. 3, No. 4, Aug. 1997.

R.A. Dalke, F.H. Sanders, and B.L. Bedford, "Electromagnetic compatibility testing of a dedicated short-range communication system," NTIA Report 98-352, Jul. 1998.

For more information, contact:
Nicholas DeMinco
(303) 497-3660
e-mail ndeminco@its.bldrdoc.gov
Roger A. Dalke
(303) 497-3109
e-mail rdalke@its.bldrdoc.gov

Railroad Telecommunication Planning

Outputs

- Project 25 land-mobile radio speech quality under different channel spacing and interference conditions.
- Example radio coverage contour predictions comparing geographical coverages of digital and analog modulation formats.

As a result of the Federal Communications Commission's (FCC) radio spectrum realignment initiative, the FCC has directed that all newly designed land-mobile radio (LMR) equipment will incorporate narrowband technology solutions. Since future radio systems and equipment will, by necessity, be narrowband, users should begin planning now to deal with migration and compatibility issues when they introduce new equipment and systems into their existing LMR infrastructures.

The railroad industry has responded to this initiative by forming an ad-hoc industry committee, the North American Railroad Radio Network (NARRN). This committee is chartered to investigate how to best migrate the railroad industry's existing 160-MHz analog land mobile radio equipment to more modern, spectrally-efficient systems, and to develop a strategy to accomplish this migration. The Federal Railroad Administration (FRA) wishes to ensure that adopting NARRN's recommendations will not adversely affect public safety. ITS was tasked by the FRA to evaluate NARRN's proposed rechannelization plan and provide input to NARRN and the FRA regarding the efficacy of the recommended radio platform.

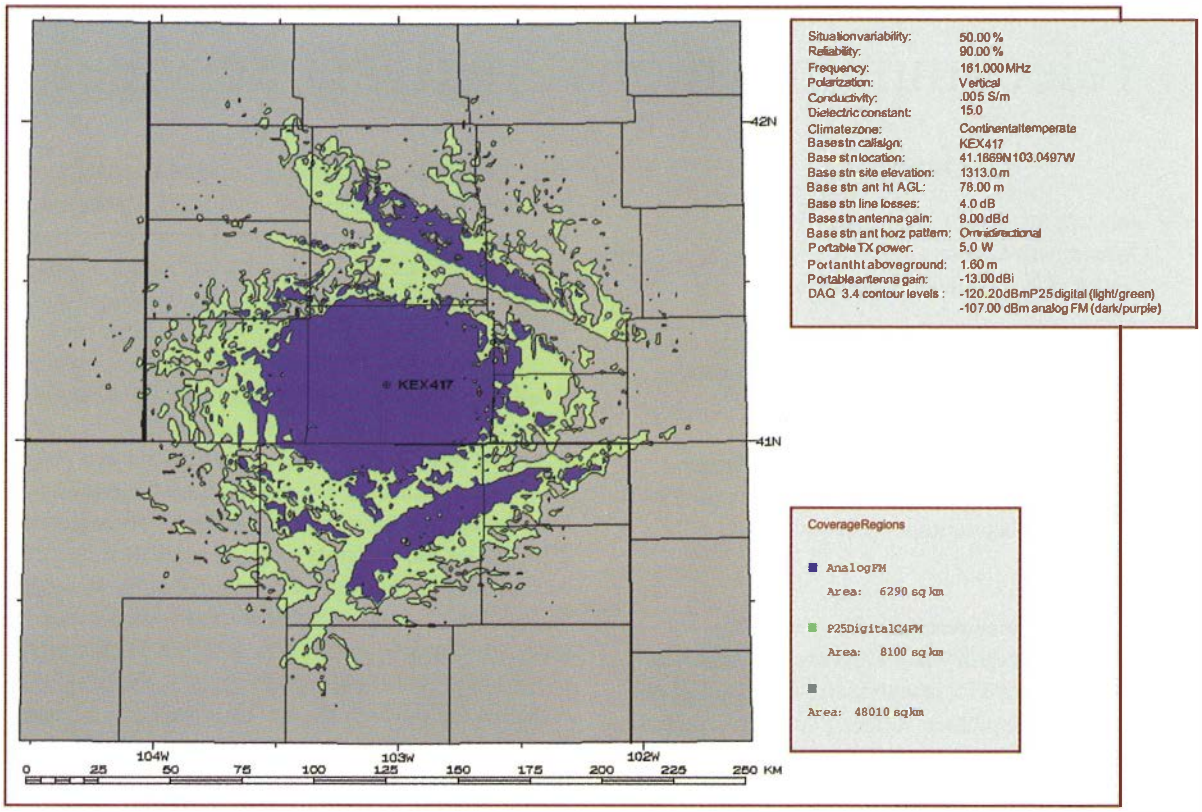
One of NARRN's recommendations is to adopt the digital radio platform adopted by the Telecommunications Industry Association. This radio platform is known as Project 25, or simply P25. P25 provides an open design standard, which any vendor can build to and ensure interoperability with other vendors' P25-compliant equipment and older, analog FM equipment.

Using a P25 radio in the NARRN channel plan environment has brought to light several important issues. First and foremost is the effect of the P25 radio's 12.5-kHz bandwidth when used in the 7.5-kHz channel spacing environment of the NARRN channel plan. The second is the improvement in speech intelligibility and geographic coverage afforded by the P25 radio.

ITS performed a series of measurements to relate the delivered audio quality of speech signals transmitted through P25-compliant radios to radio sensitivity, adjacent channel rejection and cochannel rejection parameters. The measurements were performed with the radios operated in both P25-digital and conventional analog FM modes. For a given degree of speech intelligibility, it was found that the RF sensitivity of the P25 digital mode was better than for conventional analog FM. From this data, a representative case study illustrating the improvement in radio coverage afforded by the P25 platform was performed. The Figure shows two radio-coverage contours, one for P25 digital mode and one for conventional analog FM mode.

The contours delineate the regions where it is predicted that the delivered audio quality of speech will be greater than some perceived level of intelligibility. The purple-shaded area corresponds to the region where a 5-watt portable analog FM radio will deliver good speech intelligibility to a base station site. A 5-watt portable P25 digital-mode radio will deliver comparable or superior speech intelligibility to the same base station over an even larger territory. This additional territory is denoted by the green-shaded area in the Figure.

Since the transmission bandwidth of the P25 radio is 12.5 kHz, and the channel spacing in the railroad VHF band is 7.5 kHz, considerable spectrum overlap between adjacent-channel signals can occur. Ongoing work is categorizing the delivered audio quality of a wanted speech signal, received in the presence of adjacent-channel interference. Four interference modes are of interest: (1) an unwanted digital signal interfering with a desired digital channel, (2) an unwanted analog signal interfering with a desired digital channel, (3) an unwanted analog signal interfering with a desired analog channel, and (4) an unwanted digital signal interfering with a desired analog channel. The results of this activity will directly affect "cellular" system design layouts in congested rail centers by influencing the choice of frequencies in neighboring cells.



Typical analog and digital mode terrain coverage contours, for equal speech intelligibility.

For more information, contact:
John Vanderau
(303) 497-3506
e-mail jvanderau@its.bldrdoc.gov

Telecommunications Analysis Services

Outputs

- Network access for U.S. industry and Government agencies to the latest ITS engineering models and databases.
- Broad applications in telecommunication system design and evaluation of broadcast, mobile, and radar systems.
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to the latest ITS research and engineering on a cost reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs. For information on available programs, see pp. 87-88 of this report or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations from which these scenarios are made. Results of analyses show those areas of new interference and the population and households within those areas. Figure 1 shows the result of a study done for a proposed digital station in Connecticut. In addition to determining the contribution to interference from other stations to a selected station, the model can tell the user the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to his/her station and determine the effect these modifications have on the interference the station gives other surrounding stations. In addition to creating a plot similar to that shown in Figure 1, the program creates a table which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This model can now be accessed via a network browser.

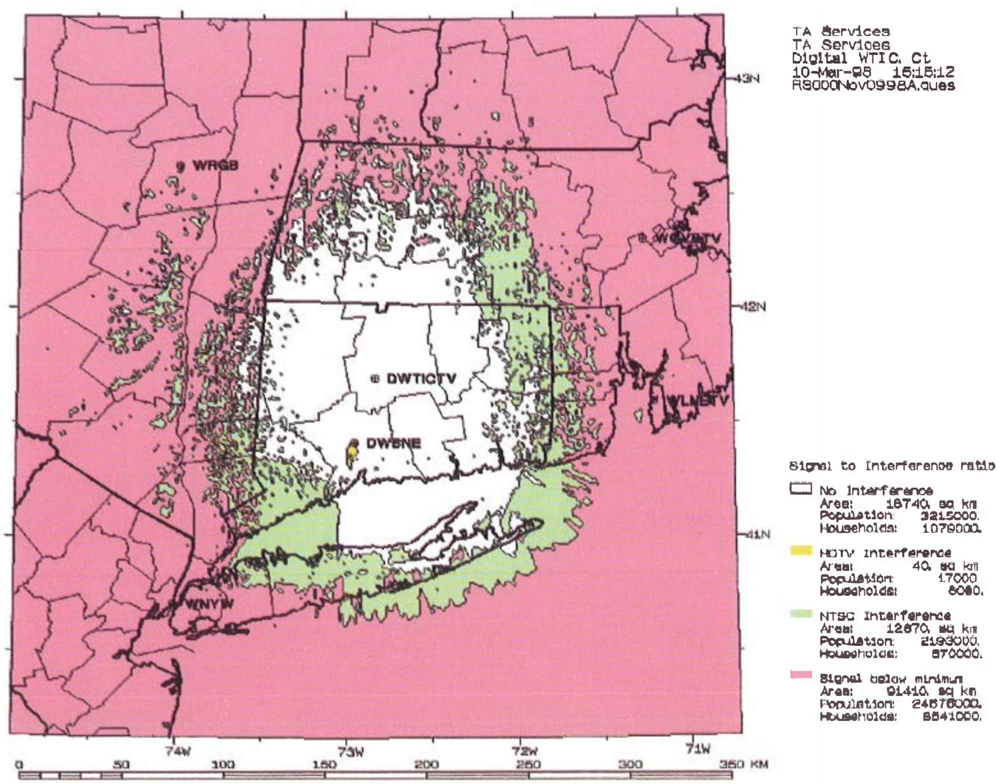


Figure 1. Interference analysis for a proposed digital station in Connecticut.

TA Services continues to develop models in the GIS environment for personal communications services (PCS) and Local Multipoint Distribution Systems (LMDS). A GIS efficiently captures, stores, updates, manipulates, analyzes, and displays all forms of geographically referenced information. The use of GIS has grown substantially over the past several years in business, Government, and academia. As a result, databases necessary for telecommunication system analysis are now becoming available in forms easily imported into the GIS environment. These databases, including terrain, roads, communications infrastructure, building locations and footprints, land type and use, and others, can be maintained in relational database management systems (RDBMS) that can be connected to the GIS or placed into the GIS RDBMS. This reduces the amount of database development necessary in PCS/LMDS modeling.

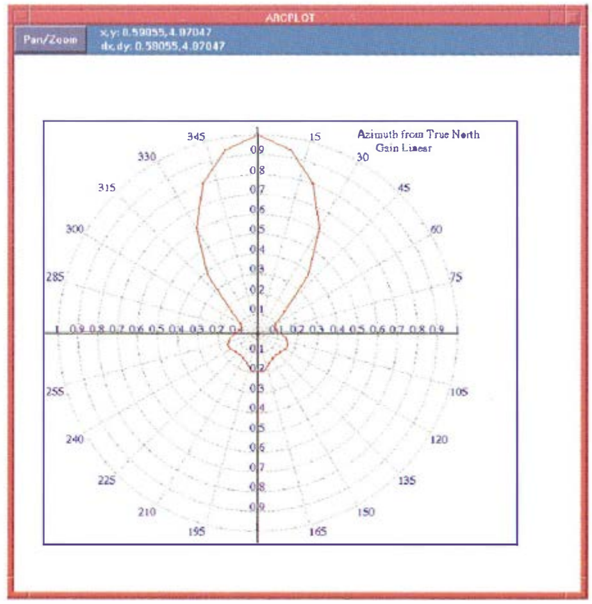


Figure 2. Antenna pattern from the user catalog in the TA Services PCS/LMDS model.

As the frequency of an application increases, the level of detail required to adequately describe the path also increases. At PCS and LMDS frequencies, it is increasingly important to know the location of trees and buildings, as well as other terrain obstructions. At these higher frequencies, it also becomes important to know what kind of vegetation a signal is penetrating. As ray tracing becomes practical in GIS models, it will become important to know the shape and materials used in buildings. Information on building heights and vegetation is not commonly available. However, some city and county Governments are beginning to enhance their GIS databases to include this data, and this trend is expected to continue. Software is available and under development that allows a user to import digital stereo photographs or other remote sensing data taken from aircraft at relatively low altitudes or even spacecraft. If this data is taken with sufficient quality it can be used to create three-dimensional surfaces for the GIS with accuracies on the order of a meter or less. This will greatly reduce the cost of developing databases with the accuracies necessary to ensure reliable analysis results.

The PCS/LMDS model currently under development at ITS allows a user to select a city or region of interest that has a database developed and imported into the model. Once on board, these environment and analysis results can be displayed in two or three dimensions.

A user can create a database of transmitters and antenna patterns from which analysis scenarios can be created. Transmitters can be described easily and placed either by defining the latitude and longitude or zooming in or out on the map and selecting the location of the transmitter. The GIS software reads the location from the map and stores it in the transmitter definition table. Antenna patterns can be imported, entered in table form, or drawn on the screen by a user as shown in Figure 2. The user can then give the pattern a name and store it in a personal catalog for future use. Analysis scenarios created by a user consist of a set of transmitters, antennas, and models chosen to produce propagation results for a region of interest. Models include a line of sight (LOS) model, a road-guided path loss model, and a diffraction model. The program allows the user to vary receiver heights as well as turn on and off the contribution of any transmitter to the overall coverage.

For more information, contact:
Robert O. DeBolt
(303) 497-5324
e-mail debolt@its.bldrdoc.gov

Augmented Global Positioning System

Outputs

- Verification of the performance of the first GWEN differential GPS reference station.
- Planning of the number and location of GWEN differential GPS reference stations required to provide nationwide signal coverage.
- Recommended frequency assignments for differential GPS reference stations.

The NAVSTAR global positioning system (GPS) is a space-based radionavigation system which consists of a constellation of 24 satellites in 6 orbital planes; it provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours per day. GPS was originally developed as a military force enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. To make GPS service available to the greatest number of users while ensuring that the national security interests are protected, two GPS services are provided. The precise positioning service (PPS) provides full system accuracy to military users. The standard positioning service (SPS) is available for civilian use but has less accurate positioning capability than PPS.

SPS accuracy of 100 m does not meet most civilian navigation and positioning requirements. Various augmentations to GPS are used to provide increased accuracy and integrity of the SPS signal. One form of augmentation, differential GPS (DGPS), can provide 1- to 10-m accuracy for dynamic applications and better than 1-m for static users. In the 1994 NTIA special publication, "A technical report to the Secretary of Transportation on a national approach to augmented GPS services," ITS recommended implementation of a radio beacon system, operating in the 300-kHz band, modeled after the U.S. Coast Guard's (USCG) local area DGPS, to provide nationwide coverage of DGPS for surface applications (DeBolt et al., 1994; see Publications Cited, p. 106). The Institute has completed a study, sponsored by the Federal Highway Administration, to determine the optimum location and operating parameters of the DGPS reference stations required to provide this civil navigation and positioning service to all surface users across the nation. The use of this service will have an enormous impact on a diverse set of uses including ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, emergency location and rescue operations, and many others that have not yet been identified.

This new service will be known as the nationwide differential global positioning system (nDGPS). The foundation of this system is the DGPS reference stations currently operating or planned by the USCG and the U.S. Army Corps of Engineers; this system provides coverage of the radiobeacon DGPS signal for coastal areas, harbors, and inland waterways.

ITS added additional DGPS reference stations to this foundation to provide nationwide coverage of the DGPS signal. To achieve this additional signal coverage, ITS used the Ground Wave Emergency Network (GWEN) sites, owned by the Air Force Air Combat Command. The GWEN system is an existing Federal Government asset that provides a cost-effective method of implementing nationwide coverage of the DGPS signal. The GWEN sites were used at existing locations or moved to new locations as required to complete the nationwide DGPS signal coverage. The GWEN sites provided the infrastructure required for a DGPS reference station (Figure 1). Installation of these GWEN DGPS reference stations has already begun, with six stations scheduled for operation in FY 99. The projected signal coverage of a typical GWEN DGPS reference station is shown in Figure 2.

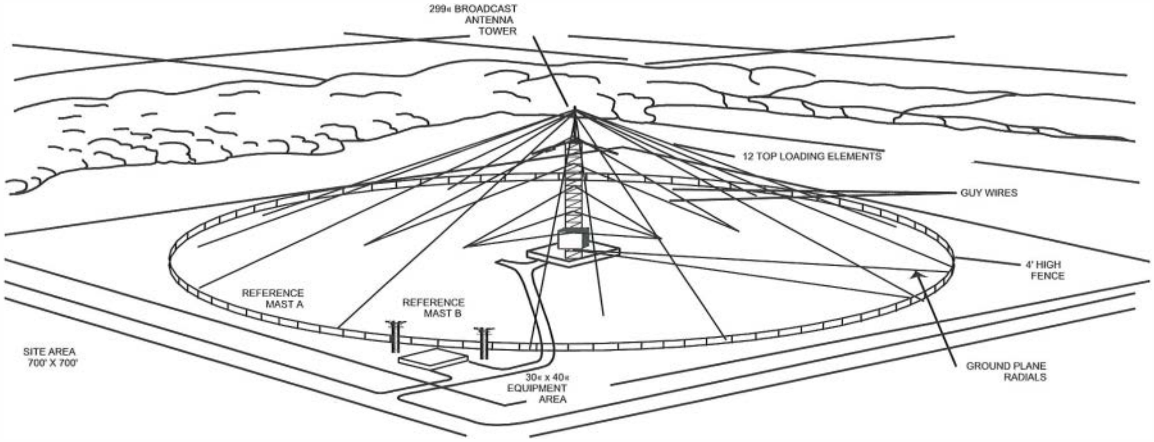


Figure 1. Typical Ground Wave Emergency Network (GWEN) transmitter site.

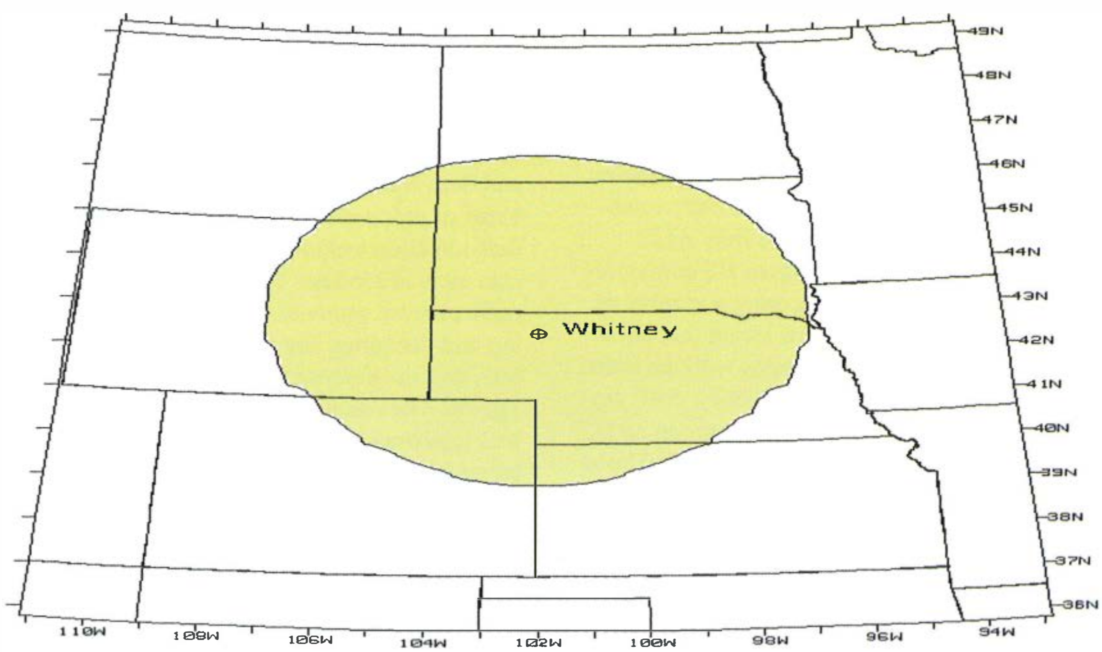


Figure 2. Predicted DGPS signal coverage from a GWEN site at Whitney, NE.

Recent Publication

J. R. Hoffman, J. J. Lemmon, and R. L. Ketchum, "DGPS field strength measurements at a GWEN site," NTIA Report 98-346, Apr. 1998.

For more information, contact:
Ronald L. Ketchum
(303) 497-7600
e-mail rketchum@its.bldrdoc.gov

Low-Cost HF Automatic Link Establishment

Outputs

- Software ALE capability for personal computers.
- Prototype HF ALE demonstration system.

The High Frequency (HF) band, 3–30 MHz, is one of the oldest wireless communications media. Although it is commonly regarded as the province of hobbyists and amateur radio enthusiasts (hams), this band has great potential value as a backup to other, more vulnerable elements of the U.S. communications infrastructure in times of national emergency. Unfortunately, achieving this potential has required highly trained operators as a result of the extreme variability, and complexity, of the HF medium. FED-STD-1045A, HF Radio Automatic Link Establishment (ALE), was developed to simplify and facilitate HF radio operation by automating the selection of transmission frequencies. The standard specifies channel sounding algorithms, transmission waveforms, and a protocol for automatically establishing and maintaining an HF radio link. ALE removes the difficulty of choosing an HF communications channel by polling and scoring a number of potential channels for link quality. Using this information, the receiving radio negotiates with the transmitting radio for a suitable link frequency. ALE dramatically reduces the time necessary to set up an HF communications link — and increases the likelihood of satisfactory communications over the selected frequency — by eliminating the need for users to understand ionospheric radio propagation. Link reliability is improved by using ALE's sounding and channel evaluation capabilities. ALE radios are easy and efficient to operate, even in the hands of the most inexperienced users.

Despite its advantages, HF ALE has not been implemented widely by non-government users because of its relatively high equipment cost. There would be substantial benefits to the National Security and Emergency Preparedness (NS/EP) missions of the National Communications System (NCS) and other Federal Agencies if ALE technology could be made more widely available. Coordination with hams in times of emergency has greatly enhanced previous disaster relief efforts. Broadening HF connectivity would speed future relief efforts. ITS is assisting the National Communications System (NCS) and its member agencies in achieving this goal by developing and demonstrating a low cost HF ALE capability for the personal computer (PC).

Under the ITS approach, FED-STD-1045A communication functions such as sounding and channel evaluation will be implemented in PC software. During the first half of FY 98, ITS engineers developed a prototype "Phase 1" ALE system that demonstrates the feasibility of using real-time software embedded in PCs to control inexpensive HF radios and modems — and to establish operational HF links. Figure 1 shows the commercial equipment that was used in developing the Phase 1 system. During the latter half of FY 98, ITS began developing a Phase 2 ALE software system that will implement the extremely robust FED-STD-1045A modem waveforms and the standard's automatic channel evaluation capabilities. ALE protocol waveforms for channel selection and negotiation will be generated and decoded in software, using ITS-developed databases of precision audio tones and ITS-developed demodulation techniques. The ALE software will also include modules for configuration management, radio control, protocol management, message encoding and decoding, signal modulation and demodulation, and the maintenance of a database of detected signals. The resulting software-based ALE radios will interwork directly with commercial, hardware-based FED-STD-1045A radios costing up to 10 times as much.

The key technical challenge in the Low-Cost ALE project is to develop a demodulation technique that is robust enough to detect the transmitted ALE tones in the presence of severe HF channel noise and interference, yet simple enough to be implemented in real-time software on a Windows® based PC. Figures 2 and 3 indicate the quality of the frequency discrimination that has been easily achievable in the ITS HF radio laboratory. In future work, ITS will select the demodulator algorithm, implement that algorithm and the other key ALE functions in software, and demonstrate the system's performance under realistic HF channel conditions. The ITS HF ALE software will bring software radio equipment to any desktop, greatly increasing the effectiveness of Federal NS/EP efforts.

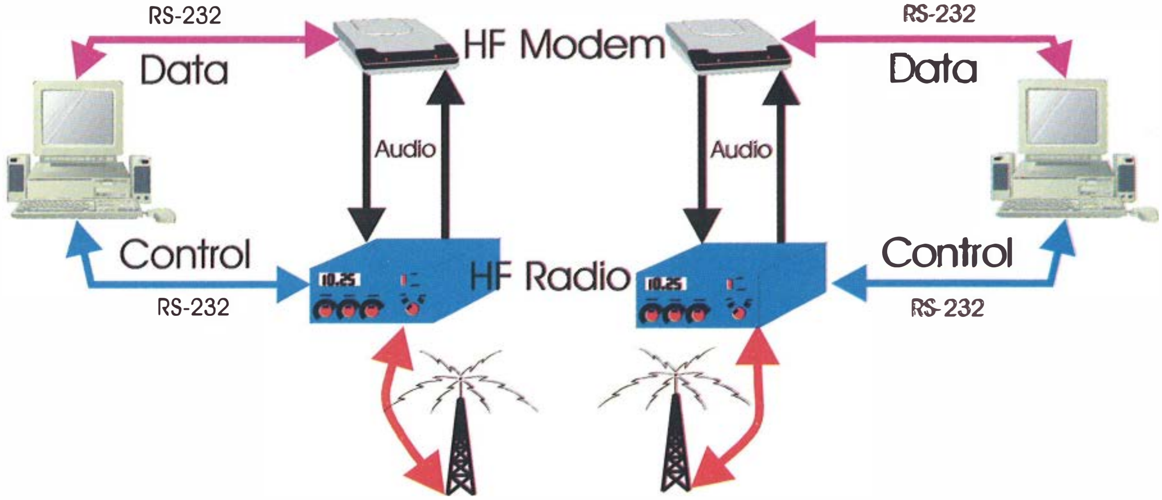


Figure 1. Phase One QuasiALE.

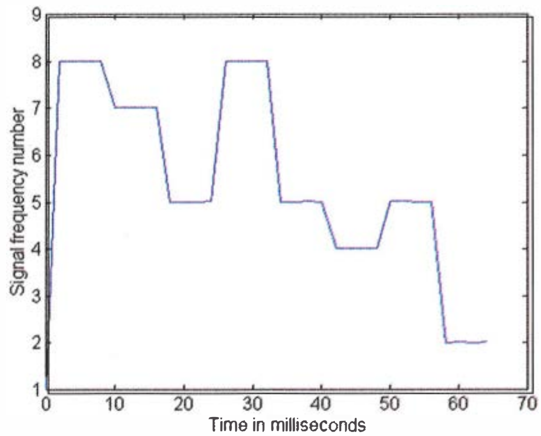


Figure 2. ALE waveform demodulation using the energy operator.

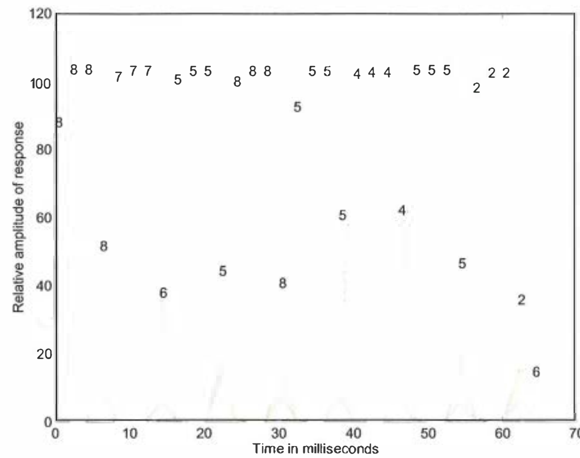
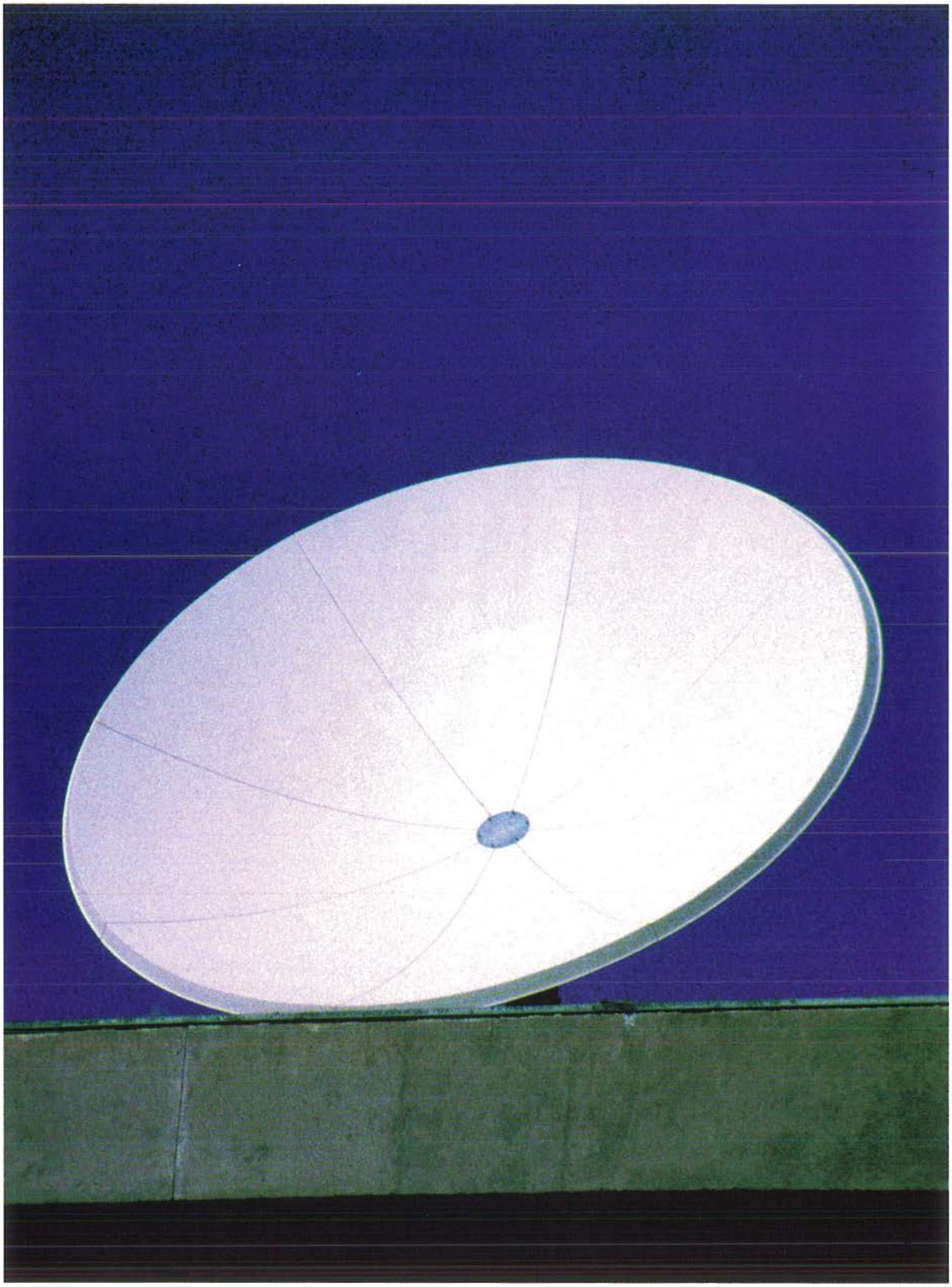


Figure 3. ALE waveform demodulation using Goertzel method.

For more information, contact:
Christopher Behm
(303) 497-3640
e-mail behm@its.bldrdoc.gov



ITS 4-GHz earth station under construction. This station is being used to determine susceptibility of satellite downlinks to interference from radar signals (photograph by F.H. Sanders).

Telecommunication System Performance Assessment

The Institute develops tools, facilities, guidelines, and procedures for telecommunication system performance assessment and applies these resources in predicting and measuring the performance of particular systems and their components on behalf of telecommunications users, equipment manufacturers, and service providers. The performance assessment resources developed and used at ITS include standard performance metrics and measurement methods; software and hardware simulation and testbed facilities capable of emulating equipment performance under repeatable laboratory conditions; environment generators that accurately reproduce desired traffic, climate, terrain, propagation, and noise/interference effects; standard source materials representing specific types of voice, video, data, and multimedia communications signals; and computer-based test equipment for collecting, reducing, analyzing, and presenting system performance data. The elements evaluated span the range from individual equipment components (e.g,. signal encoders and decoders) to end-to-end communication links and networks comprised of many independent transmission and switching elements. Institute engineers have assessed terrestrial wireless, wireline, and satellite transmission media and a variety of services and technologies including cellular radio, land mobile radio, personal communication services (PCS), synchronous optical network/synchronous digital hierarchy (SONET/SDH), asynchronous transfer mode (ATM), and both X.25-based and Internet Protocol (IP)-based packet switching. The Institute's system performance assessment results are used in advanced technology development, equipment design and prototype testing, and the evaluation and optimization of communication services from both provider and end user perspectives.

Areas of Emphasis

Radio System Design and Performance Software

The Institute applies its enhanced Jammer Effectiveness Model, a Windows-based computer program, in assessing the impacts of jamming and interference on communications and radar system performance in electronic warfare scenarios. Projects are funded by the U.S. Army National Ground Intelligence Center.

Satellite Studies

The Institute applies ITS-developed standard performance metrics in assessing satellite-based data, voice, video, and multimedia communication services and presents results in national and international standards organizations. Projects are funded by NTIA.

Multimedia Performance Handbook

The Institute develops technical information and specific examples to assist users in specifying, evaluating, acquiring, and operating video teleconferencing and other multimedia communication systems, and documents the results in successively more comprehensive releases of a CD-ROM based interactive multimedia document. Projects are funded by NCS.

Wireless Telephony Performance Measurements

The Institute measures the transmission performance and delivered audio quality of advanced digital land-mobile radio systems to assist users in LMR network design and operation. Projects are funded by Federal Railroad Administration.

Radio System Design and Performance Software

Outputs

- Current version of Jammer Effectiveness Model for communications analysis in use by the U.S. Army.
- Additional version of Jammer Effectiveness Model for radar analysis in use by the U.S. Army.
- Multiple jammer and interferer analysis capability on a wireless network.

In FY 98, ITS continued to make improvements to the Jammer Effectiveness Model (JEM). JEM, which was developed by ITS for the U.S. Army in order to evaluate electronic warfare scenarios, runs as a Windows application on a personal computer. This model is a very flexible analysis tool and can be used to perform many different types of analysis, because it is highly structured and modular in design. ITS has developed two versions of JEM: one for communications analysis and the other for radar analysis.

Each version of JEM includes a user-created catalog of equipment, ground stations, aircraft and satellite platforms; the software for creating and maintaining this catalog; a climatological database for much of the world; a library of propagation subroutines; and the analysis software. The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. In FY 98, ITS developed printer setup capability for both JEM versions. The valid frequency range of the communication version of JEM is currently 2 MHz to 300 GHz, while that of the radar version is currently 30 MHz to 20 GHz.

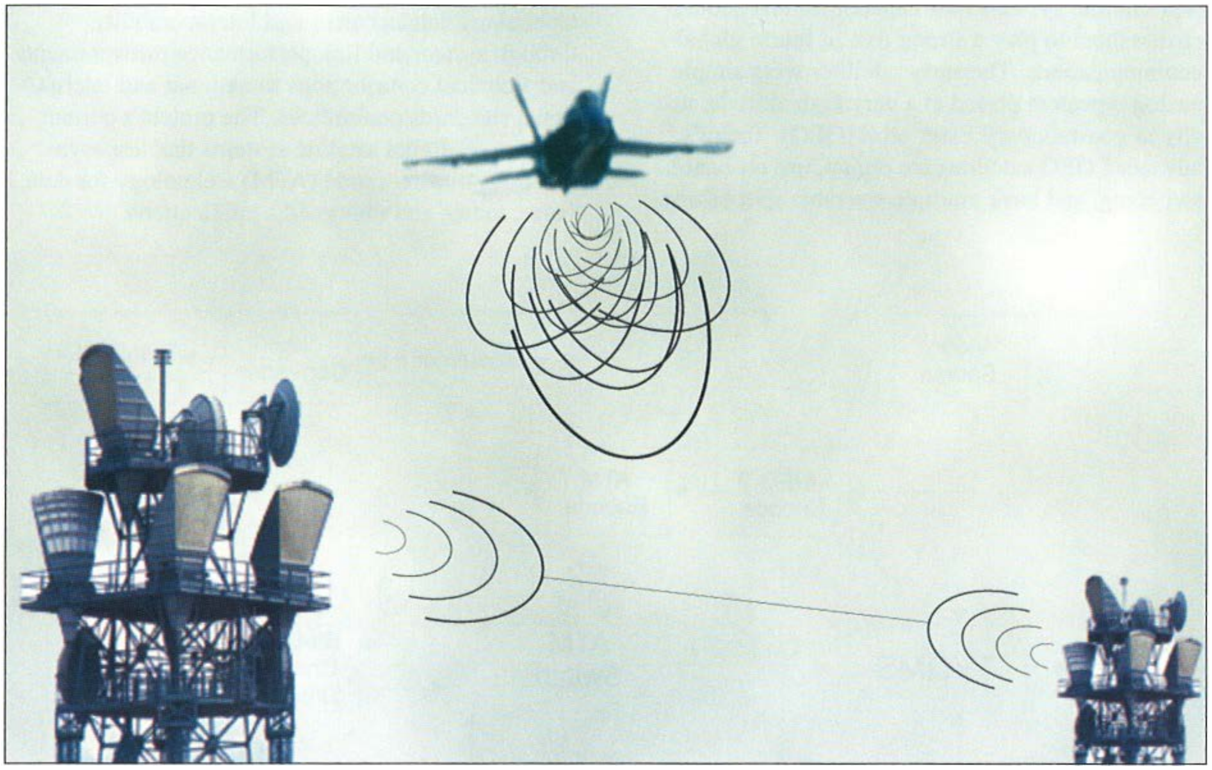
JEM uses scenarios to completely characterize a communication link or radar configuration with or without a jamming situation. The scenario description includes ground or airborne station location and physical factors such as climate and terrain. Each of the analysis programs within a scenario analyzes the case represented by the scenario description data. Data entry in JEM to create a scenario is simplified by the use of user-friendly menus and options. Databases are created as a result of this data entry and saved as scenario descriptions.

The communications analysis version of JEM is primarily used to model communication systems in electronic warfare scenarios where these systems are being jammed or interfered with. The Figure illustrates a jammer attempting to jam a point-to-point microwave communication link. This version of JEM is organized into six scenarios, each of which represents either a communication path geometry description or a jamming geometry description. The four scenario types in the communication geometry description are: ground-to-ground, ground-to-satellite, ground-to-aircraft, and aircraft-to-satellite. The two scenario types in the jamming geometry description are jamming and jammer versus network. The jamming scenario analyzes: received jammer power versus distance, received transmitter power versus distance, jammer footprint, and isopower contours. Recently added in FY 98 is an area of isopower contours computation. The jammer versus network scenario analyzes and evaluates the effects of up to three jammers on up to five communications nodes. For the jamming geometry description, the receiver, transmitter, and jammer platforms can be on the ground or airborne.

The jamming and jammer versus network scenarios are the major features of JEM for electronic warfare and interference analysis. The other four scenario types are used to help evaluate and design microwave communication systems. They allow the user to simulate a wide variety of propagation effects on the system that occur in the higher frequency ranges by including clear-air absorption losses and losses due to rain attenuation. In FY 98, the ability to perform the received signal power versus range computation independent of a scenario has been added. Also new in FY 98 is three dimensional antenna pattern capability.

The radar version of JEM allows radar analysis for different combinations of radars and jammers that are on the ground or carried by airborne stations. The radar analyses consist of either evaluating the performance of a radar trying to detect and track a target or evaluating the ability of a synthetic aperture radar to map a location. The analysis can be performed both with and without the presence of a jammer. One scenario includes the jamming of an airborne radar by a ground-based or airborne jammer to protect potential targets that can either be collocated with the jammer or separated from the jammer. A second scenario involves the jamming of a synthetic aperture radar on an airborne platform from either an airborne or ground-based jammer platform. The three dimensional geometry of these radar scenarios requires three dimensional antenna patterns which are also included in the analysis models.

There are three analysis modes available in the radar jamming scenario: a radar jammer footprint, a radar isopower contour, and a radar burn-through range. For the radar jammer footprint analysis a jammer is able to jam a radar that is on or within a contour of distance to jammer versus azimuth angle, and prevent it from detecting a target. The isopower contour analysis is a plot of signal power density about the radar or jammer versus distance and azimuth angle about the radar or jammer. The radar burn-through range analysis is the minimum range to the target versus azimuth angle at which the target is obscured by jamming. It is also the maximum range versus azimuth angle at which the radar detects the target.



A jammer attempting to jam a point-to-point microwave communication link (illustration by A. Romero).

For more information, contact:
Nicholas DeMinco
(303) 497-3660
e-mail ndeminco@its.bldrdoc.gov

Satellite Studies

Outputs

- Transportable video quality measurement system.
- Report on national security and emergency preparedness experiments using the Advanced Communications Technology Satellite (ACTS).

Recent technology advances are giving communication satellite systems new capabilities that should enable them to play a strong role in future global communications. The early satellites were simple analog repeaters placed at a very high altitude, usually in geostationary Earth orbit (GEO). Today's advanced GEO satellites are digital, use on-board switching, and have multiple steerable spot beams.

Emerging low Earth orbit (LEO), medium Earth orbit (MEO), and highly elliptical orbit satellite constellations will support direct communications with mobile and hand-held terminals, giving users access to telephone and Internet services from any point on the Earth's surface.

These advanced satellite capabilities can only be fully effective if the satellite systems are seamlessly integrated with the terrestrial networks. The Institute's Satellite Studies Project contributes to satellite technology enhancement and interoperability through system and link performance measurements and technical contributions to national and international standards committees. The project's current focus is on digital satellite systems that use asynchronous transfer mode (ATM) technology for data, voice, video, and multimedia applications.

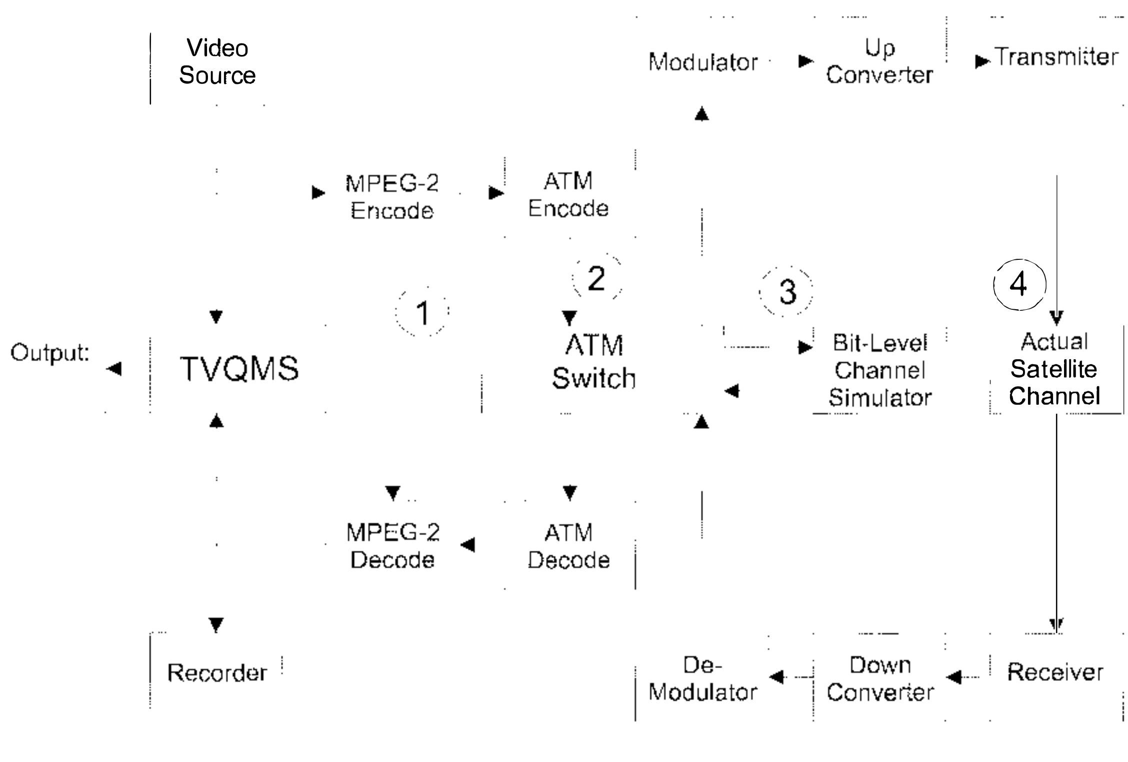


Figure 1. Test configurations for planned video quality measurements. Path 1 will determine the effects of MPEG-2 encoding and decoding. Path 2 transports the MPEG-2 over ATM. Path 3 passes the ATM cells through a bit-level channel simulator, and path 4 uses an actual satellite channel.

The transmission of ATM over satellite is currently being studied in several standards committees. The Wireless ATM group of the ATM Forum is working to promote satellite/terrestrial ATM interoperability to ensure that satellite links can be used in any part of an ATM network. To achieve this, they need a common air interface (CAI) specification. This specification is being developed by a working group in the Satellite Communications Division (TR-34) of the Telecommunications Industry Association (TIA). The Institute contributed strongly to the reference architectures developed by the ATM Forum and used in the draft CAI specification.

U.S. Working Party 4B of the International Telecommunication Union, Radiocommunication Sector (ITU-R) is developing two new Recommendations that will specify Quality of Service (QoS) objectives for ATM satellite links. These new Recommendations will complement ITU-T Recommendation I.356 (developed under ITS leadership), which defines minimum, end-to-end quality objectives for ATM networks. The need, and challenge, at this time is to determine the minimum satellite link quality required to support the ATM performance levels already agreed upon for terrestrial (fiber optic) transmission. During FY 98, the Institute developed test capabilities and experiment plans that will enable it to collect quantitative measurement data addressing that need. This experimental work will apply the Institute's unique ability to make repeatable, accurate, objective measurements of end-to-end video quality.

Many believe that MPEG-2 digital video is one of the most demanding applications for ATM network transport. During FY 98, the Satellite Communications Project staff completed a test facility that includes a transportable video quality measurement system (TVQMS) that can make quality measurements of MPEG-2 video over either simulated or real satellite channels employing ATM. The block diagram in Figure 1 illustrates several test configurations, of increasing complexity, on which the TVQMS will be used. The planned experiments will be conducted during FY 99.

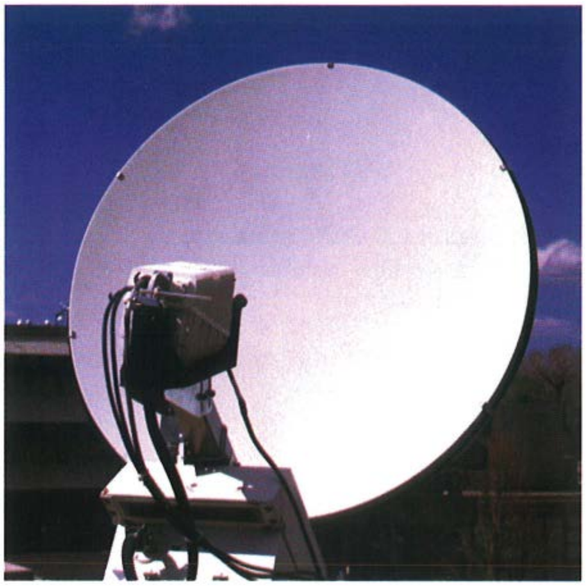


Figure 2. ACTS Earth station antenna, part of the ACTS facility at ITS in the satellite laboratory (photograph by F.H. Sanders).

Project staff members also published the results of a set of experiments performed over NASA's Advanced Communications Technology Satellite (ACTS) during FY 98. These experiments used the ACTS Earth station at ITS (see photograph of the antenna in Figure 2) and two others to form a small network. These experiments provided information on the ability of an advanced satellite to support National Security and Emergency Preparedness (NS/EP) functions using off-the-shelf applications. Desktop conferencing, local area network (LAN) bridging, and voice communications were all effectively supported. An important finding of these experiments was that satellite networks will require special protocol provisions (e.g. larger retransmission window sizes) to provide TCP/IP (transmission control protocol / Internet protocol) support comparable to that provided by terrestrial facilities.

Recent Publication

W.A. Kissick, et al., "National security and emergency preparedness communications experiments using the advanced communications technology satellite," NTIA Report 98-354, Aug. 1998.

For more information, contact:
William A. Kissick
(303) 497-7410
e-mail billk@its.bldrdoc.gov

Multimedia Performance Handbook

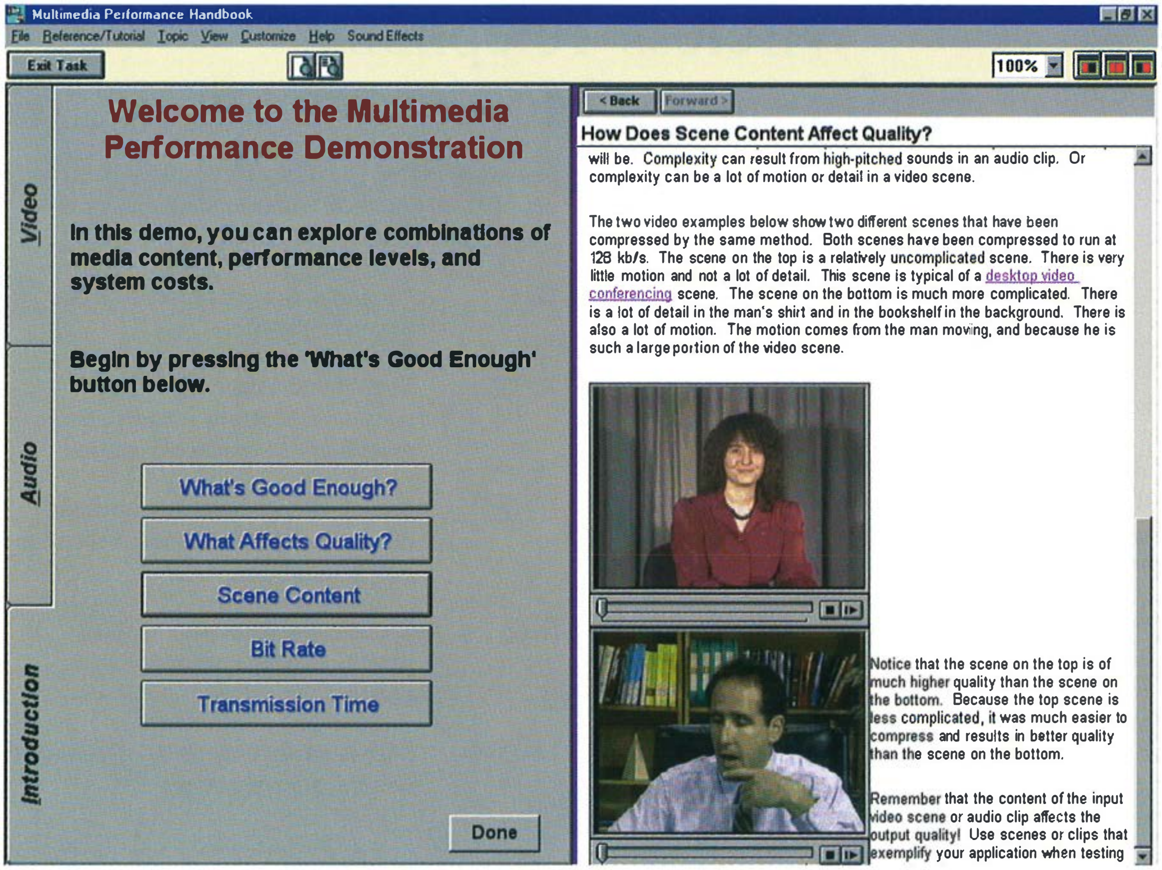
Outputs

- Interactive CD-ROM application for videoteleconferencing system performance specification.
- Tutorial and reference material on multimedia performance assessment.

Several years ago, ITS engineers recognized the need for a convenient source of practical information to assist users in assessing the performance of multimedia communication systems. They foresaw that such information would find application in the procurement of multimedia products, in product acceptance testing, and in the operation and maintenance of products after installation. Much of the necessary information had been or was being produced in related ITS programs on telecommunication performance standardization, but additional product-specific information and more systematic selection criteria were needed. For example, ITS had been involved for several years in developing techniques for objective, technology-independent measurement of video image quality. While the resulting information was extremely valuable, consumers also wanted information concerning the image quality of specific types of video monitors and other video equipment. ITS sought and received support from the National Communications System (NCS) to develop a more comprehensive quality assessment guide. This product, known as the Multimedia Performance Handbook, originally was envisioned as a printed report that would undergo frequent (and sometimes extensive) revisions to reflect technology changes. However, ITS engineers soon discovered that a more flexible and effective means of presenting this information would be an interactive multimedia application implemented on a CD-ROM.

A first prototype of the Handbook was produced in FY 95. This product integrated audio, video, graphical information, and hyperlinked text in the context of an interactive graphical user interface to present required technical information in a user-friendly computer application. During FY 97, ITS completed a substantial enhancement to the Handbook (Version 2.0), combining increased functionality with a larger information base. In FY 98, ITS provided a product that is easier to use and more versatile. The revised Handbook is well-suited to the needs of current (or future) Federal users of multimedia communications. In particular, it addresses videoconferencing (VTC) requirements that are important to the National Security and Emergency Preparedness (NS/EP) telecommunications mission of NCS. The Handbook provides a wealth of technical information and many specific examples to assist users in making effective decisions in the specification, procurement, and use of multimedia communication systems. The Handbook's extensive use of audio, video, and graphical presentations greatly enhances the impact and value of its technical content. The hyperlinking of key text allows users to skim familiar material and delve more deeply into other topics.

Version 2.0 of the Handbook implemented a new specification "applet" (a small application program) that assists users in establishing multimedia performance requirements. The applet enables users to experience interactively the likely performance of particular VTC configurations. For example, after entering the specification applet and choosing the videoconferencing application, the user can choose either desktop videoconferencing or conference room videoconferencing as the multimedia context. Assuming the former choice is made, the user is next shown the classes of video content for which performance examples will be given. On the next page, the user can choose the quality level of the videoconferencing system—low, medium, medium high, high, or source quality. The user can then see and hear examples of the performance to be expected for the selected combination of content and system quality level. The media options provided include motion video (with and without audio), audio only, and a still image frame (at half and full resolution). Numerical quality ratings (derived from ITS-developed industry performance standards) are provided to enable the user to relate the media examples to subjective and objective performance assessment scores. At each step along this interactive process, information is provided in several ways to help the user make these choices. "Tell Me More" buttons are available on each page and hyperlinks are abundant.



Example screen from the NCS Multimedia Performance Handbook.

This and other version 3.0 applets make extensive use of real audio and video clips, derived from commonly available multimedia communications systems and equipment. These clips illustrate performance impairments and demonstrate their effects on particular source material. This feature gives users a realistic view of product performance before any product is procured. The Figure shows a page from the Multimedia Performance Demonstration Applet. The applet explores several aspects of multimedia quality. Development of the Handbook was an exciting, though demanding, task. The development team used several commercially available programming tools to produce the large quantity of custom audio, video, and image data included in the document. A standard hyperlinked text browser was used to provide access to the thousands of lines of tutorial and reference information. Applets and the overall user interface were created using Microsoft Visual Basic 5.0 supplemented by special-purpose library packages. Creation of the audio and video data was the most time-intensive task. Each audio or video clip was recorded by the development team and then digitized in formats that could be played by the set of standard multimedia players included with the computer operating system. During the recording process, each source clip was processed through a number of different real or emulated coding systems to allow the effects of such coders on user perception to be illustrated. Upon the release of version 3.0 of the Handbook, the development team had produced over 600 mb of digitized audio, video, and image data. Over 500 mb of this data was digitized video!

In sum, the Multimedia Performance Handbook combines innovative use of multimedia programming techniques, unique ITS-developed performance measurement technologies, and a broad view of telecommunications to produce a tool that can substantially improve the specification and assessment of multimedia systems in Government and private sector user organizations. The Handbook also provides a model for presenting technical information in the future.

For more information, contact:
Arthur A. Webster
(303) 497-3567
e-mail webster@its.bldrdoc.gov

Wireless Telephony Performance Measurements

Outputs

- RF sensitivity, adjacent channel rejection ratio, and cochannel rejection ratio of a P25 radio.
- Delivered audio quality (DAQ) of speech signals transmitted through a P25 radio system.

The Telecommunications Industry Association's (TIA) open-standard design specification for the next generation of land mobile radios is known as Project 25, or simply P25. Organizations that plan to infuse new P25-compliant radio equipment into their radio fleets must determine the minimum level of acceptable speech intelligibility that is required. The level of speech intelligibility is directly related to the minimum acceptable levels of received signal strength and interference rejection ratio, which in turn influences the design specification for the radio network infrastructure (range of coverage, distance between adjacent channel and cochannel transmitters, etc.).

ITS measured the RF sensitivity, adjacent channel rejection ratio, and cochannel rejection ratio of a P25-compliant radio. ITS also determined the corresponding delivered audio quality (DAQ) values of speech signals transmitted through the radio under these conditions. The TIA defines the numeric values of DAQ and their corresponding quality of speech intelligibility as follows:

DAQ 1	Unusable. Speech present but not understandable.
DAQ 2	Speech understandable with considerable effort. Requires frequent repetition due to noise/distortion.
DAQ 3	Speech understandable with slight effort. Requires occasional repetition due to noise/distortion.
DAQ 3.4	Speech understandable without repetition. Some noise/distortion present.
DAQ 4	Speech easily understood. Occasional noise/distortion present.

Figure 1 shows the DAQ of analog and digital radios as functions of the analog radio's signal-plus-noise-plus-distortion-to-noise-plus-distortion (SINAD) ratio and the digital radio's bit error ratio (BER). Also shown in Figure 1 are the TIA's reported values relating DAQ to SINAD and BER.

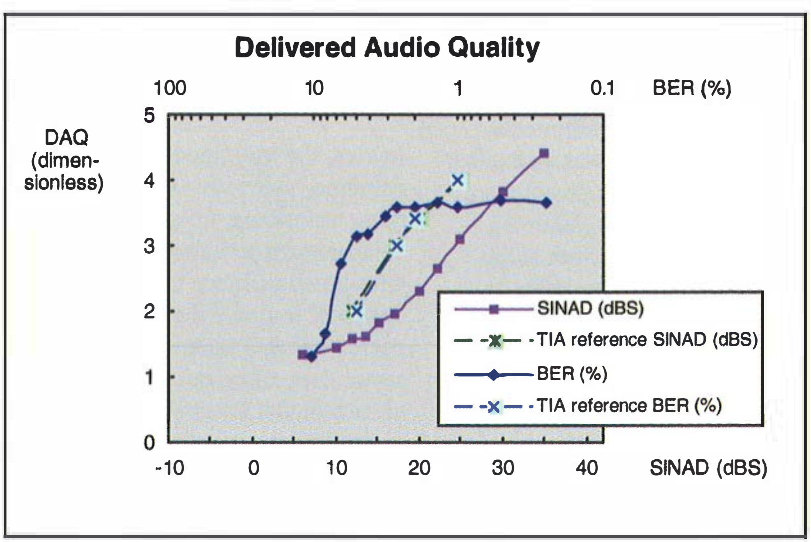


Figure 1. A comparison of Delivered Audio Quality versus analog SINAD and digital BER.

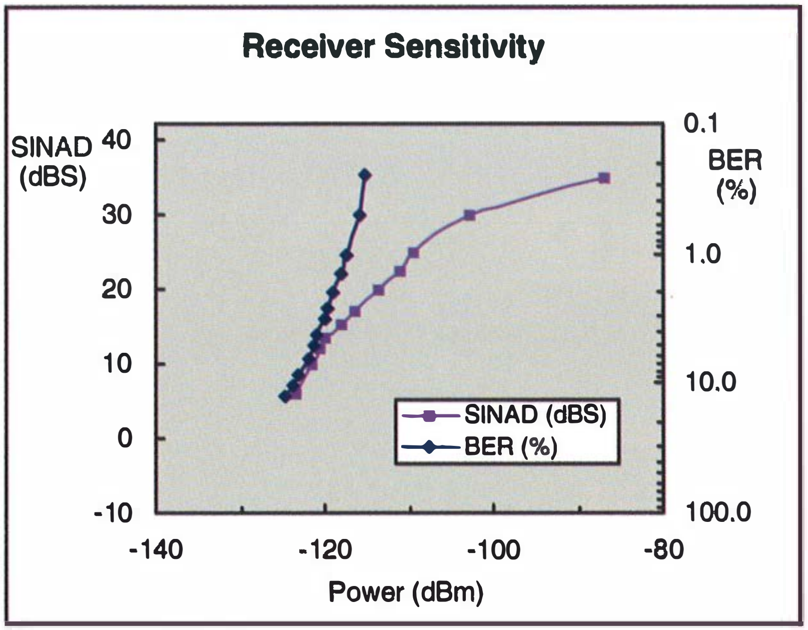


Figure 2. Typical receiver reference sensitivity levels vs. SINAD or BER.

To facilitate a direct comparison between the DAQ performance of the analog and digital operating modes, the SINAD and BER axes in Figure 1 were scaled and aligned to point-match the analog and digital DAQ values that had been reported previously by the TIA, at both the DAQ = 2 and the DAQ = 4 operating points. Using these horizontal-axis scales, TIA's analog and digital mode DAQ operating points are observed to essentially coincide at both DAQ = 3 and DAQ = 3.4.

Figure 2 shows some sample RF sensitivity data for analog and digital radios. Comparing ITS' measured DAQ data presented in Figure 1 to the receiver sensitivity data plotted in Figure 2, one can generalize that at comparable received signal strengths, digital modulation yields better received audio performance than does analog modulation. For example, Figure 1 shows that a 22 dBS analog signal and a 6.5% BER digital signal both yield a DAQ of about 2.8. From Figure 2, the RF sensitivities of a 22 dBS analog signal and a 6.5% BER digital signal are about –115 dBm and –123 dBm, respectively. Therefore, a weaker digital signal will deliver the same speech quality as will a stronger analog signal.

A thorough discussion of all these measurements (RF sensitivity, adjacent channel and cochannel rejection, and DAQ) and the consequent results can be found in NTIA Report 99-358, referenced below. Additional information, including speech files at various DAQ levels, is available at ITS' web site: http://flattop.its.bldrdoc.gov/spectrum/P25/index.htm

Recent Publication

J. Vanderau, "Delivered audio quality measurements on Project 25 land mobile radios," NTIA Report 99-358, Nov. 1998.

For more information, contact:
John M. Vanderau
(303) 497-3506
e-mail jvanderau@its.bldrdoc.gov

ITS engineers (Randy Hoffman and Yeh Lo) with a wideband impulse measurement system designed and built at the Laboratory (photograph by F.H. Sanders).

Applied Research

The rapid growth of telecommunications in the last 40 years has caused crowding in the radio spectrum. New technology requires a new understanding of the behavior of radio waves in all parts of the radio spectrum. The Institute studies all frequencies in use, extending our understanding of how radio signal propagation is affected by the earth's surface, the atmosphere, and the ionosphere. This work is resulting in new propagation models for the broadband signals used in new radio systems. Other efforts are increasing our understanding of the propagation of millimeter-wave frequencies, thus providing a huge band for future expansion of radio communication services. The Institute's historical involvement in radio-wave research and propagation prediction development provides a substantial knowledge base for the development of state-of-the-art telecommunication systems. ITS transfers this technology to both public and private users, where knowledge is transformed into new products and new opportunities.

Areas of Emphasis

Cooperative Research with Industry

The Institute engages in technology transfer through cooperative research with industry. Projects are funded by US WEST Advanced Technologies, Inc., Netrix Corporation, the American Automobile Manufacturers Association, and Hewlett-Packard Co.

Millimeter-wave Research

The Institute conducts research on the millimeter-wave radio propagation channel. The results of the research enable industry to develop and deploy LMDS systems. Projects are funded by NTIA, and Hewlett-Packard Co.

Adaptive Antenna Testbed

The Institute is developing an advanced antenna testbed to be used in the investigation of "smart" antennas, which will greatly increase the capacity of wireless communications systems. The project is funded by NTIA.

Wireless System Modeling and Simulation

The Institute conducts software simulation of wireless systems to predict performance for new radio systems. Projects are funded by NTIA and the U.S. Air Force.

HF Channel Modeling and Simulation

The Institute contributes to HF channel modeling and simulation that enables network users and administrators to optimize network utilization. Projects are funded by NTIA and the National Communications System.

Wireless Propagation Research

The Institute conducts research involving the radio propagation channels that will be employed in new wireless communication technologies such as personal communications services. This knowledge will aid both Government and industry. Projects are funded by NTIA, the U.S. Air Force, and Hewlett-Packard Co.

Impulsive Noise and Digital Systems

The Institute performs measurements to define the RF noise environment that is experienced by communication systems and develops models to predict the effect on digital communications. Projects are funded by NTIA and the National Oceanic and Atmospheric Administration.

Electromagnetic Compatibility Research

The Institute conducts research involving the electromagnetic compatibility of a variety of communications systems. Projects are funded by NTIA and the Federal Highway Administration.

Advanced Radio Technologies

The Institute conducted the 1998 International Symposium on Advanced Radio Technologies. The Institute is also involved in research of advanced radio systems including software radios and smart antennas. Projects are funded by NTIA and the Department of Defense.

Cooperative Research with Industry

Outputs

- A report detailing the field trials of six proposed PCS air-interface standards in the Boulder Industry Testbed.
- Algorithms that estimate the perceived quality of speech that has been transmitted through a telecommunications system.
- Measurements defining the electromagnetic environment near military and air-traffic control radar facilities that may have an effect on vehicular electronics.

The Technology Transfer Act of 1986 (FTTA), as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. The law was passed in order to provide laboratories with clear legal authority to enter into these arrangements and thus encourage technology transfer from Federal laboratories to the private sector. Under this Act, a cooperative research and development agreement (CRADA) can be implemented that protects proprietary information, grants patent rights, and provides for user licenses to corporations, while allowing Government expertise and facilities to be applied to interests in the private sector.

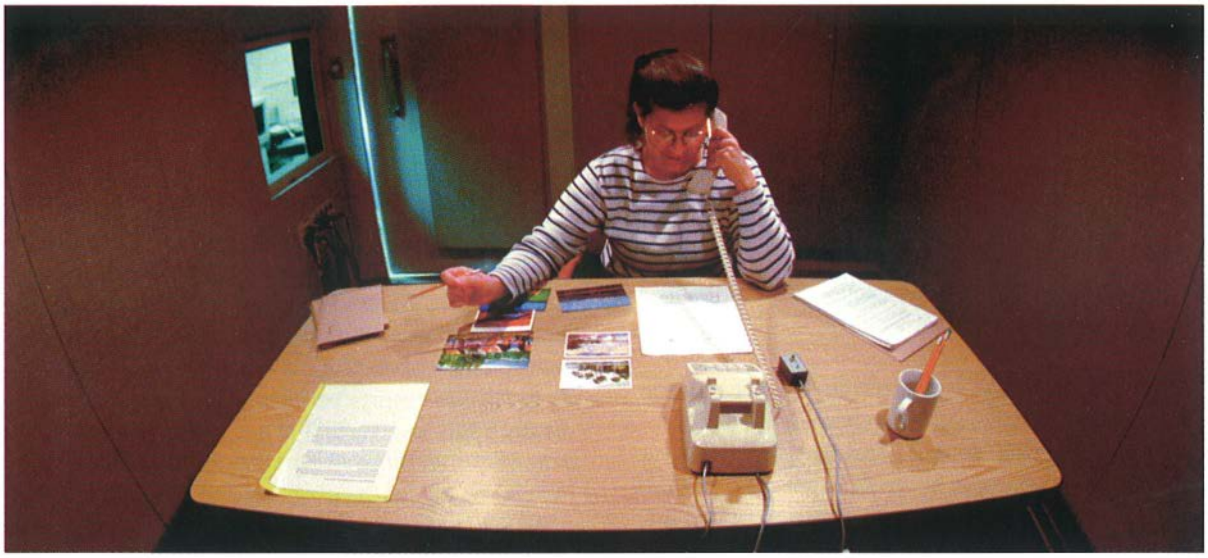
ITS participates in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. ITS has participated for a number of years in CRADAs with private sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with Bell South Enterprises; Telesis Technology Laboratories; US WEST Advanced Technologies (US WEST); Bell Atlantic Mobile Systems; GTE Laboratories Inc.; US WEST New Vector Group; General Electric Company; Motorola Inc.; Hewlett-Packard Company (HP); Integrator Corporation; AudioLogic, Inc.; Industrial Technology, Inc.; Netrix Corporation; and the American Automobile Manufacturers Association (AAMA). Not only does the private industry partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do.

Much of the Institute's work in personal communications services (PCS) has been accomplished through CRADAs. As part of a CRADA with US WEST, ITS served as a neutral independent observer as the Joint Technical Committee on Wireless Access (JTC) conducted field trials of six proposed PCS air-interface standards in the Boulder Industry Testbed. The results of these six separate field trials have been compiled and published as an NTIA report.

ITS is conducting a CRADA with AAMA to collect field data that will define the electromagnetic environment at specific locations in the United States. As electronic devices proliferate, it becomes important for the motor vehicle industry to have knowledge of the electromagnetic environment in which vehicular electronics will operate. Of specific interest are electromagnetic environments near military and air-traffic control facilities using radars. This knowledge is essential to the development of future automotive electronics.

A CRADA with Netrix Corporation of Herndon, Virginia draws on ITS expertise in objective and subjective audio quality testing. In FY 98, ITS designed, conducted and analyzed a subjective conversation test to compare a Netrix Voice-over-Internet Protocol (VoIP) product with the conventional telephone network. In the double-blind test, randomly selected pairs of subjects performed picture sorting tasks in sound-isolated rooms. Subjects used standard telephones to communicate with each other in order to accomplish the tasks. These phones were randomly switched between the two systems under test, and 128 opinions were collected for each system. This work continues with the application of ITS objective audio quality assessment tools. These tools provide real-time estimates of transmission delay and perceived speech quality for various telecommunications systems.

ITS has recently developed a family of algorithms that estimate the perceived quality of speech that has been transmitted through a telecommunications system. These novel algorithms emulate human hearing and judgment and explicitly model listeners' patterns of adaptation and reaction to spectral



Participant in a subjective conversation test, in the ITS Audio Lab (photograph by F.H. Sanders).

deviations. ITS has applied for a patent on these innovative audio quality estimation algorithms and the algorithms have attracted significant industry attention. One company has licensed the algorithms for use in cellular telephone test equipment. This equipment sends digitally recorded speech signals through a cellular network, and uses the ITS algorithm to compare the transmitted and received signals, resulting in an estimate of the customer-perceived speech quality at that location. It is expected that this new equipment will provide cellular operators with important information that can be used to optimize the coverage and services they provide.

ITS has been a premier laboratory in millimeter-wave research for two decades. Now ITS is applying this unique expertise while conducting research into radio propagation considerations for LMDS. ITS has a CRADA with HP for LMDS research. Under the current agreements, ITS has developed propagation models for the LMDS channel, conducted field measurements to characterize radio frequency propagation of an LMDS system, and developed a three-dimensional signal coverage map of the area of interest for LMDS transmission. The field measurements use an innovative impulse response measurement system called a digital sampling channel probe. This system allows measurement of the complex-valued radio channel impulse response, and is ideally suited for making outdoor impulse response measurements.

Cooperative research with private industry has helped ITS accomplish its mission to support industry's productivity and competitiveness by providing insight into industry needs. This has led to adjustments in the focus and direction of other Institute programs to improve their effectiveness and value.

ITS is interested in assisting private industry in all areas of telecommunications. The pages of this technical progress report reveal many technological capabilities that may be of value to various private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology that would be useful to them.

Because of the great commercial importance of many new emerging telecommunication technologies, including PCS, wireless local area networks, digital broadcasting, LMDS, the National Information Infrastructure, and intelligent transportation systems, ITS plans to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. In addition, ITS plans to commit substantial resources of its own to the development of these new technologies and standards.

Recent Publication

J. Wepman, "Personal communications services technology field trials," NTIA Report 98-356, Sep. 1998.

For more information, contact:
Ronald L. Ketchum
(303) 497-7600
e-mail rketchum@its.bldrdoc.gov

Millimeter-wave Research

Outputs

- LMDS 30 GHz time variability study.
- Measurement of 30 GHz signal attenuation by vegetation.

In the past few years, consideration has been given to spectrum allocation in the extremely high frequency (EHF) band so that wireless video, voice, and data services could be made commercially available to consumers. Spectrum has been allocated for one of these "wireless" services, known as Local Multi-point Distribution Services (LMDS), a type of broadband wireless access. Of particular interest is the development of broadband wireless connectivity for businesses and the home that will provide for competition to the local exchange carrier local loop for telephone and internet access services and to cable television services. LMDS has resulted in an increased interest in propagation effects for millimeter waves. A clear understanding of the millimeter-wave propagation effects for proposed deployment architectures is essential to the development and implementation of LMDS.

For over three decades, ITS has been a leader in the study of propagation effects for millimeter waves. This work includes: the development of measurement techniques; a database of measured propagation effects in urban and rural environments; and the development of analytical methods for prediction of atmospheric effects (e.g., attenuation and dispersion by molecular absorption lines). Through cooperative research agreements, ITS is making its technical expertise in millimeter waves available to the commercial sector for the planning and development of LMDS.

In recent years, ITS has completed a number of propagation experiments and studies relating to propagation in urban and suburban environments for several private sector organizations interested in LMDS. These studies resulted in a detailed analysis of area coverage for 30 GHz LMDS, including depolarization caused by vegetation (Papazian et al., 1997; and Papazian and Hufford, 1997; see Publications Cited, p. 106). In Fiscal Year 1998, ITS completed a study of seasonal variations in signal attenuation by vegetation (trees). A narrowband link at 28.8 GHz was set up on a 1000 meter path. The

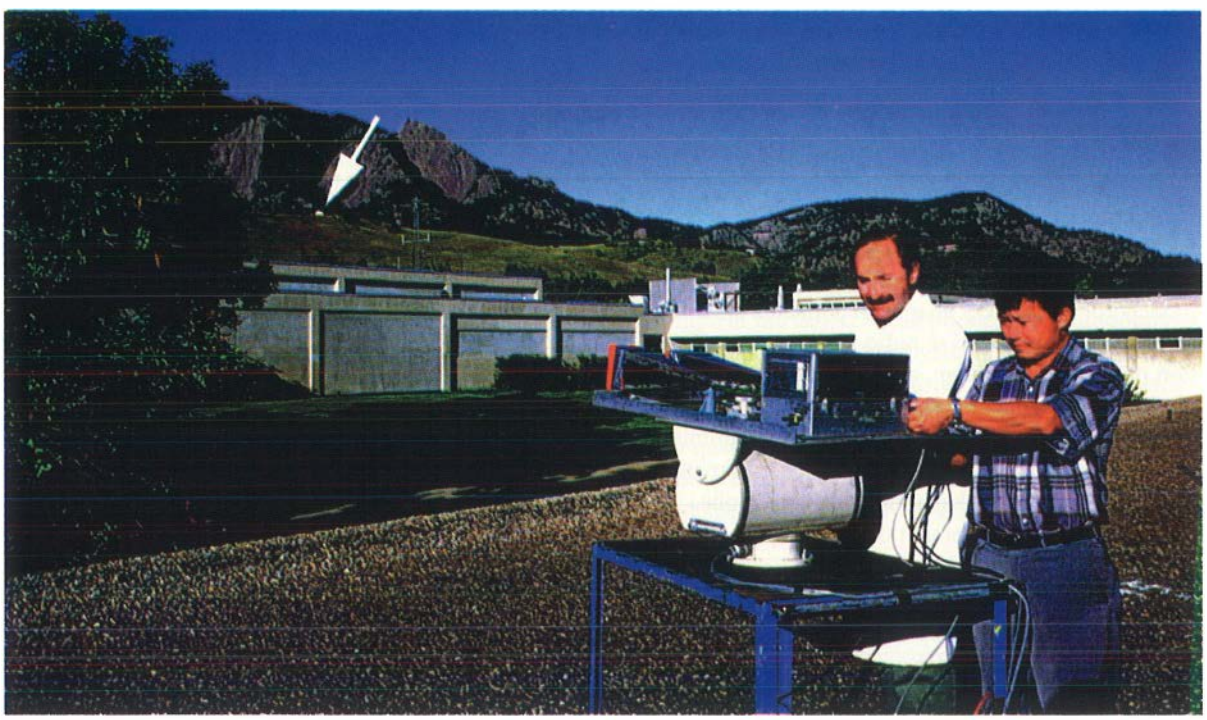


Figure 1. Measurement of 28.8 GHz signal propagation through vegetation (photo by F.H. Sanders).

transmitting antenna beamwidth was 1.2 degrees and the receiving antenna beamwidth was 6 degrees. There was a single tree about 15 meters from the receiver. Figure 1 shows the experimental setup. The dual polarized receiver was mounted on a cart. The arrow points to the transmitter location 1 km away on the mesa.

Propagation measurements were made with the tree on path and near path for several weeks with leaves both on the tree and off. Figure 2 and Figure 3 give a few preliminary results. In Figure 2 we have plotted the hourly median received signal strength over a 24-hour period. We see a 5 dB drop in power at hour 3 and a 10 dB drop at hour 13 when median wind-speeds reached 25 and 35 km/hr respectively. The CDF for this period (Figure 3) shows a 10 dB fade margin is required for 99.9% service during this period.

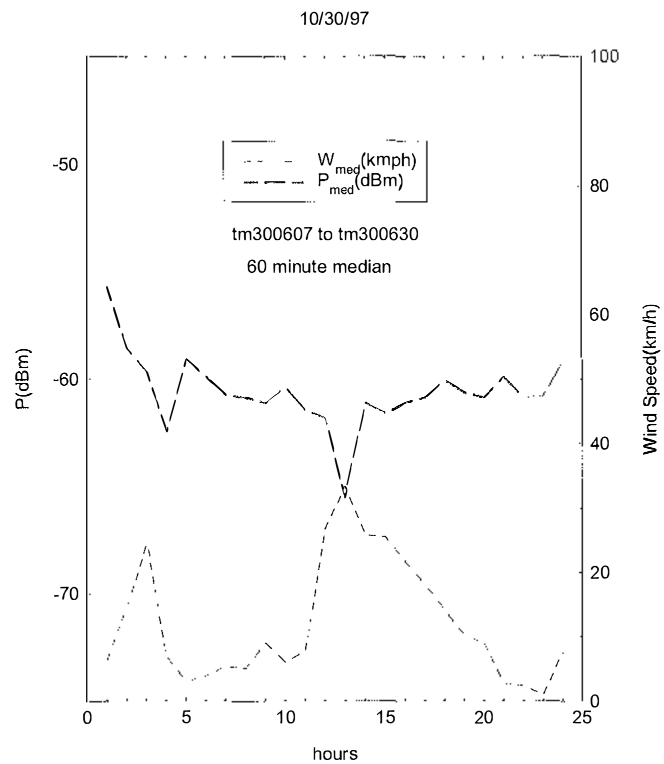


Figure 2. The hourly median wind-speed and the hourly median received power for a 24-hour period.

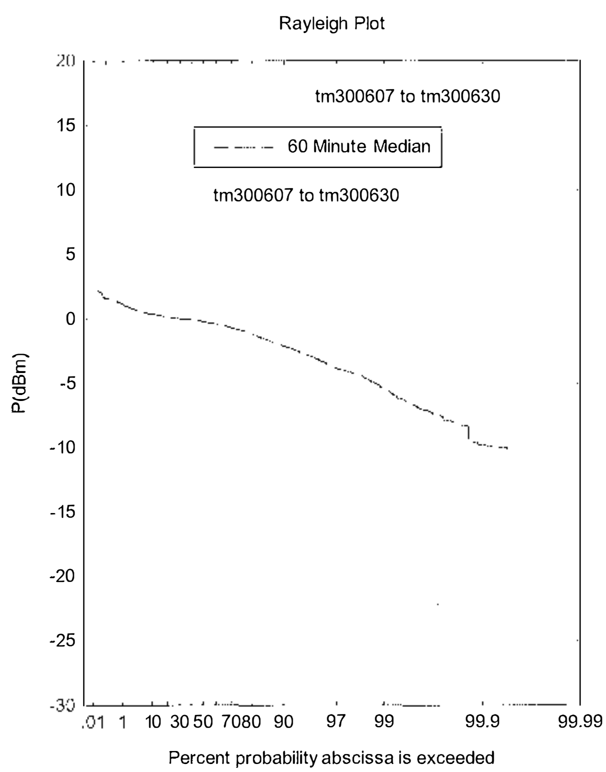


Figure 3. Cumulative distribution function for received power during the same 24-hour period shown in Figure 2.

For more information, contact:
Peter Papazian
(303) 497-5369
e-mail papazian@its.bldrdoc.gov

Adaptive Antenna Testbed

Outputs

- Wideband radio channel measurement system.
- 8 simultaneous measurement channels.
- Smart antenna fading and diversity gain statistics.
- System and combining algorithm evaluation.

The use of wireless, mobile, personal communications services (PCS) is expanding rapidly. Multiple-access schemes based on frequency division, time division, and orthogonal codes are presently used to increase channel capacity and optimize channel efficiency. Adaptive or "smart" antenna arrays can further increase channel capacity through spatial division. Antenna arrays can produce multiple beams as opposed to a simple omni-directional antenna. These numerous narrow beams can be used to divide space allowing the re-use of multiple-access schemes, thereby increasing channel capacity. Adaptive antennas can also track mobile users, improving both signal range and quality. For these reasons, next generation smart antenna systems for PCS systems have attracted widespread interest in the telecommunications industry.

ITS has developed an advanced antenna testbed (ATB) to serve as a common reference for testing smart PCS antenna arrays, signal combining algorithms, and complete systems. The ATB is based on previously developed ITS wideband channel measurement systems. These systems use a maximal length pseudo-random (PN) code generator to BPSK modulate a radio channel carrier frequency at the transmitter. The received signal is autocorrelated at the receiver with the known PN code producing an impulse response. The impulse response characterizes the channel over a wide bandwidth about the carrier frequency.

The ATB expands this concept to eight receiving channels. Thus, the radio channel seen by up to eight antennas can be simultaneously monitored. Digitization of the received data allows for post processing to examine various combining algorithms and digital beam forming. Data can be streamed continuously or in bursts depending on the channel investigation required.

An example of an ATB application is the four-element PCS antenna receiving array shown in Figure 1. The antenna elements are spaced 2, 5, and 10 wavelengths with respect to the left end element. A 511 bit PN code on a 1.92-GHz carrier frequency was used. The transmitting antenna was a van-mounted monopole. The 10 Mb/s transmitted code was sampled at a rate of 40 MHz at the receiver (oversampling is used to reduce noise). A total of 2044 samples per impulse were taken, yielding an impulse duration of 51 µs. Data were collected in the burst mode with a 3 s delay between bursts. A burst consisted of 128 impulses with a 3 ms delay between impulses, yielding a burst duration of approximately 400 ms. At normal suburban driving speeds (30-60 kph) a burst covered a 20-40 wavelength path length.

Examples of single channel power delay profile and power spectral density curves are shown in Figure 2. The channel location was a suburban neighborhood. Multipath effects appear as echoes in the impulse signal and frequency selective fading in the power spectral density. These channel data can be used to determine fading and delay statistics, diversity gain, angle of arrival, and correlation bandwidth. These results can then be used to examine expected channel performance.

The ATB system is portable: both transmit and receive systems may be van mounted. ATB measured data can be applied to the design of smart antenna PCS systems, evaluating system performance, channel model development and verification, and large communications system simulations. (See p. 81 for more information about the ATB.)

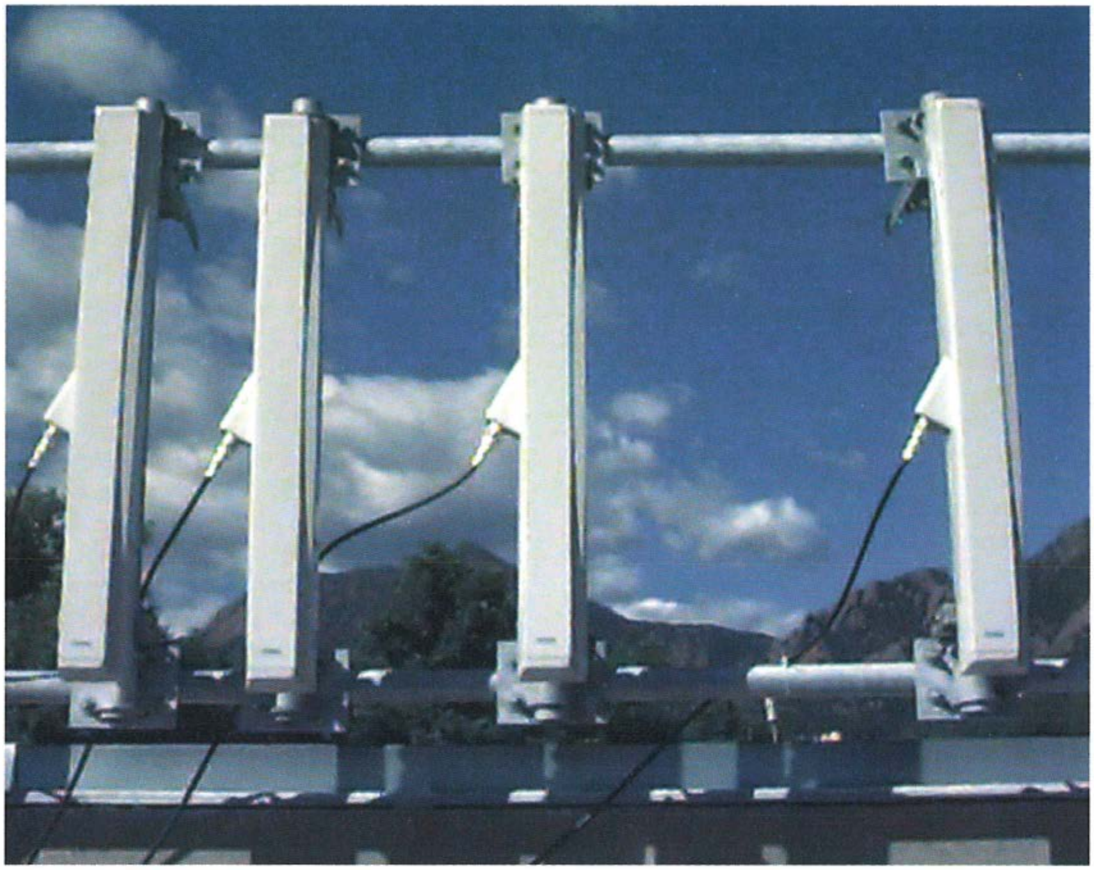


Figure 1. A four element antenna array. The elements are spaced 2, 5, and 10 λ with respect to the left end element (photograph by F.H. Sanders).

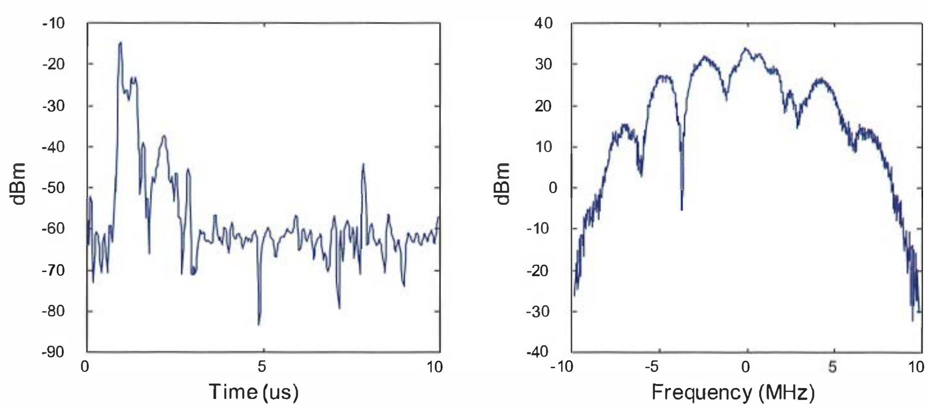


Figure 2. Impulse signal power and power spectral density for a channel with fading.

Recent Publication

P. Papazian, M. Cotton, and P. Wilson, "A test bed for the evaluation of adaptive antennas," in *Proc. 1998 Intl. Symp. on Advanced Radio Technologies*, Boulder, CO, Sep. 1998.

For more information, contact:
Perry F. Wilson
(303) 497-3406
e-mail pwilson@its.bldrdoc.gov

Outputs

- Ultra-wideband radar (UWBR) simulation and receiver analysis software modules.
- Typical transmitter and receiver spectra and waveforms.
- Predicted receiver interference peak power dependence on bandwidth (BW).
- Effect of pulse repetition frequency (PRF) on spectrum management issues.

Interest by the Government and private sector in the potential application of ultra-wideband devices has stimulated a measurement and analysis program to determine the interference effect of these devices on generic victim receivers. Our parametric results show the effect of receiver bandwidth and filter shape on peak power.

The simulated ultra wideband device shown in Figure 1 transmits a psuedo-periodic, very low duty cycle pulse train where narrow pulses were shaped with a Gaussian derivative filter and dithered according to a psuedo-noise code. These operations produce a noise-like, spread spectrum that enables the system to operate as a low-power radar imaging or communication system. Typical parameters for the system simulated are: a PRF of 10 MHz, a pulse width (before Gaussian derivative shaping) of 0.5 ns, a duty cycle of 0.5%, a shaping filter center frequency of 2 GHz, and a 3 dB bandwidth of 2 GHz.

The spectrum and time waveform are shown for the transmitter output in Figure 2 and for the receiver filter output in Figure 3. The receiving filter was centered in the middle of the radio navigation receiver band at 1.575 GHz and employed a 3 dB bandwidth half of the PRF (5 MHz) for the example in Figure 3. If the PRF is greater than the receiver BW, then the transmitted pulses are smeared over time, reducing the peak power. Received peak power was calculated from the time domain pulse trains, assuming an ideal propagation channel, and is shown as a function of receiver BW in Figure 4.

Peak power was shown to follow different logarithmic trends above (20 log[BW]) and below (10 log[BW]) the PRF. These results are of specific interest to the Government and manufacturers since they show that systems with high PRFs compared to receiver bandwidths significantly reduce peak interference. Results are provided for a Gaussian shaped filter and an ideal rectangular filter to determine the effect of filter shape on these trends.

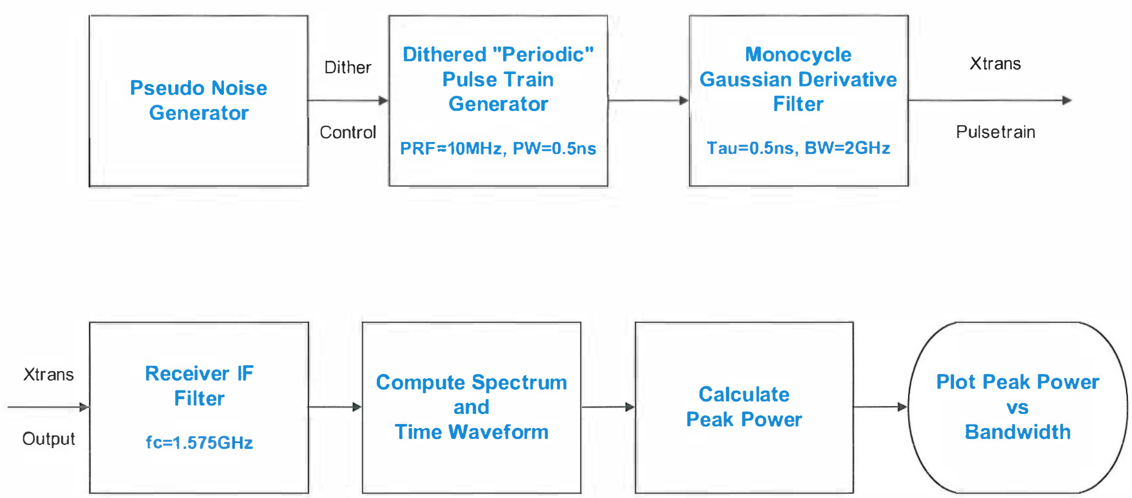


Figure 1. Ultra-wideband radar simulation and victim receiver analysis flowchart.

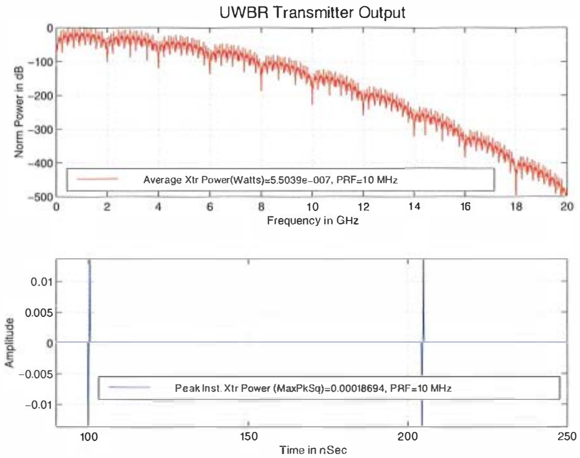


Figure 2. *UWBR output spectrum (top) and waveform (bottom).*

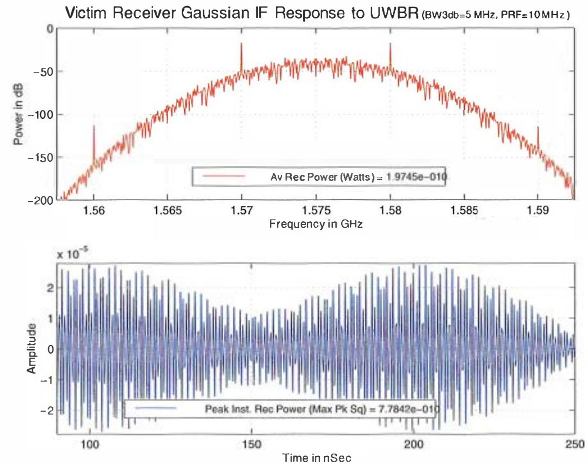


Figure 3. Victim receiver UWBR response spectrum (top) and waveform (bottom).

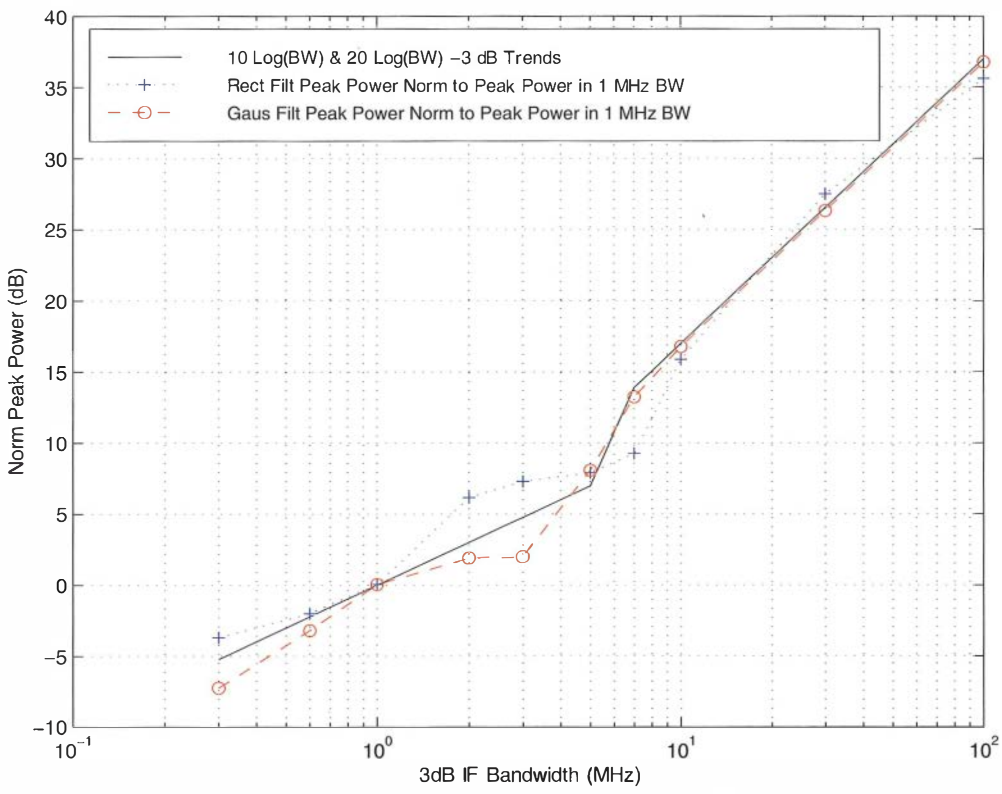


Figure 4. Victim receiver peak power analysis for UWBR transmission.

Recent Publication

E.A. Quincy, "Ship compartment channel effects on wireless FM speech performance," in *Proc. Wireless 98 Conf.* Vol. 2, Calgary, Alberta, Canada, Jul. 1998, pp. 483-502.

For more information, contact:
Edmund A. Quincy
(303) 497-5472
e-mail equincy@its.bldrdoc.gov

HF Channel Modeling and Simulation

Outputs

- Hardware-based wideband HF channel simulator.
- Software implementation of the HF channel model transfer function.
- Application of wideband model in narrowband HF modem testing.
- Contributions to international standards committees.

High-frequency (HF) radio propagation conditions vary widely as a result of long-term (sunspot cycle) and diurnal ionospheric changes and a number of short-term ionospheric phenomena (e.g., multipath, fading, and delay dispersion). Received HF signals can be corrupted by noise from man-made and natural sources (e.g., vehicle ignition, lightning), and by interference due to spectrum congestion. The variability and complexity of these effects make it desirable to test HF radio technologies and systems in the laboratory, under controlled and repeatable conditions, rather than in the field, where desired test conditions can be difficult to achieve. Laboratory testing enables the experimenter to establish the exact channel conditions under which a particular HF system feature should be tested; to quickly create variations in channel conditions that might take years to observe in the field; and to subject different HF systems to the same test conditions to facilitate comparison and optimization. The Institute has developed a wideband HF channel model and a hardware-based, computer-controlled wideband HF channel simulator that provide an efficient, accurate means of representing complex HF channels in such laboratory testing.

ITS engineers applied the simulator in several HF modem tests during FY 98. Results were presented to ITU-R Working Party 9C, which is considering adoption of the wideband HF channel model in a new Recommendation. The wideband model overcomes several limitations of the existing ITU-R HF channel model (Watterson et al., 1970; see Publications Cited, p. 106), including a restriction of bandwidth to less than 12-kHz; a restriction of the propagation model to a single skywave path; negligible delay dispersion; and stationary behavior in delay and frequency. The ITS-developed wideband model can represent HF channels with up to a 1 MHz bandwidth. The model can emulate several time-varying aspects of an HF channel: Doppler shift, Doppler spread, delay spread, and delay offset. The model can represent multiple propagation paths and can introduce a variety of noise and interference effects (Lemmon and Behm, 1991a and b; Mastrangelo et al., 1997; and Vogler and Hoffmeyer, 1988, 1990, 1992, 1993; see Publications Cited, p.106).

The Institute has also developed a software implementation of the wideband HF channel model transfer function. The program is designed to run on a personal computer. Its output is the input to the wideband simulator. The program enhances operation of the wideband simulator by making changes in transfer function easy to accomplish during testing. The program also computes spectrally averaged scattering functions. Spectral averaging makes it possible to verify the transfer function with the model input. These scattering functions are averages of many "runs" of the program. They make it possible to examine the statistics of a simulated channel to ensure that the program's primary output fairly represents the expectations of the model in terms of the input parameters that characterize the channel. The stochastic nature of the simulation makes it virtually impossible to analyze a single scattering function.

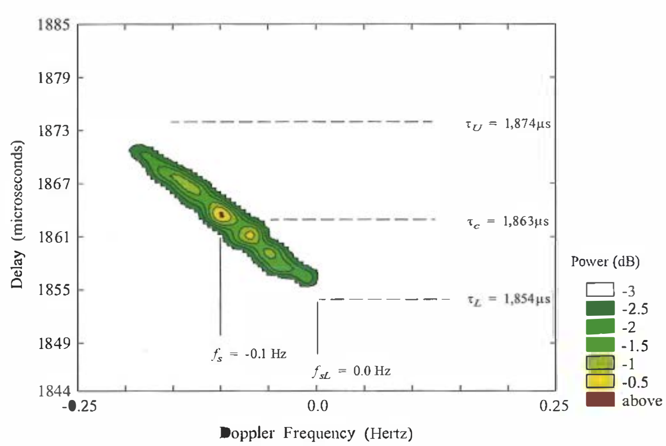


Figure 1. Spectral average scattering function contours above -3.1 dB. Average of 80 scattering functions.

The software implementation of the wideband HF channel transfer function is documented in an NTIA Report (Sutherland, 1998). Figure 1, from that report, presents the contour plot of a spectrally averaged scattering function. This function is the average of 80 scattering functions or 80 runs of the program. The input data is from 1-hop F-layer returns of the extraordinary mode over a 126-km path near the Pacific Coast during the winter. The spread of energy in both delay and in frequency is apparent. The contour plot is used to verify and validate the propagation model. The outer contour represents the 3-dB level, the level at which the input parameters are specified. For example, the graph indicates that the delay spread is approximately 17 μs. The input parameters are the upper and lower ends of the delay spread, τ_U and τ_L, respectively. The difference of 20 μs is the input delay spread. The Doppler frequency, f_s, at the mean delay, τ_c, is in the center of the 3-dB contour as expected. The expected Doppler frequency, f_{sL}, at τ_L, is approximately verified; the lower end of the 3-dB contour does not quite extend to the τ_L level. Discrepancies are associated with digital filtering effects. The model is a general design. More careful modeling of specific paths would mitigate the discrepancies at the expense of time and complexity.

The Institute has also developed a simulator that applies the wideband model in a narrowband setting. This simulator runs on a personal computer enhanced with a commercially available digital signal processing (DSP) card. This narrowband system simulates the effects of delay dispersion. During FY 98, this system was used to test HF modems in the laboratory. Results of tests conducted on several implementations of the MIL-STD-188-110A single tone waveform were reported in Behm, 1997 (see Publications Cited, p. 106). The test results were used as the basis for a contribution to Working Party 9C of ITU-R. This contribution helped to motivate adoption of the wideband channel model as an ITU-R Recommendation by demonstrating the ability of the narrowband application to simulate a harsh HF channel environment. Figure 2 shows that modem performance is vulnerable to delay spread above approximately 0.5 ms. The graph indicates the ability of the modem test system to measure bit error rate down to 0.1 over the MIL-STD-110A modems.

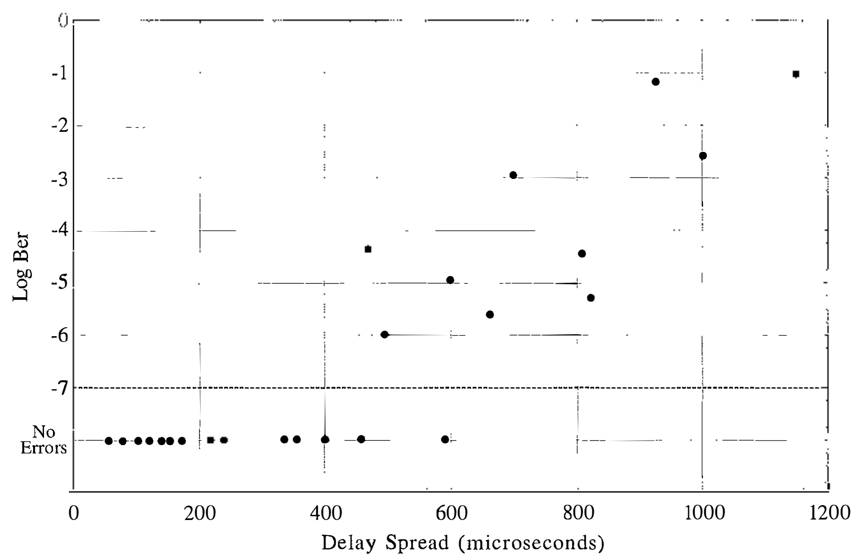


Figure 2. Scatterplot of delay spread vs. bit-error-ratio.
Results of MS-110A modem tests. Modem operating at 1200 bps. No interleaving.

Recent Publication

D. A. Sutherland Jr., "Software implementation of a wideband HF channel transfer function," NTIA Report 98-348, Jan. 1998.

For more information, contact:
Dave Sutherland
(303) 497-5161
e-mail dsutherland@its.bldrdoc.gov

Wireless Propagation Research

Outputs

- Indoor and outdoor channel modeling and measurements.
- Impulse response measurements and predictions.
- Smart antenna analysis.
- Delay spread prediction.

The Institute is involved in several research and development efforts related to wireless communications. In the past year our efforts concentrated on building penetration through reinforced concrete walls, developing measurement systems for characterizing multipath environments, and developing models to predict power delay profile characteristics for an indoor and outdoor channel.

In designing wireless telecommunications systems, it is crucial to control or determine the intersymbol interference (ISI), the bit error rate (BER), and the fading of the communications signal. Thus, there is a growing need for accurate propagation models that can predict signal levels for indoor and outdoor communication channels, as well as building penetration models. Business campuses utilizing wireless private branch exchanges (PBXs) and wireless local area networks (LANs) to provide mobile voice and data communications, vehicular communications through urban canyons to nearby relays, and micro-cellular personal communications services (PCS) deployment in malls and airports are just a few examples. For short propagation paths like these, the accurate behavior of waves reflecting off walls can be very important.

Crucial to these modeling efforts is the accurate characterization of the reflection and transmission properties of various commonly used building materials. Finite-difference time-domain (FDTD) methods can be used to determine reflection and transmission coefficients of reinforced concrete walls with a high level of accuracy. This method has been used to calculate reflection and transmission coefficients for reinforced concrete walls for a frequency range of 100 MHz to 6 GHz for various material properties and rebar configurations. Figure 1 shows results for the reflection and transmission coefficient of a reinforced concrete wall 20.32cm thick with a rebar spacing of 15.24cm and diameter of 1.91cm.

The Institute is developing a geometric optics (or ray-tracing) model for calculating the power delay profile for an indoor radio propagation channel. A recursive-imaging algorithm is used to find all possible rays with up to a specified number of wall, ceiling, and/or floor reflections. Figure 2 shows an example of a power delay profile for a room determined from the ray-trace model. With this ray-trace model, we have investigated the effect of frequency-dependent reflection coefficients of walls on the power delay profile. Figure 2 also shows a comparison of the power delay profile obtained by assuming different frequency-dependent reflection coefficients. One curve corresponds to a reflection coefficient independent of frequency (a frequency flat reflection) and the other curve corresponds to a highly frequency-dependent reflection coefficient. These two results differ in both their second-central-

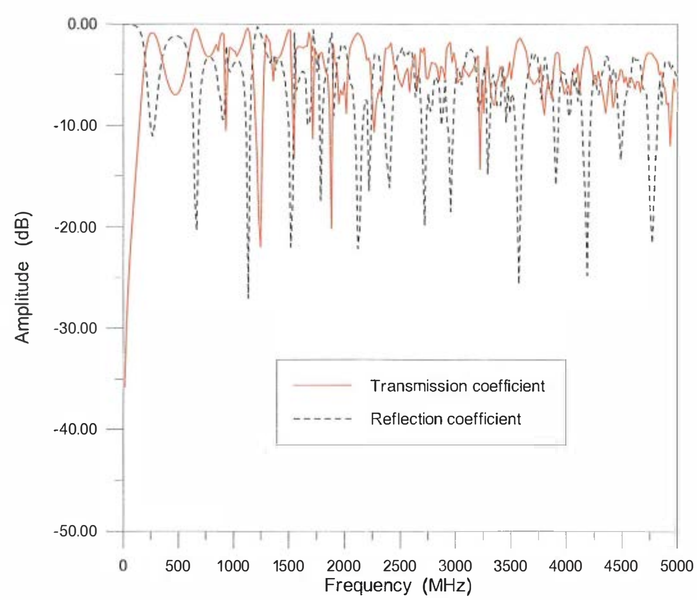


Figure 1. Reflection and transmission coefficient for a reinforced concrete wall.

moment and in their maximum delay, illustrating the importance of using accurate reflection coefficients in field prediction models.

The Institute has developed a model for quickly determining both the power delay profile and the rms delay spread of an indoor radio propagation channel. The advantage of this model over ray-trace and FDTD models is that it is based upon simple assumptions, such that the propagation characteristics of indoor propagation channels can be determined in a matter of seconds on a personal computer. Figure 3 shows a comparison of the simplified model to measured data obtained by averaging several locations throughout a large laboratory. This model is presently being extended to analyze metal warehouse and shipboard communications systems.

The Institute is also developing measurement systems for sampling various indoor and outdoor radio environments for use in capacity and diversity studies. For example, an indoor direction diversity at 5.8 GHz study has recently been completed (Achatz et al. 1998).

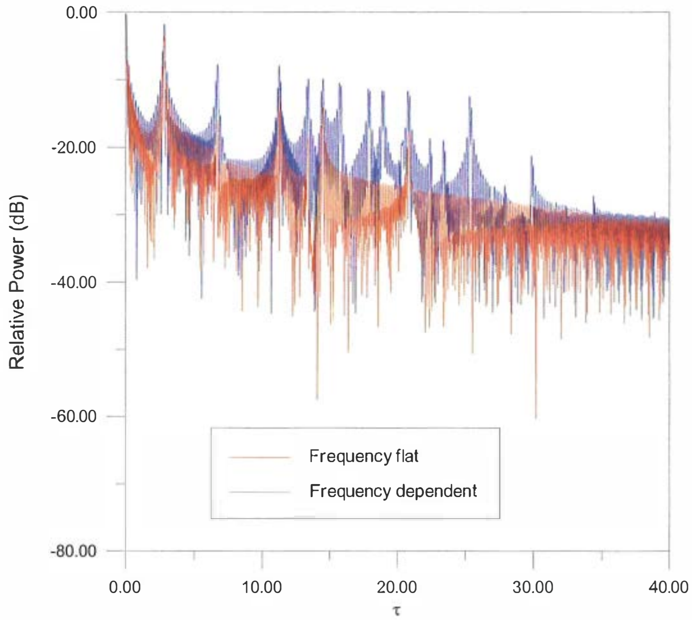


Figure 2. Power delay profile with different reflection coefficients.

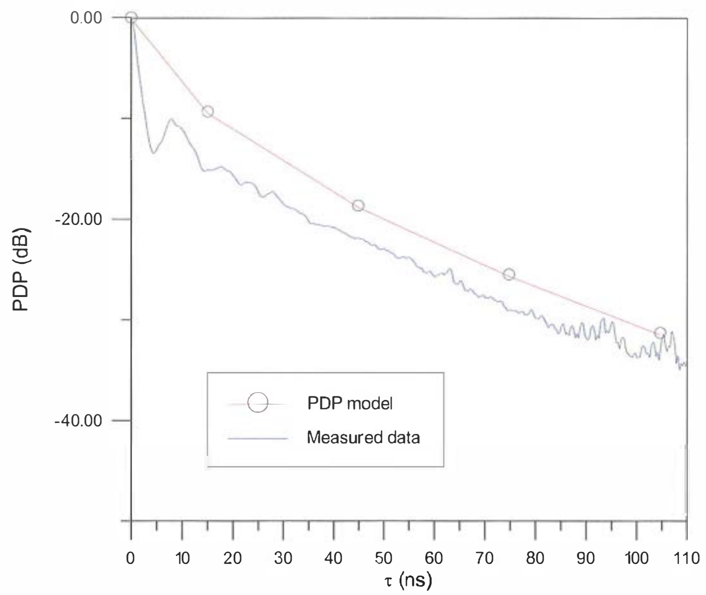


Figure 3. Comparison of the power delay profile model to measurements.

Recent Publications

C.L. Holloway, M.G. Cotton, and P. McKenna, "A simplified model for predicting the power delay profile characteristics of an indoor radio propagation channel," NTIA Report 98-353, Aug. 1998.

R.J. Achatz, Y. Lo, and E.E. Pol, "Indoor direction diversity at 5.8 GHz," NTIA Report 98-351, Jul. 1998.

P. Perini and C.L. Holloway, "Angle and space diversity comparisons in different mobile radio environments," *IEEE Trans. on Antennas and Propagation*, vol. 46, no. 6, pp. 764-775, Jun. 1998.

For more information, contact:
Christopher L. Holloway
(303) 497-6184
e-mail cholloway@its.bldrdoc.gov

Impulsive Noise and Digital Systems

Outputs

- Non-Gaussian noise measurements and models.
- Performance prediction of radio links operating in non-Gaussian noise environments.

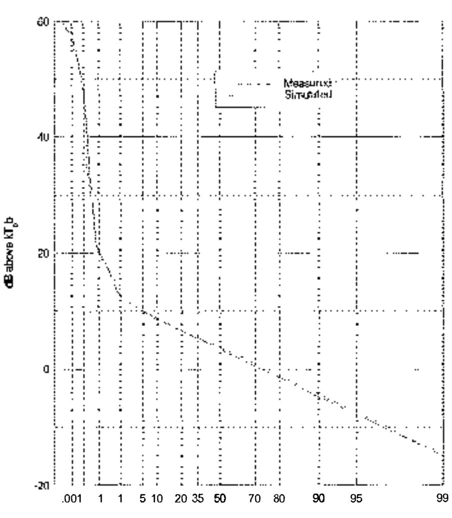
Digital radio link performance, for many applications, is dependent upon statistics of the noise that is added to the signal prior to demodulation (Spaulding, 1982; see Publications Cited, p. 106). Narrowband, radio-frequency noise is divided into two classes: white-Gaussian noise and non-Gaussian noise. White-Gaussian noise is continuous, broadband, and has Rayleigh-distributed amplitudes. The performance of digital radio links operating in white-Gaussian noise environments can be predicted from the ratio of mean signal-power to mean noise-power (SNR).

Impulsive non-Gaussian noise is composed of discrete noise "pulses" whose amplitudes are sometimes modeled with the power-Rayleigh distribution. The discrete pulses can occur randomly or periodically in time and are not necessarily broadband. Ricean non-Gaussian noise adds a continuous wave component to white-Gaussian noise. The SNR is insufficient to predict the performance of digital radio links operating in non-Gaussian noise environments.

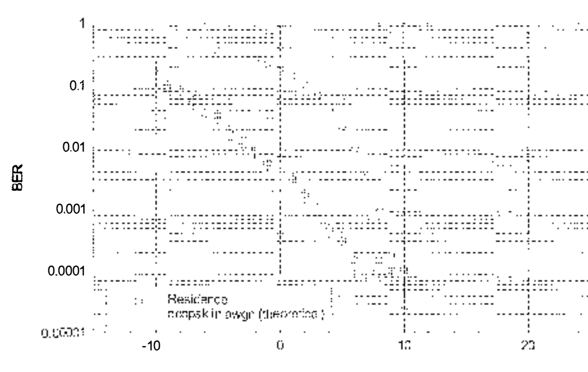
Man-made noise below 1 GHz is non-Gaussian in business environments at most locations and times. This noise is produced by sources such as electrical power distribution and transmission lines, electronic devices, electric motors, arc welders, and internal combustion engine ignition systems. Above 1 GHz, non-Gaussian man-made noise is localized to areas near a single source (Spaulding, 1996; see Publications Cited, p. 106).

The Institute has developed measurement, modeling, and simulation techniques to more fully characterize non-Gaussian radio noise statistics so that the performance of digital radio links operating in non-Gaussian noise environments can be predicted. In FY 96 ITS measured the amplitude statistics of man-made noise at 137 MHz in business, residential, and rural environments. These measurements were conducted to support the National Oceanic and Atmospheric Administration in converting their meteorological satellite radio links from analog to digital. In FY 97 ITS modeled the amplitude and pulse arrival rate of this noise and developed algorithms that could replicate it in a digital radio simulation (Dalke et al., 1998; Achatz et al., 1998).

In FY 98 ITS used the algorithms to predict the performance of a digital radio link with software simulation (Achatz and Dalke, 1998). Figures 1 and 2 show the results of some of these predictions. Figure 1a shows the amplitude probability distribution

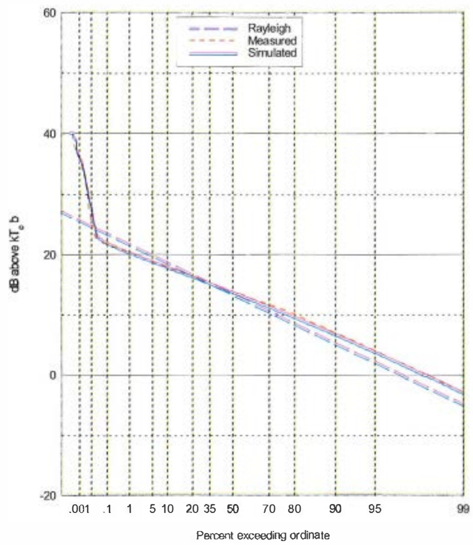


(a)

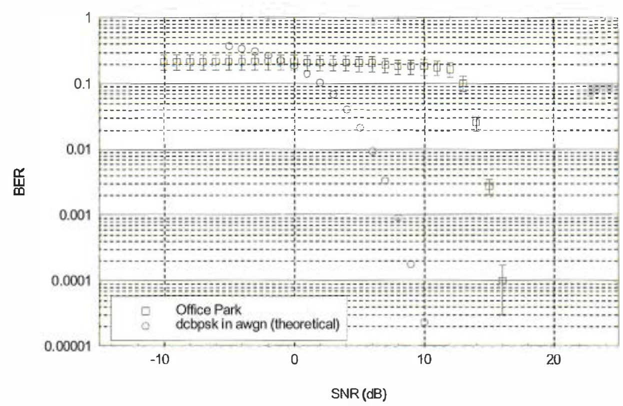


(b)

Figure 1. APD (a) and BER (b) of man-made noise at a Lakewood, CO, residence on November 10, 1996, from 3:30 p.m. to 4:00 p.m. Average noise power is 5.6 dB above kT_0b.



(a)



(b)

Figure 2. APD (a) and BER (b) of man-made noise measured in an office park in Golden, CO, on November 27, 1996, from 11:15 to 11:45 a.m. Average noise power is 14.5 dB above kT_0b.

(APD) for measured and modeled man-made noise in a residential environment. The kT_0b units on the abscissa represent the noise available from a black-body at temperature T_0 in bandwidth b. The abrupt change in slope at 1% is indicative of impulsive non-Gaussian noise.

Figure 1b shows the bit error-ratio (BER) of a differentially-coherent binary phase-shift keyed (DCBPSK) digital radio link operating in this noise environment. The circles represent performance in white-Gaussian noise whereas the squares represent performance in the non-Gaussian noise. A digital radio link operating in this noise needs 5 dB less SNR to achieve a 10^{-3} BER than it would in white-Gaussian noise.

Figure 2a shows an APD of noise measured in an office park. The abrupt change in slope at 0.01%, once again, is indicative of impulsive non-Gaussian noise. The difference in slope between measured noise and Rayleigh-distributed noise at the high exceedence probabilities is indicative of a continuous wave noise component produced, perhaps, by a spectral line of a pulsed source. Figure 2b shows that a DCBPSK digital radio link needs 8 dB more SNR to achieve a BER of 10^{-3} in this noise environment than it would in white-Gaussian noise.

The contrast between the residential and business APDs and the SNR required to achieve a 10^{-3} BER highlight the difficulty in predicting digital radio performance in non-Gaussian noise environments. In future, ITS plans to characterize the noise over a broader frequency range and over more locations and times. The information derived from this work will assist industry and government in efficiently utilizing our valuable spectral resources.

Recent Publications

R.A. Dalke, R. Achatz, Y. Lo, P. Papazian, and G. Hufford, "Statistics of man-made noise at 137 MHz," in *Proc. 1998 International Symposium on Electromagnetic Compatibility*, Denver, Co., Aug. 1998, pp. 427-431.

R.J. Achatz, Y. Lo, P.B. Papazian, R. A. Dalke, and G. Hufford, "Man-made noise in the 136 to 138-MHz meteorological satellite band," NTIA Report 98-356, Sep. 1998.

R.J. Achatz and R. Dalke, "VHF space-to-earth radio link performance in various man-made noise environments," in *Proc. 1998 IEEE Radio and Wireless Conference*, Colorado Springs, Co., Aug. 1998, pp. 257-260.

For more information, contact:
Robert Achatz
(303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Electromagnetic Compatibility Research

Outputs

- System performance.
- Immunity and emission compliance.
- System interference and susceptibility.
- Material properties modeling.

The Institute is involved in several research efforts related to electromagnetic compatibility (EMC) and electromagnetic interference (EMI). In the past year our efforts concentrated on electromagnetic characterization of composite materials, absorbing materials, anechoic chambers, radiated emissions from printed circuits boards, rf interference for wireless communication systems, and standards activities.

Advanced fiber composite materials are commonly used in aircraft and EMC/EMI shielding materials. These composite materials have made tremendous inroads into industry due to their light weight, shielding properties, and affordability. Plastics are inherently nonconductive and cannot shield sensitive electronic apparatuses and systems from electromagnetic interference (EMI) in order to comply with regulations. Conductive fibers, such as carbon fibers, nickel coated graphite fibers, copper fibers, brass fibers, and stainless steel fibers, have been used to overcome these deficiencies and make the plastics conductive. The Institute has developed mathematical expressions for the effective electromagnetic material properties of fiber composites, which can be used to calculate efficiently the reflection and transmission coefficients and the shielding effectiveness of these fiber composites. Figure 1 shows a comparison of the shielding effectiveness obtained using this effective material property model to numerical values.

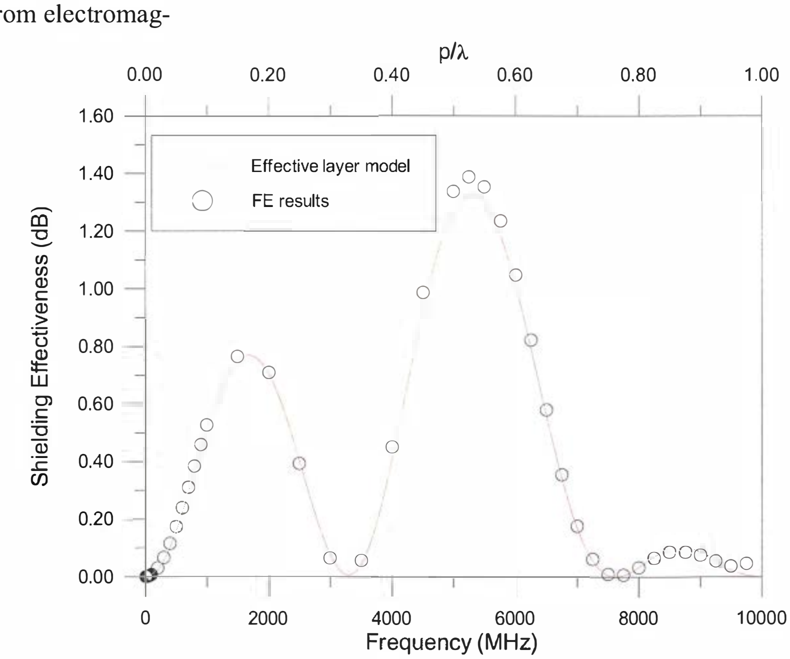


Figure 1. Comparison of shielding effectiveness for a fiber composite layer obtained from the effective layer model to numerical values based on finite element (FE) results.

In recent years there has been an increase in the demand for low frequency (30-1000 MHz) electromagnetic absorbers. This has spawned an emergence of new absorber designs. One such design is hollow pyramids. Using a technique known as homogenization, we have developed a model that efficiently calculates the performance (the reflection coefficient) of this type of absorbing structure. The reflection coefficients calculated using this model have been compared to and closely agree with measured data. Such a comparison is shown in Figure 2.

Dedicated short-range communication systems have been proposed for automatic toll collection on highways operations at locations across the United States in the 5850- to 5925-MHz band. Various search and tracking high-power radars operate at or near this frequency band and are a source of potential interference. The performance of such digital communication systems is dependent upon compatible operation and coexistence with these radars. The Institute has recently completed an electromagnetic compatibility analysis of these systems. This analysis involved both theoretical considerations and measurements utilizing a commercial system subjected to simulated radar interference. The results of this effort are of significant importance to the successful deployment of these systems and the transportation and spectrum utilization goals of the Federal Government.

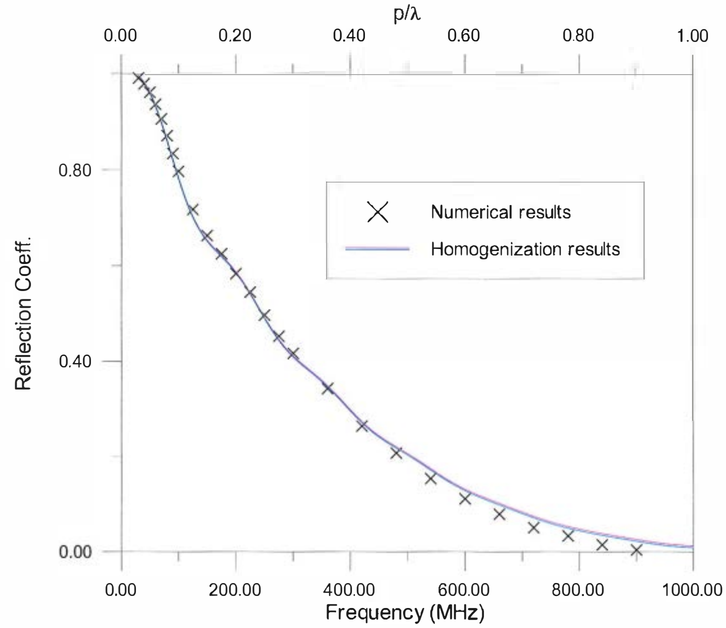


Figure 2. Comparison of the reflection coefficient of a hollow pyramidal absorber.

The use of power efficient nonlinear amplifiers with variable envelope modulations for portable microwave communication devices can result in interference with communications systems in adjacent bands. To better understand possible electromagnetic compatibility issues involving the use of such devices, ITS has completed a study which analyzes the relationship between nonlinear operation of a typical PCS portable transceiver power amplifier and battery current, adjacent band interference, and range. A mathematical model of the power amplifier based on these measurements was used to simulate the communications link for purposes of determining the power spectral density and symbol-error ratio for a digitally modulated signal using $\pi/4$ DQPSK with 35% root raised cosine filtering. The adjacent band interference characteristics and corresponding system performance were analyzed. This study provides important information regarding the spectral efficiency of a typical portable microwave communications device as a function of amplifier current.

Recent Publications

C.L. Holloway, M. Johansson, and M.S. Sarto, "An effective layer model for analyzing fiber composites," in *Proc. EMC'98 ROMA International Symposium on Electromagnetic Compatibility*, Rome, Italy, Sep. 1998.

R.T. Johnk, A.R. Ondrejka, and C.L. Holloway, "Time-domain free-space evaluations of urethane slabs with finite-difference time-domain computer simulations," in *Proc. 1998 EMC International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 290-295.

C.L. Holloway and E.F. Kuester, "Net and partial inductance of a microstrip ground plane," *IEEE Trans. on Electromagnetic Compatibility*, vol. 40, no. 1, pp. 33-46, Feb. 1998.

R.A. Dalke, F. H. Sanders, and B. L. Bedford, "Electromagnetic compatibility testing of a dedicated short-range communications system," NTIA Report 98-352, Jul. 1998.

R. Dalke, "EMC analysis of C-band radar interference for dedicated short-range communications systems," in *Proc. 1998 IEEE International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 46-50.

R. Achatz, R. Dalke, and Y. Lo, "Power amplifier model for optimizing battery current, interference, and link margin," in *Proc. 1998 IEEE International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 434-438.

For more information, contact:
Christopher L. Holloway
(303) 497-6184
e-mail cholloway@its.bldrdoc.gov

Advanced Radio Technologies

Outputs

- Development and EMC testing of an example cellular base station software radio receiver.
- Recommendations for changes needed in information requested by NTIA to accommodate system review of software radios for spectrum management.
- Organization and chairmanship of, and presentations at, the 1998 International Symposium on Advanced Radio Technologies.

Rapid advances have occurred in analog-to-digital converter, digital-to-analog converter, and especially digital signal processing technology. These advances have spawned a proliferation of research and development efforts in advanced radio technologies such as software radios and smart antennas.

While there are differing opinions as to what the definition of a software radio is, one (very broad) definition is best given by describing the receiver and transmitter separately. In a software radio receiver, the received signal is digitized and then processed using digital signal processing techniques. In a software radio transmitter, the modulated signal to be transmitted is generated as a digital signal using digital signal processing techniques. The digital signal is then converted to an analog signal for transmission. Digitization in the receiver and digital-to-analog conversion in the transmitter may occur at the RF, IF, or even at baseband. Inherent in the software radio definition is some level of programmability to change the way the transmitted and received signals are processed. Software radios present an opportunity for many advantages over traditional radios. One key advantage is in the software radio's reprogrammability or reconfigurability permitting the use of different modulation types, frequency bands, filtering, and other processing via software.

Smart antennas are antennas whose radiation patterns can be altered based upon the nature and location of the desired and undesired signals present in the environment. Potential advantages in using smart antennas include an increased carrier-to-interference ratio, increased geographic coverage area, and increased user capacity.

Work at the Institute in the area of advanced radio technologies continued in the investigation to help assess the impact of software radios on the management of Federal Government use of the radio spectrum. In support of this effort, an example software radio receiver was configured by ITS that allowed observation of signals at various stages of processing. Electromagnetic compatibility (EMC) testing on this receiver was performed in the presence of noise and various interfering signals. The example software radio receiver emulated an Advanced Mobile

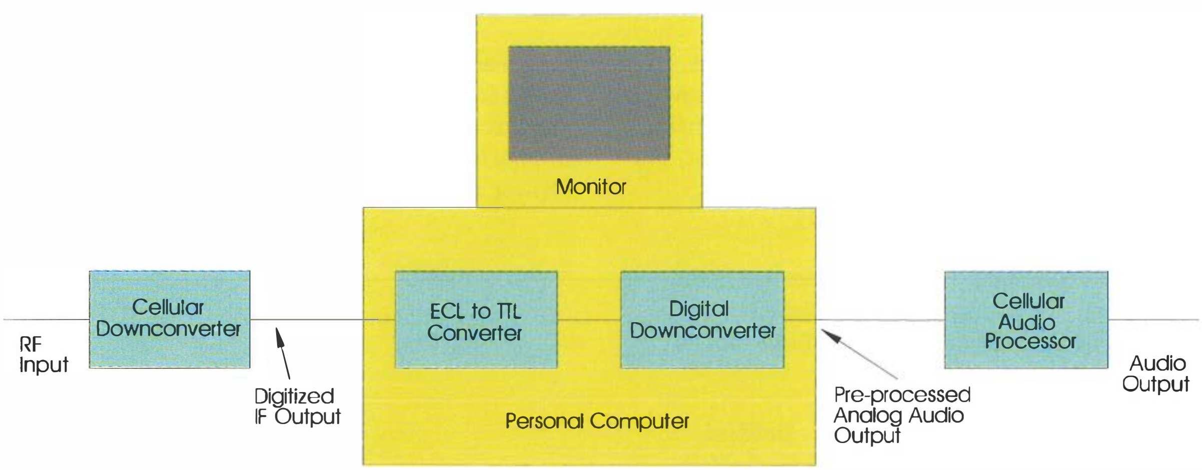


Figure 1. Block diagram of the cellular base station software radio receiver.

Phone System (AMPS) cellular base station receiver with digitization of the entire cellular B band (a 14 MHz bandwidth). The receiver was configured using a commercially available digital downconverter board that operates in a personal computer, a separate front end that includes an analog downconverter and digitizer, and an interface board designed by ITS. A simplified block diagram of the receiver is shown in Figure 1. The architecture of the receiver allowed testing to be performed at the digitized IF output, the digitally downconverted and filtered baseband, the digital FM demodulator output, and the analog audio output. The testing of the receiver at all of these outputs was exploited to help gain insight into the operation of software radio receivers and how they may behave differently than traditional radios. A sponsor report discussing the testing procedures and the details of the receiver design was written. The results of the EMC testing were provided in a presentation to the sponsor.

One difference between software radios and traditional radios is the potential for a type of distortion in the received signal called aliasing. Aliasing can occur because of the digitization process in a software radio receiver and does not occur in traditional radios. An example result from the software radio EMC testing, showing the effects of aliasing, is given in Figure 2. The aliased signal appearing at 14.65 MHz is caused by a 16.07 MHz signal present at the IF before digitization at a sampling rate of 30.72 Msamples/second.

To compliment previous work in software radio receivers, ITS conducted a brief study of the theory, concepts, and practical limitations of software radio transmitters. The key aspects of software radio transmitters were identified and studied, including digital signal processing, digital-to-analog conversion with the associated filtering, and power amplification.

Before new, major telecommunication systems or subsystems can be implemented and used by Government agencies, they must be certified by NTIA that the required spectrum is available. This spectrum certification can be obtained through the Spectrum Planning Subcommittee (a subcommittee of the Interdepartment Radio Advisory Committee (IRAC)) system review process. The NTIA transmitter and receiver equipment characteristics forms (NTIA-33 and NTIA-34) are used to obtain information needed for the system review process.

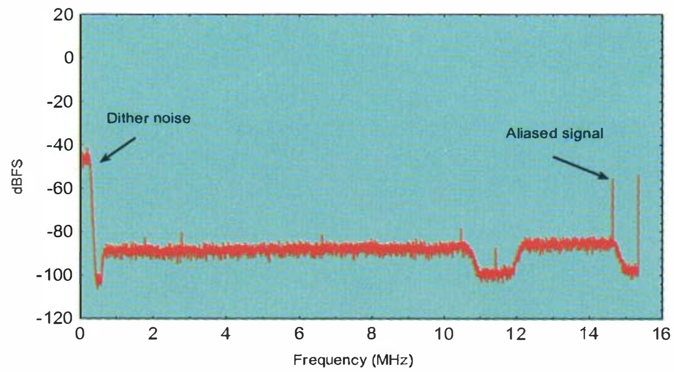
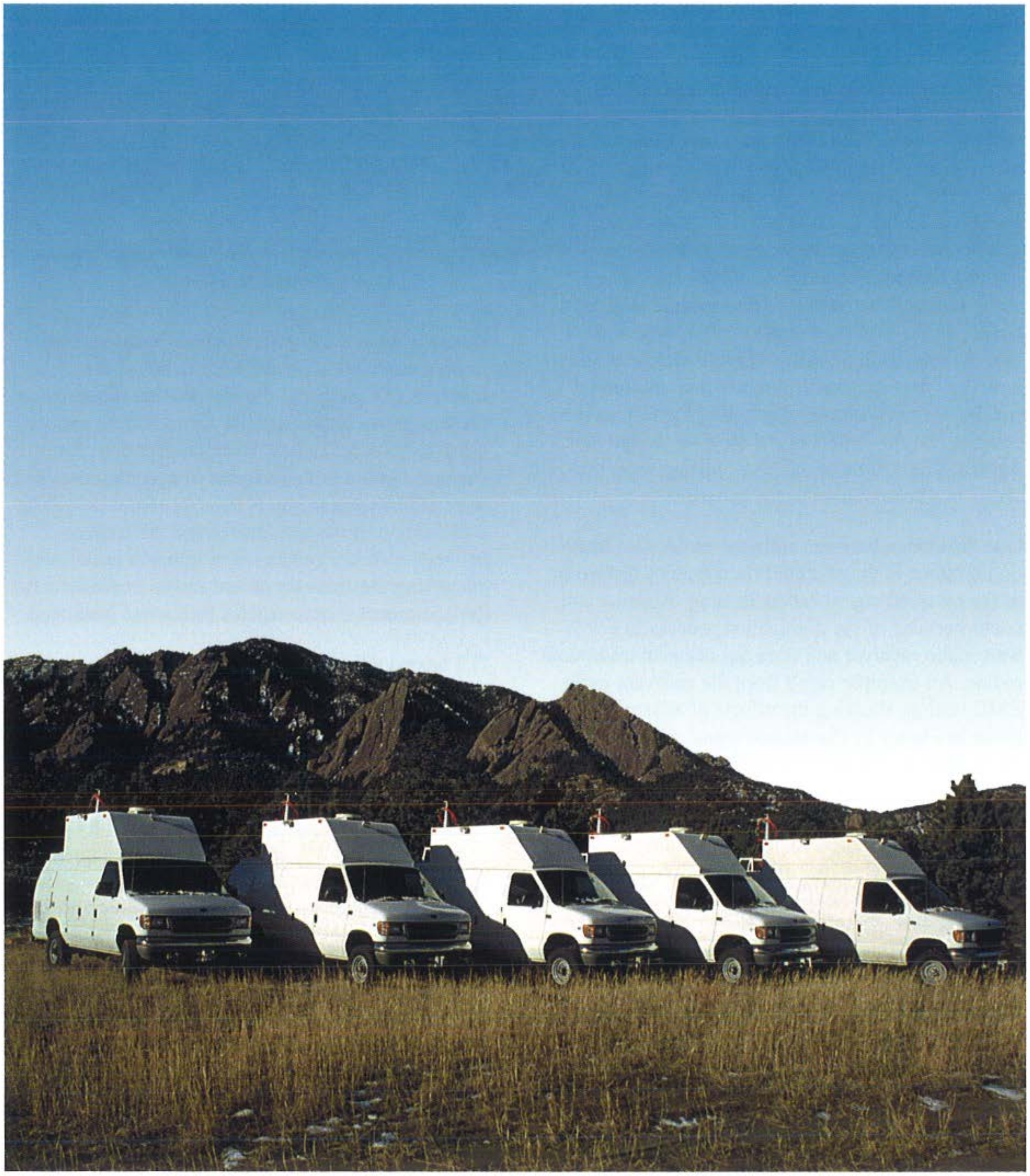


Figure 2. Effects of aliasing in the cellular base station software radio receiver.

Drawing upon the knowledge and experience gained in previous work with software radios at the Institute, ITS analyzed the information requested on the equipment characteristics forms and its applicability to software radios. Recommendations for changes needed in these forms to accommodate software radios were made. A sponsor report providing a discussion of the similarities and differences between software radios and traditional radios and discussing the analyses of and recommendations for the equipment characteristics forms was generated.

ITS hosted the 1998 International Symposium on Advanced Radio Technologies which focused on state-of-the art and future trends in software radio and smart antenna technologies and applications. Sessions included presentations by leading experts in software radio and smart-antenna fields from government, industry, and academia followed by forward-looking open roundtable discussions on emerging radio technologies and future applications. Of particular interest were sessions describing new and innovative architectures for both software radio systems and smart antennas. The Symposium consisted of 29 presentations by leading experts involved in advanced radio technology research, development, and applications. Presentations given by ITS staff included a software radio overview, an overview of spectrum management issues, and a presentation on the ITS Advanced Antenna Testbed. Approximately 240 individuals representing 12 countries attended the Symposium.

For more information, contact:
Jeffery A. Wepman
(410) 415-5541
e-mail jwepman@its.bldrdoc.gov



Radio Frequency Interference Monitoring System (RFIMS) vans awaiting delivery to the FAA. A fleet of these vans has been designed, developed, and built by ITS for the FAA (photograph by F.H. Sanders).

ITS Tools and Facilities

Adaptive Antenna Testbed

The adaptive antenna testbed (ATB) is a multi-channel test facility based on ITS digital sampling channel probe technology (see pp. 66-67). The VMEbus based system can simultaneously characterize eight wideband radio channels. The received signals are digitized for flexible post processing. Data from multiple channels can be used to test the diversity gain resulting from various signal combining algorithms. Digital beam forming techniques may also be examined. The present ATB configuration has a nominal bandwidth of 20 MHz about carrier frequencies in the range 0.5-3.0 GHz.

The advanced antenna testbed provides a common reference for evaluating next-generation personal communication services (PCS) antenna systems. A well-characterized cell site in Boulder, CO serves as a known platform for evaluating existing and new PCS components and systems. Alternately, the ATB transmitting and receiving systems may be van-mounted for site mapping studies at any required location.

Advanced Communications Technology Satellite Test Facility

The central element of this test facility is a complete Earth station (ES) specifically designed for use with NASA's Advanced Communications Technology Satellite (ACTS). This ES was provided to ITS by NASA under a Memorandum of Understanding between the two agencies. The ACTS was launched by NASA to support satellite technology advancement through communications experiments. It operates at Ka-band and is capable of on-board switching to provide highly flexible connectivity between any two, or within any group, of ACTS ES's. The ES at ITS is capable of supporting a raw T1 rate (1.544 Mb/s) or 1.8 Mb/s integrated services digital network (ISDN) communications.

Other major equipment and capabilities in this test facility include: an ISDN switch, terminal adapters, and narrowband ISDN interfaces; an ATM switch and ATM interfaces; data communications test sets implemented on UNIX workstations, a voice quality measurement system; and the most recent addition, an ITS-developed, standards-based objective video quality measurement system.

During the past year, NASA decided to allow the ACTS orbit to become inclined. Although the orbit is still geosynchronous, it is not geostationary. Satellite station-keeping in the east-west direction will be maintained, but station-keeping north-south has been disabled to conserve on-board fuel. This will extend the useful life of the satellite for a number of years. The antenna and control systems in the ES at ITS were upgraded during FY 98 to support the required tracking. The ITS ACTS test facility is available for use by other Government agencies, industry, and academia following application to (and approval by) the NASA ACTS Experiment Office.

Audio Quality Laboratory

The Audio Quality Laboratory supports the Institute's audio quality research and standards development. The laboratory equipment allows high-quality recording, processing, analysis, and reproduction of audio signals. Audio Quality Laboratory equipment includes digital audio tape recorders, compact disk players, digital audio encoders and decoders, a spectrum analyzer, signal generators, level meters, mixers, amplifiers, processors, speakers, and microphones. Workstations equipped with 16-bit digital-to-analog and analog-to-digital converters provide for additional signal conversion and processing flexibilities.

The Audio Quality Laboratory is interconnected with the Multimedia Subjective Testing Laboratory. Together, these two laboratories support subjective analyses of audio signals through listening and conversation tests. Additional connections to the Video Quality Laboratory and the Integrated Networks Testbed enable integrated testing of multimedia communication systems that transport audio, video, and data communications.

Digital Sampling Channel Probe

ITS has developed and patented an innovative digital sampling channel probe (DSCP) which has recently been reconfigured as a VME based system. The probe, consisting of both a transmitter and a receiver, is used to make complex impulse response measurements of outdoor communication channels and in turn determine the wideband propagation characteristics. Such measurements are used for modeling and simulation. Employed extensively for channel characterization of cellular and personal communications services, ITS has included additional features for the study of adaptive antenna arrays used in mobile communications. Unlike the analog sliding correlator equivalent, the DSCP is capable of impulse responses acquisitions within the period of one PN code word length (typically 51 s). The probe has typically been configured for a null-to-null bandwidth of 20 MHz, providing a delay resolution of 100 ns and a maximum measurable delay of 51 s. Bandwidths as large as 50 MHz have also been used. The most recent developments add a quad channel capability, making it possible to perform spatial and polarization diversity experiments. By using synchronized timing, the probe can measure absolute time-of-flight from transmitter to receiver. In addition, it has the capability for a rapid succession of acquisitions over extended periods of time and thus the ability to determine Doppler spread at high vehicle speeds. The present system uses an AGC and is, therefore, capable of measuring signals within a range of power seen in cellular sites characterized by severe multipath and shadow fading. Concurrent acquisition of GPS has given the system the capability of marking the data with speed and location.

A wide bandwidth (0.2 - 1.0 GHz null-to-null), high frequency (1.5 - 30.0 GHz) digital sampling probe is also under development and is particularly suited for indoor measurements where high resolution is required. For further information on this system as well as existing channel probes, look for a full description at the following web site address:

http://www.its.bldrdoc.gov/pub/chprobe/dsp.htm

FED-STD-1037C Search Engine

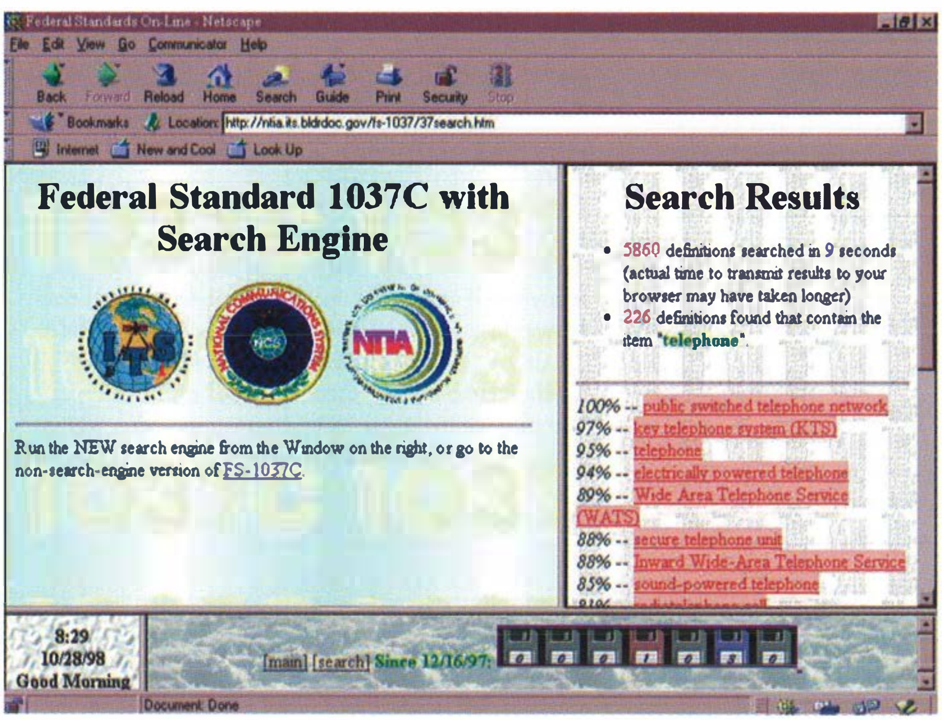
The search engine developed for Federal Standard 1037C, Glossary of Telecommunication Terms (see pp. 28-29) was tailored specifically to search for any character string in the entire text file of the 5800-entry glossary and to display on screen the ordered results of the search. The search engine is installed online at

http://glossary.its.bldrdoc.gov/fs-1037

and is available for anyone to use, with easy-to-follow, menu-driven instructions.

The illustration shows the on-screen results after using the search engine to find the occurrence of the word "telephone" in all entries in the glossary. In 9 seconds, the search engine found 226 definitions using the word "telephone." All occurrences are displayed in the right-hand frame (with a browser using frames). Scrolling to the bottom of the list in the right-hand frame, the user is invited to perform another search for a different character string.

The central advantage of the search engine is that it significantly speeds a user's access to any particular entry in the 400-page glossary. Thus, the search engine promotes a more organized and more thorough review of the entire glossary.



Results of using the FED-STD-1037C search engine to find the word "telephone" in the glossary.

HF Communications System Test and Evaluation Facility

The ITS HF Communications System Test and Evaluation Facility supports ITS and its clients in the development, optimization, and testing of advanced HF technologies and systems. Its primary components are (1) audio compact disk (CD) equipment and software for testing HF radio automatic link establishment (ALE) interoperability; (2) HF radios, modems, and modem software; and (3) narrowband and wideband real-time HF channel simulators. This facility is used particularly in testing the performance and interoperability of HF communications systems supporting National Security and Emergency Preparedness. The facility also is used in conducting proof-of-concept testing that is critical to Federal standards development. The audio CD equipment and associated software have been used to test ALE protocols and techniques for adaptive HF radios as defined in Federal Standard 1045A (FED-STD-1045A). All ALE radios procured by the U.S. Government must perform the functions defined in this Standard. This ensures that all ALE radios will interoperate successfully regardless of vendor. Since each radio system must be tested feature-by-feature to verify its interoperability, ITS has developed a digital audio CD for ALE interoperability testing to ensure uniform, standardized conditions and repeatable results. This reference interpretation and implementation of FED-STD-1045A is available to all Government agencies, industry, and other ALE users. With a standard audio CD player, anyone can use the ALE CD to test a radio against FED-STD-1045A. The test is performed by connecting the headphone jack output of the player to the voice-activated input of an HF transceiver. By playing a selected portion of the CD, the transceiver transmits a call to an ALE radio under test. The HF channel and modem software simulator consists of software modules for ALE protocol testing, error correction, and linking protection techniques used in ALE radios. Through simulation studies using these products, throughput and delay effects of advanced networking features such as sounding, polling, direct and indirect message routing, automatic message exchange, and store-and-forward message exchange can be determined. System users and administrators can use these results to choose the proper mix of network features and functions to achieve maximum channel efficiency. These results also are useful to HF ALE radio users, standards developers, network designers, and radio manufacturers and vendors.

The real-time hardware channel simulation capability consists of a conventional narrowband (Watterson Model) channel simulator, a narrowband simulator based on the ITS wideband HF model, and a wideband channel simulator. All of these simulators were developed at ITS. Each simulator has a unique capability for representing the channel conditions encountered on HF communication links to evaluate the performance of HF radios under a variety of repeatable, controllable conditions. The wideband channel simulator employs state-of-the-art digital signal-processing technology to implement new mathematical models of the propagation, noise, and interference environments. Unlike past HF channel simulators that are only valid over narrowband (several kHz bandwidth) channels, the new simulator is based on a fundamentally new approach that enables the simulation of wideband (on the order of 1-MHz bandwidth) as well as narrowband channels, both disturbed and nondisturbed. The HF channel simulator is used to test the operation of complex state-of-the-art HF systems over simulated HF transmission paths. This includes testing systems that use robust transmission algorithms such as code-combining, Golay, and other forward-error correction codes with either broadcast or automatic repeat request modes.

The test facility has been used for interoperability and performance testing of advanced HF modems and ALE systems. For example, the facility has been used to conduct proof-of-concept testing of robust, high-speed systems such as the proposed Federal Standard 1052, Data Link Protocol. The facility also has been used in tests needed by the National Communications System, the National Reconnaissance Office, and the Federal Emergency Management Agency. In one recent test, ITS staff members compared modems that employ simple, cost-effective protocols such as PACTOR, AMTOR, ARTOR, SITOR, CLOVER II, ALE, and G-TOR to determine their suitability in emergency situations.

Integrated Networks Simulation Environment

Computer-based simulation is used widely in performance prediction and design optimization in the field of telecommunications engineering. ITS is expanding its telecommunications modeling and simulation capabilities through the development of a comprehensive laboratory environment for network-level simulation. The modeling and simulation tools available in the Institute's network-level simulation environment include the object-oriented Optimized

Network Engineering Tools (OPNET) program; the Block Oriented Network Simulation (BONeS) program for developing, executing, debugging, and analyzing simulation models; and several ITS-developed network-monitoring and analysis tools. These programs are hosted on Silicon Graphics, SUN, and NT workstations in a networked environment to allow sharing of resources. The OPNET, BONeS, and ITS-developed network simulation tools have flexible capabilities for modeling and testing complex telecommunications networks including Ethernet and FDDI local area networks, packet- and circuit-switched networks, asynchronous transfer mode networks, satellite links, and other systems. ITS has also developed a computer model to simulate the effect of different TCP/IP parameters when sending e-mail over HF radio links under different ionospheric conditions. This will aide in determining optimum settings for emergency HF usage.

Integrated Networks Test Bed

This facility provides integrated services digital network-switching and emulation capabilities, and a wide range of facilities to support broadband network testing including a real-time asynchronous transfer mode (ATM) switching capability. In conjunction with a broadband network emulator that implements synchronous optical network and synchronous digital hierarchy (SONET/SDH) transmission protocols, this capability enables researchers to study the effects of transmission errors and traffic loading on ATM network performance. The ATM switches can route live streams of digitized audio, video, or other digital information through SONET/SDH equipment operating at transmission speeds up to 155 Mbit/s. The laboratory is interconnected and interoperable with the Audio Quality, Video Quality, and Multimedia Subjective Testing Laboratories (described separately in this section). The set of applications of this group of integrated laboratories includes support for the development of performance standards pertaining to multimedia communications.

ITS Internet Services

ITS provides public Internet access to NTIA/ITS publications, program information and on-line Telecommunications Analysis Services used by other Federal agencies, research partners and private industry. Restricted-access services including electronic mail lists are used to facilitate communications with project sponsors and partners, and to support ANSI T1 standards committees. Some highlights of ITS Internet Services include:

- The on-line version of FED-STD 1037C, *Glossary of Telecommunication Terms*, featuring over 5800 technical definitions linked together in hypertext. Available at http://glossary.its.bldrdoc.gov/fs-1037/
- Recent ITS publications including NTIA Reports and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs.html
- Telecommunications Analysis Services. Available at http://www.its.bldrdoc.gov/tas/
- An overview of the ITS mission and programs. Available at http://www.its.bldrdoc.gov/bluebook/
- A complete listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/home/people/staff.html
- Anonymous FTP distribution of some ITS developed software programs. Available at *ftp.its.bldrdoc.gov*

For more detailed information regarding ITS information services please e-mail webmaster@its.bldrdoc.gov or contact Darren L. Smith (303) 497-3960.

ITS Local Area Network

ITS maintains a highly flexible local area network (LAN) to support intranetworking services and laboratory interconnection. A structured cabling system interconnects all offices and laboratories with both optical fiber and Category 5 twisted-pair cabling to support high-bandwidth communications on demand. Over 200 devices are supported on 10Base-T and 100Base-TX ethernet segments. Connections can also be made to laboratory testbeds featuring synchronous optical network/asynchronous transfer mode (SONET/ATM). This provides ITS with great flexibility and rapid reconfiguration capability for new programmatic needs.

For more detailed information regarding ITS information services or network technology, please e-mail netmgr@its.bldrdoc.gov or contact Darren L. Smith (303) 497-3960.

Mobile Radio Communication Performance Facility

The Telecommunications Industry Association has endorsed an open-standard design specification for the next generation of land-mobile radios. This specification is known as Project 25, or simply P25. As public safety agencies plan their migration strategies to infuse new P25-compliant radio equipment into their radio fleets, a determination of acceptable speech intelligibility is required. The level of speech intelligibility is directly related to the minimum acceptable levels of received signal strength and interference rejection ratio, which in turn influences the design specification for the radio network infrastructure (range of coverage, distance between adjacent channel and cochannel transmitters, etc.). ITS has the capability to measure P25 performance parameters, such as RF sensitivity and adjacent channel rejection ratio. ITS also possesses the ability to determine the delivered audio quality of speech signals transmitted through P25-compliant radios. Figure 1 shows a block diagram of a test configuration to determine the delivered audio quality of transmitted speech in the presence of adjacent channel or cochannel interference. Figure 2 shows an example set of performance curves relating the delivered audio quality of transmitted speech to adjacent channel interference rejection. These types of measurements can be performed for a variety of radio channel and interference environments, and mission-oriented audio samples of these speech transmissions can be provided to clients, with the delivered audio quality scores and radio channel environment conditions. Several transmitted speech samples may be heard at ITS' internet site, http://flattop.its.bldrdoc.gov/spectrum/P25/index.htm

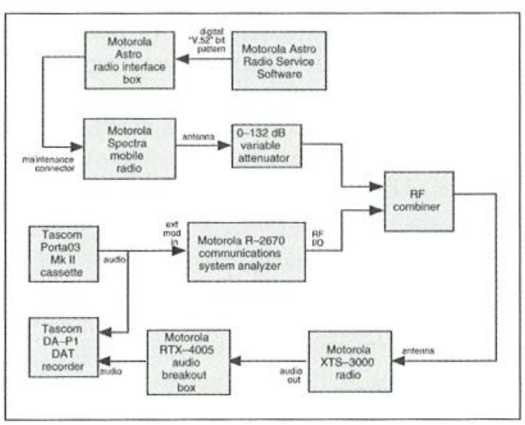


Figure 1. Block diagram of the test configuration to obtain transmitted speech samples for delivered audio quality scoring.

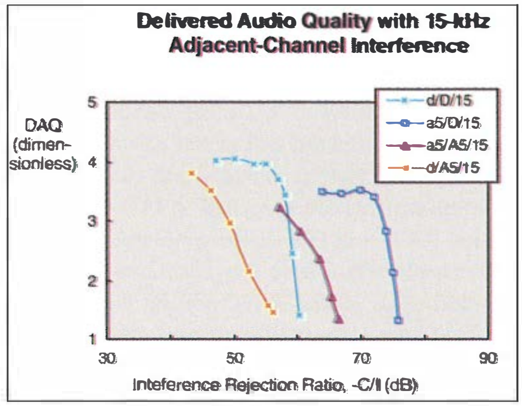


Figure 2. Typical delivered audio quality vs. interference rejection ratio performance measurement. Conditions shown: unwanted digital signal, 15 kHz offset, interfering with desired digital channel (d/D/15), unwanted 5-kHz deviation analog signal, 15 kHz offset, interfering with desired digital channel (a5/D/15), unwanted 5-kHz deviation analog signal, 15 kHz offset, interfering with desired 5-kHz deviation analog channel (a5/A5/15), and unwanted digital signal, 15 kHz offset, interfering with desired 5-kHz deviation analog channel (a5/A5/15).

Mobile Radio Propagation Measurement Facilities

ITS maintains a measurement vehicle capable of radio channel characterization over a wide frequency range. The vehicle is equipped with on-board power, a telescoping mast, azimuth elevation controllers, and a global positioning system with dead-reckoning backup. A suite of measurement equipment also is available for use in this vehicle. This includes wide-band systems for measuring radio channel impulse response at 450MHz ,1350MHz, 1920 MHz and 30.3 GHz. In addition there is narrow-band measurement capability up to 96 GHz. Impulse response measurement capability at 30 GHz with 2ns resolution has been enhanced with the addition of a fully digital wideband recording system.

During the past year ITS increased its mobile channel measurement capability with the addition of a VME computer-based system. This system has real-time processing capability using onboard digital signal processing as well as increased data throughput for multi-channel data. This increased capability allows continuous recordings of the mobile radio channel. Multi-channel acquisition can be used for antenna arrays measurements or multi-frequency broadband measurements. This data can then be used to simulate and model radio systems.

Multimedia Subjective Testing Laboratory

The Multimedia Subjective Testing Laboratory provides controlled acoustic and visual environments for the subjective testing of audio and video signals. These environments are specified in ITU-T Recommendation P.800 and ITU-R Recommendation BT.500 respectively. These specifications address background noise levels, reverberation times, wall colors, light levels, room dimensions, and other properties. The Multimedia Subjective Testing Laboratory consists of two separate rooms that conform to these specifications.

Because two separate rooms are available, the laboratory can support conversation, teleconferencing, and video teleconferencing tests as well as listening and viewing tests. Electronic screens and pens are used in some tests to automate the collection of responses from test subjects. Other supporting audio and video equipment in the laboratory includes cameras, monitors, microphones, loudspeakers, headphones, and handsets. Professional quality analog and digital audio and video recording and playback equipment are available as well.

Radio Spectrum Measurement Systems

ITS has designed, constructed, and currently operates a number of automated spectrum measurement systems. The Radio Spectrum Measurement System (RSMS), ITS's primary system, is a vehicularly mounted, self-contained facility for measurements between 1 MHz and 24 GHz. ITS also has available a number of suitcase-deployable systems called Compact Radio Spectrum Measurement Systems (CRSMS). RSMS and CRSMS facilities incorporate a combination of commercial off-the-shelf hardware, hardware custom-designed by ITS, and control software written by ITS. The RSMS is RF-shielded, and includes two 30-ft masts, an on-board 10-kW generator, air conditioners, four full-height equipment racks, and storage space. CRSMS capabilities utilize the same software but typically include only as much hardware as is required for any given measurement task. Local arrangements must be made for CRSMS shelter and power.

Both RSMS and CRSMS rely extensively upon computer control of measurements. These systems can be operated in fully automatic, semi-automatic, and fully manual modes. Mobile radios, fixed communication links, radars, personal communication systems, earth station uplinks, industrial, scientific, and medical devices, broadcast signals, and special-purpose transmitter systems can be measured. For a complete description of the RSMS, go to ITS on-line publications (http://ntia.its.bldrdoc.gov) and download applicable appendices from any RSMS measurement report (e.g., Appendix A of NTIA Report 97-334; see Publications Cited, p. 106).

RFIMS Development Lab

Under the FAA Radio Interference Monitoring System (RFIMS) Program, ITS engineers have created the RFIMS Development Lab. The lab houses and maintains complete RFIMS hardware and software configurations. The lab is available to all nine FAA regions as well as FAA Headquarters and Technical Center to support their use of RFIMS. RFIMS is a custom radio spectrum measurement system integrated into a mobile field platform. In the RFIMS Development Lab, ITS engineers can quickly and accurately re-create field measurements and simulate FAA data acquisition. The RFIMS Development Lab allows ITS engineers to assist the FAA in troubleshooting any problems, identifying anomalies, and verifying field results from deployed units. The RFIMS program currently has three mobile units deployed in three FAA regions. Eight more RFIMS will be deployed in 1999.

Spectrum Compatibility Test and Measurement Sets

The introduction of new systems in close frequency proximity to older ones often causes electromagnetic compatibility (EMC) problems. Although models and simulations provide much useful information in guiding design decisions, the complexity of modern systems and the existing spectral environment often requires real world measurements of a proposed system's effects within its proposed operating environment to determine its impact on other users of the radio spectrum. Another problem is the production of a controlled interfering signal with known characteristics in environments where the suspected interferer may be unavailable for use. This includes situations such as laboratory tests using interference from ship or aircraft mounted radars or communications systems. In both situations a system which could simulate the spectral emissions of other devices with a wide range of latitude is needed.

To meet these needs, ITS engineers have developed two different types of interference generators. The first system is the Broadband Arbitrary Waveform

Transmitter (BAWT) that is used to simulate the spectral output of a wide variety of radar and communication systems. These signals can be coupled directly into the system under test or they can be transmitted into the target system's antenna to more accurately gauge its response to a real interference situation. In cases where the exact form and characteristics of the proposed interferer are poorly known, a second type of generator may be used. This device, the Broadband Noise Generator (BBNG) produces a noise-like signal at the frequency of interest with a bandwidth determined by the investigator. This signal is typically directly coupled into the target system for measurement purposes. The BBNG is especially useful for assessment of system performance in the presence of noise-like spurious emissions from adjacent-band systems.

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 within the test area. This allows research concerned with low signal levels, such as from deep space, extraterrestrial low-signal satellites, or very sensitive receiver techniques, to be conducted without the interference found in most areas of the nation. As the use of electronic systems (e.g., garage door openers, computers, citizen band radios, cellular telephones, arc welders, and microwave ovens), the number of radio and television stations, and new uses for the radio frequency spectrum increase, the average level of electromagnetic energy across the spectrum will also increase. This is important to companies that develop sensitive radio receivers and signal-processing equipment, since the equipment is often saturated by the background signal level. This facility is available for use by private parties on a reimbursable basis.

Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provide the latest engineering models and research data developed by ITS to industry and other Government agencies. TA Services is interactive and is becoming Web-based. It is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 3-arc-seconds (90 m) resolution for much of the world and 5-min resolution data for the entire world; the 1990 census data; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (arcinfo). Other Government databases and reports are available through a bulletin board service available to all users of TA Services as they are developed. TA Services has developed models that predict communication system coverage, and interference for many broadcast applications. New models in the GIS environment for personal communications services (PCS) and local multipoint distribution services (LMDS) have been developed (see Telecommunications Analysis Services, pp. 44-45). The following is a brief description of some programs available through TA Services.

PATH PARAMTRS - Calculates Great Circle distances and bearings between user-specified locations, and also provides delta-H and average terrain heights for those locations.

PCS/LMDS - Allows the user to create or import surfaces that may include terrain, buildings, vegetation and other obstructions in order to perform line-of-sight and diffraction studies.

FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND - Allow a user to search the FCC database for particular stations or by search radius around a point of interest.

INMOD - Calculates and lists intermodulation products in a user-specified receiver bandpass from up to 40 transmitters, 40 receivers (up to seventh order), and with up to 5 concurrently operating transmitters.

PROFILE - Extracts path profiles according to user-specified input parameters, such as location and bearing. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user also can receive plots of the profiles adjusted for various K factors depending upon the intended use of the path. For microwave links, Fresnel zone clearance can be determined easily from the plots so that poor paths can be eliminated from a planned circuit or network.

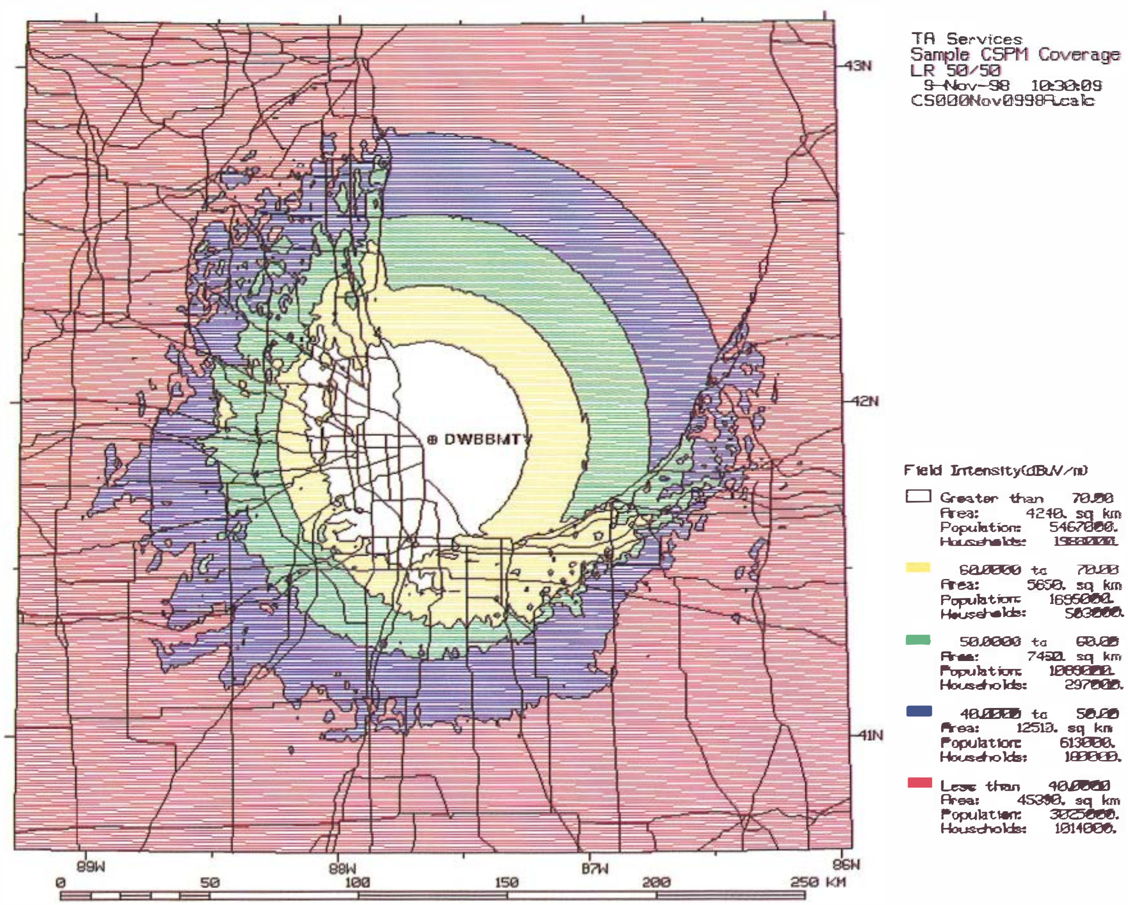
HORIZON - Plots the radio horizon around a specified location in the U.S.-digitized topographic data. It is generally used for sighting satellite terminals and radars so that terrain-shielding effects and limits on the visible elevations can be determined.

SHADOW - Plots the radio line-of-sight (LOS) regions around a specified location in the United

States using digitized topographic data. It shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.

COVERAGE - Calculates the receive signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model can be chosen for calculations.

CSPM - Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the Figure below. Plotted outputs can either be faxed directly to the user or plotted in brilliant colors on clear plastic to a specified scale for overlaying on geopolitical maps. This is the most detailed of the signal calculation programs available and uses ITS's Irregular Terrain Model in a point-to-point mode. The FCC rules, as well as other widely available models, also can be chosen. New models are placed on-line within CSPM as they become available. CSPM is capable of combining coverage from several transmitters to show the coverage from a network of stations. Interference regions also can be plotted to determine potential interference from a user-specified transmitter within the area of interest. The plots show the population, households, and areas covered within each of the signal ranges. The most ambitious use of CSPM to date involves determining the population covered by education television stations.



Example of a transmitter coverage using CSPM.

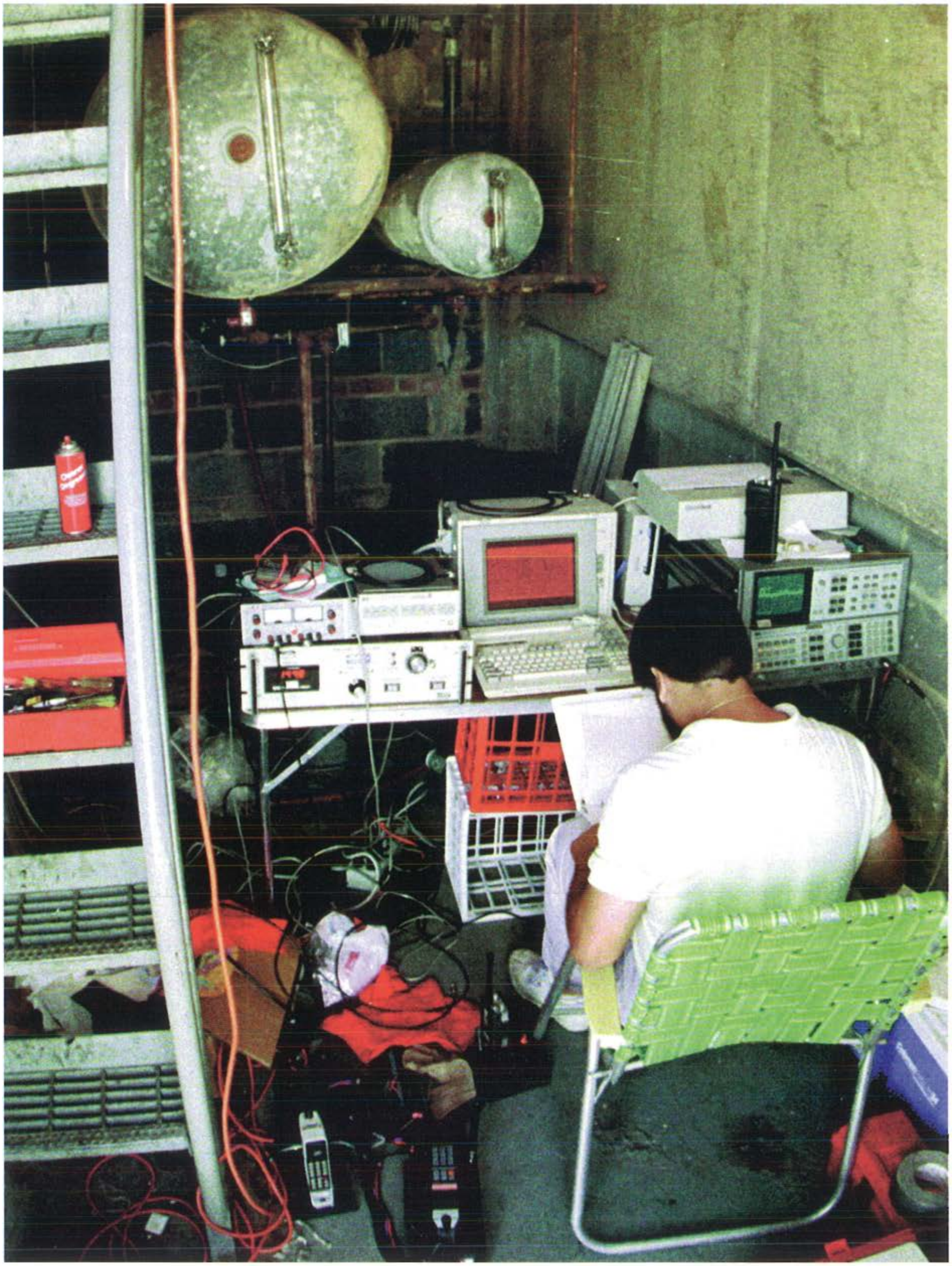
Video Quality Laboratory

The ITS Video Quality Laboratory contains objective and subjective measurement facilities that are used to develop and test automated techniques for assessing the quality of video and image data. The video quality studies conducted in this laboratory support national and international standardization and associated Government and industry technology assessment needs. The objective measurement facilities include (1) several high performance workstations that are used for prototyping and testing the video and image parameters; (2) an ensemble of switcher-connected broadcast quality cameras, video recorders (including an ITU-R Recommendation BT.601, 360 Mbits/sec digital video recorder), video monitors, video capture and display equipment, video signal generators, and video coders/decoders (codecs); and (3) an 80-GB read/write optical jukebox, a 12-GB 4mm tape drive, and an 8-GB 8mm tape drive, all for storing digitized images. The objective quality measurement software, written in C++, can perform pixel-accurate and field-accurate processing of sampled input and output video streams in accordance with ANSI T1.801.03-1996 (Digital Transport of One-Way Video Signals — Parameters for Objective Performance Assessment). The Multimedia Subjective Testing Laboratory provides a means for validating objective video and image parameters implemented in computer-based measurement systems. The video quality laboratory hardware and software have been designed specifically to address the difficult problem of assessing the end-to-end quality of digital video systems. For example, video codecs are used in conjunction with the Integrated Networks Testbed to generate impaired digital video for objective and subjective quality testing.

Wireless Link Simulation Laboratory

This ITS laboratory provides an environment to simulate wireless systems and channels for performance prediction of data, compressed or uncompressed speech and images, and fax source transmission. ITS specializes in end-to-end results by performing channel characterization measurements, modeling the measurements, imbedding the models in simulation software, and predicting the system performance and spectrum requirements via simulation. Typically, predicted speech and image quality are determined as a function of signal-to-noise ratio, carrier-to-interference ratio, and bit error ratio for a selected radio system and channel parameters. Real-time link bit error generator models are available for each simulation used to study the effects of the link conditions on various sources and may also be employed as a link model in wireless network simulation. These capabilities are useful in determining predicted performance of proposed wireless systems and standards and may be used to determine design and deployment specifications for these systems.

PC/DOS-based, Windows 95, and UNIX-based link software simulation packages and a generic channel simulator software package are available to perform wireless simulations, predict performance, predict spectrum requirements, and perform signal processing. Laboratory hardware consists of RISC and Pentium workstations to run simulation and signal processing software. An audio cassette, S-VHS recorder and players, and S-VHS TV monitor are available for storing and demonstrating speech, images, and video. Programmable digital signal-processing boards and card cage are available to download wireless link simulations for real-time testing of transmitters, receivers, and channel models. A programmable 6-MHz bandwidth hardware channel simulator is also available for testing transmitters and receivers.



ITS suitcase measurement system deployed on a rooftop in Washington, D.C. in 1990-91. This photograph was taken during an Other Agency-funded microwave receivability project that was classified at that time, but has subsequently been declassified (photograph by F.H. Sanders).

ITS Projects in FY 1998

Department of Commerce

Telecommunications Assessment and Strategic Plan - Determine what telecommunications resources and capabilities are presently available within the various organizations of the Department. Develop a structured, effective, and efficient methodology for moving the Department's telecommunications infrastructure into the 21st century.

Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Department of Defense

Adaptive Radio and Adaptive Antenna Symposium - Plan, organize, host, and chair a symposium on adaptive radio and adaptive antenna technologies, in order to gather information on new developments in these technologies.

Project Leader: Christopher L. Holloway (303) 497-6184
e-mail cholloway@its.bldrdoc.gov

Federal Aviation Administration

FAA Radio Frequency Interference Monitoring Systems - Integrate and test prototype mobile RFIMS measurement systems. Procure and test additional mobile systems, install subsystems and software into each new vehicle, perform final integration testing, and deliver the vehicles to the FAA.

Project Leader: Patricia J. Raush (303) 497-3568
e-mail praush@its.bldrdoc.gov

Federal Highway Administration

Electromagnetic Compatibility of the Intelligent Transportation System - Develop communication systems to provide information to travelers, their vehicles, and the infrastructure. Support development of standards and identify spectrum issues related to electromagnetic compatibility (EMC) of the intelligent transportation systems. Perform measurements for an EMC analysis to determine the levels of radio frequency radiation coupled from an Earth station operating in the 5875- to 5925-MHz band to a highway environment location. Perform an EMC analysis for dedicated short-range communications systems in this band. Determine potential worst case interference distances, conduct testing, and perform analysis to identify techniques to mitigate interference. Add map boundary modifications to existing propagation model for low and medium frequencies.

Project Leaders: Robert J. Matheson (303) 497-3293, Roger Dalke (303) 497-3109, Nicholas DeMinco (303) 497-3660, and Frank H. Sanders (303) 497-5727
e-mail matheson@its.bldrdoc.gov, rdalke@its.bldrdoc.gov, ndeminco@its.bldrdoc.gov, and fsanders@its.bldrdoc.gov

Technical Support for Implementation of a Nationwide Global Positioning System Service - Provide continuing support for the implementation of a nationwide DGPS Service. Utilize results obtained in field testing to develop a network of fewer total DGPS reference stations, in order to reduce the number of potential interference problems and the number of stations that must be operated and maintained.

Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Federal Railroad Administration

Telecommunications Study - Review the railroad's next generation telecommunications system design and demonstration projects to be used on positive control systems and advise the Federal Railroad Administration on telecommunication issues.

Project Leader: John M. Vanderau (303) 497-3036
e-mail jvanderau@its.bldrdoc.gov

Hewlett-Packard Company

Local Multipoint Distribution Service Model Development - Develop computer models to predict excess path loss for the local multipoint distribution system signal.

Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Industrial Technology, Inc.

Calibration and Verification Listening Test - Conduct a subjective test that will result in data that will be used to calibrate and verify the operation of a cellular telephone test instrument currently under development.

Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Miscellaneous Federal and Non-Federal Agencies

Telecommunications Analysis Services - Make available to other Government agencies and to the public, through user-friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

National Communications System

Advanced Audio Quality Testing - Test and verify advanced audio quality measurement algorithms. Develop techniques to integrate existing video quality measurement algorithms with newly developed algorithms. Prepare results for the *Multimedia Performance Handbook*.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Broadband Digital Telecommunications - Test and verify broadband multimedia quality measurements. Contribute results to national and international standards organizations.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

Digital Voice over HF Radio Transmissions - Select and test vocoders and modulation methods for use in the low baud rate HF environment, in order to provide increased clarity and reliability for HF emergency radio operations.
Project Leader: Christopher Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

FTSC Standards Coordination - Develop and test a search engine to work on all hyperlinked Federal Standards. Develop and maintain a "Federal Standards Online" web page, integrated with the search engine. Analyze technological and economic impact assessments of prospective Federal Telecommunication Recommendations and Standards.
Project Leader: Evelyn M. Gray (303) 497-3307
e-mail egray@its.bldrdoc.gov

HF Modem Performance and Interoperability Testing - Upgrade the ITS HF testbed to aid in the performance of extensive, unattended testing of HF equipment under simulated, degraded atmospheric conditions. Conduct performance tests on new low-cost modems, and assess software-based and hardware-based modem interoperability.
Project Leader: Timothy J. Riley (303) 497-3307
e-mail triley@its.bldrdoc.gov

International HF Radio Standards Development - Gain international acceptance in the ITU-R of the NCS-sponsored HF channel and noise/interference models and the HF channel and noise/interference simulators. Incorporate Federal Standard HF ALE technology in the ITU-R Adaptive HF Handbook.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Land Mobile Radio Interoperability Standards - Assist in developing interoperability standards for digital land mobile radio. Lead the Encryption Task Group, develop security standards, provide systems engineering support to other Task Groups, and participate in various committees.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@its.bldrdoc.gov

Low-Cost ALE Controller: Develop Low-Cost DSP Card - Develop the hardware portion of the low-cost ALE controller/modem, based on DSP technology, for volunteer radio operators to use in conjunction with HF SSB radios.
Project Leader: Christopher Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Low-Cost ALE Controller: Develop DSP Software - Develop the software portion of low-cost ALE controller/modem, based on DSP technology.
Project Leader: Robert A. McLean (303) 497-5947
e-mail rmclean@its.bldrdoc.gov

Multiband, Multimode Wireless Communications Standards - Participate in U.S. Technical Group 8/1 and ITU-R Technical Group 8/1, which are in the process of developing recommendations for the next generation of wireless systems.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

***Multimedia Performance Handbook* -** Design and implement Version 3.0 of the Multimedia Performance Handbook, conduct preliminary testing, and perform standards work in T1A1 and the FTSC.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

***Multimedia Performance Handbook:* Desktop Video Teleconferencing Testing -** Produce preliminary performance information concerning a typical desktop video teleconferencing system. Produce content for the *Multimedia Performance Handbook* and contribute to national and international standards bodies.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

***Multimedia Performance Handbook:* Handbook Revision, Subjective Testing, and Standards Development -** Convert the Handbook to web compatible software technology. Perform a subjective quality measurement experiment involving the transmission of low-rate video teleconferencing signals. Help develop international standards for the measurement of the quality of MPEG coded video.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

National HF Radio Standards Development - Provide effective leadership and administrative support for the Federal Telecommunications Standards Committee's HF Radio Subcommittee. Develop technical contributions and complete texts for proposed new or revised Federal HF radio standards. Complete and publish an HF ALE handbook to assist communication managers, administrators, and operators in planning, implementing, and controlling HF ALE networks.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Performance Assessment of HF E-mail Protocols - Quantify the performance of Internet e-mail utilizing a DSP-based HF channel simulator over various channel conditions. Conduct over-the-air tests to demonstrate system performance and assess an HF-optimized protocol stack for sending Internet e-mail messages over HF channels.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Real-Time Channel Simulation to Support ITU-R Contributions - Demonstrate the limitations of the ITU-R Narrowband HF (NBHF) model. Compare the difference between a current NATO standardized NBHF simulator and the ITS NBHF simulator, based on the more generalized ITS Wideband HF channel model, in order to assess the effect of delay spread on NBHF modem performance.
Project Leader: Christopher Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Standards Publication Support - Provide the following expert standards publication support to NCS: enhancement of the Federal Standard 1037C search engine, electronic distribution of FED-STD-1037C and other Federal Standards, and maintenance planning for FED-STD-1037C.
Project Leader: Evelyn M. Gray (303) 497-3307
e-mail egray@its.bldrdoc.gov

Wideband HF Simulator Testing to support Standards Development - Validate both narrowband and wideband channel simulators using procedures specified by the NATO HF Communications System Group.
Project Leader: Christopher Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

National Institute of Standards and Technology

Communication Standards for Office of Law Enforcement Standards - Provide engineering support, scientific analysis, technical liaison, and test design and implementation in the development and validation of criminal justice communications standards.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

National Oceanic and Atmospheric Administration

NOAA Weather Satellite System Analysis - Provide consulting services for the in-band man-made noise model developed by ITS.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

National Security Agency

Secure Telecommunications Analysis Services - Develop a secure TA Services with new NSA-supplied algorithms which NSA can utilize remotely.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Standards Development for Personal Communications Services - Present standards requirements from anticipated Federal users of wireless products and services, stressing incorporation of synchronous dat services with STU-111 applications in the proposed TR41.6 unlicensed personal communications services standards.
Project Leader: Steven M. Davidson (303) 497-3411
e-mail sdavidson@its.bldrdoc.gov

National Telecommunications and Information Administration

Audio Quality Standards - Develop perception-based objective audio quality assessment techniques and standards contributions in support of advanced audio-coding and integrated services digital network standards within T1 and the International Telecommunication Union-Telecommunication Standardization Sector.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

Broadcasting and Related Propagation Studies - Provide engineering support to the Executive Branch to select the best alternatives for efficient use of the broadcasting spectrum. Develop tools to evaluate the FCC's planned allocation for high-definition television assignments, and develop techniques for high-definition television station owners to evaluate their station's performance.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Broadband Networks - Build the infrastructure necessary for ITS to lead in the development of a broadband research community by expanding and enhancing the Institute's capabilities for broadband networks performance measurement.
Project Leader: William R. Hughes (303) 497-3728
e-mail whughes@its.bldrdoc.gov

Broadband Wireless Standards - Provide leadership and technical contributions to national and international wireless standards development that enhance domestic competitiveness, improve foreign trade opportunities, and facilitate more efficient use of the radio spectrum. Actively support the International Telecommunication Union-Radiocommunication Sector, the Joint Technical Committee for Personal Communications Services Air-Interface Standards, and the IEEE 802.11 Wireless Local Area Networks Standards Committee.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Broadband Wireless Systems Research - Support the development of broadband radio technologies and applications, especially high-data-rate, digital communications. Measure and model millimeter-wave propagation. Measure and model broadband indoor propagation and support the development of wireless local area network standards.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Digital Networks Performance for the Global Information Infrastructure - Develop and promote the adoption of a new ANSI standards project in T1A1 that will provide a focus for U.S. contributions on GII/Internet performance in the ITU-T.
Project Leader: William R. Hughes (303) 497-3728
e-mail whughes@its.bldrdoc.gov

International Standards - Provide leadership to T1 and U.S. International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) committees and international work groups. Prepare technical contributions to advance ITU-T standards development and draft recommendations on integrated services digital networks and associated voice, data, and video communication services.
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Personal Communications Services Interference Modeling - Extend the ITS-developed personal communications services (PCS) interference model to cover additional PCS technologies. Participate in technical working groups to produce a handbook assisting equipment manufacturers and field personnel in avoiding and eliminating PCS to PCS interference.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

Personal Communications Services Radio System Tools - Provide support for the development of personal communications services radio technology through measurements, modeling, and simulation of the radio channel; analyze spectrum issues including spectrum sharing, interference, and access methods; and provide technical support for national and international standards development.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Radio Spectrum Measurement System - Support Federal Government spectrum management needs through development of new capabilities for the radio spectrum measurement system (RSMS). Develop new techniques, algorithms, and hardware for the RSMS.
Project Leader: Bradley J. Ramsey (303) 497-3165
e-mail bramsey@its.bldrdoc.gov

Radio Spectrum Measurement System Operations - Support Federal Government spectrum management needs through spectrum measurements. Spectrum measurements quantify Government and non-Government spectrum occupancy, the emission characteristics of individual emitters, and the electromagnetic compatibility of systems that use radio spectrum.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Satellite/ATM Interoperability - Examine and promote the interoperability of satellite and terrestrial systems and services, with an emphasis on ATM and related protocols. Measure and provide information on the performance and interoperability of communications links that include satellites.
Project Leader: William A. Kissick (303) 497-7410
e-mail wkissick@its.bldrdoc.gov

Spectrum Engineering Models - Provide engineering and analysis in support of the Office of Spectrum Management of NTIA regarding studies of spectrum utilization and electromagnetic compatibility.
Project Leader: Robert J. Matheson (303) 497-3293
e-mail rmatheson@its.bldrdoc.gov

Spectrum Technical Studies - Use state-of-the-art spectrum measurement techniques, algorithms, and hardware to perform spectrum management research for the Office of Spectrum Management of NTIA.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Video Quality Standards - Develop video quality assessment techniques and standards contributions in support of digital transmissions systems relevant to the National Information Infrastructure within T1 and the International Telecommunication Union-Telecommunication Standardization Sector. Develop the required technology for assessing performance of digital video transmission systems and transfer this technology to other Government agencies and end-users, national and international standards bodies, and the U.S. telecommunications industry.
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

Netrix, Inc.

Netrix Conversation Test - Conduct subjective and objective measurements of speech quality, using a conversation test and prototype speech quality test instruments. Measurements will be made on existing and emerging speech compression and transmission technologies.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

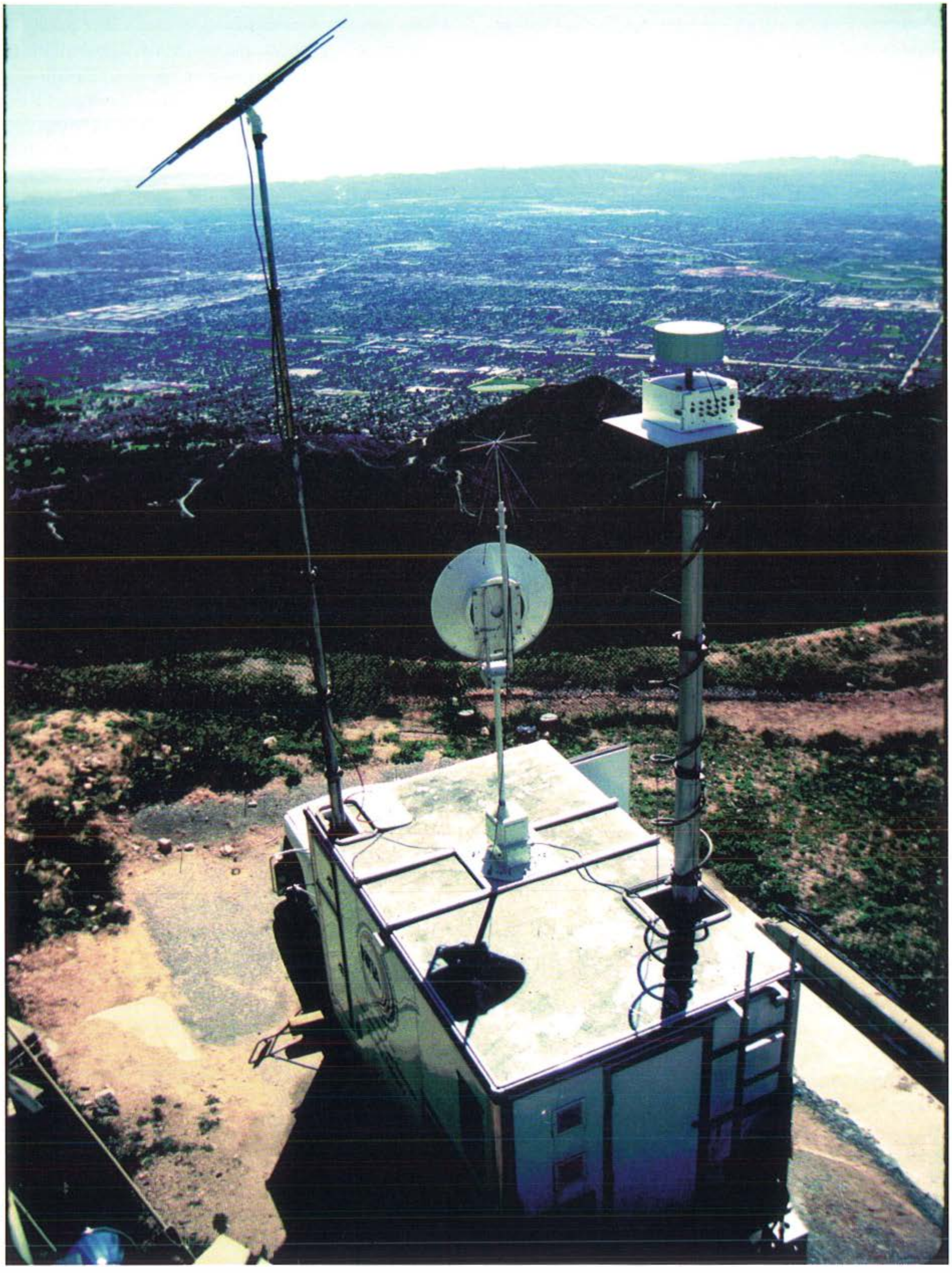
U.S. Air Force

Investigation of CW Waves Through Reinforced Concrete and Circular Waveguides - Obtain an analytical solution of electromagnetic waves propagating through reinforced concrete walls, in order to study the propagation and attenuation characteristics of the walls. Investigate the propagation of a signal through a 15-inch circular hole in the ground to determine the optimum frequency for communications.
Project Leader: Christopher L. Holloway (303) 497-6184
e-mail cholloway@its.bldrdoc.gov

Radar Target Identification Development - Assist in the development of optimal feature sets and classifiers for automatic target recognition using radar sensor data.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

U.S. Army

Jammer Effectiveness Model - Develop a Jammer Effectiveness Model using the AMOS interface shell and ITM, GWAPA, and IONCAP propagation models.
Project Leader: Nicholas DeMinco (303) 497-3660
e-mail ndeminco@its.bldrdoc.gov



The Radio Spectrum Measurement System (RSMS) above Los Angeles during a broadband NTIA spectrum survey (photograph by F.H. Sanders).

ITS Publications in FY 1998

NTIA Publications

R.J. Achatz, Y. Lo, P.B. Papazian, R.A. Dalke, and G.A. Hufford, "Man-made noise in the 136 to 138-MHz VHF meteorological satellite band," NTIA Report 98-355, Sep. 1998.

Satellite radio system performance in the 136 to 138-MHz VHF meteorological satellite band is compromised by man-made noise external to the receiver. Methods used for predicting man-made noise power in this band are based on measurements conducted in the 1970's. These methods may be inaccurate due to technological advances such as quieter automotive ignition systems and the proliferation of consumer electronic devices such as the personal computer. This report describes noise power measurements the Institute for Telecommunication Sciences performed in the 136 to 138-MHz VHF meteorological satellite band. Statistics of average noise power were compared to those of measurements conducted in the 1970's. The noise power measurements were also used to model instantaneous noise power for simulation of radio links.

R.J. Achatz, Y. Lo, and E.E. Pol, "Indoor direction diversity at 5.8 GHz," NTIA Report 98-351, Jul. 1998.

Complex impulse response measurements of a warehouse building were made at 5.8 GHz with a sliding correlator channel probe. These measurements were made with vertically and horizontally polarized directional antennas so performance improvement due to polarization- and direction-diversity could be evaluated. Improvement in performance was determined by changes in the radio channel's delay spread. Performance improved with direction diversity; however, adding polarization diversity yielded little improvement over direction diversity alone.

R.A. Dalke, F.H. Sanders, and B.L. Bedford, "Electromagnetic compatibility testing of a dedicated short-range communication system," NTIA Report 98-352, Jul. 1998.

Dedicated short-range communication systems have been proposed for operation at locations across the United States in the 5850- to 5925-MHz band. Various search and tracking high-power radars operate at or near this frequency band and are a source of potential interference. The successful operation of such digital communication systems is dependent upon compatible operation and coexistence with these radars. The Institute for Telecommunication Sciences has performed a series of interference tests to determine the electromagnetic compatibility of DSRC systems used for automatic toll collection and high-power 5-GHz radars. The methods used to perform the tests and results are presented in this report.

J.R. Hoffman, J.J. Lemmon, and R.L. Ketchum, "DGPS field strength measurements at a GWEN site," NTIA Report 98-346, Apr. 1998.

Field strength measurements of a 300-kHz differential global positioning system signal transmitted at a Ground Wave Emergency Network site at Appleton, Washington were conducted. Data were acquired continually along five different routes and tagged with geographical position. Field strength along each individual route was plotted against distance from the transmitter and related to geological landmarks. Results were used as model inputs and to compare measured signal strengths with model predictions.

C.L. Holloway, M.G. Cotton, and P. McKenna, "A simplified model for predicting the power delay profile characteristics of an indoor radio propagation channel," NTIA Report 98-353, Aug. 1998.

Multipath channels in indoor wireless communication systems exhibit a characteristic power delay profile, which can be a detriment to system performance. In this paper, we present a simplified model for calculating the decay rate of the power delay profile for propagation within rooms. This simplified model provides a time-efficient means of predicting system performance. Predictions of this indoor power delay profile (IPDP) model are compared to results obtained from a finite-difference time-domain (FDTD) model. Additionally, comparisons of the IPDP model to measured data are presented. The rms delay spread is the second central moment of the power delay profile of a propagation channel and is a measure of the communication link degradation due to multipath. We also show results of the estimated rms delay spread from this model and show comparisons to the measured data. This IPDP model can be used to investigate the effects of variable room size and properties of the surfaces (or walls) on the decay characteristics of the power delay profile.

C.L. Holloway and E.F. Kuester, "Analysis and calculations of the ground plane inductance associated with a printed circuit board," NTIA Report 98-344, Nov. 1997.

A knowledge of the net inductance of the ground plane can aid in the analysis and investigation of printed circuit board emissions. In this report, we present a method, based on the concept of partial inductance, to determine the net inductance of the ground plane associated with a microstrip line. This method is based on a previously derived expression for the current density on the ground plane. We show calculations for the net, self-partial, and mutual-partial inductance of the ground plane for various trace geometries of practical interest. We also illustrate how the classical transmission line inductance of a microstrip line can be obtained from the concept of partial inductance. Comparisons to different experimental results are also given.

W. Ingram and E. Gray, "A federal standard on electronic media," NTIA Report 98-350, Aug. 1998.

Federal telecommunications standards have traditionally been distributed in hard copy, i.e., in book form, with mandated 5-year revisions requiring a new book or new change pages for every updated edition. Distributing Federal telecommunications standards on the World Wide Web (Web) or on CD ROM in electronic form presents possibilities for speeding and enhancing user access to specific subsections of the document, providing wider distribution to the intended audience, and promoting conservation of paper resources at the same time. Federal Standard 1037C on the Web and on CD ROM represents successful applications of HTML. In several ways, a large telecommunications glossary was ideally suited for presentation in hypertext format. The most significant advantage to the hypertext format is the rapidity with which users can jump from definition to definition without having to turn a precise (and often large) number of pages to arrive at the next desired definition. Yet, the very great size of the *Glossary* introduced one of the biggest hurdles in its hypertext development. The ITS editors of the *Glossary* surmounted that hurdle by using Perl scripts to generate automatically the many thousands of required hyperlinks in the large glossary. This paper describes those automated techniques. In addition, the paper addresses special considerations (of equipment, software, and image display) for presenting a user-friendly HTML product.

In the months since the electronic version of Federal Standard 1037C first became available, more than 450 copies of the CD ROM version have been distributed and the Web version has been accessed more than 75,000 times. This shows that there is a wide and ready audience for electronic access to the *Glossary*, and, very likely, other Federal standards.

W. Kissick, D. Sutherland, M. Weibel, W. McCoy, M. Ruhl, R. Toense, U. Borkar, and M. Hariharan, "National security and emergency preparedness communications experiments using the advanced communications technology satellite," NTIA Report 98-354, Aug. 1998.

Many government telecommunications needs, especially those that support National Security and Emergency Preparedness (NS/EP) missions, are becoming increasingly dependent on commercially available equipment and services. This is consistent with the goals and concepts of the National Information Infrastructure. This report examines the use of an advanced satellite — in this case, NASA's Advanced Communications Technology Satellite (ACTS) — with ISDN and frame relay protocols to support NS/EP communications requirements. A network using three ACTS Earth stations was established as a research facility. With this small network, several experiments were performed. Using new objective methods, voice quality was measured over the satellite and compared to other connections such as commercial, terrestrial lines. The performance of applications —

desktop conferencing, file transfer, and LAN bridging — that are likely to be useful in NS/EP situations, was determined. The performance of TCP/IP running over frame relay was examined. The results indicate that advanced satellites can be very useful for emergency communications due to the rapidity that Earth stations can be deployed, the ease of reconfiguring the satellite, and the practicality of using commonly available applications running over commonly used protocols. However, there are some limitations to the performance of some applications or parts of applications due to the propagation delay of a satellite channel. Telecommunications protocols such as TCP/IP must be significantly modified to perform well over a satellite channel and to take full advantage of bandwidth-on-demand capabilities of an advanced satellite.

F.H. Sanders, G.R. Hand, and V.S. Lawrence, "Land mobile radio channel usage measurements at the 1996 Summer Olympic Games," NTIA Report 98-357, Sep. 1998.

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the ITS radio spectrum measurement system and portable measurement systems to collect data for spectrum utilization assessments. This report details an NTIA project to measure and analyze land mobile radio channel usage statistics in the metropolitan area of Atlanta, Georgia, before, during, and after the 1996 Summer Olympic Games.

D.A. Sutherland, Jr., "Software implementation of a wideband HF channel transfer function," NTIA Report 98-348, Apr. 1998.

This report presents an analytic model implemented as the computer program of the transfer function of a wideband HF channel model for use in a hardware simulator. The transfer function is the basic input to the hardware simulator. The mathematical basis of the program and the propagation model is presented. Parameters that characterize the skywave paths of a particular HF ionospheric condition are inputs to the program. The program code is listed and documentation is provided. Graphical verification using spectrally averaged scattering functions indicates that the transfer function program performs well and should find use as both an engineering tool and as the basis for a new standard propagation model.

M. Terada, "Analysis of spectrum utilization and message length statistics for the railroad land mobile radio service," NTIA Report 98-345, Nov. 1997.

In support of the Federal Railroad Administration of the United States Department of Transportation, the Institute for Telecommunication Sciences (ITS) has completed a field spectrum utilization survey designed to examine individual channel utilization and message length distributions. The measurement system was developed by ITS staff members to measure signal strength in each of the 91 channels used by the railroad industry in the frequency band from 160.215-161.565 MHz. The measurement system surveyed three different sites selected for varying conditions such as the different types of traffic over the channels, propagation environments, line-of-sight conditions, and electromagnetic interference.

J.M. Vanderau, R.J. Matheson, and E.J. Haakinson, "A technological rationale to use higher wireless frequencies," NTIA Report 98-349, Apr. 1998.

Trends within the wireless and mobile communications industry are examined and extrapolated into the near future. The paper examines the relationships between propagation loss and antenna gain at higher frequencies, shows how dense intelligent infrastructure affects cell size and system capacity, and describes the improving high frequency capabilities of rf electronics technology. The authors conclude that frequencies above 3 GHz may be uniquely suited to many wireless applications, but that non-traditional system architectures and technologies will need to be used.

S.D. Voran, "Objective estimation of perceived speech quality using measuring normalizing blocks," NTIA Report 98-347, Apr. 1998.

Perceived speech quality is most directly measured by subjective listening tests. These tests are often slow and expensive, and numerous attempts have been made to supplement them with objective estimators of perceived speech quality. These attempts have found limited success, primarily in analog and higher-rate, error-free digital environments where speech waveforms are preserved or nearly preserved. How to objectively measure the perceived quality of highly compressed digital speech, possibly with bit errors or frame erasures, has remained an open question. We describe a new approach to this problem, using a simple but effective perceptual transformation, and a hierarchy of measuring normalizing blocks to compare perceptually transformed speech signals. The resulting estimates of perceived speech quality were correlated with the results of nine subjective listening tests. Together, these tests include 219 4-kHz bandwidth speech encoders/decoders, transmission systems, and reference conditions, with bit rates ranging from 2.4-64 kb/s. When compared with six other estimators, significant improvements were seen in many cases, particularly at lower bit rates, and when bit errors or frame erasures were present. These hierarchical structures of measuring normalizing blocks, or other structures of measuring normalizing blocks, may also address open issues in perceived audio quality estimation, layered speech or audio coding, automatic speech or speaker recognition, audio signal enhancement, and other areas.

J.A. Wepman (ed.), "Personal communications services technology field trials," NTIA Report 98-356, Sep. 1998.

Technology field trials for six personal communications services (PCS) common air-interface technologies (whose standards were developed by the Joint Technical Committee on Wireless Access) were performed at the US West Boulder Industry Test Bed (BITB). The BITB provided a common environment for the field testing of all of the technologies. The same configuration (cell site layout, antenna type, and antenna orientation) was used for all of the systems tested as high-tier systems. Similarly, another configuration was used for all systems tested as low-tier systems. Field testing of the technologies typically consisted of four general types: area coverage testing, handoff testing, interference testing, and voice quality testing. Results from these field trials, and descriptions of the measurement and data analysis procedures, are presented in this report.

Outside Publications

R.J. Achatz and R. Dalke, "VHF space-to-earth radio link performance in various man-made noise environments," in *Proc. IEEE 1998 Radio and Wireless Conference*, Colorado Springs, CO, Aug. 1998, pp. 257-260.

The performance of a differentially-coherent binary-phase-shift-keyed radio link operating at a frequency of 137 MHz in various man-made noise environments was determined by Monte-Carlo simulation. The man-made noise was generated by a model built from noise measurement data. The results show that the performance can be severely degraded in links that operate in residential and business environments or near power lines. Further measurements and analysis is needed to determine the extent of this degradation.

R.J. Achatz, R.A. Dalke, and Y. Lo, "Power amplifier model for optimizing battery current, interference, and link margin," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 434-438.

The power amplifier consumes a large fraction of the total battery current used by a portable transceiver. The power amplifier's bias and input power can be adjusted to decrease battery current demands. These adjustments may introduce nonlinearities in the power amplifier gain that will increase out-of-channel power and decrease the link margin when variable envelope digital modulations are used. In this paper we describe a portable transceiver power amplifier model, derived from measurements, that allows engineers to optimize battery current, out-of-channel interference, and link margin. The models and approach presented in this paper are useful for assessing the electromagnetic compatibility of portable transceivers and receivers operating in adjacent bands.

D. Bodson, E.M. Gray, and W.J. Ingram, "Federal Standard 1037C now available three ways," *NS/EP Telecom News*, Issue 1, pp. 21-24, 1998.

No abstract used.

G.W. Cermak, S. Wolf, E.P. Tweedy, M.H. Pinson, and A.A. Webster, "Validating objective measures of MPEG video quality," *SMPTE Journal*, vol. 107, no. 4, pp. 226-235, Apr. 1998.

In 1996, the American National Standards Institute (ANSI) adopted ANSI T1.801.03, which presents a number of new objective video quality metrics for quantifying the effects of digital compression and transmission impairments. The measurements in ANSI T1.801.03 were selected based on an extensive multilaboratory quality assessment study that included video systems from bit rates of 64 kbits/sec to 45 Mbits/sec and video test scenes that spanned a wide range of spatial and temporal coding difficulties. The set of objective video quality measurements effectively accounted for subjective judgments by human viewers. While 25 video systems were tested, this multilaboratory study did not include MPEG video systems and did not cover any bit rates between 1.6 and 10 Mbits/sec. This paper presents the results from two MPEG studies designed to fill in the bit-rate gap in the previous multilaboratory study.

R.A. Dalke, "EMC analysis of C-band radar interference for dedicated short-range communications systems," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 46-50.

Dedicated short-range communication systems have been proposed for operation at locations across the United States in the 5850- to 5925-MHz band. Various search and tracking high-power radars operate at or near this frequency band and are a source of potential interference. The performance of such digital communication systems is dependent upon compatible operation and coexistence with these radars. In this paper we derive analytical expressions that can be used to estimate the performance of dedicated short-range communication systems that are subject to pulsed RF interference.

R. Dalke, R. Achatz, and Y. Lo, "Statistics of man-made noise at 137 MHz," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998, pp. 427-431.

Statistical noise models that simulate man-made noise are essential for the design of radio systems. Recently, the Institute for Telecommunication Sciences measured man-made VHF radio noise in the 136 to 138 MHz meteorological satellite band. These measurements were made as part of a link analysis for the broadcast of digital satellite weather images at 137 MHz. The measured noise statistics were used to develop analytical representations of the first-order probability distributions for man-made noise in various environments (business, residential, and rural). Such noise models are useful for simulating the performance of communications systems in environments where non-Gaussian man-made noise may degrade system performance. The statistical models as well as first-order probability distributions for several environments are presented in this paper.

S.M. Davidson, "Standardized and comparable measurements using LabVIEW ," in *Proc. NIWeek98 Conf.*, Austin, TX, Aug. 1998.

In most measurement systems there is a need to have standardized and comparable measurements. This is especially important for any system that must deal with safety issues and measurements at varied locations. This paper describes the design and development of a measurement system that automatically records and recalls parameters required for a complex measurement through the use of LabVIEW control defaults, log files, and a custom file system. This process provides a high degree of confidence that measurements taken by different users at different locations are standardized and immediately comparable.

E. Gray, W. Ingram, and D. Bodson, "The ABCs of writing a technical glossary," *Technical Communication*, pp. 23-32, First Quarter 1998.

This paper identifies and explains format rules, style rules, and lexicographic conventions that have been shown to improve the clarity and precision in a technical glossary. Rationale for the rules of language, presentation, and style are examined.

This paper also describes the computer-display techniques and file-management system used in committee to develop Federal Standard 1037C, *Glossary of Telecommunications Terms,* and to display the results both in the meeting room and on the Internet between meetings. In addition, this paper describes the interactive mode of developing the glossary in committee; this mode allowed the participants to address actively, thousands of proposed definitions, revisions, and drawings, and to display the results of their deliberations on computer monitors in meetings and on the World Wide Web.

C.L. Holloway, M. Jonansson, and M.S. Sarto, "An effective layer model for analyzing fiber composites," in *Proc. EMC '98 ROMA: International Symposium on Electromagnetic Compatibility*, Rome, Italy, Sep. 1998.

In this paper, we present expressions for the effective material properties of fiber composites that are commonly used in aircraft and EMC/EMI shielding materials. These expressions can be used to calculate efficiently the reflection and transmission coefficients and the shielding effectiveness of these fiber composites. We compare results of the reflection coefficient obtained from these effective properties to results obtained from a finite-element (FE) solution of the actual periodic fiber composite. This comparison indicates that the model presented here is accurate for representing the properties of fiber composites.

C.L. Holloway and E.F. Kuester, "Net and partial inductance of a microstrip ground plane," *IEEE Trans. on Electromagnetic Compatibility*, vol. 40, no. 1, pp. 33-46, Feb. 1998.

A knowledge of the net inductance of the ground plane can aid in the analysis and investigation of printed circuit board emissions. In this paper, we present a method, based on the concept of partial inductance, to determine the net inductance of the ground plane associated with a microstrip line. This method is based on a previously derived expression for the current density on the ground plane. We show calculations for the net, self-partial, and mutual-partial inductance of the ground plane for various trace geometries of practical interest. We also illustrate various trace geometries of practical interest. We also illustrate how the classical transmission line inductance of a microstrip line can be obtained from the concept of partial inductance. Comparisons to different experimental results are also given.

R.T. Johnk, A. R. Ondrejka, and C.L. Holloway, "Time-domain free-space measurements of carbon-doped urethane slabs with FDTD simulations and system verification," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, pp. 290-295, Aug. 1998.

This paper describes the extraction of electrical material properties of lossy, carbon-doped urethane slabs using a free-space time-domain reflectivity measurement system developed by the National Institute of Standards and Technology (NIST). In order to validate the measurement results, the measurement system was simulated using finite-difference time-domain (FDTD) techniques. Reflectivity measurement results and theoretical predictions as a function of carbon-doping, frequency, and angle of incidence are presented. Complex permittivity results are also presented for two urethane slabs with different carbon-doping levels.

C. Jones and D.J. Atkinson, "Development of opinion-based audiovisual quality models for desktop video-teleconferencing," in *Proc. Sixth International Workshop on Quality of Service (IWQoS '98)*, Napa Valley, CA, May 1998.

This paper discusses the analysis of an audiovisual desktop video-teleconferencing subjective experiment conducted at the Institute for Telecommunication Sciences. Objective models of the individual audio and video quality are presented. Also discussed is an objective model of the audiovisual quality based upon the results of the individual objective audio and video quality models. Finally, a subjective model of audiovisual quality based upon users' ratings of the audio and video quality is discussed.

P.B. Papazian, K.C. Allen, and M.G. Cotton, "A test bed for the evaluation of adaptive antennas used for mobile communications," in *Proc. IEEE 1998 Aerospace Conference, Snowmass at Aspen*, CO, Mar. 1998.

This paper describes an advanced antenna test bed which will be used for mobile communications research. The test bed provides a common environment for testing advanced antennas and measurement data gathered in a realistic environment for evaluation of advanced antenna algorithms. The test bed was previously used to field test the five current personal communications services (PCS) technology standards in the United States. The test bed cells are described and a typical PCS field trial measurement is presented. A wideband measurement system developed for advanced antenna measurements is described. The system uses multiple mobile transmitters using maximal length pseudo random noise generators to modulate a radio frequency (RF) carrier. This provides a wideband signal for characterization of the radio channel. Central to the measurement methodology is the capability to characterize radio wave propagation simultaneously on each antenna element of an antenna array. A multichannel receiver employs IF digitization and raw data storage to maximize post-processing capabilities. Its features allow a random sampling of the radio channel suitable for mobile communications research. The receiver also has the capability to continuously stream data that is suitable for modeling and simulation studies of specific communication systems.

P.L. Perini and C.L. Holloway, "Angle and space diversity comparisons in different mobile radio environments," *IEEE Trans. on Antennas and Propagation* (special issue), vol. 46, no. 6, pp. 764-775, Jun. 1998.

The angle diversity performances of two types of high-gain multibeam antennas — 24 vertically polarized 15° beams, and 12 vertically polarized 30° beams — were tested and compared to the space-diversity performances of traditional sector antenna configurations. The antennas were tested at 850 MHz in dense urban and rural cellular mobile radio environments. A vehicle equipped with a mobile transmitter was driven in the coverage area, while the received signal strength (RSS) was recorded on multiple receiver channels attached to multibeam and sector antennas at the base site. The RSS data recorded included fast (Rayleigh) fading and was averaged into local means based on the mobile's position/speed. The fast fading was extracted from the recorded RSS, and the fading distributions of the two multibeam antennas tested were studied in two distinctly different mobile environments. Fading cumulative distributions for the angular diverse antennas were compared to those of spatially diverse antennas. Diversity gain was calculated and compared to traditional space diversity in these mobile environments. Results in urban environments indicated that angular diversity performance was comparable to space diversity (~-8 dB improvement). Rural tests typically suggested that both space diversity and angular diversity provided little or no (<2 dB) fading reduction. A description of the experiment, data reduction and analyses, and calculation of diversity gain are presented. The motivation for this experiment is the application of fixed multiple beam antennas (FMBA) in cellular radio and digital personal communication systems.

E.A. Quincy, "Ship compartment channel effects on wireless FM speech performance," in *Proc. IEEE 10th International Conference on Wireless Comm.*, vol. 2, Jul. 1998, pp. 483-502.

In this research we modeled and simulated an existing UHF analog wireless trunked FM radio system operating in steel ship compartments and predicted speech quality performance. A fading Ricean channel with equal power in the dominant path and multipath and a 10 Hz Doppler fading rate was used in the simulations. Band-limited noise resulted in speech quality that ranged from barely intelligible with a carrier-to-noise ratio (CNR) of 0 dB to slightly noisy at a CNR of 40 dB. These results can be calibrated with the existing FM system field performance and used as a benchmark for comparing and predicting improvements by simulation of the proposed digital PCS modems.

E.A. Quincy, R.A. Stafford, C.L. Holloway, M.G. Cotton, and A.S. Ali, "Wavelet compression distortion measures for SAR images in ATR," in *Proc. Sixth ATR Conference*, vol I, Oct. 1997, p. 15.

This research investigates and develops distortion measures for assessment of wavelet compression effects on synthetic aperture radar images. The end objective is to select those measures that relate most directly to aided/automatic target recognition (ATR) performance. Windowed measures were developed that relate to ATR feature size. These were the most sensitive to distortion, and they provide an effective method for assessing tradeoff between compression and distortion. We compare mean-square-error (MSE), maximum MSE, peak signal-to-noise ratio, entropy, edge energy and functions of these in our paper.

P. Raush, J. Kub, B. Bedford, T. Sparkman, S. Davidson, and E. Gray, "The radio frequency interference monitoring system (RFIMS)," in *Proc. IEEE 1998 International Symposium on Electromagnetic Compatibility*, Denver, CO, Aug. 1998.

The mobile Radio Frequency and Interference Monitoring System (RFIMS), developed for the Federal Aviation Administration (FAA), is designed to monitor radio frequency emissions from 100 kHz to 18 GHz, using both custom-designed and commercial off-the-shelf hardware and software, combining to form a computer-controlled integrated electronics package. The system allows a variety of spectrum-monitoring methods which are used to characterize the RF emissions of various FAA and commercial transmitters. These include radars, navigational aids, HF communication systems, and commercial broadcast systems. This paper describes the RFIMS design objectives and discusses the power of RFIMS as a spectrum monitoring tool and as an interference-resolution mechanism.

C. Redding and D. Weddle, "Value assessment of automatic link maintenance in modern HF data networks," in *Proc. Nordic HF Conf.*, Fårö, Sweden, Aug. 1998.

Applications of high frequency (HF) radio communications are increasingly evolving toward digital data applications such as automatic transfer of facsimile, e-mail, and computer files, as well as message traffic and other HF data. This more sophisticated use of the medium is a shift away from the use of voice as the primary means of HF communications. The change is consistent with new HF technology made possible by continued improvements in computer technology at affordable costs. The new technologies include automatic link establishment, forward error correcting HF modems, digital signal processing, and other computer-based improvements such as automatic repeat request protocols that produce higher data rates and lower error rates. The Institute for Telecommunication Sciences, under the sponsorship of the National Communications System, initiated an effort to assess advanced HF technology that could provide the basis for the next generation of adaptive HF standards. One such adaptive HF radio system was employed on an HF link between the United States (US) and Australia. This paper reports preliminary results of the trials conducted over this link, focusing on the automatic link maintenance characteristic. It further relates these and other findings to the emerging third-generation adaptive HF standard, which is being developed in the US for data-intensive HF networks.

N.B. Seitz and K.C. Glossbrenner, "Performance standards for the GII, " *IEEE Communications Magazine*, pp. 116-121, Aug. 1998.

This article summarizes the traditional process for developing international telecommunication performance standards and describes enhancements that will be needed to adapt the process for use in the emerging global information infrastructure (GII). The necessary enhancements are being developed under the auspices of ITU-T Study Group 13.

T.G. Sparkman, "Characterizing U.S. airport emitters using the radio frequency interference monitoring system and LabVIEW®," in *Proc. NIWeek98 Conf.*, Austin, TX, Aug. 1998.

As a part of the Federal Aviation Administration's (FAA's) ongoing radio frequency (RF) monitoring in and around airports, the radio frequency interference monitoring system (RFIMS) analyzes the power output of aeronautical emitters nationwide. The RFIMS spectrum signature module verifies the emitters' operative parameters as an indication of emitter health. The LabVIEW® software which controls the RFIMS instruments via GPIB makes RFIMS both a unique and very powerful tool for frequency spectrum management.

S.D. Voran, "Perception-based bit-allocation algorithms for audio coding," in *Proc. IEEE ASSP 1997 Workshop on Applications of Signal Processing to Audio and Acoustics*, New Paltz, NY, Oct. 1997.

We describe six algorithms for bit allocation in audio coding. Each algorithm stems from the minimization of a different perceptually-motivated objective function. Three of these objective functions are extensions of existing ones, and three are new. Closed-form bit-allocation equations result in five cases, and an iterative approach is required in the sixth.

S.D. Voran, "A simplified version of the ITU algorithm for objective measurement of speech codec quality," in *Proc. IEEE 1998 International Conference on Acoustics, Speech, and Signal Processing*, Seattle, WA, May 1998.

ITU-T Recommendation P.861 describes an objective speech quality assessment algorithm for speech codecs. This algorithm transforms codec input and output speech signals into a perceptual domain, compares them, and generates a noise disturbance value, which can be used to estimate perceived speech quality. The performance of this algorithm can be judged by the correlation between those estimates and actual listener opinions from formal subjective listening tests. We show that significant simplifications can be made to the P.861 algorithm with very minimal effect on its performance. Specifically, for the portions of the algorithm under study here, 64% of the floating point operations can be eliminated with only a 3.5% decrease in average correlation to listener opinions. The resulting simplified algorithm may offer a practical new objective function to drive parameter selections, excitation searches, and bit-allocations in speech and audio coders.

S.D. Voran, "Observations on frequency-domain companding for audio coding," in *Proc. Eighth IEEE DSP Workshop*, Bryce Canyon National Park, UT, Aug. 1998.

Frequency-domain companding can be used in conjunction with audio coders that produce white coding noise. Previous work has demonstrated empirically that this technique colors white coding noise so that it is better masked by audio signals, resulting in higher perceived audio quality. This paper offers additional theoretical background and empirical results on this companding technique. A simplifying assumption of previous work is analyzed, the effect of the companding exponent α on the spectral flatness measure is investigated, and optimal values of α are identified for PCM and ADPCM speech coding.

S. Wolf, M.H. Pinson, A.A. Webster, G.W. Cermak, and E.P. Tweedy, "Objective and subjective measures of MPEG video quality," in *Proc. 139th SMPTE Technical Conference*, New York, NY, Nov. 1997.

In 1996, the American National Standards Institute (ANSI) adopted ANSI T1.801.03, which presents a number of new objective video quality metrics for quantifying the effects of digital compression and transmission impairments. The measurements in ANSI T1.801.03 were selected based on an extensive multilaboratory quality assessment study that included video systems from bit rates of 64 kbits/sec to 45 Mbits/sec and video test scenes that spanned a wide range of spatial and temporal coding difficulties. The set of objective video quality measurements effectively accounted for subjective judgments by human viewers. While 25 video systems were tested, this multilaboratory study did not include MPEG video systems and did not cover any bit rates between 1.6 and 10 Mbits/sec. This paper presents the results from two MPEG studies designed to fill in the bit-rate gap in the previous multilaboratory study. In these studies, we concentrated on bit rates from 1.5 - 8.3 Mbit/sec and examined the performance of MPEG 1 and MPEG 2 codecs (coder-decoders) specifically. The effectiveness of the ANSI standard objective video quality metrics was examined for these bit rates and coding technologies. Our analysis revealed that the objective video quality metrics primarily measure four principal components of video quality: added edges, lost edges, added motion, and lost motion; we found that parameters selected from these principal components can be used as effective predictors of subjective quality ratings for entertainment video systems.

Publications Cited*

American National Standards Institute (ANSI), ANSI T1.801.03-1996, "American National Standard for Telecommunications — Digital Transport of One-Way Video Signals — Parameters for Objective Performance Assessment," New York, NY, 1996.

American National Standards Institute (ANSI), ANSI T1.518-1998, "Telecommunications — Objective Measurement of Telephone Band Speech Quality Using Measuring Normalizing Blocks (MNBs)," New York, NY, 1998.

C. J. Behm, "A narrowband HF channel simulator with delay spread," in *Proc. HF Radio Systems and Techniques Conference*, IEEE Conference Publication Number 441, Jul. 7-10, 1997, pp. 388-391.

R.O. DeBolt et al., "A technical report to the Secretary of Transportation on a national approach to augmented GPS services," NTIA Special Publication 94-30, Dec. 1994.

J.G. Ferranto, "Interference simulation for personal communications services testing, evaluation, and modeling," NTIA Report 97-338, Jul. 1997.

J.J. Lemon and C.J. Behm, "Wideband HF noise/interference modeling — Part I: First order statistics," NTIA Report 91-277, May 1991. "Part II: Higher-order statistics," NTIA Report 93-293, Jan. 1993.

J.F. Mastrangelo, J.J. Lemon, L.E. Vogler, J.A. Hoffmeyer, L.E. Pratt, and C.J. Behm, "A new wide-band high frequency channel simulation system," *IEEE Transactions on Communications*, vol.. 45, no. 1, pp. 26-34, 1997.

National Communications System, Federal Standard 1037C, "Glossary of Telecommunication Terms," Arlington, VA, 1996.

National Communications System, Federal Standard 1045A, "Telecommunications: HF Radio Automatic Link Establishment," Arlington, VA, Oct. 18, 1993.

P. Papazian, G.A. Hufford, R. Achatz, and R. Hoffman, "Study of the local multipoint distribution service radio channel," *IEEE Transactions on Broadcasting*, vol. 43, no. 2, Jun. 1997.

P. Papazian and G.A. Hufford, "Time variability and depolarization of the LMDS radio channel," in *Proc. 1997 Wireless Communications Conference*, Boulder, CO, Aug. 1997.

F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at San Diego, California," NTIA Report 97-334, Dec. 1996.

A.D. Spaulding, "Digital system performance software utilizing noise measurement data," NTIA Report 82-95, Feb. 1982.

A.D. Spaulding, "The natural and man-made noise environment in personal communications services bands," NTIA Report 96-330, May 1996.

Telecommunications Industry Association, TIA/EIA Telecommunications Systems Bulletin TSB-84, "Licensed PCS to PCS Interference," Dec. 1997.

Telecommunications Industry Association, TIA/EIA Telecommunications Systems Bulletin TSB-88, "Wireless Communications Systems — Performance in Noise and Interference-Limited Situations — Recommended Methods for Technology — Independent Modeling, Simulation and Verification," Jan. 1998.

L.E. Vogler and J.A. Hoffmeyer, "A model for wide-band HF propagation channels," *Radio Science*, vol. 28, no. 6, pp. 1131-1142, 1993.

L.E. Vogler and J.A. Hoffmeyer, "A new approach to HF channel modeling and simulation - Part I: Deterministic model." NTIA Report 88-240, Dec. 1988. "Part II: Stochastic model." NTIA Report 90-255, Feb. 1990. "Part III: Transfer function." NTIA Report 92-284, Mar. 1992.

C.C. Watterson, J.R. Juroshek, and W.D. Bensema, "Experimental confirmation of an HF channel model," *IEEE Transactions on Communication Technology*, COM-18, pp. 792-803, 1970.

*Publications cited in the report that are not Fiscal Year 1998 reports.

Abbreviations/Acronyms

AAMA	American Automobile Manufacturers Association
ACTS	Advanced Communications Technology Satellite
ADPCM	adaptive differential pulse-code modulation
ALE	automatic link establishment
ALERT	Advanced Law Enforcement Response Technology
AM	amplitude modulation
AMPS	advanced mobile phone system
ANSI	American National Standards Institute
APCO	Association of Public Safety Communications Officials
APD	amplitude probability distribution
ATB	antenna testbed
ATCRBS	air traffic control radar beacon system
ATIS	Advanced Traveler Information System
ATM	asynchronous transfer mode
ATR	automatic target recognition
AWIPS	Advanced Weather Interactive Processing System
BAWT	broadband arbitrary waveform transmitter
BBNG	broadband noise generator
BER	bit error ratio
B-ISDN	broadband integrated services digital network
BITB	Boulder Industry Test Bed
BONeS	block oriented network simulation
BPSK	binary phase-shift keying
BW	bandwidth
C2CEN	Command and Control Engineering Center (U.S. Coast Guard)
CAI	common air interface
CD	compact disk
CDMA	code division multiple access
CD-ROM	compact disk read-only memory
CNR	carrier-to-noise ratio
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	compact radio spectrum measurement system
CSUD	call setup delay
DAQ	delivered audio quality
DBS	direct broadcast satellite
DCBPSK	differentially-coherent binary phase-shift keying
DGPS	differential global positioning system
DOC	Department of Commerce
DOD	Department of Defense
DOS	disk operating system
DOT	Department of Transportation
DQPSK	differential quadrature phase-shift keying
DSCP	digital sampling channel probe
DSP	digital signal processing
DSRC	dedicated short-range communication
DTV	digital television

EMC	electromagnetic compatibility
EMI	electromagnetic interference
ES	Earth station
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDDI	fiber distributed data interface
FDTD	finite-difference time domain
FED-STD	Federal Standard
FHWA	Federal Highway Administration
FM	frequency modulation
FMBA	fixed multiple beam antenna
FQPSK	Feher quadrature phase-shift keying
FRA	Federal Railroad Administration
FTP	file transfer protocol
FTS	Federal Telecommunications System
FTSC	Federal Telecommunications Standards Committee
FTTA	Federal Technology Transfer Act
GEO	geostationary earth orbit
GHz	gigahertz
GII	Global Information Infrastructure
GIS	geographic information systems
GMSK	Gaussian minimum-shift keying
GPS	global positioning system
GSM	Global System for Mobile
GWEN	Ground Wave Emergency Network
HF	high frequency
HP	Hewlett-Packard
HTML	hypertext markup language
HTTP	hypertext transfer protocol
IAB	International Academy of Broadcasting
IEEE	Institute of Electrical and Electronics Engineers
IEP	integrated electronic package
IETF	Internet Engineering Task Force
IM	intermodulation
IP	Internet protocol
IPDP	indoor power delay profile
IRAC	Interdepartment Radio Advisory Committee
ISDN	integrated services digital network
ISI	intersymbol interference
ITAC	International Telecommunications Advisory Committee
ITS	Institute for Telecommunication Sciences
	Intelligent Transportation System
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITU-R	International Telecommunication Union-Radiocommunication Sector
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
JTC	Joint Technical Committee on Wireless Access
JTIDS	Joint Tactical Information Distribution System
JEM	Jammer Effectiveness Model
kHz	kilohertz
LAN	local area network
LEC	local exchange carrier
LEO	low earth orbit
LL	lower layer

LMDS	local multipoint distribution service
LMR	land mobile radio
LOS	line-of-sight
MCM	multicarrier modulation
MCS	measurement control system
MEO	medium earth orbit
MHz	megahertz
MNB	measuring normalizing block
MP	measurement point
MPEG	Motion Picture Experts Group
MSE	mean-square error
MSK	minimum-shift keying
NARRN	North American Railroad Radio Network
NASA	National Aeronautics and Space Administration
NAVSTAR	Navigation Satellite Timing and Ranging
NBHF	narrowband HF
NBWF	necessary bandwidth formulas
NCS	National Communications System
nDGPS	nationwide differential global positioning system
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NSA	National Security Agency
NS/EP	National Security and Emergency Preparedness
NTIA	National Telecommunications and Information Administration
OFDM	orthogonal frequency-division multiplexing
OLES	Office of Law Enforcement Standards
OPNET	optimized network engineering tools
OSM	Office of Spectrum Management
OSTM	Office of Systems and Telecommunications Management
OT	Office of Telecommunications
P25	Project 25
PBX	private branch exchange
PC	personal computer
PCM	pulse-code modulation
PCS	personal communications services
PDH	plesiochronous digital hierarchy
PN	pseudo-random
PPS	precise positioning service
PRF	pulse-repetition frequency
QoS	quality of service
RDBMS	relational database management system
RF	radio frequency
RFIMS	radio frequency interference monitoring system
RISC	Reduced Instruction Set Computer
RSMS	radio spectrum measurement system
RSS	received signal strength
RTCM	Radio Technical Commission for Maritime Services
RTP	real time protocol
SDH	synchronous digital hierarchy
SEAD	Spectrum Engineering and Analysis Division
SINAD	signal to interference noise and distortion
SNR	signal-to-noise ratio

SONET	synchronous optical network
SPS	standard positioning service
SRC	source
SSB	single sideband
S-T	spatial-temporal
S-VHS	super VHS (Video Home System)
TA Services	Telecommunications Analysis Services
TCP	transmission control protocol
TIA	Telecommunications Industry Association
TSB	Technical Service Bulletin
TVQMS	transportable video quality measurement system
UDP	user datagram protocol
USCG	U.S. Coast Guard
US WEST	US West Advanced Technologies, Inc.
UWB	ultra wideband
UWBR	ultra-wideband radar
VHF	very high frequency
VoIP	Voice-over-Internet Protocol
VQEG	Video Quality Experts Group
VTC	video-teleconferencing
VTS	Vessel Traffic Service
WLL	wireless local loop
WWW	worldwide web
xDSL	various digital subscriber line
XIWT	Cross-Industry Working Team

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA