Institute for Telecommunication Sciences

1996 Technical Progress Report

U.S. Department of Commerce
Mickey Kantor, Secretary
Larry Irving, Assistant Secretary for
Communications and Information

Certain commercial equipment and software products 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 or software identified is necessarily the best available for the purpose.

Contents

A cellular telephone antenna near Boulder, Colorado (photograph by D.J. Atkinson).

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.

Aerial view of the Boulder Laboratories, home of ITS (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 1996 fiscal year consisted of $4.3 million of direct funding from the Department of Commerce and approximately $6.3 million for work sponsored by other Federal Government agencies and U.S. industry.

History

ITS began in the 1940's 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. More recently, 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.

- Telecommunications Standards Development: The Institute contributes to and develops Federal, national, and international telecommunications standards.

- Telecommunication Systems Planning: The Institute analyzes the needs of users, and present and future telecommunication technologies to assist in the development of organizational plans for the effective use of telecommunications.

- Telecommunication Systems 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.

- 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 local Governments to support international and national competitiveness, hasten the advent of new technology to users, and expand the capabilities of national and local 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 Oceanic and Atmospheric Administration.

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 is not duplicated throughout many Federal agencies and industry. 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 significant technical contributions made by ITS during Fiscal Year 1996 that have significance for both the public and private sector.

This point-to-point microwave link has been vacated; the spectrum it used to occupy may become available for new technologies and services. The Institute provides spectrum engineering support to Government and industry in rapidly evolving telecommunications fields (photograph by F.H. Sanders).

Spectrum Planning and Assessment

NTIA is responsible for managing the Federal Government's use of the radio spectrum. Part of this responsibility is to establish policies concerning spectrum assignment, allocation, and use. ITS supports these requirements by performing spectrum measurements and studies. These measurements and studies are directed toward the goals of assessing current and future spectrum use; identifying existing and potential electromagnetic compatibility (EMC) problems among telecommunication systems belonging to Government and private-sector organizations; providing recommendations for resolving EMC conflicts that may exist in the radio spectrum; and recommending changes in spectrum use to promote spectrum efficiency and improve spectrum management procedures. The Institute's spectrum analyses are directed toward ensuring that increasingly crowded radio spectrum is used with maximum efficiency, allowing current users to accomplish their missions while finding ways to accommodate new users, services, and technologies.

ITS also provides technical support and guidance for NTIA in the development and advocacy of the United States' position at international spectrum allocation conferences. Decisions made in these international bodies significantly affect spectrum allocations and use both in the United States and worldwide. Major impacts occur in such areas as U.S. export markets and interoperability of global communication systems.

ITS uses its technical expertise to develop new software and hardware for support of Federal Government spectrum management. Many of these products are useful to the private sector, and are available to the private sector on a reimbursable basis.

Areas of Emphasis:

ITU-R Activities

The Institute helps to develop international standards on radio spectrum operations and specific radio systems through participation and chairmanships in the working groups of the International Telecommunication Union-Radiocommunication Sector. Projects are funded by NTIA.

Domestic Spectrum Analysis

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

Radio Spectrum Surveys

The Institute performs usage measurements across a wide range of radio frequencies and geographic locations. This information is used to determine trends in spectrum crowding and to identify spectrum that might be used to provide new services. Projects are funded by the Department of Defense (DOD), DOT, and NTIA.

Spectral Assessment of Government Systems

The Institute performs emission measurements on radio systems as required to verify proper operation, identify and mitigate interference, and develop techniques for improving system electromagnetic compatibility characteristics. Projects are funded by DOD and NTIA.

Radio Frequency Interference Monitoring System

The Institute provides expertise in spectrum measurement systems to other Government agencies by designing and developing spectrum measurement capabilities. Projects are funded by the Federal Aviation Administration.

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), formerly the International Consultative Radio Committee (CCIR), 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 2-4 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).

Study Groups of the ITU-R

Study Group	Area of Concentration
1	Spectrum management
3	Radio wave 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.

ITS is an active participant in both international and national committee work. One ITS staff member holds the office of international chairman of a working party and several ITS staff participate in the committee meetings of the international study groups. Two ITS staff members are U.S. study group chairmen and other ITS staff members participate in U.S. study groups' activities. One ITS staff member is an international rapporteur on short-path radio wave propagation issues relating to the service needs of systems such as personal communications services and wireless local area networks.

The following illustrates how ITS, other Federal agencies, and private industry contribute in the area of radio propagation, which is the specialty of Study Group 3. To properly model the total effect of the atmosphere on an RF propagation link, rain and atmospheric absorption must be considered. In particular, water vapor plays a significant role in the atmosphere's absorption characteristics. For this reason, it is essential that global statistics of water vapor are maintained for individuals who lack the benefit of locally measured distributions. ITU-R recommendation P.835 notes that the distribution of water vapor in the atmosphere may be approximated by

$$\Delta(h)=\Delta_0 \bullet \exp(-h/h_0)$$

where Δ is the water vapor, h is an arbitrary height above the surface in km, and h_0 is a scale height of 2 km. This relationship may be integrated from h=0 to *h6 4* to find an empirical relationship between path and surface conditions represented by

$$P=2\Delta_0$$

where P is the total precipitable water along the vertical path in mm. The results indicate that, given total precipitable water, surface water vapor may be derived by dividing by a factor of 2. In order to validate this assumption, data from several sites with 5-10 years of twice daily radiosonde measurements were collected. The data extracted from the radiosondes included total precipitable water and surface water vapor density. Within the United States, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and two commercial companies (Science and Technology Corporation and Stanford Telecom), have collected and analyzed water vapor data to produce scatter plots such as those shown in Figures 1 and 2. The data validate the empirical relationship and provide new material that may be used by the ITU for worldwide propagation prediction methods. ITS aids in the development of input documents, which provide the data from measurement and analysis campaigns such as this, to modify or prepare new ITU-R recommendations.

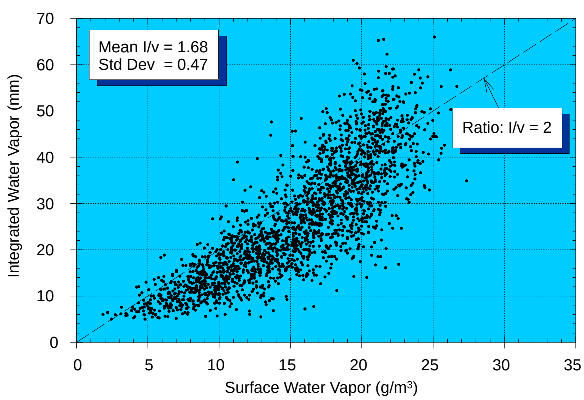


Figure1. Scatter plot of water vapor data from Kennedy Space Center, Florida.

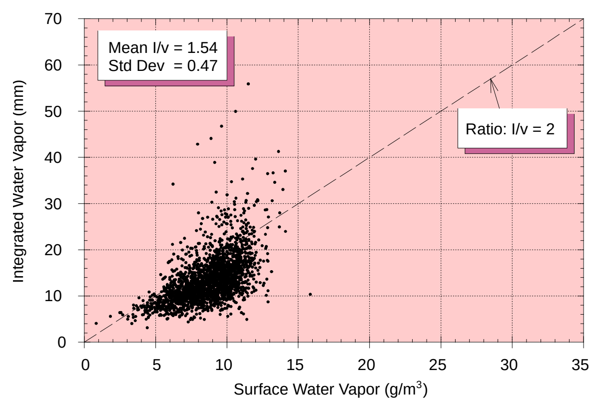


Figure 2. Scatter plot of water vapor data from Oakland, California.

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

Domestic Spectrum Analysis

Outputs

- Participation in the Federal Law Enforcement Wireless Users Group and the Public Safety Wireless Advisory Committee.
- Assistance to the Federal Communications Commission in technical studies of high-definition television.
- Investigation of alternative mobile radio architectures.

The year 1996 may be the year of big decisions for Government mobile radio systems. ITS has actively supported a technical basis for making the best possible decisions in areas being considered by several national committees. The Federal Law Enforcement Wireless Users Group (FLEWUG) is a committee of Federal representatives concerned with designing a joint Department of Justice/Department of Treasury nationwide law enforcement radio network. Presumably, many other Federal agencies would want to use this system, possibly as a replacement for their present single-agency systems. The Public Safety Wireless Advisory Committee (PSWAC) is a committee that is planning to ask the Federal Communications Commission (FCC), at the request of Congress, for a block of radio frequencies in which to build the next generation of state and local public safety radio systems.

Both of these committees are describing next-generation radio networks involving billions of dollars of public funding. PSWAC, for example, is currently asking for radio spectrum worth as much as $30 billion. An analysis of the PSWAC request suggests that it is based on the use of traditional long-range radio architectures to meet high-density traffic requirements in large urban areas. However, most modern radio systems designed to serve dense urban areas (e.g., cellular phone and personal communications services; PCS) have used short-range architectures, which require much less radio spectrum.

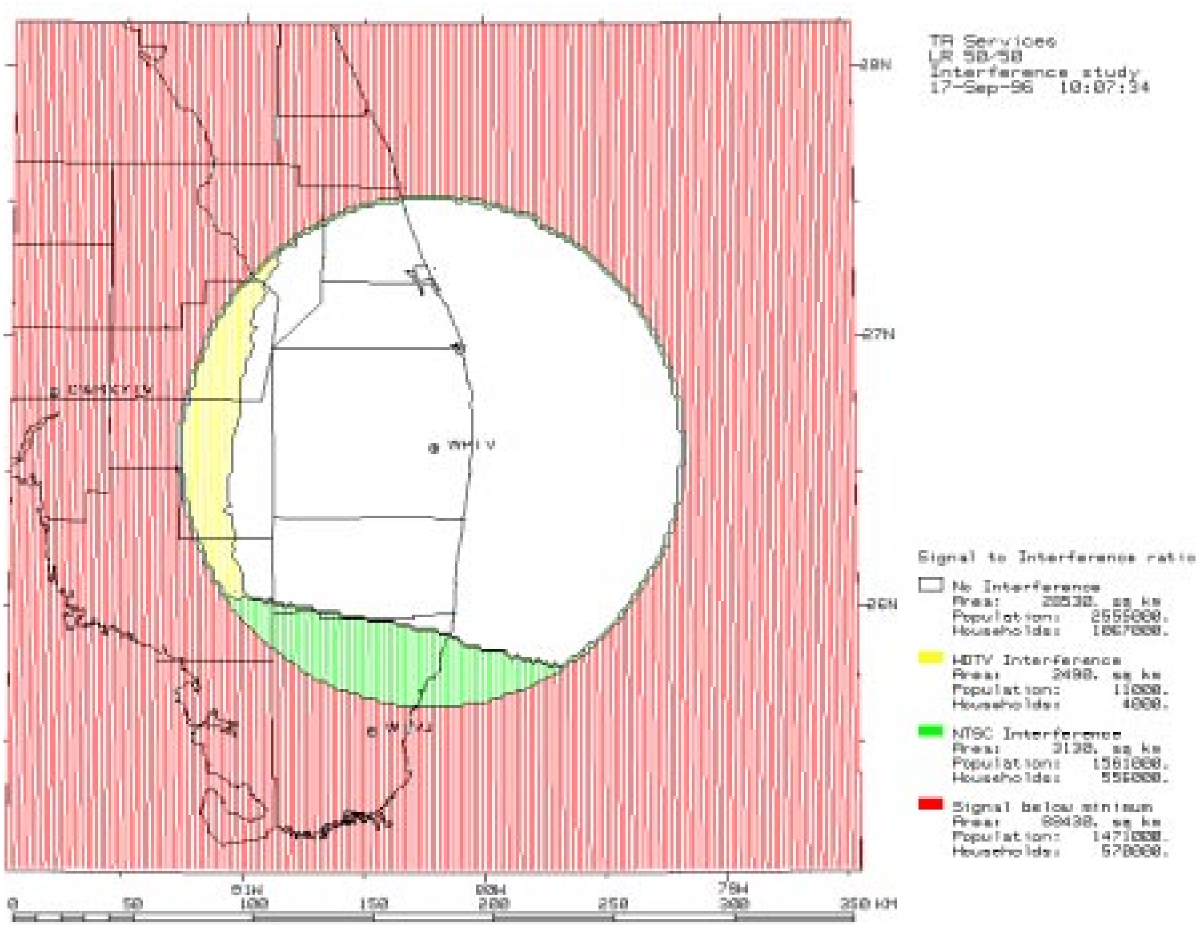
ITS has been working actively with PSWAC; the Institute specifically has suggested more modern approaches to radio communications using less spectrum and providing service at less cost. ITS has been examining whether public safety communications needs could be met by existing spectrum-efficient systems that have proved immensely usable in all other areas of national activity. The use of short-range systems in urban areas possibly could reduce spectrum needs to 10% of the present estimate, as well as providing other significant benefits.

The FLEWUG's challenge is to provide greatly improved services at a lower cost by sharing a common system with many different agencies. In addition to providing a single system with greater capacity and coverage, a shared system might provide greatly improved interagency communications during natural disasters and other emergencies. However, a shared network would provide substantial administrative, technical, and operational challenges for the user agencies. ITS is examining the problems and advantages of such shared networks, so that such networks can be recommended for national systems, if appropriate.

In conjunction with the FCC, ITS is studying how best to provide a high-definition television (HDTV) channel for each existing NTSC television station. ITS will use improved interference modeling programs to verify FCC calculations of coverage and interference. These calculations may have great importance for future decisions on advanced television broadcasting, since television broadcasters believe HDTV coverage must be at least as good as their existing NTSC coverage.

The Figure shows an example of calculations of coverage for station WPTV in southern Florida and a proposed HDTV channel. Two almost coincident circles show that the areas of adequate signal strength are almost identical (and that the terrain is almost flat). In this example, there are two colored areas inside the circular coverage areas of the NTSC and HDTV stations. The green area shows where the existing NTSC station is not adequately received because of a co-channel-interfering signal from existing station WTVJ in Miami, Florida. The yellow area shows where the proposed HDTV station would receive interference from a proposed station (DWRKY-TV) further west. Although these two interference-limited areas have about the same area (2,460 vs. 3100 km^2), they have much different populations (9,000 vs. 1,527,000 people), since the green area includes heavily populated Miami suburbs. Hence, in this example, the proposed HDTV station would benefit from an increase, compared to the existing NTSC station, of more than 1.5 million potential interference-free viewers.

The example shows computations for a single station. Massive studies involving the set of all existing television stations are required, as well as optimizing strategies, to provide answers about how many television channels are needed to provide all existing broadcasters with matching HDTV channels.



Example of HDTV coverage analysis.

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

Radio Spectrum Surveys

Outputs

- Channel-by-channel usage statistics and maximum, minimum and average spectrum occupancy levels in mobile radio bands before, during, and after the 1996 Summer Olympic Games.
- Results of San Diego, California broadband spectrum occupancy survey measurements.
- Environmental radio noise measurements in the HF spectrum.

As part of the ongoing NTIA mission to manage Federal spectrum and assess current and future trends in spectrum use, ITS routinely performs broadband spectrum occupancy measurements at selected locations. The results of these measurements are provided to the Office of Spectrum Management (OSM) in the Department of Commerce, to spectrum management offices in other Federal agencies, and sometimes as publicly available NTIA Reports. Spectrum surveys can be performed for sponsors in other Federal agencies and private industry on a reimbursable basis. Spectrum survey measurements help identify crowded spectrum and spectrum that can be used for new technologies and services. In 1996, ITS used both the radio spectrum measurement system (RSMS) and several compact radio spectrum measurement systems (CRSMS's) to perform spectrum surveys for OSM and the U.S. Army.

The largest 1996 spectrum survey was performed in Atlanta, Georgia, before, during, and after the 1996 Summer Olympic Games. Figure 1 shows the view of Atlanta from an ITS measurement location. The purpose of this survey was to determine the impact of a major spectrum-loading event on levels of channel use in land mobile radio (LMR) bands. LMR bands between 138 and 940 MHz were measured. The ultimate goal was to determine the maximum

Figure 1. View of downtown Atlanta from a CRSMS measurement site. Located on a high-rise rooftop, this monitoring system was one of three that measured spectrum occupancy and usage during the 1996 Summer Olympic Games (photograph by F.H. Sanders).

crowding that would be expected to occur in LMR bands in an emergency situation. The Olympic Games involved an unprecedented level of use of radio communication systems, and thus provided an excellent opportunity to measure such emergency LMR use levels.

RSMS and two CRSMS units were deployed at three sites in the Atlanta area. These systems ran continuously in a fully automated mode from one week before the Olympics until two weeks after the Games ended. Measured channel usage statistics indicated the percentage of time that each LMR channel was occupied at each measurement location.

Occupancy data (maximum, minimum, and average received spectral power levels) were acquired simultaneously in the LMR bands. An example data graph is shown in Figure 2.

Spectrum survey results are often made available to the public as NTIA Reports. In 1996, data from the 1995 spectrum survey in San Diego, California were released as such a report (see Recent Publications, below). An NTIA Report on the Atlanta, Georgia usage measurements will be published in FY 97. A spectrum survey also was performed for the U.S. Army in 1996. Noise was measured in HF bands at selected locations using CRSMS units.

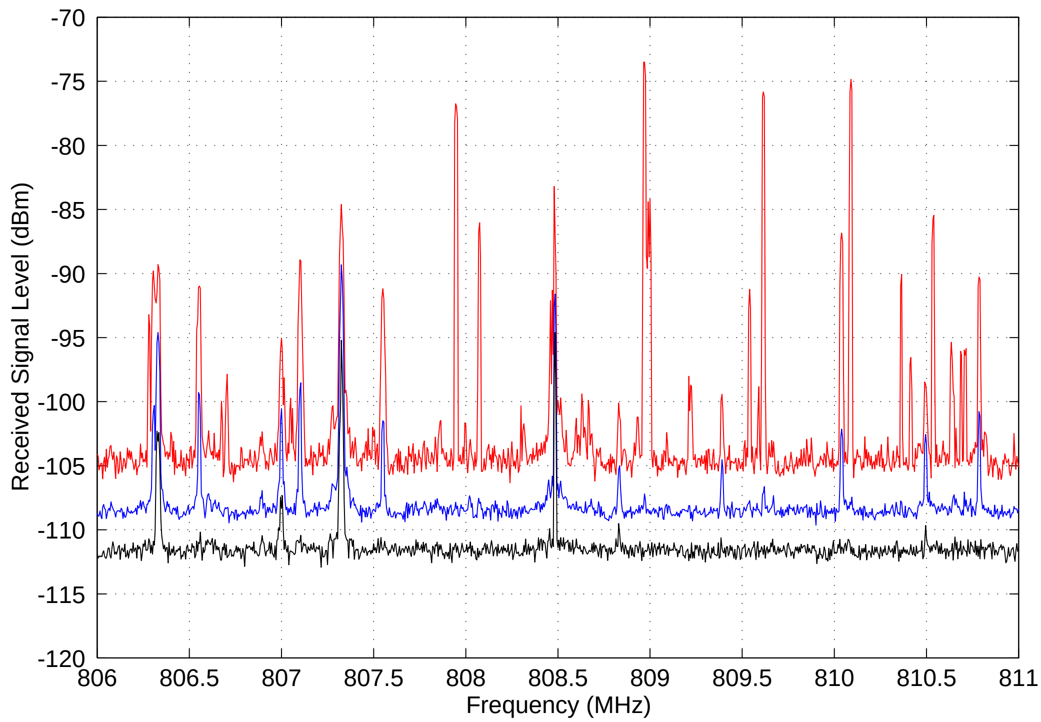


Figure 2. Land mobile spectrum occupancy data from one of the Atlanta 1996 Olympic Games measurement sites. Maximum, minimum, and average received power levels are shown for the period of the Games. Channel-by-channel usage statistics were measured simultaneously with these occupancy data.

Recent Publications

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

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

Spectral Assessment of Government Systems

Outputs

- Resolution of an ongoing interference conflict between radars and earth stations on the Pacific Coast.
- Measurements and tests to determine the electromagnetic compatibility between existing maritime radios and new radios that use channels half as wide.
- Electromagnetic compatibility measurements for another agency to determine the possibility of locating new satellite facilities at a location with previously installed facilities.

As more users and services attempt to use existing spectrum, accurate measurements of emissions from radio and radar systems have become critical to determining the sources of existing and potential electromagnetic compatibility (EMC) conflicts. EMC conflicts are commonly manifested as interference; part of the Institute's mission is to support NTIA in the elimination of EMC conflicts involving Government systems. To achieve this goal, ITS maintains measurement capabilities that are tailored to analyze and resolve EMC conflicts (Figure 1). In 1996, the Institute worked with the Office of Spectrum Management (OSM), the Department of Defense, and private-sector radio manufacturers to assess emissions from Government systems and eliminate existing and potential EMC conflicts.

Some increase in interference has been due to the introduction of new technologies, such as digital replacement of analog systems. Other conflicts have arisen due to the introduction of susceptible communication systems into spectrum adjacent to high-power, broadband emitters such as radars. Both conflicts were found to be occurring when, in 1996, teams from ITS, OSM, and the Department of Defense engaged in a joint effort to determine the

Figure 1. Electromagnetic compatibility measurements in progress on board a boat in Tampa Bay. The measurements determined interference characteristics of new maritime radios that operate with channels only half as wide as currently available radios (photograph by F.H. Sanders).

nature of frequent interference from radars to satellite earth stations on the U.S. West Coast (Figure 2). The interference sources were positively identified; tests conducted by the teams also determined that the only technically feasible method for mitigating the interference was to alter the operating procedures for the type of radar involved. New operating procedures have been specified for these radars.

As a follow-up to the West Coast tests, detailed measurements were performed by ITS on this radar type on the East Coast. The measurements, conducted with the assistance and cooperation of the Department of Defense and the radar manufacturer, showed that the radar type met the radar spectrum engineering criteria. This was a significant finding; it meant that EMC conflicts can occur even if all applicable technical standards for emissions have been met.

Attempts to use spectrum more efficiently, such as dividing the channels in mobile bands in half (so as to achieve twice as many channels in the same amount of spectrum) can create new EMC conflicts because the new equipment must be economical to procure, but must also operate within stricter spectrum tolerances than older equipment. In 1996, the Institute performed measurements jointly with OSM on prototype narrowband maritime radios. The test results showed the technical specifications that the narrowband radios will have to meet if EMC conflicts with other marine radios are to be avoided.

The Institute also contracted with a Department of Defense agency for an EMC study to determine the feasibility of deploying a new earth station at an overseas location where another earth station for a different service already exists. Measurements on emissions from an existing station were performed at White Sands, New Mexico; analysis was subsequently performed in Boulder, Colorado. The results showed that the stations could operate together compatibly, if certain conditions for physical separation and antenna gain limits were met.

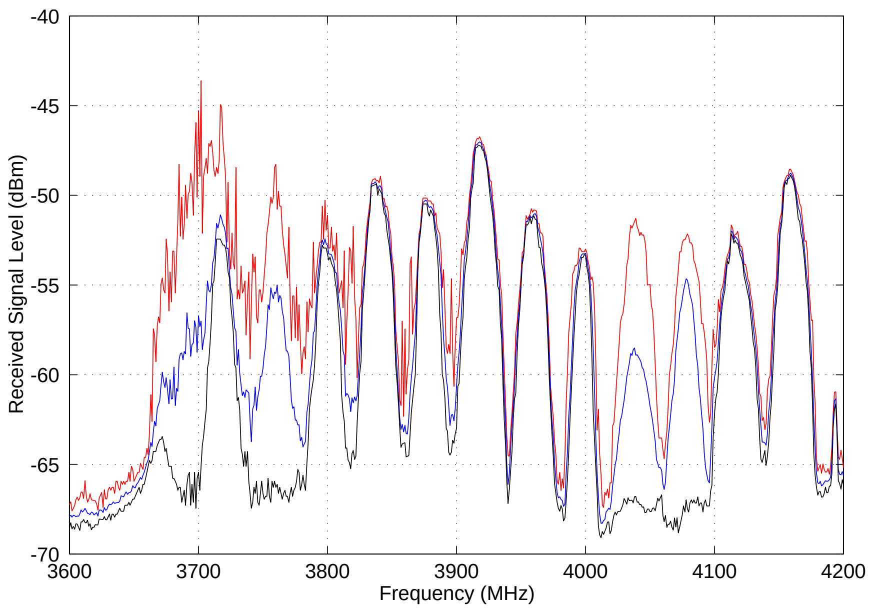


Figure 2. Cumulative graph of data scans recorded at an earth station during an interference event. Curves show maximum (red), minimum (black), and average (blue) signal levels. Desired signals are smooth curves; interference is superimposed on these curves as a rough, maximum-level curve between 3660-3800 MHz.

Recent Publications

F.H. Sanders, R.L. Hinkle, and B.J. Ramsey, 1996, “AEGIS radar emission spectrum characteristics,” NTIA Technical Note 96-1, Aug. 1996.

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

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

Radio Frequency Interference Monitoring System

Outputs

- Hardware and software designs.
- Integrated vehicle design drawings, documentation, and lists.
- Measurement control system integration description, definitions, and flowcharts.
- Integrated electronic package documentation, description, definitions, and detailed drawings.

The ITS radio spectrum measurement system (RSMS) has been used for many years to support spectrum management tasks for the Department of Commerce and other Federal agencies. When the Federal Aviation Administration (FAA) decided to develop a fleet of mobile radio frequency measurement systems, named the Radio Frequency Interference Monitoring System (RFIMS), they selected ITS to design and build the systems.

As part of this three-phase project, the RFIMS program team is (1) analyzing FAA requirements and developing a custom radio spectrum measurement system; (2) designing, building, and testing a prototype mobile system; and (3) integrating and testing production mobile systems. Also as part of this program, ITS will plan and manage associated support requirements, including documentation and training. Software management, development, and documentation play a critical role in all three phases.

Each task includes three areas of system design: the vehicle, the integrated electronic package (IEP), and the measurement control system (MCS). During the first phase, now completed, ITS assessed requirements, evaluated options, and developed an RFIMS specification. ITS personnel analyzed FAA requirements and selected the optimal design features to meet those needs. The vehicle will be a standard van with three 6-ft custom racks in the interior. The mechanical aspects of the vehicle, the electrical generation system, heating and air conditioning, communications equipment, interior arrangement of equipment racks, seating, and equipment storage have been specified.

The IEP is an integrated set of radio measurement and signal test equipment that performs both specialized measurements and general spectrum monitoring. The IEP consists of three subsystems: the measurement antenna package, the tower-top preselector, and the rack-mounted equipment. The antenna package includes several antennas, chosen to cover the frequency range and measurement needs of the FAA. All are mountable on a pan/tilt platform on a telescoping mast. The tower-top preselector enhances the sensitivity, selectivity, and dynamic range of the measurement system. All other electronic equipment in the vehicle will be rack mounted. Figure 1 shows the rack layout of the vehicle. User comfort, frequency of equipment use, accessibility of the equipment front and rear panels, and experience gained from previous ITS vehicles were all considerations in the rack layout design. IEP design deliverables included the basic measurement system hardware, selection of specific equipment, and calibration hardware.

Many of the standard measurements and spectrum-monitoring requirements dictate the need for automated control of components to ensure the standardization of the measurement technique. Others require a measurement algorithm that cannot be implemented without automated control. In both cases, a control system is required for consistent recording of measurement results. ITS is producing the MCS that will control the measurement system and record the measurements. MCS deliverables included the selection of computer hardware and system software, the preliminary design of measurement routines applicable to specific FAA equipment and problem resolution situations, system calibration (that could be modified by FAA personnel), software documentation manuals, and on-line help files. The system will be able to operate in automatic mode (via local computer) or manual mode (via the instrument front panel controls.) Ease of use is a primary software requirement of the FAA. Figure 2 shows the preliminary design of the main window of the RFIMS.

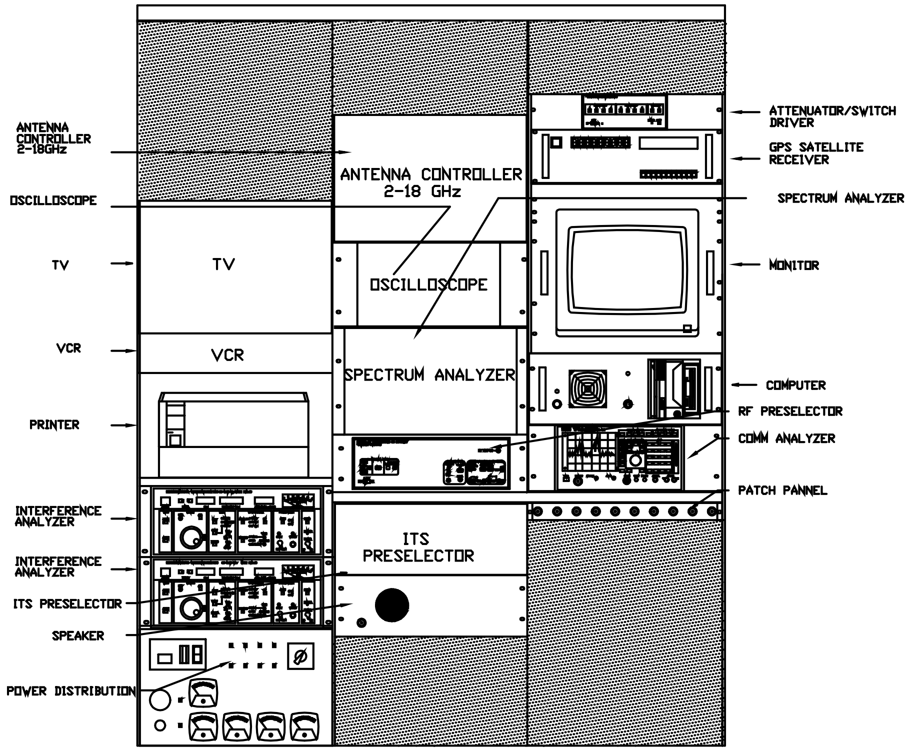


Figure 1. RFIMS rack-mounted equipment layout.

Figure 2. Software main window of the RFIMS.

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

ITS staff member edits a video tape that is part of an ANSI standard (photograph by D.J. Atkinson).

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, 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 fora are blueprints for technology evolution and can influence billions of dollars in telecommunications research and development investments worldwide.

Areas of Emphasis

ITU-T Standardization Activities

The Institute leads U.S. ITU-T committees and work groups, prepares technical contributions to advance ITU-T standards development, and drafts proposed ITU-T recommendations and compatible national standards. Projects are funded by NTIA.

Video Quality Standards Development

The Institute contributes to the development of standards defining perception-based, technology-independent video quality measures. Projects are funded by NTIA and by the National Communications System (NCS).

Audio Quality Standards Development

The Institute contributes to the development of standards that specify technology-independent measures of audio quality as perceived by human listeners. Projects are funded by NTIA and NCS.

Broadband Networks

The Institute contributes to the development and deployment of broadband integrated services digital network/asynchronous transfer mode (B-ISDN/ATM) technologies through network performance measurement studies and standardization activities. Projects are funded by NTIA and NCS.

Telecommunication Terminology Standards

The Institute leads and contributes to the development of telecommunications terminology standards in Federal, national, and international fora. Projects are funded by NCS.

Wireless Standards Support

The Institute contributes to the development of industry standards for personal communications services and wireless local area networks and provides objective testing and evaluation of the associated technologies. Projects are funded by NTIA and U.S. West Advanced Technologies.

Standards for Radiocommunication Systems

The Institute provides leadership and technical support to the FTSC in developing interoperability and performance standards for HF and land mobile radio systems. Projects are funded by NCS.

ITU-T Standardization Activities

Outputs

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

The International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) plays a preeminent role in the cooperative planning of public telecommunications systems and services worldwide. The technical standards (recommendations) developed in the ITU-T have substantial impact on 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 recommendations of particular importance to U.S. Government and industry.

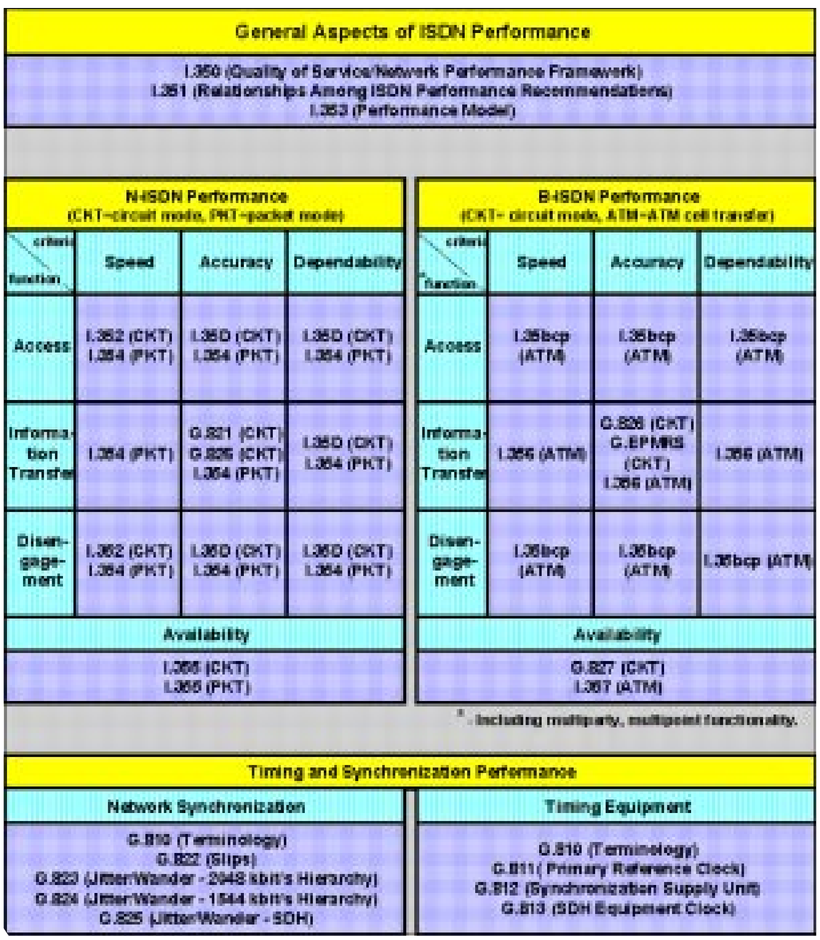
The Institute provides strong support to the U.S. Department of State in leading the U.S. Organization for the ITU-T. Institute personnel serve on the U.S. International Telecommunications Advisory Committee (ITAC), provide technical leadership and administration for U.S. ITU-T Study Group B, and head the U.S. Delegations to international meetings 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 9 (Television and Sound Transmission), 10 (Languages for Telecommunication Applications), 11 (Switching and Signaling), and 13 (General Network Aspects). Study Group 13 develops recommendations for advanced broadband networks using high-speed synchronous digital hierarchy (SDH) and asynchronous transfer mode (ATM) systems, and is leading ITU-T efforts to define the Global Information Infrastructure (GII) envisioned by Government leaders and network planners in many countries.

During FY 96, the Institute assisted the Department of State and other U.S. ITAC members in preparing for the World Telecommunications Standardization Conference (WTSC). The WTSC approves the overall ITU-T work program for each 4-year study period, establishes the ITU-T study groups, assigns technical projects (questions) to each study group, and formally approves proposed changes in ITU-T work methods and relationships. ITS contributions to the WTSC planning process proposed innovative ways of strengthening U.S. industry participation in the ITU-T consistent with national objectives. In other U.S. ITAC work, ITS headed the U.S. Delegation to a May 1996 meeting of ITU-T Study Group 13 at which 8 revised and 13 new recommendations were approved. At this meeting, ITS participated in developing 29 new and revised questions that will guide the Study Group 13 technical program during the 1997-2000 ITU-T Study Period. Several of the proposed new questions deal with cooperative international development of the GII.

The Institute also provides strong leadership in ITU-T and American National Standards Institute (ANSI)-accredited standards committees whose work is relevant to the Department of Commerce goals. During FY 96, Institute representatives (1) provided technical leadership of ITU-T Working Party 4/13, and the ITU-T Rapporteurs Groups for Questions 13 and 22/12; (2) continued technical contributions and assumed new management responsibilities in ANSI-accredited Technical Subcommittee T1A1; and (3) provided organizational and administrative assistance to Technical Subcommittee T1S1. Working Party 4/13 develops performance specifications and measurement methods for narrowband and broadband integrated services digital networks (ISDNs). The Question 13/12 and 22/12 Rapporteurs Groups define subjective and perception-based objective quality of service measures for speech transmission and audio/visual systems. Technical Subcommittee T1A1 develops performance and signal-processing standards for emerging broadband networks and multimedia services. Technical Subcommittee T1S1 develops service, architecture, and signaling standards for North American ISDN applications. An ITS staff member assumed a new leadership role as T1A1 Information Director during FY 96. Initial work resulted in the implementation of electronic document-handling procedures that advanced the development of technical standards in the T1A1 Subcommittee.

During FY 96, the Institute's leadership and technical contributions in ITU-T Study Group 13 significantly assisted the completion of two revised ISDN performance Recommendations: I.356 and I.351. Recommendation I.356 specifies numerical performance objectives and quality of service classes for international ATM connections. The specified values will facilitate ATM network planning and will assist users in selecting ATM network services to meet their broadband communication needs. Recommendation I.351 defines the overall framework for a set of related recommendations that collectively provide a comprehensive basis for the specification and apportionment of performance in narrowband and broadband ISDNs.

The Figure illustrates the overall scope of ITU-T Study Group 13 Working Party 4 performance standardization activities as summarized in Recommendation I.351. Four distinct types of performance recommendations are being developed. *General* recommendations define the performance description framework, principles, and reference models used in other recommendations. *Primary* recommendations define protocol-specific performance parameters, objectives, and measurement methods for narrowband and broadband ISDNs in the context of the ITS-developed 3x3 matrix framework. The matrix identifies three protocol-independent telecommunication functions: access, user information transfer, and disengagement. Each function is considered with respect to three general performance concerns (or "performance criteria"): speed, accuracy, and dependability. Recommendations within a particular cell define one or more "primary parameters" that characterize performance relative to that particular function/criterion pair. *Availability* recommendations distinguish service outages from intervening periods of acceptable performance (by comparing observed primary parameter values with corresponding outage thresholds) and establish limits on the frequency and duration of outage periods. *Timing and synchronization* recommendations specify accuracy and precision objectives for network time and frequency reference sources and distribution systems.



Relationships among ISDN performance recommendations.

During FY 96, Institute staff members also spearheaded technical work on a key domestic B-ISDN performance standard, ANSI T1.511. This revised standard will specify and allocate cell transfer performance objectives for national ATM services. It is being developed as a "delta" document that will reference the performance parameter definitions and objectives specified in ITU-T Recommendation I.356. This approach will maximize compatibility among national and international performance standards—a key objective of ITS participation in ITU-T standardization activities.

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

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 compression and transmission techniques offer an economical means of implementing video communication services in emerging national and global information infrastructures. However, the quality of digital video systems cannot be evaluated using the static test patterns and waveform reproduction measures traditionally used in assessing analog video systems. ITS engineers are addressing this problem through the development and standardization of a fundamentally new methodology for video quality assessment. The ITS-developed methodology employs natural video scenes (rather than artificial test patterns) as input material, and captures the observable effects of a wide range of impairments using *perception-based* video quality parameters. These parameters have been selected for their correlation with the subjective assessments of human viewer panels. The ITS-developed parameters are specified in American National Standards Institute (ANSI) T1.801.03-1996 (“American National Standard for Telecommunications - Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment”), published in February 1996. These parameters can be used to characterize both spatial and temporal distortions in the output video.

Figure 1 illustrates the use of one objective parameter that was developed at ITS and included in ANSI T1.801.03-1996. This parameter measures the perceptual effects of error blocks. Error blocks are a form of distortion in which one or more blocks (groups of pixels) in the output image bear no resemblance to their counterparts in the current or previous scene. Error blocks often are caused by transmission errors in compression systems that use the discrete cosine transform (DCT). DCT-based compression systems are specified, for example, in Motion Picture Expert’s Group (MPEG) standards and in International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) video-conferencing recommendations (e.g., H.261/H.263). The ITS-developed measure calculates temporal gradients for each image pixel by subtracting, pixel by pixel, *frame n-1* (one frame earlier in time) from *frame n*. The right-hand image in Figure 1 shows the absolute magnitude of the temporal gradients for two successive frames; the larger temporal gradients (white areas) are due to the sudden appearance of error blocks. The temporal information (*TI*) feature is computed from the temporal gradient image by summing all the energy, or white areas. *TI* thus quantifies the total motion that is present at each video frame. The sudden appearance of the error blocks produces a relatively large amount of added *TI*. The graph in Figure 1 shows how the appearance and disappearance of an error block causes spikes, or sudden increases, in the *TI* values. The perceptibility of these error blocks is related to the logarithmic ratio of the output to the input *TI* values. Thus, error blocks are more noticeable in low-motion scenes.

During FY 96, ITS engineers demonstrated the effectiveness of temporal and spatial gradients in analyzing the quality of a video data set that included 10 MPEG systems (operating from 1.5-8.3 Mb/sec) and 8 analog broadcast systems with different quality levels. The analysis of this data set was completed as part of a cooperative research and development agreement with a large U.S. video service provider. A panel of viewers was used to subjectively rate the mean opinion score (MOS) of the video on a quality scale from 1 (very annoying impairment) to 5 (imperceptible impairment). Figure 2 shows the results from two different predictive models plotted against the MOS of the viewer panel. Figure 2(a) used ITS-developed objective metrics from temporal and spatial gradients; Figure 2(b) used the traditional peak signal-to-noise ratio (PSNR) metric (obtained by subtracting the output image from the input image and summing the resultant error). The model, based on gradients, explains about 80% of the subjective information, while the model based on PSNR explains only 20% of the subjective information.

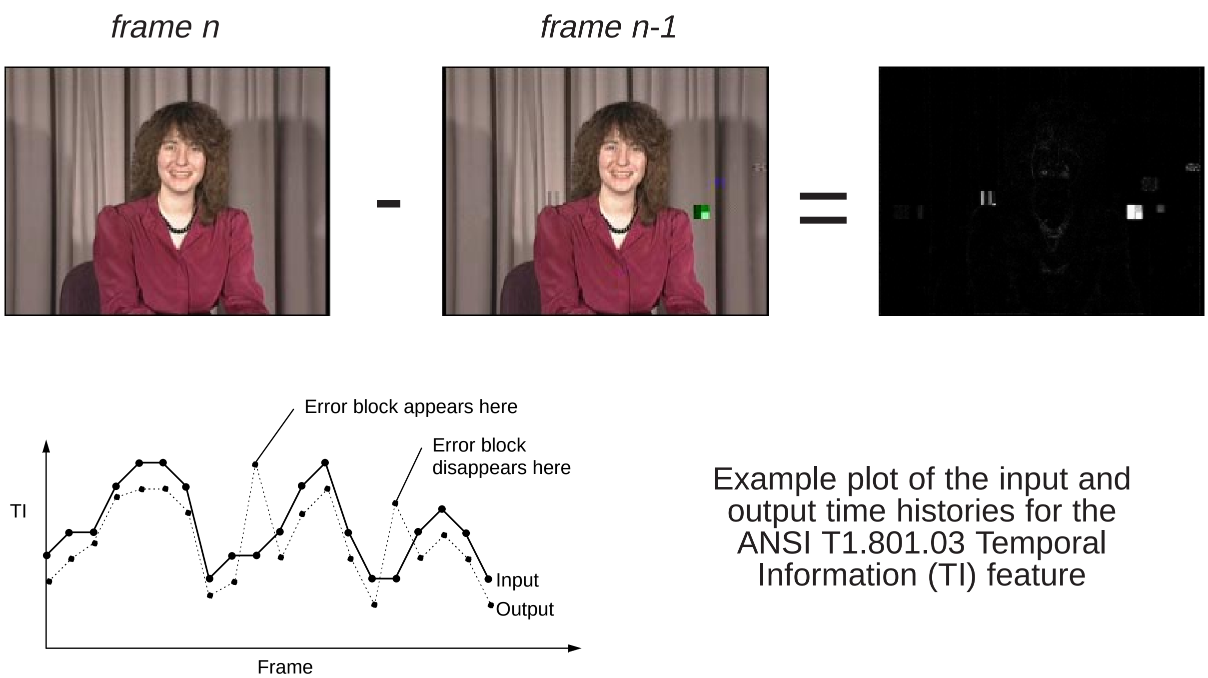


Figure 1. Objectively measuring the perceptual effects of error blocks.

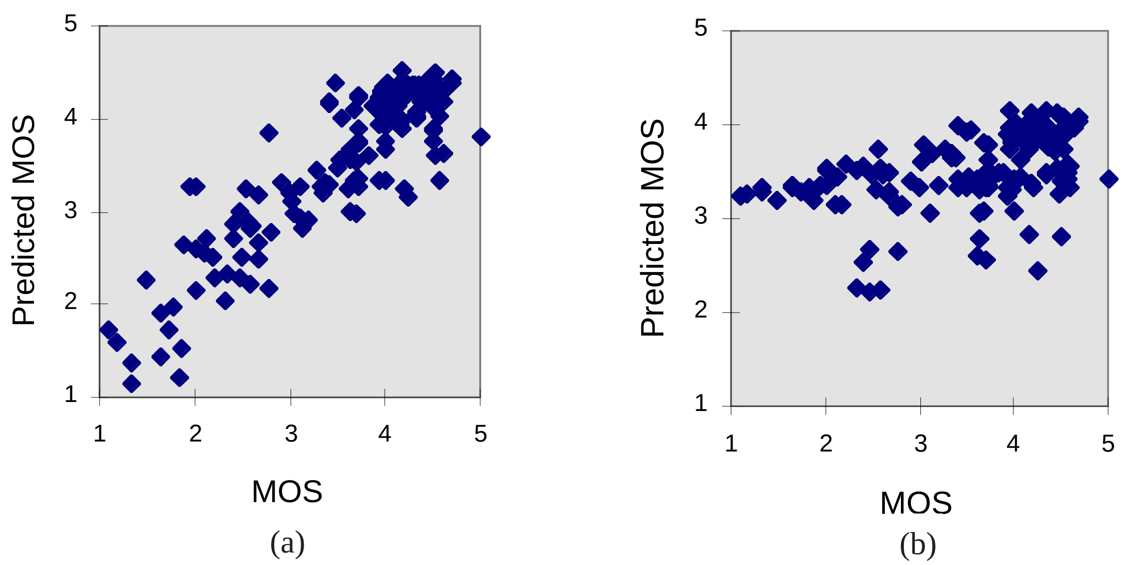


Figure 2. Model predictions for an MPEG data set: (a) = model using spatial and temporal gradients and (b) = model using PSNR.

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

Audio Quality Standards Development

Outputs

- Objective audio quality assessment algorithms.
- Prototype audio quality test instruments.
- Contributions to standards organizations.

With technologies for digital audio encoding, compression, and transmission becoming more and more diverse, there is a growing need for objective audio quality measures that correlate well with human perception. Existing and proposed systems for transmitting audio signals over digital networks now include 4-kHz speech systems, with bit rates ranging from 1.2-64 kbit/s; 7-kHz speech systems, with bit rates from 16-64 kbit/s; and 15- to 20-kHz multichannel audio systems, with bit rates from 64-128 kbit/s per channel.

Many digital systems represent audio signals by encoding their frequency content or other characteristics rather than by simple waveform representation. The encoded bit streams may be carried by radio, wire, or optical fiber transmission systems and may be multiplexed with video and data streams in multimedia communications. Increasingly, digitized audio signals are being transported in asynchronous transfer mode (ATM) cells, which can be subject to variable delay and other impairments not previously observed. The interactions among audio signal content, source coding, channel coding, and channel conditions are complex and system-dependent. Not surprisingly, traditional waveform reproduction measures developed for wired 4-kHz analog telephony often are ineffective in assessing the listener-perceived quality of digital audio systems.

The most fundamental and accurate measures of audio quality are the subjective responses of users. These responses can be obtained formally by conducting subjective listening tests. However, in many situations the time and expense required by these precisely controlled tests are not justified. In its Audio Quality Standards Development program, the Institute addresses these situations by developing practical alternatives to subjective listening tests: digital signal-processing algorithms that objectively estimate perceived audio quality in ways that correlate well with subjective listener judgments. The development of these objective audio quality assessment algorithms parallels subjective testing operations. Objective estimates of perceived audio quality are compared with the corresponding subjective test results to ensure that truly useful algorithms are developed.

During FY 96, ITS staff designed and constructed a subjective testing facility to support this work (Figures 1 and 2). The subjective tests are conducted in an acoustically isolated and treated room that conforms with international recommendations for subjective listening and viewing tests. Before a test begins, the test subject is given a basic hearing screening to ensure that his or her hearing characteristics do not deviate too far from average hearing characteristics. Test participants hear test materials through headphones or loudspeakers and use an electronic pen to record their responses on a small screen. This system allows a participant to proceed through a test at a comfortable pace, and eliminates the need for manual data entry after a test is completed. Workstations equipped with 16-bit digital-to-analog converters control the reproduction of test material and the collection of responses. FY 96 activities included a substantial initial test in the new subjective testing facility: 24 participants each responded to 200 recordings, taken from 50 different audio systems.

The ITS approach to the development of objective audio quality assessment algorithms is *perception based*. The basic premise of the perception-based approach is that by transforming audio signals into an appropriate perceptual domain, only information that is perceptually relevant is retained. By definition, that information is both necessary and sufficient for the accurate assessment of audio quality, independent of the coding, transmission, and decoding applied to the audio signals. In seeking appropriate perceptual transformations, ITS staff members study the modeling of human hearing processes as well as higher-level processes of perception and discrimination. Key elements of the human hearing processes are frequency-dependent sensitivity, limited frequency resolution, limited temporal resolution, and amplitude transfer characteristics. In general, these processes are neither linear nor time-invariant.

Figure 1. ITS staff member using the audio control station for the ITS subjective testing facility (photograph by D.J. Atkinson).

Once audio signals have been transformed into the perceptual domain, they must be compared in a way that mimics human judgement. While much is known about human hearing, relatively little is known about human judgement of sounds. Subjective tests provide the empirical data that allow the development of useful comparison algorithms. ITS staff have developed a novel comparison technique that is based on a sequence of time- and frequency-domain normalizations, conducted over decreasing time and frequency scales.

One important objective of the Institute's Audio Quality program is to advance the development of audio performance standards in the American National Standards Institute (ANSI)-accredited Standards Working Group T1A1.7 (Signal Processing and Network Performance for Voiceband Services). Institute staff members presented technical contributions summarizing recent research findings at T1A1.7 meetings during FY 96. The Institute

Figure 2. Test participant listens to audio recordings and responds using an electronic pen and screen (photograph by D.J. Atkinson).

also contributed to related performance studies in International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) Study Group 12. An Institute staff member serves as Associate Rapporteur on Question 13/12, which addresses methods of modeling and measuring nonlinear distortion processes in voice transmission. Relevant results also were presented in the Federal Telecommunications Standards Committee's Multimedia Telecommunication Performance Measurements Subcommittee, which is led by ITS.

The Institute's results on objective audio quality have been disseminated widely through technical publications and presentations at meetings and workshops involving industry, Government, and academia. During FY 96, staff members demonstrated ITS-developed prototype audio quality test instruments to industry and Government visitors and to attendees at technical standards meetings. The prototype instruments consist of personal computers with 16-bit analog-to-digital and digital-to-analog converters. Custom software implements objective measures of audio quality in real time, enabling researchers to identify more quickly the most practical and useful measures. These prototype instruments have generated significant industry interest and are expected to lead to the development of commercial products that implement the Institute's objective audio quality assessment algorithms.

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

Broadband Networks

Outputs

- B-ISDN/ATM emulation and measurement capabilities and results.
- Multimedia performance measurement capabilities and results.
- Standard performance parameters and measurement methods.

Emerging broadband integrated services digital network (B-ISDN) and asynchronous transfer mode (ATM) technologies offer unprecedented transmission capacity and channel assignment flexibility to network designers. They are expected to play a key role in realization of the “information superhighways” envisioned by industry and Government planners worldwide. However, these technologies have transmission performance characteristics fundamentally different from those observed in traditional isochronous networks, and require complex traffic control and resource management mechanisms that are not yet fully defined. The Institute’s Broadband Networks program contributes to the development and successful deployment of B-ISDN/ATM technologies through network performance measurement studies and associated standardization activities. During FY 96, ITS staff members developed a laboratory infrastructure for multimedia performance experiments, investigated the relationship between physical-layer, ATM-layer, and application-layer performance with B-ISDN/ATM test equipment, and published an NTIA Report summarizing these investigations (see Recent Publications, below).

As multimedia and other National Information Infrastructure (NII) applications evolve, it will become increasingly important for providers and users to understand the relationships among performance values observed at different network protocol layers. During FY 96, ITS personnel used the video and broadband network portions of the laboratory infrastructure illustrated in Figure 1 to investigate the relationships among physical-layer, ATM-layer, and application-layer performance for two types of video

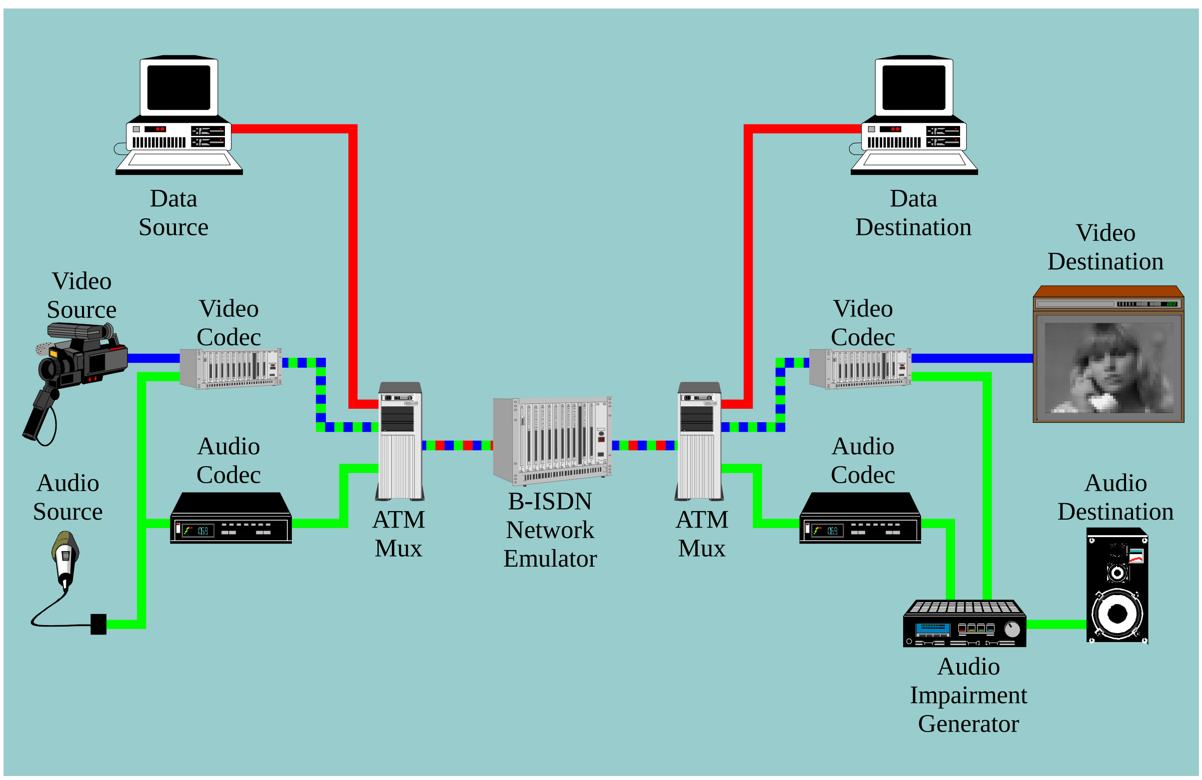


Figure 1. Infrastructure for multimedia performance experiments.

signals: differential pulse code modulated (DPCM) video at 45 Mb/s and International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) Recommendation H.261 video at 384 kb/s and 1.536 Mb/s. Experiment results indicated that small variations (less than 10%) in physical-layer performance can cause much larger variations (greater than an order of magnitude) in the higher-layer performance parameters. These results were influenced by several factors, including the types of physical-layer impairments introduced, the types of error control used, and the performance parameter definitions. The first two factors were varied in the experiments.

The types and distribution of physical-layer errors were varied through modification of the parameters of the physical-layer error model. Viewed in its finite state representation, this model consists of four states: error free, low error, moderate error, and severe error, as illustrated in Figure 2. Changing the specific error levels determined by the states and the frequency of transition between the states provides the control required to implement a variety of error scenarios. For example, in the video experiment, two different types of "severe" impairments were introduced: (1) a very high bit error ratio (10^{-2}), causing a fairly high percentage of errored and lost cells over a 20-ms period; and (2) a loss of signal, causing total data loss over a 1- to 2-ms period. The effects of clustering or dispersing physical-layer errored second events in time also were examined. In one scenario, the errored seconds occurred in isolation at approximately 6-s intervals; in the other, the errored seconds occurred successively, averaging 10 consecutive errored seconds in a 60-s period.

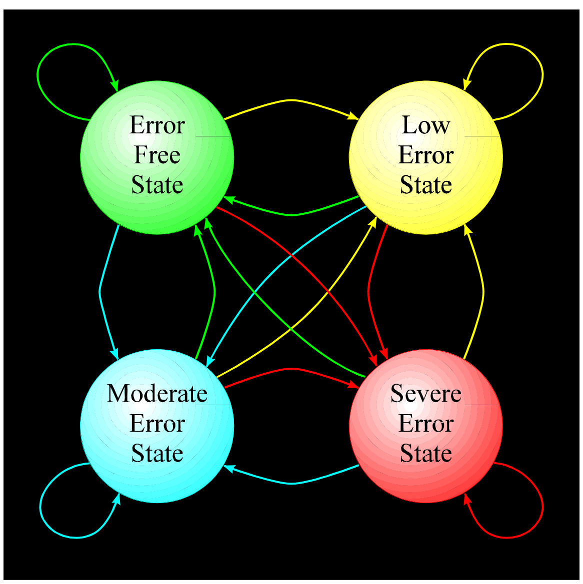


Figure 2. Physical-layer error model used in multi-layer performance comparisons.

Variation in the emulated system's response to errors was achieved through selection of the video algorithms used. The DPCM video-coding equipment had virtually no error correction/detection capabilities, and an error in the bit stream was observed to cause a momentary visible flicker in the displayed video. At higher error ratios, a strobe-like effect, that viewers would subjectively classify as "annoying," was produced. The H.261 video, on the other hand, was fairly robust to error ratios up to 10^{-5}, but could take several seconds to recover when an error did appear. When errors became severe, the H.261 video occasionally "froze" as the coders/decoders lost synchronization; in these extreme cases, recovery took as long as a minute. This variability could be addressed through the development of a "vertically integrated" performance model (e.g., performance parameters that indicate the relationship between user-perceived performance and network transmission artifacts). Experiments to examine the feasibility of this approach are ongoing.

The experiments and results summarized here are described more comprehensively in an NTIA Report published during FY 96. The report also summarizes development of the ITS Broadband Network Emulator and related B-ISDN/ATM infrastructure capabilities.

Recent Publications

D.J. Atkinson, "Exploring B-ISDN performance: selected experiments and results," NTIA Report 96-329, Apr. 1996.

For more information, contact:
D.J. Atkinson
(303) 497-5281
e-mail dj@its.bldrdoc.gov

Telecommunication Terminology Standards

Outputs

- U.S. contributions to ISO/IEC information technology vocabulary standards.
- Camera-ready copies of *American National Standard Dictionary for Information Technology* and *Glossary of Telecommunication Terms* (Federal Standard 1037C).
- CD-ROM and HTML/World Wide Web versions of Federal Standard 1037C.

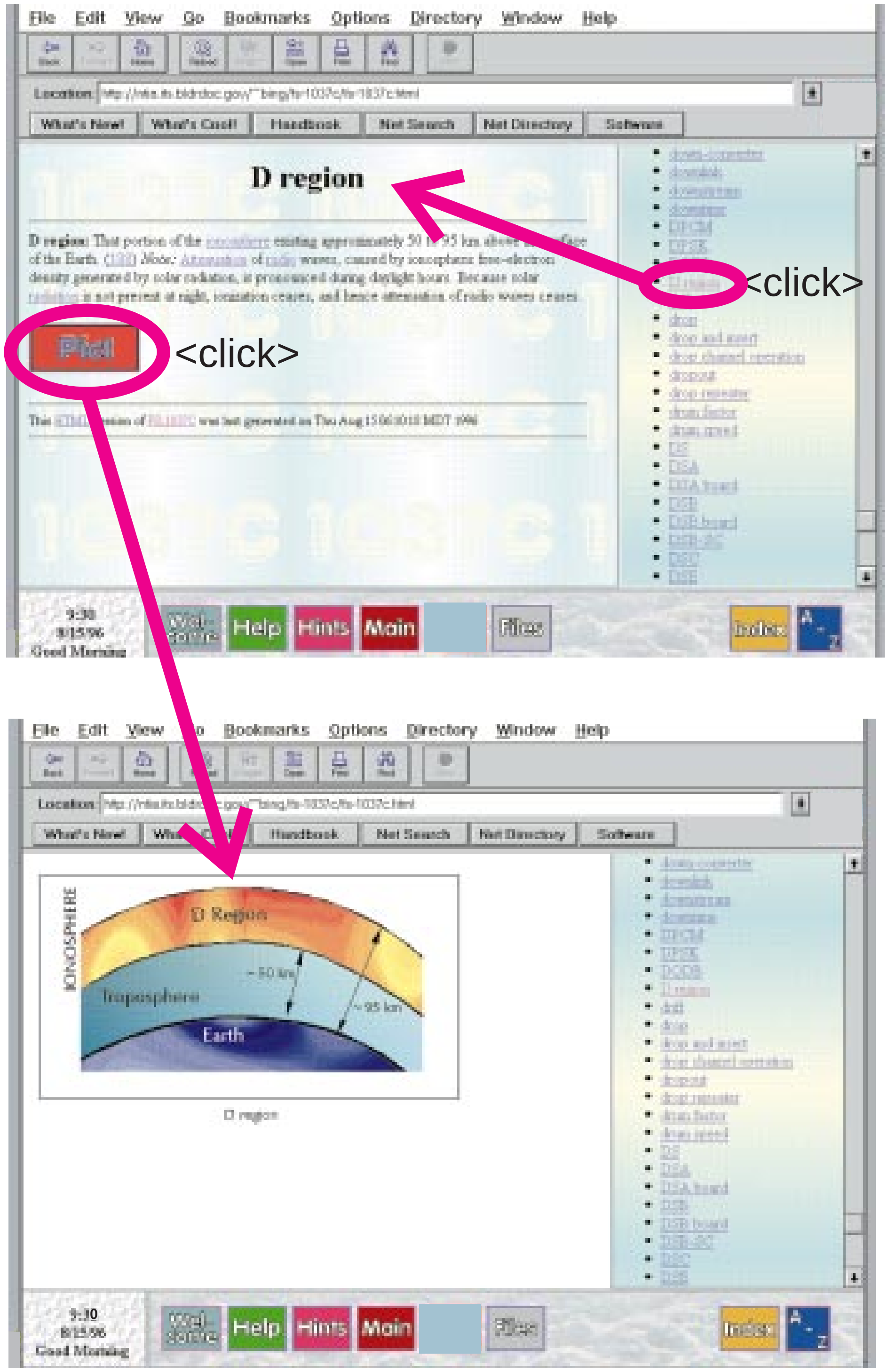
Clear communication of facts and ideas depends upon a common understanding of terminology. Such understanding is particularly important—and particularly difficult to achieve—in the rapidly growing field of telecommunications. Specification and deployment of advanced telecommunication systems depends on consistent interpretation of a specialized vocabulary that is immense, complex, and dynamic. Common understanding of telecommunication terminology also is important in ensuring the marketability of U.S. telecommunication products and services in international trade. Telecommunications and information terminology standards developed under ITS leadership contribute strongly to clarity and precision in telecommunication publications and specifications—and indirectly, to all of the aforementioned goals.

Standardized definitions of telecommunication terms are being developed in Federal, national, and international fora. ITS contributes to vocabulary standards in all three fora under the sponsorship of the National Communications System (NCS). The Institute's work in the Federal forum benefits NCS by standardizing vocabulary in—and thereby promoting advancement of—National Security Emergency Preparedness and the National Information Infrastructure. During FY 96, ITS continued its leadership of the Federal Telecommunications Standards Committee Subcommittee to Revise Federal Standard 1037B. The group completed and delivered the camera-ready copy of Federal Standard 1037C, *Glossary of Telecommunication Terms*, in September 1996. Institute staff members also developed a hypertext version of that 5800-entry glossary. More than 80 illustrations are included—many of which are in color in the hypertext version. One such illustration is shown in the Figure. The hypertext version of the Standard resides at *http://glossary.its.bldrdoc.gov/fs-1037* on the World Wide Web. The hypertext version and a compatible .PDF version are also accessible on a CD-ROM available from the NCS. The CD-ROM includes browsers to allow access to both versions of the document on several popular computer platforms. Users of the hypertext glossary can navigate quickly in a nonsequential mode by clicking on defined terms within definitions, or by clicking on defined terms in the subject index in Appendix B. Making the Standard available in hypertext on the World Wide Web has significantly advanced the cause of a common, standard vocabulary for telecommunications by extending access to the document to a worldwide audience.

In national fora, ITS leads American National Standards Institute (ANSI)-accredited Technical Committee X3K5 in developing the *American National Standard Dictionary for Information Technology* (ANSDIT). An ITS staff member also serves as project editor for this information terminology standard. During FY 96, a camera-ready revision of this document was delivered to ANSI for publication as American National Standard X3.192.

In the international arena, ITS serves as convener of the joint International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Working Group 7, Vocabulary for Data Communications. Working Group 7 met twice during FY 96 to develop vocabulary for databases, e-mail, and network management. An ITS representative also serves as project editor for the English text of several parts of ISO/IEC-2382, *Information Technology—Vocabulary*.

In each committee, ITS works to promote a congruence of definitions so that communication is enhanced for all users of all of the related terminology standards. By actively participating in several such fora, ITS promotes compatibility between Federal Standard 1037C and other vocabulary standards, including ISO/IEC-2382, the ANSDIT, and specialized terminology standards such as the *National Information Systems Security Glossary*. The benefits of common vocabulary in all three are-



Two successive screens visible when navigating through the hypertext version of Federal Standard 1037C, Glossary of Telecommunication Terms.

nas—Federal, national, and international—reach beyond the vocabulary committee and the laboratories to the purchaser's desks, and into the telecommunications marketplace worldwide.

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

Wireless Standards Support

Outputs

- Independent observation of the common air-interface technology field trials of the Joint Technical Committee on Wireless Access.
- Conference paper on wireless local area network smart antenna performance improvement.

Wireless technology is on the verge of creating a revolution in communications. Wireless systems and technologies encompass a wide variety of both existing and emerging systems and technologies. These include land mobile radio, HF radio, broadcast radio and television, and multichannel multipoint distribution service; wireless telephone systems such as cellular and personal communications services (PCS) systems; paging; packet radio; wireless local area networks (WLANs); wireless digital modems; and satellite-based systems. New systems and technologies are being developed for both new types of services, such as PCS, and for traditional services, such as broadcast television and radio. With the plethora of new wireless systems and technologies being developed, the need for standards is becoming increasingly important. Without standards for these systems, interoperability of systems is not possible and there is the risk of the user being faced with an overwhelming number of ad hoc, disjointed systems and services. Because of the importance of wireless standards for the development and deployment of future wireless systems and technologies, the Institute is actively involved in supporting standards in areas such as PCS and WLANs.

In the United States, technical standards for the PCS common air interface were developed in the Joint Technical Committee on Wireless Access (JTC). The JTC is a joint activity between Committee T1 of the American National Standards Institute (ANSI) and the Telecommunications Industry Association (TIA). Within the JTC, draft standards for six air-interface technologies for licensed PCS were developed and forwarded to ANSI (see the Table).The JTC field trials for the six air-interface technologies have been completed. The IS-95-based code-division multiple access (CDMA), the IS-136-based time-division multiple access (TDMA), personal access communication system (PACS), and PCS 1900 technologies are currently full standards. The Omnipoint

PCS Technologies and Associated Parameters

Base Technology	Omnipoint (new)	IS-95	PACS (new)	IS-136	GSM	W-CDMA (new)
Access Method	TDMA/ CDMA	CDMA	TDMA	TDMA	TDMA	CDMA
RF Band-width	5 MHz	1.25 MHz	300 kHz	30 kHz	200 kHz	5 MHz
Bit Rate (no overhead)	32 kbps	Two Rates Available: 8 kbps or 13.3 kbps	32 kbps	7 kbps	13 kbps	32 kbps
System Type	High and Low Tier	High Tier	Low Tier	High Tier	High Tier	High and Low Tier
Error Control (voice)	None	FEC	None	FEC	FEC	FEC
System Capacity Relative to AMPS	16x	10x	0.8x	3x	2-3x	16x

TDMA/CDMA and the wideband CDMA technologies are currently trial use standards. The TIA is in the process of incorporating the PCS IS-95- and IS-136-based technologies into their respective digital cellular standards. The other four technologies are overseen by Committee T1.

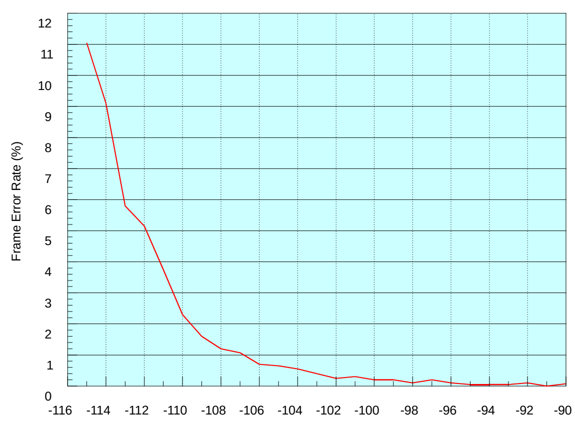
The Institute has supported the PCS standards process by serving as independent observers in all of the JTC PCS technology field trials. In FY 96, to conclude the JTC field testing, the Institute participated as independent observers in both the PACS field trials and the Omnipoint composite TDMA/CDMA field trials. As independent observers, ITS reviewed test procedures, observed the execution of the tests, and directly participated in the data collection, storage, and analysis.

Field testing for all six of the air-interface technologies included measurements of received signal strength, and voice quality and error rate performance as a function of location both with and without interference. Handover testing also was performed. The measurement data were analyzed and the results reported for each technology in a series of six JTC reports. ITS is currently developing a single, concise summary of the field trials that will be published as an NTIA Report. An example of the measurement results, showing frame error rate vs. received signal level for a PCS system during the field trials is given in the Figure.

The demand for WLANs is increasing rapidly as laptop computers and personal digital assistants gain popularity. In addition, WLANs provide a solution to local area network connectivity in applications where cables either cannot be used or are prohibitively expensive. ITS has supported WLAN standards development by its participation in the IEEE 802.11 WLAN standards committee, and its work in radio channel measurements, modeling, and radio system simulation. WLAN devices will operate in the 2.4-GHz industrial, scientific, and medical (ISM) band under the current IEEE 802.11 draft standard. Future WLAN devices will probably move to less congested, higher-frequency bands such as the 5.8-GHz ISM band or the 5-GHz European high performance radio local area network (HIPERLAN) band.

In support of WLAN operation at these higher frequencies, ITS conducted an impulse response measurement study at 5.8 GHz in a warehouse environment. The measurements were made at specific locations throughout the warehouse using an omnidirectional, vertically polarized receive antenna. At each location, 12 impulse response measurements were made using both a horizontally and vertically polarized directional transmit antenna at 6 distinct azimuthal orientations (0, 60, 120, 180, 240, 300 degrees). An additional impulse response measurement was made at each location using an omnidirectional transmit antenna.

Data from these measurements were analyzed to determine WLAN performance improvement using angle-of-arrival discrimination and polarization diversity. The results from this analysis were presented in a paper at the Wireless Communications Conference in Boulder, Colorado in August 1996. These results showed that RMS delay spread (a parameter derived from impulse responses that can be correlated to radio performance) could be reduced using angle-of-arrival discrimination, thus providing improved radio performance. Including polarization diversity with angle-of-arrival discrimination did not substantially reduce the RMS delay spread and therefore would not substantially improve radio performance.



Example frame error rate performance vs. received signal power for a PCS system during the JTC field trials.

Recent Publications

R.J. Achatz, Y. Lo, and E. Pol, "Wireless local area network smart antenna performance improvement," in *Proc. Wireless Communications Conf.*, Boulder, Colorado, 1996, pp. 17-19.

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

Standards for Radiocommunication Systems

Outputs

- Federal Telecommunications Standards subcommittee leadership.
- APCO Project 25 task group leadership.
- Federal standards for HF and land mobile radiocommunications.
- Leadership in the Modular Multifunction Information Transfer System Forum.

The National Communications System (NCS) Technology and Standards Division has overall responsibility for managing the Federal Telecommunications Standards Program (FTSP). The FTSP is implemented through an interagency committee structure that comprises the Federal Telecommunications Standards Committee (FTSC) and several related subcommittees. ITS staff members provide leadership and technical contributions in two FTSC subcommittees that develop Federal standards for radiocommunication systems: the High Frequency Radio Subcommittee (HFRS) and the Land Mobile Radio Subcommittee (LMRS). These activities promote technology advancement in the radiocommunications industry and improve the interoperability and effectiveness of radiocommunication systems supporting National Security Emergency Preparedness, and law enforcement needs.

Prior ITS and HFRS efforts have produced a series of Federal standards that specify interface, protocol, and performance requirements for HF automatic link establishment (ALE) radio systems. Commercial radio equipment that implements these standards is becoming widely used in the Federal Government. During FY 96, ITS led the HFRS in preparing three additional Federal standards in this series. The first of these, Federal Standard 1052, specifies technical requirements for high-speed HF modems. This standard was formally approved for publication during FY 96. The other two standards specify baseline ALE radio parameters and requirements for addressing and registration in ALE networks. These standards were completed in draft form and will be coordinated among U.S. Government and industry organizations in FY 97.

To maximize the benefits of standardization, ITS helped promote the development of international standards compatible with the HF ALE standards developed in FTSC. Working with other Federal agencies and the HF Industries Association (HFIA), ITS submitted technical proposals and measurement data supporting ALE standardization to two international standards organizations: the International Telecommunication Union-Radiocommunication Sector Study Group 9C (Fixed Services) and the NATO Communications Standardization Group. Figure 1 summarizes some key linkages between the HFRS and related national and international HF standards organizations.

The Institute also is assisting NCS and the FTSC in developing interoperability standards for digital land mobile radio equipment used in public safety applications. The LMRS is developing advanced land mobile radio (LMR) standards in cooperation with the Association of Public-Safety Communications Officials (APCO) and the National Association of State Telecommunications Directors under APCO Project 25. During FY 96, an Institute representative chaired the APCO Project 25 Encryption Task Group, which develops Project 25 information system security standards. Institute staff members also participated in the Telecommunications Industry Association (TIA) TR 8.3 Encryption Committee and other Project 25 task groups to ensure that their LMR standards meet Federal requirements. Relevant FY 96 outputs included:

- TIA Interim Standard IS102.AAAA, APCO Project 25 DES Encryption Protocol.
- TIA Telecommunications Systems Bulletin TSB102.AAAB, APCO Project 25 Security Services Overview.
- TIA Telecommunications Systems Bulletin TSB102.AACA, APCO Project 25 Over-The-Air-Rekeying (OTAR) Protocol.
- TIA Telecommunications Systems Bulletin TSB102.AACB, Project 25 Over-The-Air-Rekeying (OTAR) Operational Description.
- TIA Interim Standard IS102.AAAC, DES Encryption Conformance.

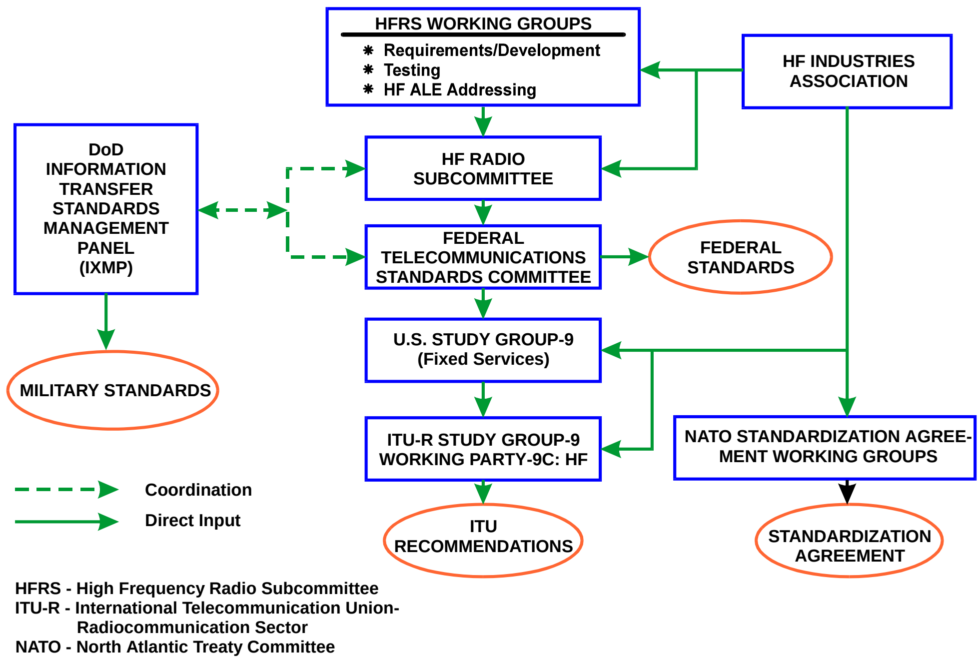


Figure 1. Relationships among U.S. and international HF radio standardization organizations.

- TIA Telecommunications Systems Bulletin, TSB102.AACC, Conformance Test for Project 25 Over-The-Air-Rekeying (OTAR) Protocol.

All of the these documents have been adopted as APCO Project 25 Standards and proposed for adoption as Federal Information-processing Standards.

ITS staff played a strong role in the organization and leadership of a new radio system standardization group, provisionally called the Modular Multifunction Information Transfer System (MMITS) Forum, during FY 96. The Forum's initial membership includes over 100 organizations involved in the development and use of advanced radiocommunication systems and services. Its mission is to specify a modular architecture to facilitate the development of frequency-agile, multiprotocol software-defined radios using advanced digital signal-processing capabilities. The resulting specifications will facilitate interworking among radio systems and services in military, civilian Government, and private sector wireless applications. Figure 2 is the MMITS plan for software-defined radio system development. Institute leadership in MMITS will contribute to realization of this plan.

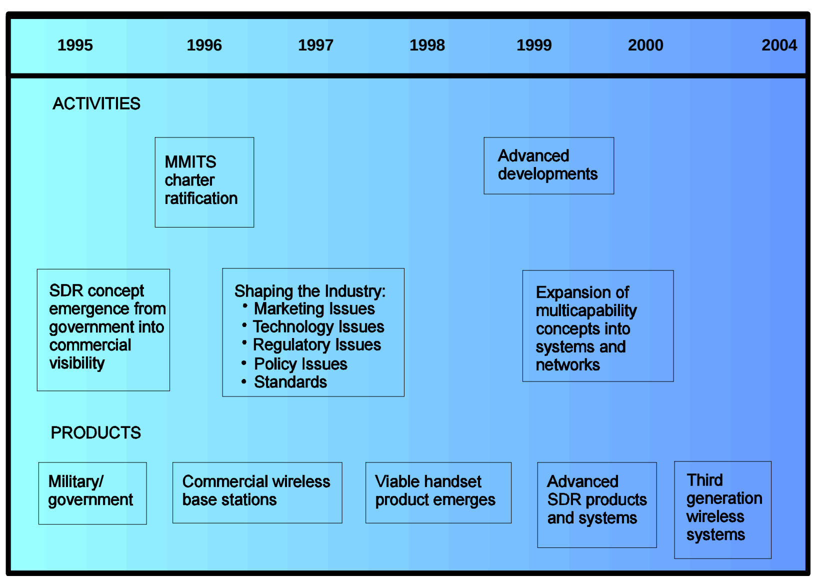
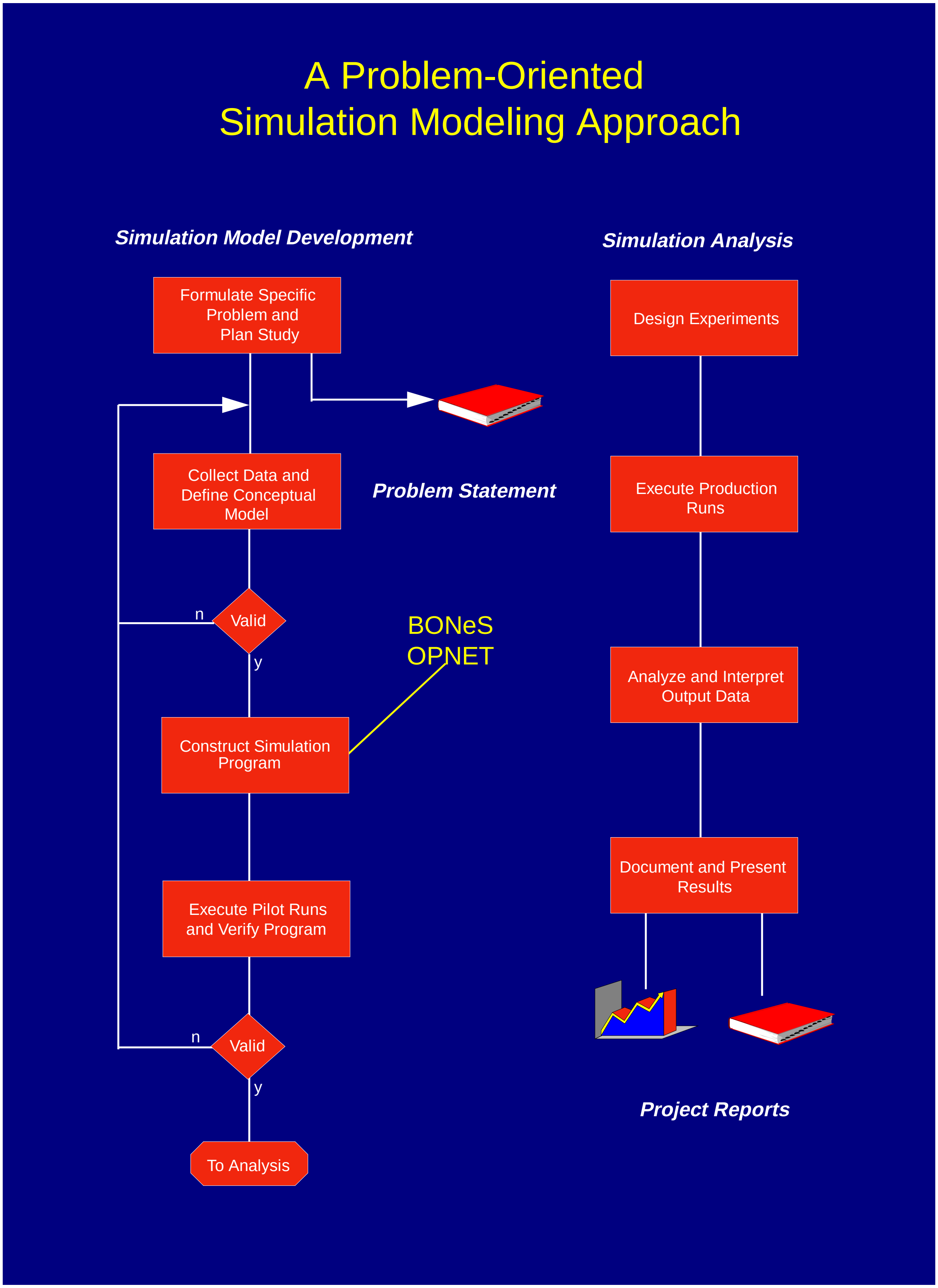


Figure 2. Modular Multifunction Information Transfer System Forum plan for software-defined radio (SDR) system development.

For more information, contact:
James A. Hoffmeyer
(303) 497-3140



This simulation modeling process supports system engineering design through the review and assessment of conceptual solutions.

Telecommunication Systems Planning

A major element of the ITS mission is to serve as a central Federal resource to assist other Government agencies in planning, designing, maintaining, and improving their telecommunications systems and networks. Over the years, ITS has developed a seven-step telecommunications planning process that helps to organize and facilitate these activities.

The seven steps are: (1) requirements definition (e.g., mission, business plan, connectivity and traffic profiles, and safety and security needs); (2) review of existing systems (from an operational, performance, and cost perspective); (3) review and assessment of internal factors (i.e., those within agency control); (4) review and assessment of external factors (e.g., Office of Management and Budget, General Services Administration, and other applicable guidelines and directives); (5) technology assessment (i.e., what is available, or will be available); (6) development of telecommunications alternatives (based on the data developed from all other planning activities); and (7) formulation of an integrated plan (based on the selection of the best alternative). A particular technical project may involve all or only some of these activities, depending on the plan's scope and the agency's specific needs.

Areas of Emphasis

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).

Advanced Systems Planning

The Institute performs engineering analyses to determine the spectrum efficiencies associated with current communication systems and planned implementations of positive train separation and advanced train control systems. Projects are funded by the Federal Railroad Administration.

Multimedia Performance Handbook

The Institute contributes to the advancement of the National Information Infrastructure through development and promulgation of interactive, CD-ROM-based guidelines and applications for multimedia system procurement and assessment. Projects are funded by NTIA and the National Communications System.

Telecommunications Analysis Services

The Institute provides network-based public access to the latest ITS research results, engineering models, and databases supporting wireless telecommunications system design and evaluation. The project is funded by NTIA and by users of the services on a cost-reimbursable basis.

Augmented Global Positioning System

The Institute determines optimal locations for differential global positioning system reference stations, examines the needs of system users, and performs field evaluations of existing beacon system stations, to support the design and optimization of a nationwide navigation and positioning service. Projects are funded by the Department of Transportation and the FHWA.

PCS Networks

The Institute develops and applies computer-based simulation tools in assessing the performance and interoperability of emerging personal communications services equipment. Projects are funded by NTIA.

Intelligent Transportation Systems Planning

Outputs

- Electromagnetic compatibility analysis of intelligent transportation systems and subsystems.
- Support for intelligent transportation systems committees for communications, spectrum, and electromagnetic compatibility.

Surface transportation in the United States is becoming more of a problem as traffic congestion continues to increase. For many areas of the country, building more roads is financially and environmentally prohibitive. Traffic congestion in the United States causes a loss in productivity, increased accidents, wasted energy, and increased vehicle emissions. Intelligent transportation systems use computer and telecommunications technology to provide information to travelers about road and transit travel conditions and can monitor, guide, and control the operation of vehicles. By applying these techniques, these systems can improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy, and promote economic productivity in a transportation system. Maintaining safety on the Nation's streets and highways is also a primary concern. Intelligent transportation systems can enable travelers to make more informed choices about routes, times, and modes of travel. With intelligent transportation systems, authorities can better manage transportation systems traffic. Some examples include the ability to: rapidly respond to road accidents to restore traffic flow, redirect traffic away from the most congested routes, provide information on ride sharing, provide traffic control at intersections and on street networks, meter ramps on freeways, reserve lanes for buses and high-occupancy vehicles, and provide automatic in-transit commercial vehicle weigh-in and toll collection.

Intelligent transportation systems include a wide range of electrical and electronic devices and equipment. These devices and equipment, coupled with external signals and interference from external sources represent a complex interactive electromagnetic environment with emitters and receptors. The operation of radio communications equipment and other electronic devices around vehicles equipped with these systems could cause interference to the resident automotive electronic systems and the electronic equipment in the rest of the environment.

Electromagnetic compatibility (EMC) is a primary factor in the performance, safety, and effective operation of intelligent transportation systems. EMC is the ability of electronic equipment to achieve a specified level of operability in an uncontrolled environment. It involves the orchestration and integration of system components in a fashion that will control interference coupling, and is a primary consideration in intelligent transportation system design. The Institute has participated in many activities that address EMC during the initial conception, design, development and testing phases of intelligent transportation systems.

Recent activities and accomplishments on intelligent transportation systems at the Institute include:

1. Measurements of high-level electric field strength in the roadway environment. The results will be used to determine the operating environment for intelligent transportation subsystems.

2. An analysis of the electronic toll and traffic management (ETTM) system that determined the potential EMC problems that might result if large numbers of ETTM systems were placed into operation near 2.4 and 5.8 GHz. The characteristics of the roadway environment near 2.4 and 5.8 GHz were examined. This included Government radars and other industrial, scientific, and medical (ISM) systems. The compatibility of a generic ETTM system with these existing radars and ISM systems was determined.

3. An assessment of propagation models for use in the analysis and design of intelligent transportation subsystems. This assessment was performed to evaluate the capability of using existing models. Recommendations for future development in propagation models for intelligent transportation systems in the roadway environment were made.

4. An evaluation of an AM subcarrier operational test that is currently being performed for a proposed advanced traveler information system (ATIS). The system would be used to disseminate information to travelers in the rural roadway environment.

5. An analysis of AM subcarrier systems that will support the design and field testing of the AM subcarrier evaluation effort for ATIS.

6. Measurement and verification testing of FM subcarrier system coverage. This testing will support the prediction of area coverage for an FM subcarrier system for ATIS in rural and urban environments.

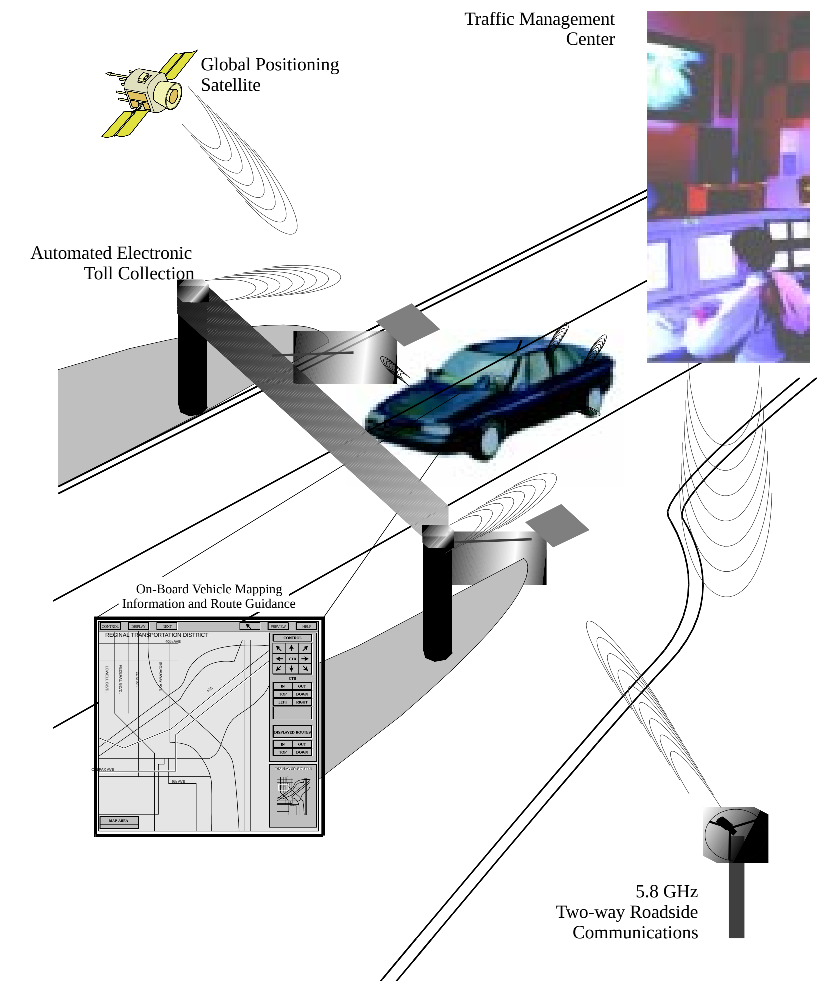
7. FM subcarrier coverage and performance prediction of selected U.S. areas. These predictions will be made for regions that differ dramatically in terrain and population density. These regions may implement the FM subcarrier form of ATIS.

8. Development of radio wave propagation models for the analysis of automated toll collection systems, short range communication systems, and ATIS.

9. Ongoing support for intelligent transportation systems communications committees, including the High-speed Data Subcommittee, Intelligent Transportation Systems Telecommunications Committee, and the Transportation Research Board.

Future activities at the Institute include: (1) characterization and measurement of the electromagnetic environment, (2) spectrum planning, (3) propagation model development, (4) determination of suitable new communications technology for intelligent transportation systems, (5) prediction of radio coverage for communication systems, (6) selection and establishment of an EMC requirement standard for intelligent transportation systems, (7) creation of an EMC control plan, (8) selection and development of an EMC testing standard for intelligent transportation systems, and (9) creation of an EMC test plan. The Institute also will be involved in system architecture evaluation in the EMC concept and design phases and will assure EMC for demonstration projects during the course of systems development.

The Figure is a pictorial representation of the ATIS concepts of electronic traffic management and toll collection; in-vehicle information and route guidance for navigation with the global positioning system and low frequency differential correction signals; and updated traffic and road condition information from a traffic management center via an FM and AM subcarrier data broadcast.



Pictorial representation of Advanced Traffic Information System for intelligent transportation systems.

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

Advanced Systems Planning

Outputs

- Measurements of railroad radio channel use.
- Estimates of bandwidth requirements for the positive train separation system.
- Evaluation of total radio spectrum needed for future railroad operations.

The Federal Railroad Administration (FRA) promotes safe railroad transportation and encourages infrastructure and technology to realize that goal. ITS has supported the FRA by evaluating the telecommunications aspects of safe train movement.

The Association of American Railroads and the Railways Association of Canada have proposed specifications for the North American advanced train control system (ATCS). ATCS is a data communication-based system that transmits command and control information between dispatch centers, locomotives, track maintenance vehicles, and wayside devices. It is intended to provide more economical, efficient, and safer train movement in North America.

Most railroads have adopted an incremental approach to implementing the complex ATCS by conducting small-scale experiments and pilot projects to become more familiar with the technology and its impact. System interoperability between railroads is a key issue because locomotives owned by one railroad commonly run on track owned by another. The Burlington Northern (BN) and Union Pacific (UP) railroads have initiated a joint pilot program to implement and test technology designed to achieve positive train separation (PTS). The safety objectives associated with PTS include prevention of collisions between trains, prevention of collisions between trains and track maintenance vehicles, and prevention of speeding by trains (Figure 1).

The pilot program will be implemented on over 863 miles of BN/UP track in Washington and Oregon. Compatible equipment on BN and UP locomotives and compatible software in the two railroads' operations centers will allow "handoff" of trains from one operation center to another without interruption or degradation of the on-board safety functions.

The system provides a nonvital safety overlay to existing railroad traffic control and signaling systems by enforcing movement authorities and speed restrictions for PTS-equipped trains. The PTS system accomplishes this through the server, locomotive, and communications segments. The primary function of the server segment is to determine enforceable movement authorities and speed limits. This information is transmitted to the locomotive segment through the communications segment, which incorporates both wireline and wireless networks. The locomotive segment warns the crew of violations, and if the crew does not respond, the train is automatically slowed or stopped.

Adequate radio frequency spectrum is crucial for the implementation of PTS systems. ITS consulted with the FRA throughout the Federal Communications Commission (FCC) rulemaking on "refarming" the VHF and UHF bands containing railroad allocations. PTS and ATCS, when fully implemented by all railroads, will add to the required spectrum needed by the railroad industry. ITS has begun the following three-step process to evaluate that need: (1) determine current use of the railroad-allocated spectrum; (2) determine the spectrum needed to fully implement PTS/ATCS; and (3) estimate the future need of the railroads for voice communications, PTS/ATCS, and new services such as video communications.

During the first step, ITS measured the spectrum used by current railroad channel assignments. Three cities, where radio communications are expected to be heavy, were selected for the measurements:

Figure 1. High-speed passenger train with wayside equipment to monitor passing trains (photograph courtesy of the Federal Railroad Administration).

Chicago, Illinois; St. Louis, Missouri; and Kansas City, Missouri and Kansas. An ITS measurement van was located near railroad yards in each city and measurements were made continuously for about one week at each site. During the measurement period, the channels were monitored with a spectrum analyzer by sweeping across all channels about once per second. This gave information on the channels that were in use at each site. By tallying the time period that each channel was used from sweep to sweep, message statistics for the radio channels were gathered. Figure 2 shows a channel utilization plot for the Chicago, Illinois site over a 24-hr period of the railroad band from 160.215-161.565 MHz. Figure 3 shows the distribution of message durations over the 24-hr period. Most of the traffic lasted for only a few seconds as would be expected of the dispatch-to-mobile communications. Some of the traffic lasted for minutes and included instructions from the dispatch to the conductor of the locomotives.

The second step of the study included an evaluation of the spectrum required to support a fully implemented, nationwide PTS/ATCS. This process estimated the size and number of messages transmitted from a train, the associated wayside equipment, and the affected track forces, starting with train initiation and ending with train termination. The message traffic was scaled to include all locomotives, wayside equipment, and track forces that may be transmitted from one base or repeater station. From this total message traffic estimate, the required bandwidth to support the traffic was calculated.

The third step is to complete the evaluation, based upon results of the first two steps and to project the need by the railroads for new services. Because much of the railroad operations include linking locomotives and rail cars, detecting defects such as cargo overhanging rail cars, and checking track conditions in front of the locomotive, video services will play a considerable role in the future of railroad communications. A report will be prepared estimating the total need of radio spectrum by the railroad industry.

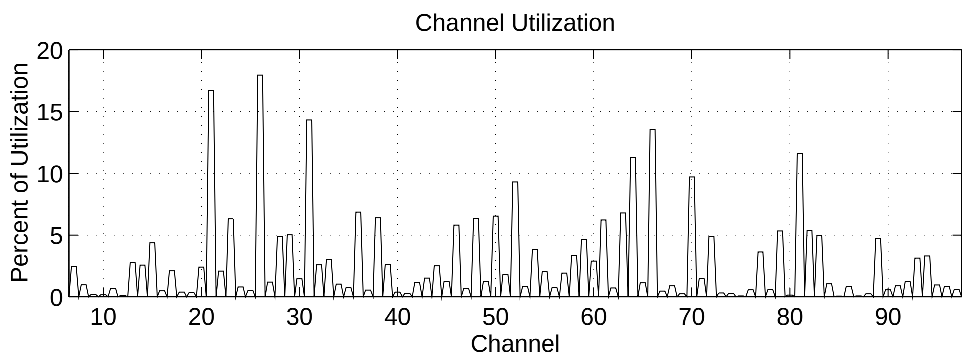


Figure 2. Relative radio channel utilization for the Chicago, Illinois railroad measurement site.

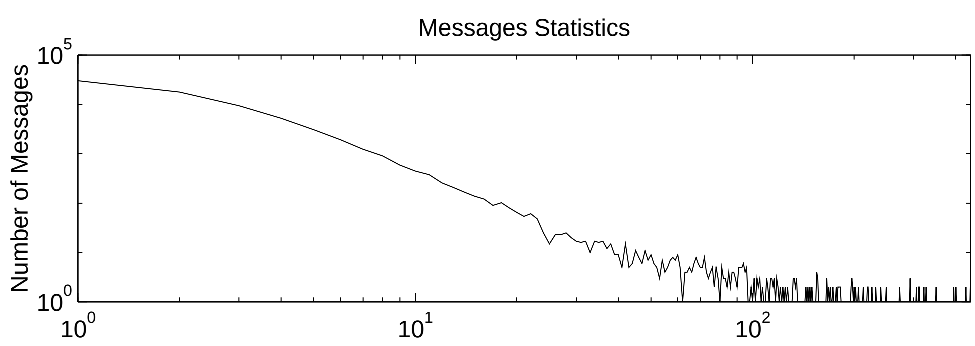


Figure 3. Distribution of message durations over the 24-hr period for the Chicago railroad measurement site.

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

Multimedia Performance Handbook

Outputs

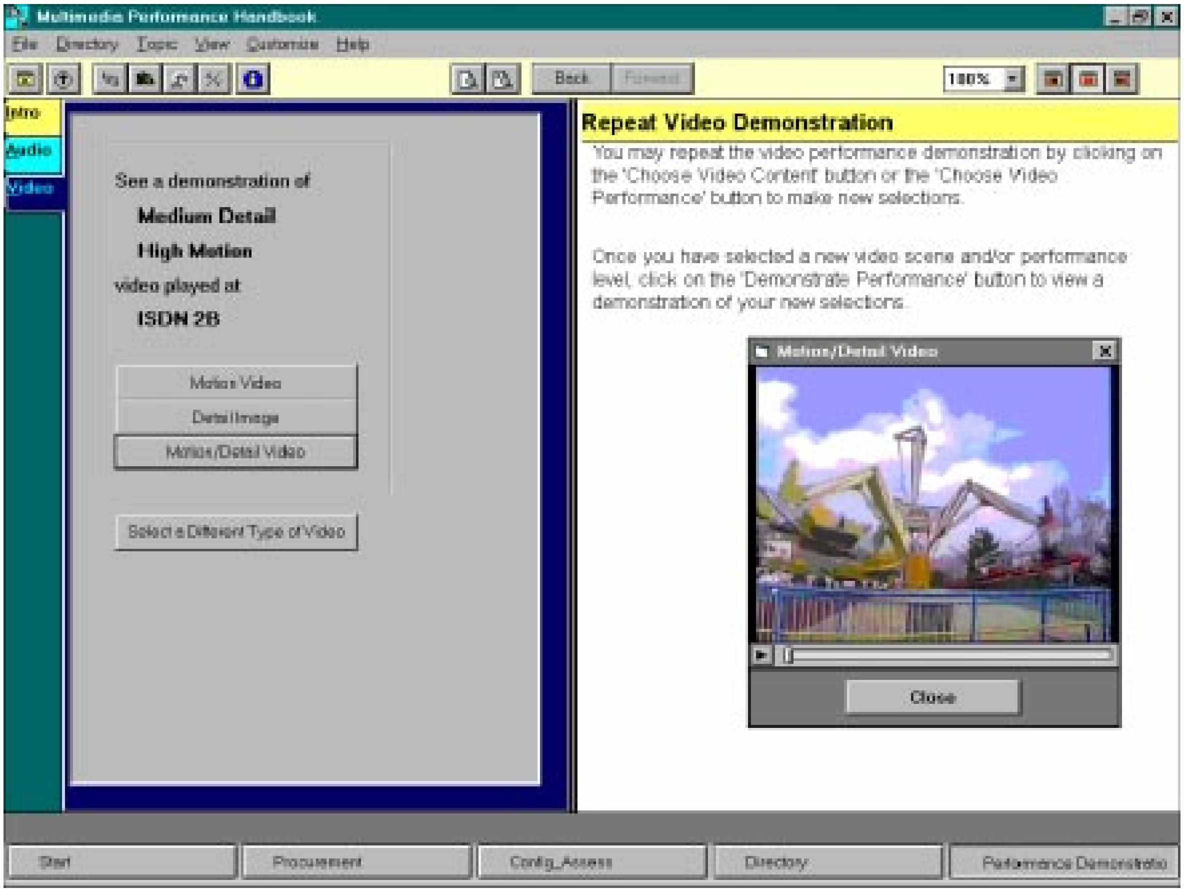
- Application of objective quality measures to multimedia services.
- Interactive Applets for procurement specification and configuration assessment.
- Tutorial and reference material on multimedia performance assessment.

Several years ago, ITS technical staff members recognized the need for consumer-oriented information concerning the performance of multimedia communication systems, equipment, and services. They foresaw that such information would find application in the procurement of multimedia products, in product acceptance testing after procurement, and in the maintenance of products after installation. Much of the necessary information had been or was being produced in the ITS program of telecommunications quality research, but additional product-specific information and more comprehensive 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 video monitors and other video equipment. ITS sought and received support from the National Communications System (NCS) to develop a more comprehensive quality assessment tool. 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 changes in technology. However, ITS engineers soon decided that a more flexible and effective means of presenting this information would be an interactive multimedia data access application implemented on a CD-ROM.

A first prototype of the Handbook was produced in FY 95. This product integrated the use of audio, video, graphical, and hyperlinked text in the context of an interactive graphical user interface to present required technical information in a user-friendly manner. Two new versions of the Handbook have subsequently been produced, each with increased functionality and larger information bases. In its complete form, the Handbook will provide a wealth of technical information and many specific examples to assist users in making effective decisions in the specification and procurement 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. Hyperlinking of key text allows users to skim familiar material while delving more deeply into other topics. The Handbook can be used both in a linear fashion (like a book read cover to cover) and in a nonlinear fashion (like a book browsed randomly). Users may employ each of several Applets (small application programs that act as interactive assistants) to solve particular problems or to gain knowledge in particular areas. Applets can be accessed from designated *Reference/Tutorial* sections or (by clicking on a *Library* button) from any other point in the Handbook.

The Handbook implements two complementary functional modes: the *Procurement* mode and the *Configuration Assessment* mode. The *Procurement* mode is implemented as a large Applet that assists users in the specification of a multimedia system for a particular application. This mode specifies appropriate performance metrics for multimedia equipment and services. The understanding and proper specification of these performance metrics can help ensure that a procured multimedia system economically meets the quality requirements of the intended application. After selecting various options, the Procurement Applet displays a spreadsheet of suggested performance specifications. While providing the Applet with information leading to the specification, users can learn more about the quality aspects of the selected multimedia application.

The Figure shows a screen image from the Performance Demonstration Applet. This Applet allows the user to interactively specify the characteristics of a system, and then subsequently hear or see how their specification affects system performance. The operation of this Applet illustrates one of the Handbook's most valuable features: the use of real audio and video clips, derived from commonly available multimedia communications systems and



Example screen from the NCS Multimedia Performance Handbook.

equipment, to provide a realistic view of product performance before any product is procured.

The *Configuration Assessment* mode of the *Multimedia Performance Handbook* is designed to allow a user of multimedia services and equipment to determine the level of performance that can be expected from a particular configuration of multimedia service environments. The Configuration Assessment Applet of the Handbook can help answer the question, for example, "What will head-and-shoulders video look like if my communications path includes a PSTN modem at 28.8 kbps, a wireless link at 9.6 kbps, and an ISDN connection at 128 kbps?" The user can see a simulation of what the video might look like, obtain an estimate of the cost of such a system, and develop a spreadsheet of values for applicable quality metrics to ensure that required quality levels are met. Such capabilities will be useful both in procurement specifications and in product-acceptance testing.

The *Multimedia Performance Handbook* shows great promise for use by consumers as an interactive tool in the procurement of multimedia communications systems, equipment, and services. The 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 will systematically provide the specification and assessment of multimedia systems in Government and private sector user organizations. It also represents a model of how ITS and other research organizations may present technical information in the future.

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

Telecommunications Analysis Services

Outputs

- Easy access for U.S. industry and Government agencies to the latest ITS research results and engineering models and databases.
- Broad applications in telecommunication system design and evaluation of broadcast, mobile, and radar systems.
- Standardized method 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 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.

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. Other Government databases and reports become available through a bulletin board service to all TA Services users as they are developed. For more information on available programs see the Tools and Facilities section of this report or call the contact listed below.

TA Services currently is focusing on the development of 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.

TA Services continues to develop models in the GIS environment for personal communications services (PCS). 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; business, Government, and academia now employ GIS in many different applications. As a result, databases necessary for telecommunication system analysis are now becoming available in forms easily imported into the GIS environment. These databases include terrain, roads, communications infrastructure, building locations and footprints, land type and use, and many others. These databases can be maintained in commonly used and available relational database management systems (RDBMS) that can be connected to the GIS or placed into the GIS RDBMS. This greatly reduces the amount of database development necessary in PCS modeling.

Information on building heights and vegetation is needed for short-path models; however, it is not commonly available. 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 taken from aircraft at relatively low altitudes or even spacecraft. With sufficient photo quality, this data 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 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, this environment can be displayed in two or three dimensions as shown in Figures 1 and 2, respectively. 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 3. The user can then give the pattern a name and store it in a personal catalog for future use.

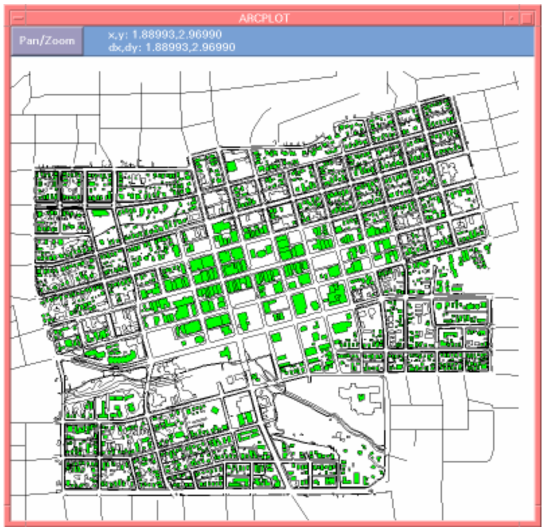


Figure 1. Two-dimensional view of Boulder, Colorado from the TA Services PCS model.

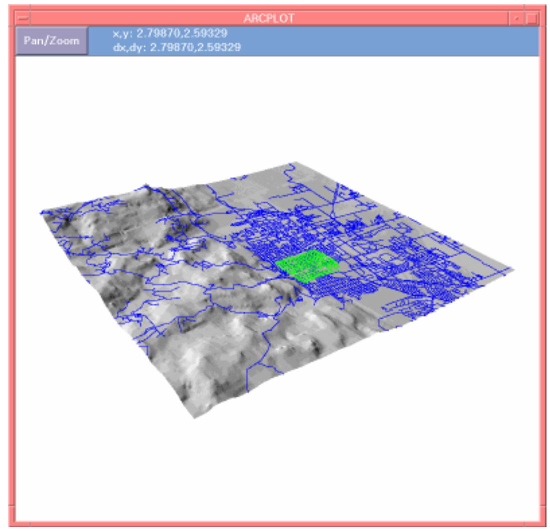


Figure 2. Three-dimensional view of Boulder, Colorado from the TA Services PCS model.

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 road-guided path loss model, an over-building model, and a time-domain model. The model also allows the user to see all line-of-sight regions. The model has an analysis menu that allows the user to override the selection of appropriate models in the transmitter definition table and force a view of only one model for all transmitters. This menu also controls the results and options for viewing data. The model has a plot menu which allows the user to zoom in, out, left, right, up, or down in the view area and to turn on or off the option to view each cell's data value. From this menu the user also can select contours and the colors of each contour in all subsequent output result displays. Figure 4 shows the coverage of a PCS transmitter located on a courtyard between buildings in downtown Boulder, Colorado. Figures 1 and 4 show the roads, blocks, and building outlines of downtown and were imported into the GIS model from a CAD package used by the City of Boulder for city planning.

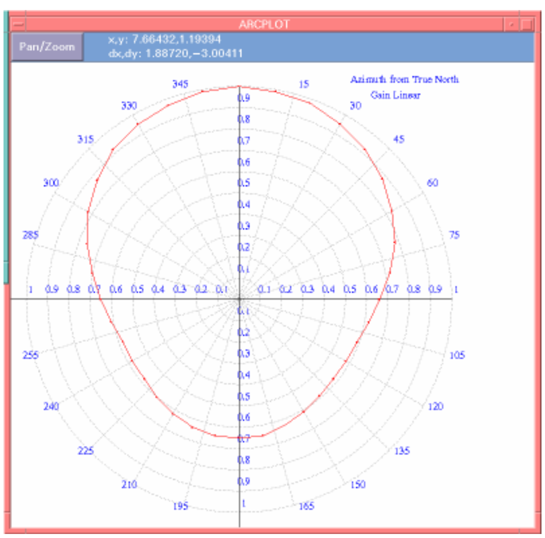


Figure 3. Antenna pattern from the user catalog in the TA Services PCS model.

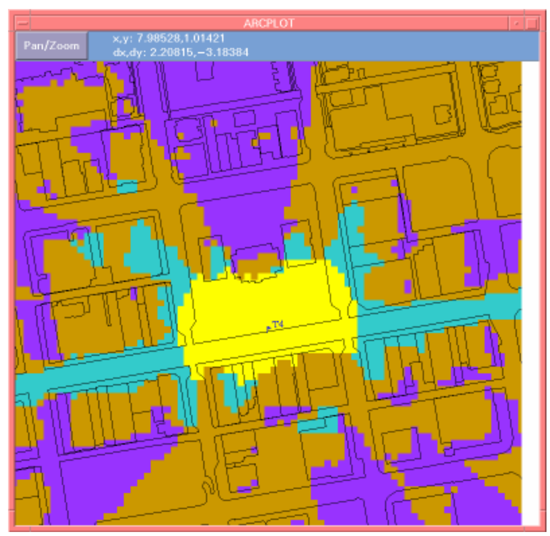


Figure 4. Model output for the Boulder, Colorado scenario in the TA Services PCS model.

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 existing differential GPS reference stations.
- Planning of the number and location of differential GPS reference stations required to provide nationwide signal coverage.
- Installation guidelines for differential GPS reference stations.

The NAVSTAR global positioning system (GPS) is a space-based radionavigation system that is operated for the Federal Government by the Department of Defense (DOD) and jointly managed by the DOD and Department of Transportation (DOT). NAVSTAR is a constellation of 24 satellites in 6 orbital planes; it provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hrs per day. GPS originally was developed as a military enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. In an effort to provide GPS service to the greatest number of users while ensuring that 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.

The 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 accuracy for static users. In NTIA Special Publication 94-30, "A technical report to the Secretary of Transportation on a national approach to augmented GPS services," ITS recommended implementation of a low frequency/medium frequency radio beacon system, modeled after the U.S. Coast Guard's (USCG) local area DGPS, to provide nationwide coverage of DGPS for surface applications (DeBolt et al., 1995). The Institute is now conducting 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 national navigation and positioning service (NNPS) to all surface users across the nation. The use of NNPS 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.

DGPS is a land-based system consisting of four main components, as shown in Figure 1.

1. A reference station, placed at a precisely surveyed position, that receives and processes GPS satellite position information from orbiting GPS satellites, calculates corrections from the known position, and broadcasts these corrections via a radiobeacon to participating DGPS users in the radiobeacon's coverage area.

2. A control station, that remotely monitors and controls the DGPS reference stations via data communications lines.

3. A communications link, that provides data communications between the reference stations and the control stations.

4. User equipment, consisting of a GPS receiver and a radiobeacon receiver, that automatically applies the corrections to received GPS position information to achieve position accuracies of better than 10 m.

DGPS reference stations currently operating or planned by the USCG and the U.S. Army Corps of Engineers provide coverage of the radiobeacon DGPS signal for coastal areas, harbors, and inland waterways. This existing capability provides the DGPS signal to a majority of the nation (Figure 2).

ITS has recommended increasing the capability of this existing system by installing DGPS reference stations at Ground Wave Emergency Network (GWEN) sites, owned by the Air Force Air Combat Command. The GWEN system is an existing Federal Government asset that is scheduled for decommissioning in the same time frame that the DGPS radiobeacon system would be installed. Use

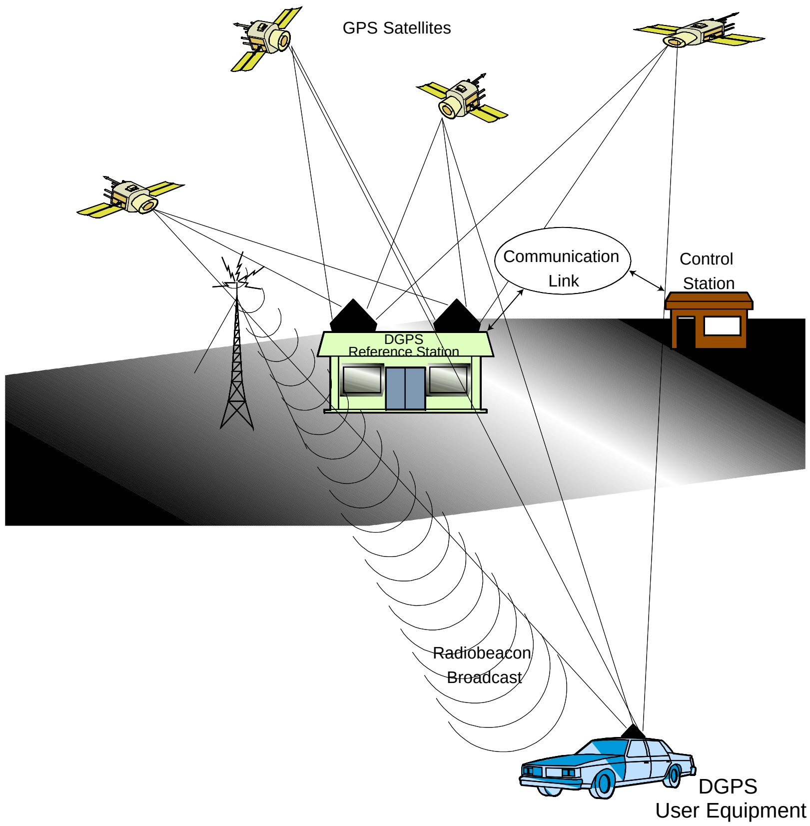


Figure 1. DGPS system architecture.

of the GWEN sites would provide a cost-effective method of implementing nationwide coverage of the DGPS signal. It would avoid the cost associated with decommissioning the sites, and the cost and delay of land acquisition and environmental impact statements required for additional DGPS reference stations. The combination of the existing DGPS reference stations and the additional stations at 15 of the GWEN locations will provide radiobeacon signal coverage to over 90% of the nation (Figure 3). A minimum number of additional DGPS reference stations would be required to complete the nationwide coverage and realize completion of the NNPS.

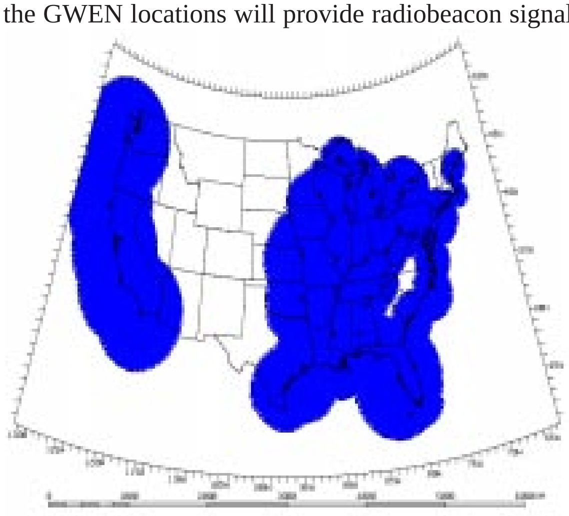


Figure 2. Existing DGPS signal coverage.

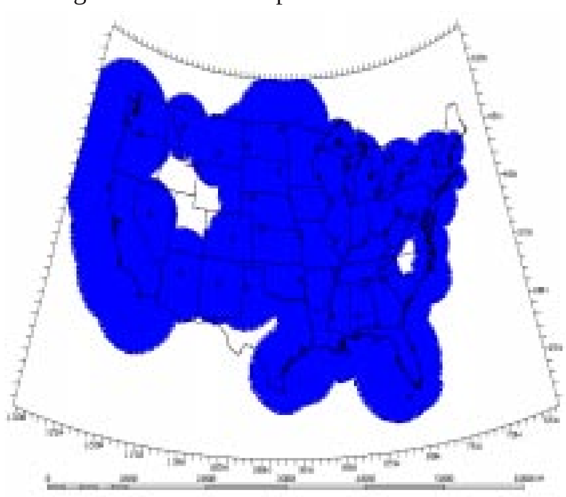


Figure 3. DGPS signal coverage with GWEN.

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

PCS Networks

Outputs

- Code-division multiple access and PCS 1900 noise models.
- Interference simulation for PCS 1900 evaluation.
- Technical report on noise/interference modeling.

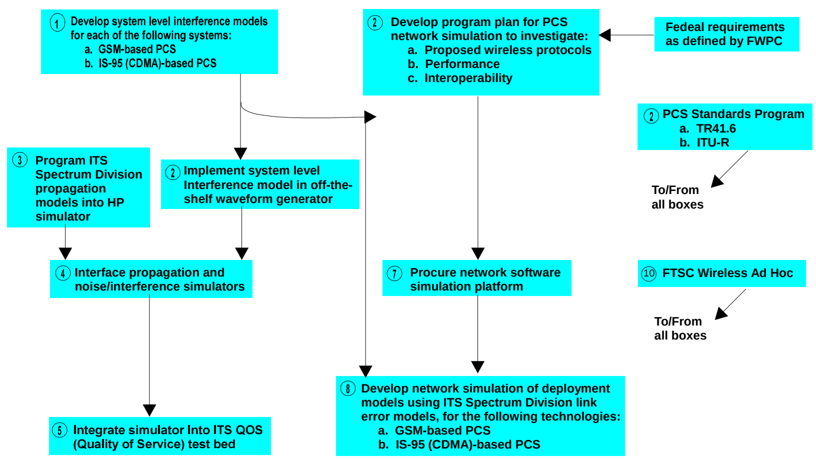
Wireless communications technologies have an almost unlimited growth potential, both in the United States and in the larger global economy. Networks that provide personal communications services (PCS) will figure prominently in this growth: the worldwide market for PCS equipment is in the billions of dollars. The Federal Government is providing spectrum for PCS communications and expects to make extensive use of emerging PCS networks in meeting its own wireless communication needs. However, effective implementation of PCS networks will require careful matching of PCS equipment capabilities with planned applications. The facilities currently available for evaluating emerging PCS technologies are limited. The Institute's PCS Networks program is contributing to development of the necessary PCS evaluation tools.

The overall scope of the PCS Networks program is illustrated in Figure l. A particular goal is to develop accurate means of assessing interference effects, which are expected to be a key limiting factor in the deployment of PCS. During FY 96, ITS engineers developed network-level interference models for global system for mobile (GSM) communications-based and IS-95-based PCS technologies (Block 1 of Figure 1), and began implementing these interference models (and associated propagation models) in commercially available waveform generation and simulation equipment (Blocks 2 and 3). This effort will lead, in FY 97, to a real-time link simulator that will be useful in testing the interoperability and performance of a wide variety of PCS and other wireless communications systems (Blocks 4 and 5). Because the interference and channel propagation simulators are programmable, the integrated simulation system will be capable of emulating the interference and propagation environment of essentially any wireless communication system. The propagation models being used were developed by ITS under PCS projects described in the Applied Research section of this report (page 57).

The other blocks in Figure 1 show other aspects of the PCS Networks program including the PCS Standards program. During FY 96, Institute staff continued to participate in the development of unlicensed PCS standards through contributions to Telecommunications Industry Association (TIA) Committee TR41.6. Unlicensed PCS technologies are expected to enhance the economy and flexibility of customer premise distribution systems by eliminating wiring costs and constraints on the location of telecommunication terminals within buildings. Under the sponsorship of the Department of Defense, the Institute participated actively in defining Federal user requirements and proposed technology solutions for unlicensed PCS equipment. This equipment is being standardized by the TIA TR41.6 committee for operation in the recently allocated 1910- to 1930-MHz frequency band. In their present form, the unlicensed PCS standards are suited primarily for wireless private branch exchange voice services, but all contain provisions for the addition of data services. Institute staff members contributed to proposed technology solutions for wireless user premises equipment including STU-III equipment.

Figures 2 and 3 show outputs of the ITS-developed network-level PCS interference model for a GSM-based system known as PCS 1900. Both figures show the simulation of the PCS 1900 uplink interference waveform caused by eight mobile stations in each of six nearby interfering cells, as seen at the primary cell's base station receiver. In Figure 2, the transmitted power levels of the interfering mobile stations have been made equal—an assumption often made by PCS system designers. As expected, the resulting voltage envelope distribution appears Rayleigh distributed, although it is somewhat distorted in form because of the relatively small number of interferers. In Figure 3, the transmitted power level of one interfering mobile station has been increased by a factor of 10. The graph clearly demonstrates that the voltage envelope is no longer Rayleigh distributed; it also illustrates the strong effect a single dominant interferer can have. The model's ability to accurately represent a variety of real-world interference conditions should make it useful in assessing and optimizing PCS network performance.

Multiyear PCS Networks Program



Legend

- GSM • Global Mobile System
- CDMA • Code Division Multiple Access
- CRADA • Cooperative Research And Development Agreement
- FTSC • Federal Telecommunications Standards Committee
- FPLMTS • Future Public Land Mobile Telecommunications Service
- FWPC • Federal Wireless Policy Committee

Program Outputs

- TOOLS
- CAPABILITIES
- APPLIED RESEARCH
- STANDARDS ACTIVITIES
- JOURNAL AND CONFERENCE PAPERS; NTIA REPORTS

Figure 1. Multiyear PCS Networks program.

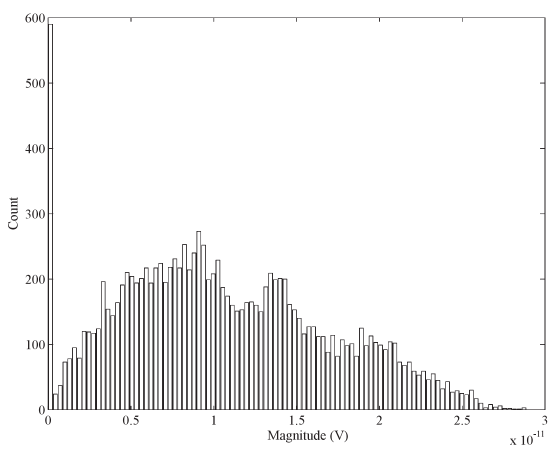


Figure 2. Voltage envelope histogram.

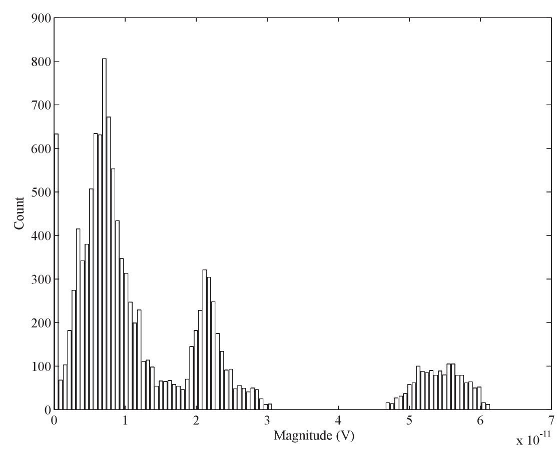


Figure 3. Voltage envelop with the addition of a single dominant interferer.

For more information, contact:
Steven M. Davidson
(303) 497-3411
e-mail davidson@its.bldrdoc.gov

Sixty-ft antenna at the ITS Table Mountain Radio Test Facility.

Telecommunication Systems Performance Assessment

Telecommunication system performance usually is understood to be either specifications of the communication performance requirements of a user or characterization of the performance provided by a particular communication system or service. The Institute assesses the performance of a variety of communications transmission systems and digital communications networks. Assessment tools developed by the Institute include automated analysis techniques, used during the system-design process for predicting performance of a telecommunication system in any specified environment, and test and measurement systems for evaluating the performance of either prototype or operational transmission systems and networks.

These tools are used to evaluate the performance of a variety of voice, data, and video telecommunication systems that may be entire networks or specific transmission links. These assessments address performance for a wide variety of transmission media, including terrestrial radio and satellite transmission systems and wireline systems such as local area networks (LANs). Both hardware and software models are used to develop and verify transmission system designs and to evaluate system performance.

Specific assessments conducted during FY 96 included expansion of the Jammer Effectiveness Model to include radar systems; development and application of methods to evaluate performance requirements for satellite-based, broadband communications networks; development of methods to test advanced HF radio systems; and traffic-flow modeling of LAN interconnection scenarios.

Areas of Emphasis

Radio System Design and Performance Software

The Institute expanded the Jammer Effectiveness Model to include radar systems performance, as well as communication system analysis, in jamming environments and adapted the model to run as a Windows application. Projects are funded by the U.S. Army National Ground Intelligence Center.

Satellite Studies

The Institute uses the Advanced Communications Technology Satellite (ACTS) to determine and evaluate requirements for performance, interface, and interoperability standards for satellite-based, broadband communications networks. Projects are funded by NTIA and the National Communications System (NCS).

Advanced HF Testing and Evaluation

The Institute produced a set of 13 audio compact disks that provide both clean and degraded tones for HF radio automatic link establishment. The Institute continues to develop and use a laboratory test bed to evaluate HF modems and associated protocols, and participate in developing and using an international field test bed to conduct over-the-air tests in support of Federal standards for adaptive HF radios. Projects are funded by NCS.

Network Flow Modeling

The Institute develops computer-based modeling and simulation tools to study the performance of large-scale data communication networks as a function of network capacity and offered traffic. Projects are funded by NTIA and the U.S. Army.

Radio System Design and Performance Software

Outputs

- Current version of the Jammer Effectiveness Model for communications analysis in use by the U.S. Army.
- Additional version of the Jammer Effectiveness Model for radar analysis under further development for the U.S. Army.

The Jammer Effectiveness Model (JEM) was expanded in FY 96 to include not only communication systems analysis in a jamming environment, but also radar systems performance in a jamming environment. The latest version of JEM runs as a Windows application and is user-friendly and menu-driven. This model is highly structured and modular in design, which allows for greater flexibility and expandability. The radar analysis capability is obtained by creating a separate version of JEM with the appropriate models for radar calculations. The analysis and design capability of this program was available previously only on mainframe computers.

The JEM version developed as a communications analysis model is used primarily by the U.S. Army to model communication systems in electronic warfare scenarios. The model 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. Current scenario types that can be analyzed are ground-to-ground, ground-to-satellite, ground-to-aircraft, aircraft-to-satellite, jamming from an airborne or ground jammer, and jammer versus network from an airborne or ground jammer. The communication links or network being jammed can have transmitters or receivers either airborne or ground-based. The jammer versus network scenario has been modified recently to handle multiple jammers.

The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. The valid frequency range of JEM currently is from 2 MHz to 300 GHz and includes complete analysis capability for both the jamming and the jammer versus network model scenarios.

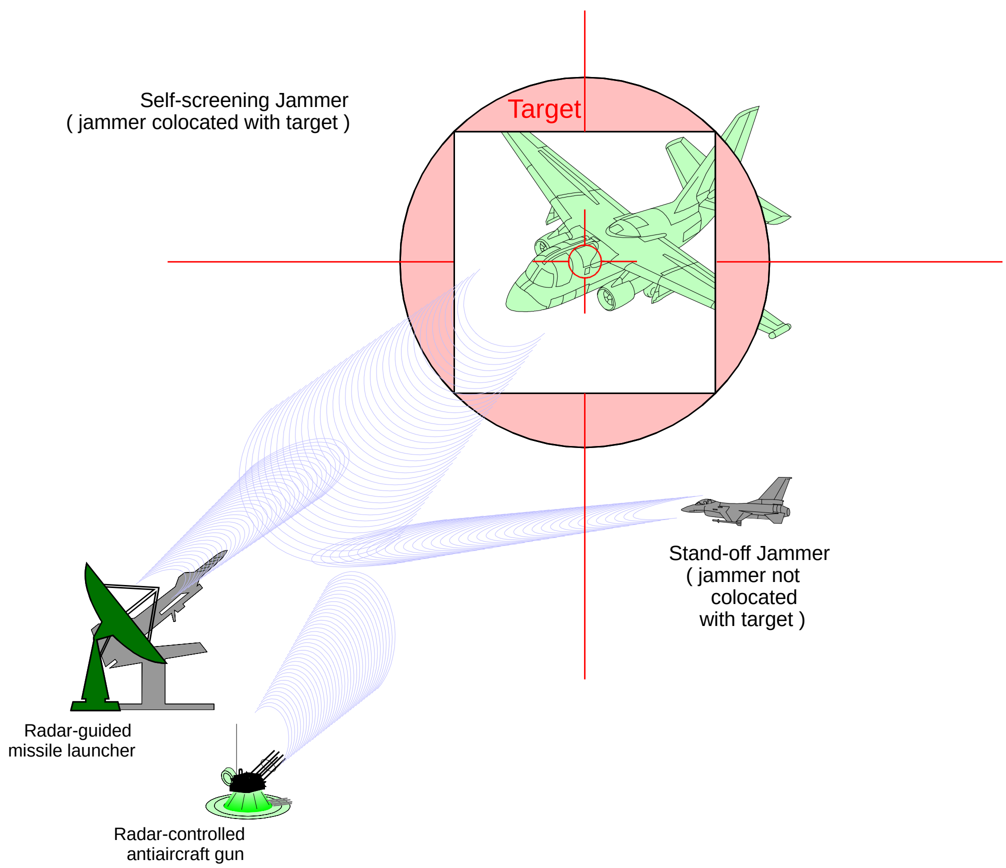
Data entry in the JEM is simplified by user-friendly menus and options. Databases are created as a result of this data entry and saved as scenario descriptions. These scenario descriptions completely characterize the communication link or jamming situation. The scenario description includes ground or airborne station location and physical factors such as climate and terrain. Each of the analysis programs within a scenario analyze the case represented by the scenario description data.

The communications analysis version of JEM is organized into six scenarios. A scenario 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. 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 scenarios are used as an aid in evaluating and designing 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. The user can perform several different analyses on the data without re-entering it.

The radar version of JEM that is currently under development will allow radar analysis of different combinations of radars and jammers that are on the ground or carried by airborne stations. The radar analyses consist of either performance evaluation of a radar trying to detect and track a target, or evaluation of 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 either can 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. Deception jammers, false target generators, and broadband noise jammers are all included in the analysis models. The three-dimensional geometry of these radar scenarios will require 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 also is the maximum range versus azimuth angle at which the radar detects the target.

The Figure illustrates a stand-off and self-screening airborne jammer attempting to avoid detection by a ground-based radar. The ground-based radar will direct missiles and antiaircraft guns to destroy the target aircraft. The stand-off jammer is protecting other airborne targets by jamming the ground-based radar. The self-screening jammer is protecting itself from detection by the ground-based radar.



A stand-off and self-screening jammer avoiding detection by enemy ground-based radar.

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

Satellite Studies

Outputs

- Advanced satellite capabilities for National Security Emergency Preparedness.
- Satellite standards development.
- PEACESAT system engineering support.

Satellites have distinct advantages over terrestrial telecommunication facilities in a number of practical applications. Satellites have a natural broadcast capability: a single geostationary satellite can provide coverage ranging from a small region (e.g., a 160-km diameter circle) to almost an entire hemisphere of the earth. Satellites can economically support communications in remote areas, and can provide broad and highly reliable coverage to mobile stations. Temporary communications systems that must be deployed rapidly are often best served by satellites. Advanced satellites with electronically steerable "spot beam" antennas and on-board baseband switching can serve as "on-demand" backups for failed or overloaded links in a terrestrial network. The Advanced Communications Technology Satellite (ACTS), launched several years ago by the National Aeronautics and Space Administration (NASA), has provided opportunities to study (and optimize) innovative satellite technologies supporting these and other applications. ITS operates a regional ACTS earth station and test center that supports such experiments, and uses these ACTS facilities in its own satellite communications research.

The Institute's FY 96 Satellite Studies program focused on measurement of ACTS performance in supporting representative user applications. ITS staff members organized a four-party ACTS Collaboration when several ACTS experimenters determined that they had similar goals and interests. By combining equipment, the Collaboration formed a three-node satellite network (Figure 1) that includes ACTS earth stations and terrestrial connections and can support a wide range of experiments. ITS led the Collaboration, provided liaison with NASA and the National Communications System (NCS) Office of Programs, and performed one of the application experiments, which dealt with voice quality. The National Institute of Standards and Technology (NIST), Computer Systems Laboratory (CSL) performed application experiments on desktop conferencing and local area network (LAN) bridging. COMSAT Laboratories assisted NIST/CSL with satellite access, provided the frame relay software for the ACTS earth stations, and performed an experiment using Internet protocols. MITRE Corp. contributed to the design of experiments that were relevant to National Security Emergency Preparedness (NS/EP) communications needs and assisted the other collaborators with their experiments. NCS sponsored much of the work. The NCS mission to provide communications in support of NS/EP gave the Collaboration a common purpose.

The Institute's voice quality testing experiment applied an ITS-developed objective Voice Quality Assessment System in evaluating the user-perceived quality of satellite-derived voice channels. Mean opinion scores for the satellite-derived channels were shown to be nearly the same as those of terrestrial channels (excluding effects of delay). Tests of PC-based desktop video conferencing using relatively low-speed (256 kbit/s) ACTS channels showed that satellite delay and errors do not significantly degrade application effectiveness except for highly interactive functions, such as joint document manipulation. The LAN-bridging experiments examined ACTS performance in transferring large data files between computers located in LANs at each end of a satellite link. An example application is the retrieval of maps or weather information in an NS/EP scenario. In one experiment, the digital file of the weather map shown in Figure 2 was transferred. The

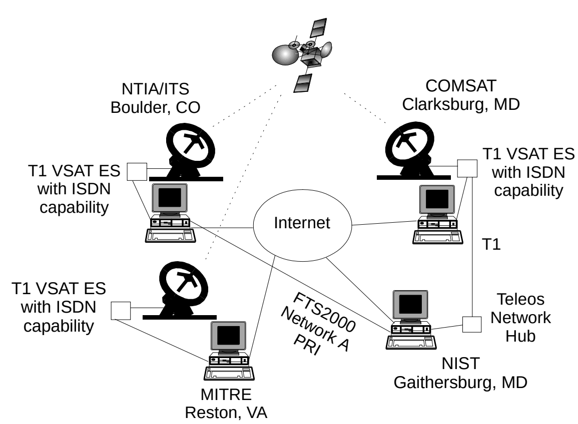


Figure 1. Experimental network including ACTS earth stations.

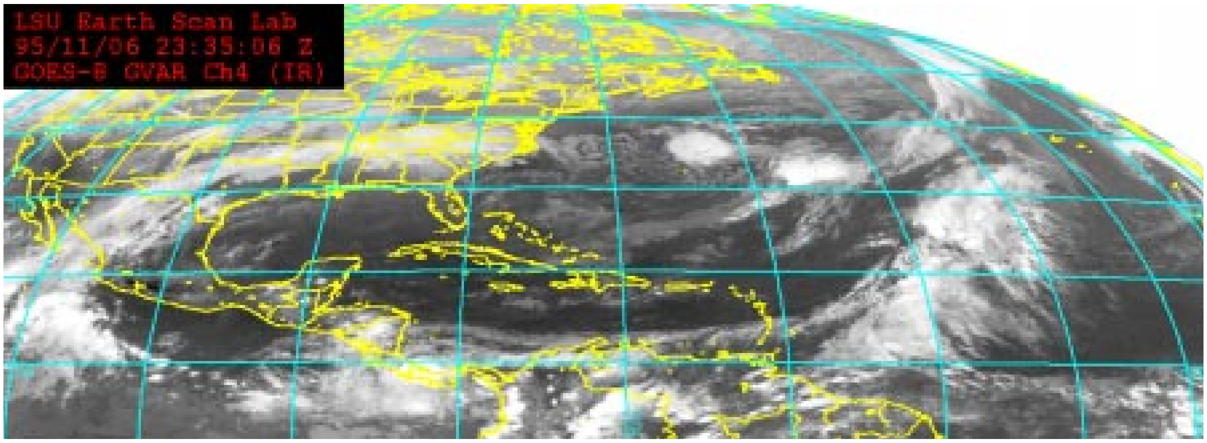


Figure 2. Image of a weather map used in LAN bridge and file transfer experiments.

experiment showed that satellite propagation delays can reduce throughput by as much as α when transmission control protocol (TCP) implementations not optimized for satellite communications are used. Bit-error rates less than 10^{-4} had negligible impact on the observed transfer rates.

TCP in its default form is relatively inefficient in transferring data over satellite channels, particularly at bit rates above 64 kbit/s. Modifications can be made to TCP to improve its performance for "long-fat" channels. Among these are an increased window size, more detailed round-trip-time tracking, and a process called slow start. Figure 3 shows throughput results measured in the Collaboration experiments for three versions of TCP. The lower curve shows the throughput for TCP with default parameters. The middle curve, for TCP with modified parameters, shows the improvement with an increased window size. The upper curve (for TCP-LFN) shows that with increased window size, more frequent round-trip time measurements, and slow start, TCP was able to make nearly full use of the available bandwidth. This protocol experiment also demonstrates the bandwidth-on-demand capability of ACTS.

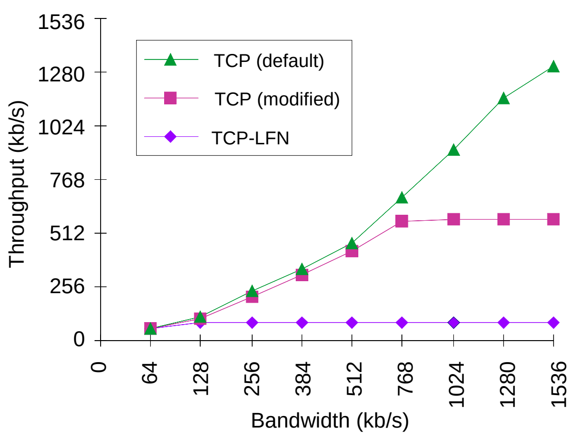


Figure 3. Throughput vs. bandwidth over ACTS for three versions of TCP/IP.

The interworking of satellite and terrestrial communications systems is of particular interest in the Satellite Studies program. During FY 96, ITS personnel began participating in two standards development organizations addressing satellite/terrestrial interface issues: Telecommunication Industry Association (TIA) Committee TR-34 (Satellite Equipment and Systems) and International Telecommunication Union-Radiocommunication Sector (ITU-R) Working Party 4B (Fixed Satellite Service). Contributions are focused on the performance of hybrid networks.

The Institute's Satellite Studies program also supports the Pan-Pacific Education and Communication Experiments by Satellite (PEACESAT) program. This program was established in 1971 to provide teleconferencing and data communications for about 40 locations in 21 countries in the Pacific basin. It provides interisland communications to support education, telemedicine, emergency communications, and other applications promoting economic development. During FY 96, ITS supported NTIA in testing the PEACESAT system's ability to accommodate new digital services. Results will allow more access to the Internet for PEACESAT users.

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

Advanced HF Testing and Evaluation

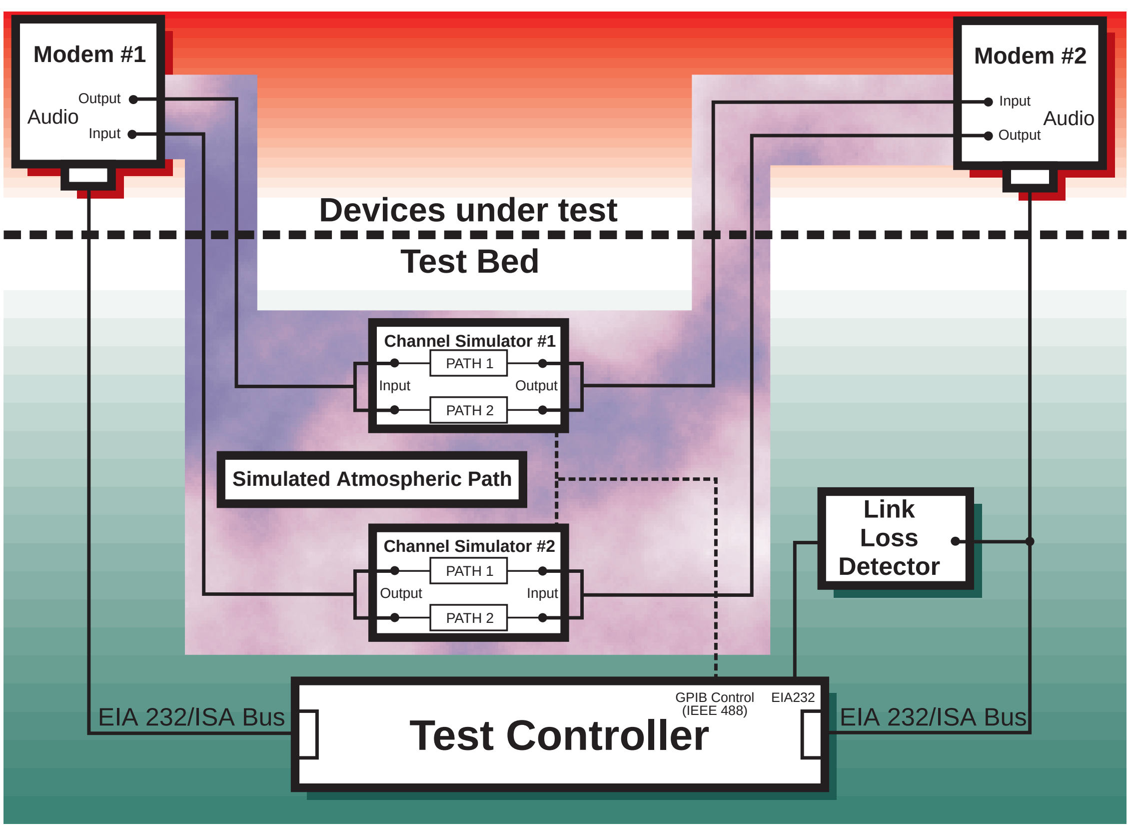
Outputs

- Facility for evaluating digital HF modems and protocols.
- Contributions to HF radio standards development.
- Audio compact disks for automatic link establishment interoperability testing.
- Anonymous FTP access to software for generating reference ALE tones.

The Federal Emergency Management Agency, the Department of Defense, and other Federal agencies depend heavily on HF radio to supplement wireline and satellite communications in natural disaster and national emergency situations. Communications efficiency and interoperability are vital in these situations, which increasingly require several different agencies to coordinate time-critical operations. HF radio technologies are being upgraded to meet these growing demands through innovations such as computer-controlled automatic link establishment (ALE). The Institute has contributed strongly to HF radio enhancement through laboratory and field testing of ALE and other HF technology advances.

The HF modem/protocol test bed at ITS supports this activity (see the Figure). The test bed's two narrowband HF channel simulators enable ITS engineers to subject HF modems and protocols to a wide range of controlled and repeatable channel conditions. The computer-based test controller permits extensive, unattended testing and allows experimental conditions to be changed with little or no equipment reconfiguration.

The Institute's HF simulation and laboratory test capabilities are supplemented by extensive field test facilities. During FY 96, ITS engineers continued cooperative work with counterparts in other organizations to develop an international test network for



HF modem/protocol test bed.

HF communications. The initial network will have nodes located at ITS, the Australian Defence Science and Technology Organization (Salisbury, South Australia), Rome Laboratories (Rome, New York), U.S. Navy NraD (San Diego, California), and Rockwell International (Richardson, Texas). The network is being developed in support of the National Communications System (NCS), which oversees Federal telecommunications standardization. NCS periodically solicits advanced HF radio technology contributions from Government and industry through announcements in the *Federal Register* and *Commerce Business Daily*. ITS and its partners will evaluate these and other technology contributions to advance the state-of-the-art in adaptive HF networking, high-speed data transmission, and reliable communications in stressed environments. Results will influence the development of national and international HF radio standards.

During FY 96, ITS personnel also continued the development of an HF radio ALE network simulation capability based on proposed Federal Standard 1046 (“Telecommunications: HF Radio Automatic Networking”). The efficiency, throughput, and delay of HF networks can be improved substantially through proper selection and use of advanced network features such as frequency scanning, sounding, polling, alternate or indirect routing, connectivity information exchange, automatic message exchange, and store and forward message exchange. However, these features have overhead implications and must be used carefully. Through computer simulation, ITS will study the impacts of these capabilities on network performance, both as an aid in preliminary evaluation of proposed standards and in support of over-the-air network tests. Results will aid users, designers, and system administrators in determining efficient network resource configuration and use.

Finally, ITS is developing test suites for assessing HF ALE protocol implementations. During FY 96, ITS engineers used an ALE protocol model, based on the ITS-developed Federal Standard 1045A (“Telecommunications: HF Radio Automatic Link Establishment”) to create an innovative, effective, and economical ALE radio test product called the ALE Clean and Degraded Tones audio compact disk set. This set of 13 CDs includes one Clean Tones CD and 12 Degraded Tones CDs. The Clean Tones CD contains 65 tracks of calibration tones and ALE-specific signals. These signals correspond precisely to the Federal Standard 1045A specifications and are uncorrupted by transmission effects. Each Degraded Tones CD contains several tracks of calibration tones, followed by 25 tracks containing 100 calls. Each CD was created under varying simulated channel conditions (see the Table).

The Clean Tones CD has been used successfully in laboratory testing and has been distributed widely in the HF radio industry. The Degraded Tones CDs will be used to assess radio system compliance with probability-of-linking statistics specified in Federal Standard 1045A. The ALE CD set directly supports the continuing ITS function of HF radio performance and interoperability testing. It has proven to be very useful to HF radio vendors and users in interpreting and analyzing prototype implementations of the Federal Standard. ITS is providing continued support to the High Frequency Industry Association and other Government agencies in extending the ALE CD capabilities to meet the needs of both radio users and vendors.

The ALE CDs are now available to the public through NIST Special Databases. The Clean Tones CD is listed in the NIST Standard Reference Data Products Catalog 1995-96 (NIST Special Publication 782, 1995-96 Edition). The Degraded Tones CDs will be listed in the next edition of the catalog. For more information, phone (301) 975-2208, FAX (301) 926-0416, or e-mail SRDATA@enh.nist.gov.

The audio tones recorded on the CDs were created using an ITS-developed computer program called *alecall*. This program also can create sound files on a personal computer, which then may be output through a sound card. This ability to create ALE calls “on the fly” is useful for real-time laboratory testing and analysis. The *alecall* program is available to the public by anonymous FTP through the Internet. FTP to *ntia.its.bldrdoc.gov* and enter ftp as your user name and your full e-mail address as the password. Retrieve the readme.txt file from the /dist/ale-cd directory for detailed file instructions.

CD Channel Conditions

CD #	Channel Conditions	SNR (dB)
CD02-05	Gaussian Noise	-2.5 thru 0.0
CD06-08	CCIR Good	0.5 thru 8.5
CD10-13	CCIR Poor	1.0 thru 11.0

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

Network Flow Modeling

Outputs

- Large-scale network simulation tools.
- Network component loading and message delay characterizations.
- Network planning recommendations.

Design of large-scale data communication networks requires quantitative means of relating offered traffic and network capacity with network performance characteristics such as message transfer delays. The Institute maintains several computer-based modeling and simulation tools that facilitate such studies. One of these tools, the ITS Network Flow Model (NFM), has been used to provide network planners with first-level estimates of network component loads and message transfer delays in several local area network (LAN) interconnection scenarios. The NFM is based on the Block Oriented Network Simulation (BONeS) software system.

A key requirement for the NFM is to produce network characterizations that reflect variations in user traffic over time. ITS has developed a flexible bimodal traffic generator for the BONeS system that controls the arrival of network messages in any hourly period over a 9-hr business day. The traffic generator produces traffic peaks during the midmorning and midafternoon hours, corresponding to the observed peaks in typical office activity. The message interarrival statistics are controlled by a Poisson process, which is used frequently in simulating human interactions with a system.

In a recent application, the NFM was used to examine traffic flows in a two-tier network interconnecting 2,500 users (Figure 1). In the modeled configuration, the first tier (backbone) network connects five subnetworks. Each subnetwork connects five user groups. Each user group has 100 users. Typically, each user group would be localized in a separate building or work area. The modeled backbone and second-tier networks could be either 10-Mbit/s Ethernet or 100-Mbit/s fiber-distributed data interface (FDDI) facilities. The structure of the model could be modified easily to represent any similar network architecture. The number of users in each group, the number of messages per day, the network

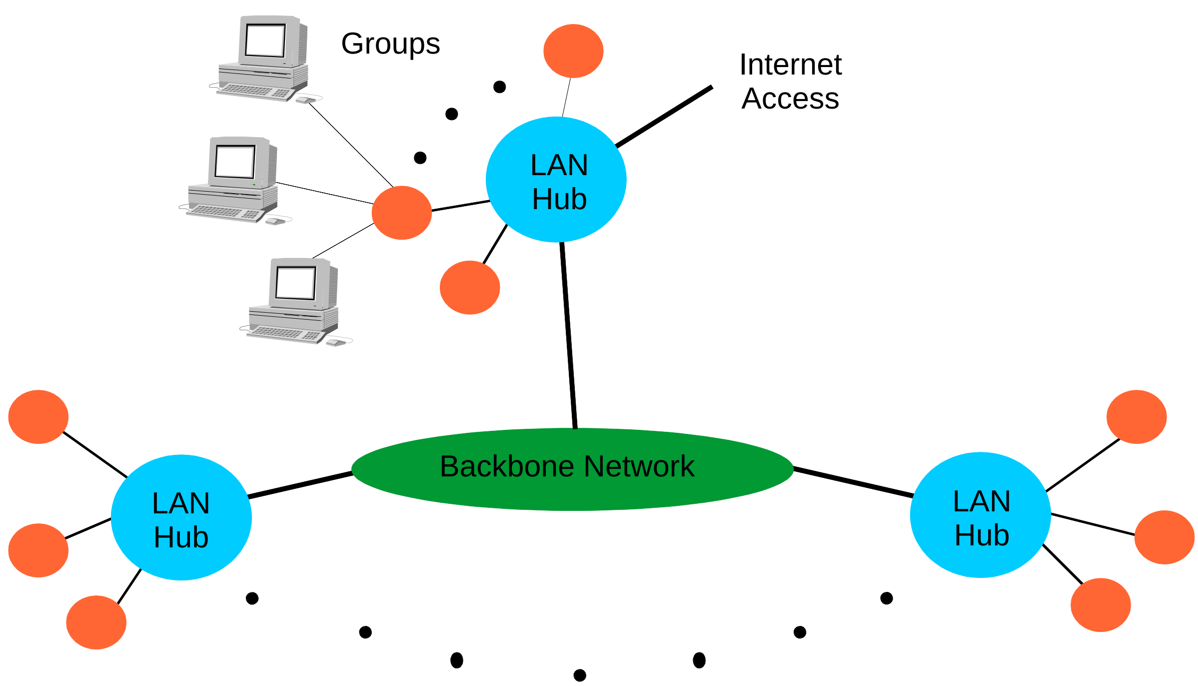


Figure 1. Two-tiered network examined by the Network Flow Model.

transmission speeds, and the lengths of individual messages are all variable input parameters.

Figure 2 shows a representative output of the NFM for the LAN interconnection scenario described. The plots depict average traffic loads on the 10-Mbit/s backbone network as a function of time for each of four message types (e-mail, server, ftp, and World Wide Web). The plots also show corresponding average and maximum loads for the four message types combined. The traffic data are aggregated on a second-by-second basis and are averaged over 60-s periods. The maximum load is the largest traffic level observed in any 1-s interval over the same 60-s period. At Ethernet speeds, the backbone LAN is saturated during peak periods, with averages well above the recommended 6 Mbit/s maximum. Figure 2 also demonstrates that e-mail traffic is the main contributor to the total load, as expected.

Figure 3 shows corresponding NFM simulation results for message transfer delays. In this example, the daily traffic load is approximately 150,000 messages for the 2,500 users. During peak traffic periods, delays that exceed 35 s could be experienced in the Ethernet network configuration. In the FDDI configuration, corresponding delays averaged 40-50 ms. Figure 3 also shows the delays of each LAN independently. The most sensitive LAN at the Ethernet speed is the backbone, which accounts for most of the long delays. ITS recommended that this network be considered as an upgrade to FDDI, since 30-s transmission delays are unacceptable for many interactive computer applications.

The data plotted in Figure 3 also show that larger delays are experienced during the afternoon peak period as compared to the morning peak period. This asymmetry is attributable to queuing effects. Network planners and system administrators must be sensitive to such effects in balancing traffic, capacity, and performance requirements to achieve cost-effective network designs.

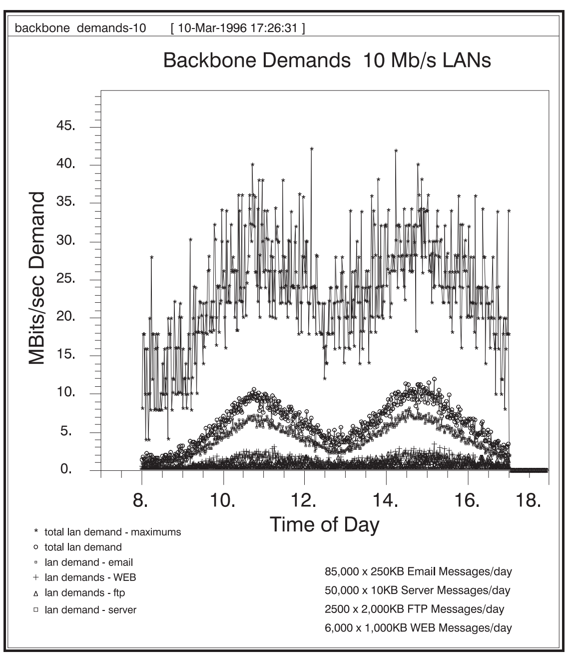


Figure 2. Network Flow Model simulation of local area network traffic loads.

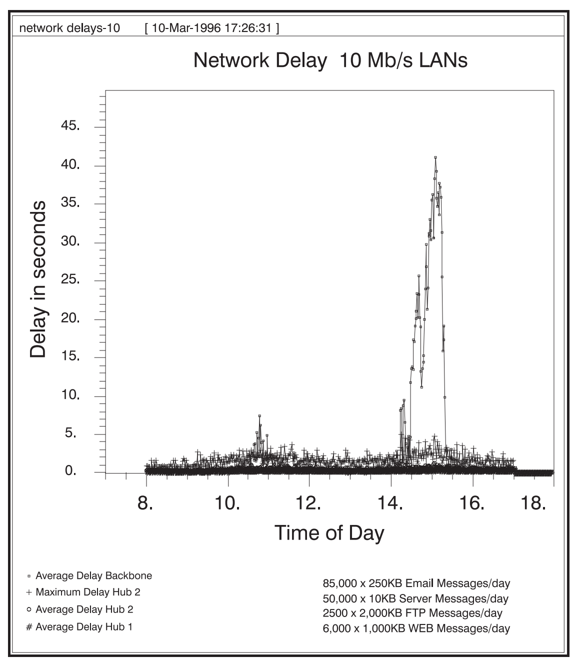
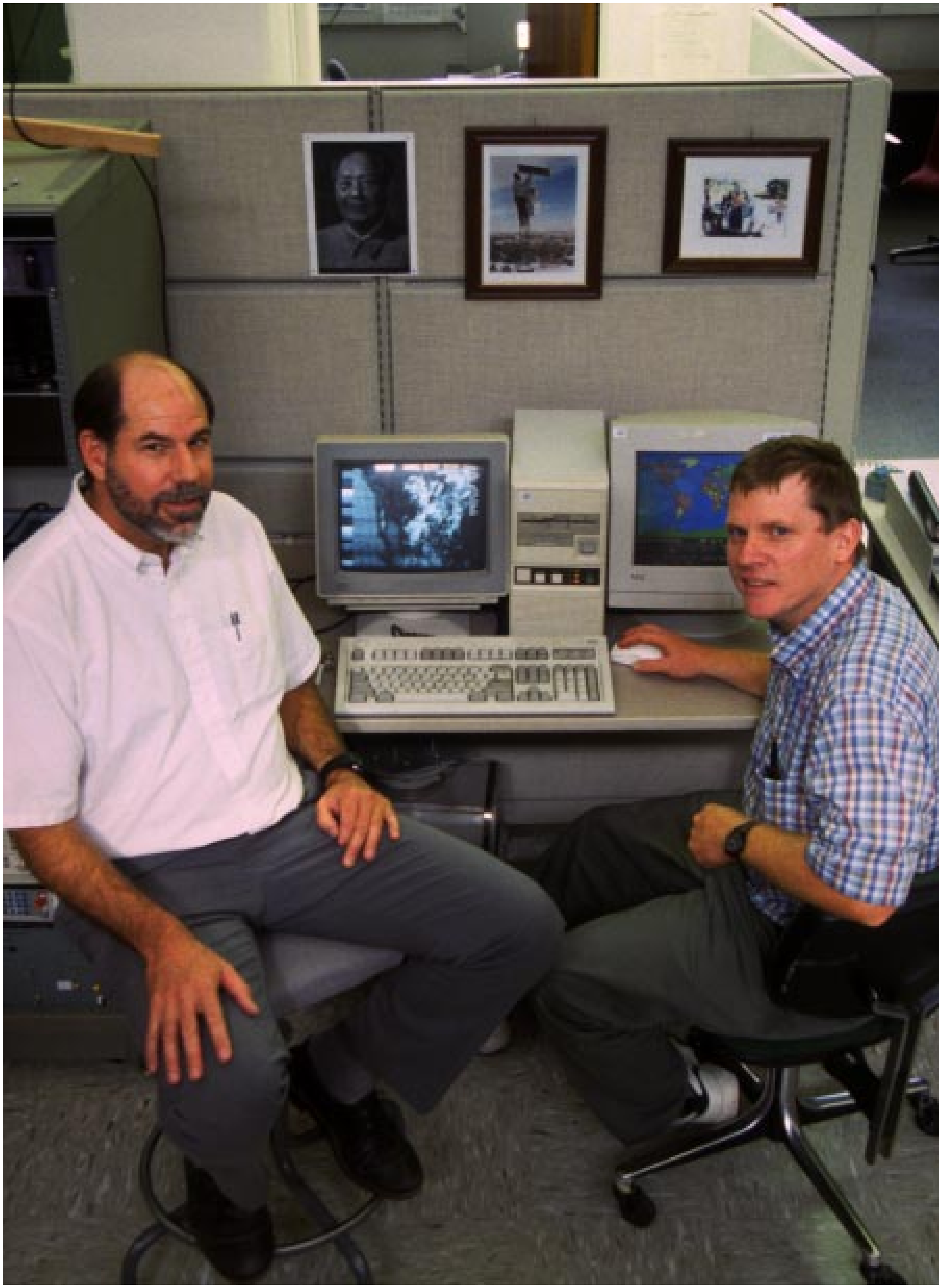


Figure 3. Network Flow Model simulation of message delays.

For more information, contact:
Steven M. Davidson
(303) 497-3411
e-mail sdavidson@its.bldrdoc.gov



ITS staff members performing tests on the National Oceanic and Atmospheric Administration weather satellite receiver (photograph by F.H. Sanders).

Applied Research

The rapid growth of telecommunications over the last 40 years has caused crowding in the radio spectrum. New technology has required a new understanding of radio wave behavior in all parts of the radio spectrum. The Institute studies the lowest frequencies to the highest frequencies in use.

This work extends ITS' expert understanding of the ways that radio signal propagation is affected by the earth's surface, the atmosphere, and the ionosphere. It is resulting in new propagation models for the broadband signals used in some of the new radio systems. Other efforts are increasing our understanding of the propagation of millimeter-wave frequencies, providing a large band for future expansion of new 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. (US WEST), Telesis Technologies Laboratory (TTL), Integrator Corp., Motorola, Inc., the American Automobile Manufacturers Association, and Hewlett-Packard Co. (HP).

Advanced Radio Research

The Institute conducts research of digital radio receivers with the ultimate goal of digitizing the RF signal at the output of the receive antenna. This technology will become increasingly important as mobile cellular, satellite, and personal communications services radio systems are developed. This project is funded by NTIA.

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, HP, and TTL.

Wireless Propagation Research

The Institute studies 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 as these systems are developed and deployed. Projects are funded by NTIA, US WEST, Motorola, Inc., and HP.

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 National Security Agency.

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.

Advanced Radar Research

The Institute studies the effect of the radio propagation channel on many radar applications. This knowledge allows simulation of the total system in order to predict radar performance. The project is funded by NTIA and the National Center for Atmospheric Research.

Cooperative Research with Industry

Outputs

- Simulation model of broadband millimeter-wave propagation to assist in the evaluation, planning, and deployment of local multipoint distribution services.
- Models of broadband radio propagation channels that will be employed in wireless technologies for a rural community communications infrastructure.
- Continuous wave and wideband measurements at 28-30 GHz for characterization of broadband propagation in urban and suburban environments.

The Technology Transfer Act of 1986, 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 is actively engaged 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 Laboratory (TTL); US WEST Advanced Technologies (US WEST); Bell Atlantic Mobile Systems; GTE Laboratories, Inc.; US WEST New Vector Group; General Electric Company; Motorola, Inc. (Motorola); Hewlett-Packard Company (HP); Integrator Corp.; 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. Under CRADAs with Motorola and US WEST, ITS has conducted field measurements to characterize the PCS radio channel in a variety of urban and suburban environments. The data obtained from these field measurements is used to validate simulation models that the Institute has developed. As part of the CRADA with US WEST, ITS served as a neutral independent observer as the Joint Technical Committee on Wireless Access (JTC) conducted field trials of proposed PCS air-interface standards in the Boulder Industry Test Bed. Trials were completed on six PCS air-interface standards and the results have been reported to the JTC.

ITS has entered into 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. This knowledge is essential to the development of future automotive electronics.

ITS has developed a PCS/local multipoint distribution service (LMDS) propagation model, within a geographic information system, to predict line-of-sight coverage of the PCS/LMDS signals (see the Figure). As part of a CRADA with Integrator Corp., ITS will use a terrain database with this PCS/LMDS model to produce signal coverage patterns for rural communities; Integrator Corp. will investigate the feasibility of wireless local or metropolitan area network technology as the basis for a rural community communications infrastructure.

ITS has been a premier laboratory for millimeter-wave research for two decades. Now ITS is applying this unique expertise while researching radio propagation considerations for LMDS. ITS has CRADAs with TTL and HP for LMDS research. Under the current agreements, ITS is developing propagation models for the LMDS channel, making field measurements to characterize radio frequency propaga-

PCS/LMDS line-of-sight coverage for Boulder, Colorado.

tion of an LMDS system, and developing 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 the measurement of the complex-valued radio channel impulse response, and is ideal for making outdoor impulse response measurements. The three-dimensional signal coverage map is generated using the PCS/LMDS propagation model in conjunction with a digital elevation model.

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 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 continues to commit substantial resources of its own to the development of these new technologies and standards.

Recent Publications

R. Dalke, G. Hufford, and R. Ketchum, "Radio propagation considerations for local multipoint distribution systems," NTIA Report 96-331, Aug. 1996.

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

Outputs

- Journal article on analog-to-digital converters for radio receiver applications.
- NTIA Report on RF and IF digitization in radio receivers.
- Presentation on direct digitization at the RF in radio receivers at the 1996 National Radio Science Meeting.

As advances in technology provide increasingly faster and less expensive digital hardware, more of the traditionally analog functions of a radio receiver will be replaced with software or digital hardware. The final goal for radio receiver design is to digitize directly the RF signal at the output of the receive antenna and therefore implement all receiver functions in either software or digital hardware. Figure 1 shows an example of this ideal receiver employing direct digitization at the RF.

The trend in receiver design is evolving toward this goal of the ideal receiver by incorporating digitization closer and closer to the receive antenna for systems at increasingly higher frequencies and wider bandwidths. While radio receivers with analog RF front-ends using digitization at baseband have been around for many years, the popularity of receivers using digitization at the IF is increasing rapidly. Digitization at the RF, without an initial downconversion, currently is used in only very restricted applications where the maximum frequency is relatively low and/or the spurious-free dynamic range (SFDR) requirements are relatively low.

There is keen interest in replacing analog hardware with digital signal processing in radio receivers for several reasons. One reason is the potential for the reduction in product development time since changes can be implemented in software instead of altering the hardware. Digital technology can offer a more ideal performance for implementing signal-processing functions. The repeatability and temperature stability can be substantially better. Functions that are not implementable in analog hardware (such as finite impulse response filters) can be implemented in software. The tuning or "tweaking" typically required in an analog implementation to achieve the desired performance is not required for digitally implemented signal-processing functions. Cost-effective multipurpose radios can be designed to allow reception of different modulation types and bandwidths simply by changing the software that controls the radio. Finally, there can be significant cost savings in implementing the receiver.

The Institute initiated a general study of the theory, concepts, and practical hardware limitations of radio receivers that use digitization at the RF or IF. This was the first phase of an effort to investigate the impact of radios that use digitization at the RF or IF on management of the Federal radio spectrum. This initial study examined the key factors in radio receivers that use digitization at the RF or IF: analog-to-digital conversion and digital signal processing. (While not explored in this study, for applica-

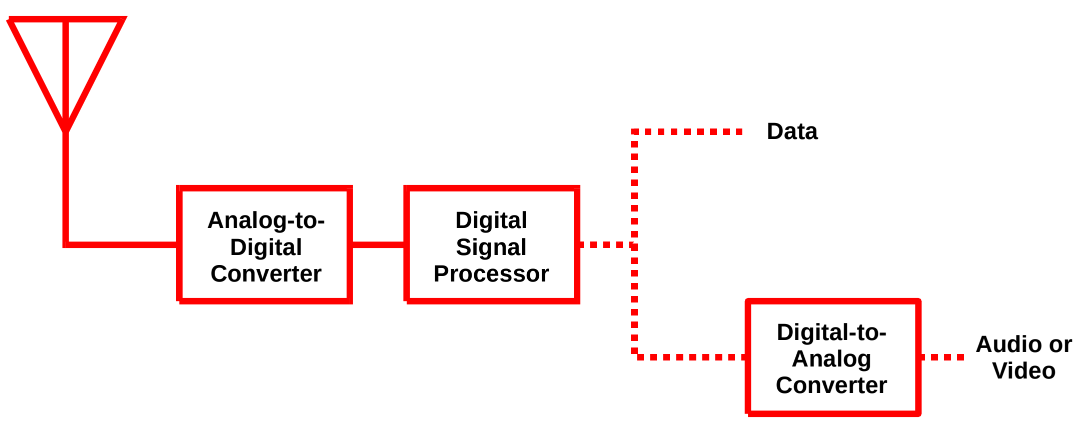


Figure 1. Ideal receiver employing direct digitization at the RF.

tions requiring analog output, such as voice, digital-to-analog conversion also is a factor.)

Results of this study revealed many interesting and important findings. Digitization at the RF, in general, requires some type of bandlimiting (filtering) and amplification before the actual digitization takes place. The required amount of filtering and amplification is application-specific. While analog-to-digital converter (ADC) performance is improving rapidly, Figure 2 shows that there is a tradeoff: high sampling rates or high resolution can be achieved, but not both simultaneously. Therefore, the high sampling rate ADCs required for wide bandwidth applications may not have sufficient SFDR. Digitization at the RF now is being considered for satellite receivers since a large SFDR is not a necessity, very high sampling rate ADCs already exist, and even faster ADCs are being developed. For receiver applications requiring a large SFDR, such as HF communications, digitization at the IF is currently a more practical option.

The study concluded that digital signal processors may present an even greater limitation than ADCs in radio receivers using digitization at the RF or IF. The speed, size, and cost of these processors are important for a particular radio receiver application. Examples of the processing speed of different processing platforms are shown in Figure 3. The requirement for real-time operation for many radio receivers places a heavy burden on these processors. The amount of time required for signal processing is a function of the bandwidth of the signal, the speed of the processor, and the number and complexity of the algorithms required to perform the needed radio receiver functions.

Various quantization techniques, nonlinear compression devices, postdigitization algorithms for improving dynamic range, sampling downconverters, and specialized integrated circuits were investigated in the study since they are expected to be useful in the development of radio receivers employing digitization at the RF or IF. Several examples of radio receivers (currently existing or in development) that use digitization at the RF or IF were identified in the study.

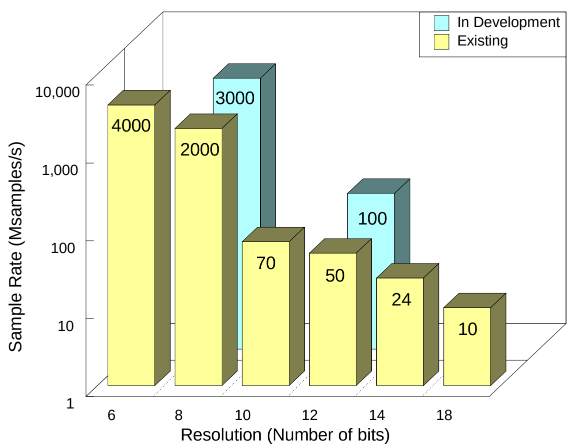


Figure 2. Examples of high-speed ADC performance.

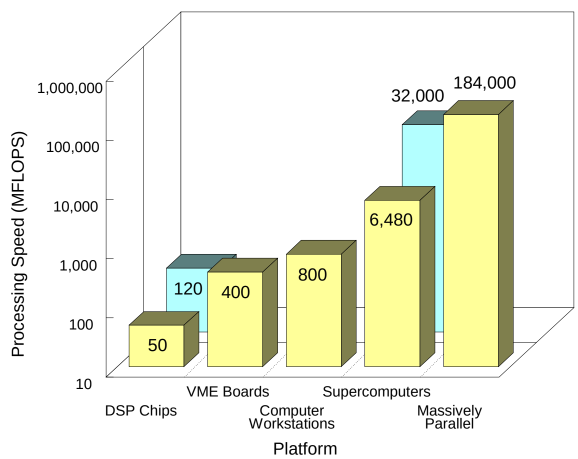


Figure 3. Examples of processing technology.

Recent Publications

J.A. Wepman and J.R. Hoffman, "RF and IF digitization in radio receivers: theory, concepts, and examples," NTIA Report 96-328, Mar. 1996.

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

Millimeter-wave Research

Outputs

- Channel measurements of local multipoint distribution service propagation.
- Millimeter-wave propagation channel models.
- Simulation of local multipoint distribution service performance, including the effects of nonlinear radio equipment, the propagation channel, and noise.

In the past few years, consideration has been given to the reallocation of frequencies in the extremely high frequency (EHF) band so that wireless video, voice, and data services could be made commercially available to consumers. The potential availability of spectrum for these “wireless” services has resulted in an increased commercial interest in propagation effects for millimeter waves. Of particular interest is the development of a wireless alternative to cable television and local exchange carrier offerings called local multipoint distribution services (LMDS). A clear understanding of the interplay between millimeter-wave propagation effects and methods proposed for the broadcast and reception of such services is essential to the development and implementation of LMDS.

For over two decades, ITS has been a leader in the study of propagation effects for millimeter waves. This work includes the development of measurement techniques; an extensive database of measured propagation effects such as multipath in urban and rural environments (including the effects of vegetation); and the development of analytical methods for prediction of atmospheric effects (e.g., attenuation and dispersion by absorption lines). Through cooperative research agreements, ITS is applying its technical expertise in millimeter waves to areas of commercial interest in the planning and development of LMDS.

There are several unanswered questions relating to radio propagation in urban and suburban environments that need further study to properly address the viability of LMDS for terrestrial digital broadcasts. As part of the millimeter-wave research efforts, ITS recently completed a comprehensive study of the LMDS radio propagation channel in a variety of suburban environments. This study included field measurements at 28.8 and 30.3 GHz, as well as a statistical analysis of the data and the development of propagation channel models. For this study, the millimeter-wave measurements were used to determine area coverage, multipath effects, time variations of the received power, excess path loss (relative to free space), signal depolarization, and the effects of variations in receiver height on area coverage for an LMDS broadcast cell.

The LMDS measurements were made using the ITS wideband probe (Violette, et al., 1983). A narrowband signal was used to make received power measurements over a large dynamic range with high sensitivity. The wideband signal provided 2-ns multipath resolution. In addition to calculating the area coverage and related parameters discussed above, the measured impulse response data was used to develop an appropriate time-varying radio channel model (tap delay line) that can be used in conjunction with the digital simulation models developed by ITS. An example of three-dimensional impulse responses resulting from this measurement program are shown in Figure 1.

The successful implementation of proposed terrestrial digital broadcast systems (e.g., television) requires an estimate of the expected bit error probabilities based on the various radio system components that will be implemented (e.g., modulation, coding, equalization, and nonlinear amplifier effects) and the radio propagation channel. Given the complex nature of both the radio system and the propagation channel, simulations are required to estimate bit error probabilities and service coverage areas. ITS has developed a computer simulation model that can be used to predict bit error probabilities as a function of the radio propagation channel, channel equalization, digital modulation methods, and radio system components (e.g., amplifiers and filters).

An important consideration in the implementation of broadband terrestrial broadcast using millimeter waves is the nonlinear effects of the transmitter amplifier. The traveling wave tube amplifier (TWTA) is a highly efficient broadband millimeter-wave amplifier and has been proposed for use in LMDS transmission systems. The nonlinear charac-

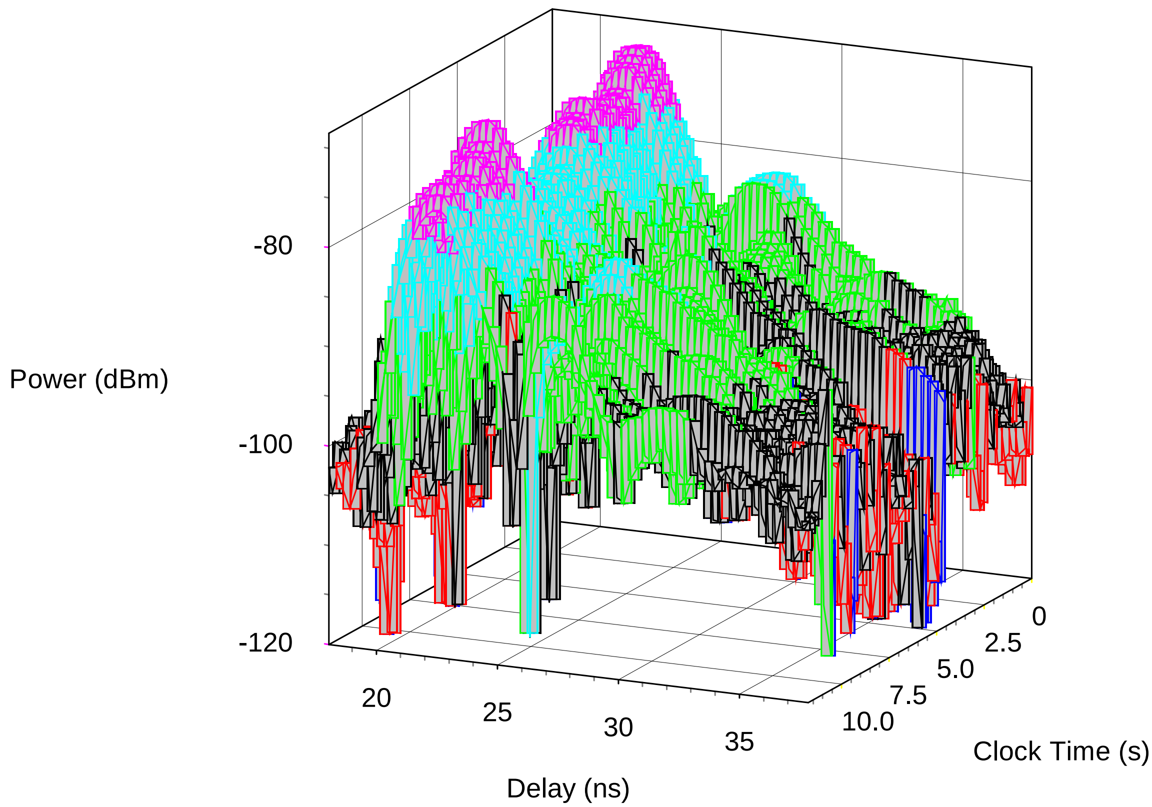


Figure 1. Measured three-dimensional impulse responses for moderate wideband channel.

teristics of this type of amplifier result in signal distortion which is due primarily to intermodulation. Using the ITS model, we can for example, predict how the TWTA affects symbol error probability for a variety of modulation methods. In Figure 2, the symbol error ratio is plotted as a function of input backoff (and carrier-to-intermodulation ratio; C/I) for 64 quadrature amplitude modulation (64QAM) and 64 trellis-coded modulation (64TCM). In this example, RF bandwidth = 7.2 MHz, transmitter filter rolloff = 50%, and three carriers have a guard band of 20%. The results indicate that trellis coding significantly reduces the symbol error ratio when the amplifier backoff is greater than 5 or 6 dB.

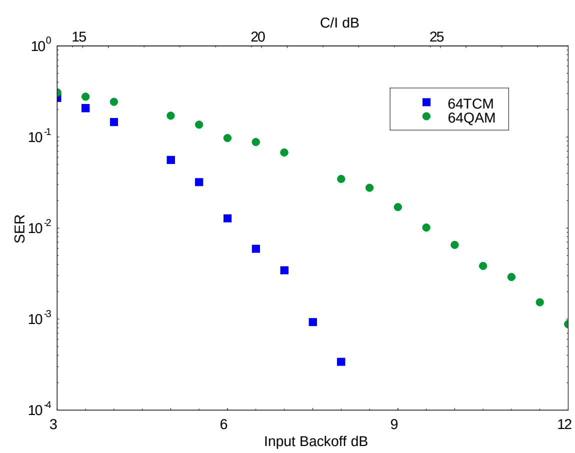


Figure 2. Simulated traveling wave tube amplifier nonlinear effects on the received symbol error ratio (SER) for 64QAM and 64TCM.

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

Wireless Propagation Research

Outputs

- Indoor channel modeling.
- Impulse response prediction for an indoor propagation channel.
- Delay spread prediction of the multipath channel.

In designing wireless telecommunication systems, it is important to control the intersymbol interference (ISI), or more importantly, the bit error rate (BER). The ISI is related directly to the multipath phenomena resulting from objects such as walls, furniture, and people in the propagation path between the transmitter and receiver (Figure 1). The delay spread of the impulse response of the propagation channel is a measure of the multipath effects. The BER in most wireless systems is proportional to the square of the ratio of the delay spread to the symbol period. Therefore, in choosing the maximum data rates for a particular system, it is important to know the delay spread for the indoor environment where the system is to be deployed. The Institute is involved in several research efforts to estimate the impulse response and delay spread for indoor propagation channels.

The Institute has developed a geometric optics (or ray-tracing) model for calculating the impulse response of an indoor radio propagation channel. The mobile impulse response generator (MIRG) is implemented on a personal computer and calculates the impulse response of an ideal indoor 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. The plane wave Fresnel reflection coefficients are used to calculate the reflection of the rays that strike one of these surfaces. Typically, impulse responses generated using only five reflections provide a sufficient description for an indoor channel. However, the higher-bounce capability allows for the study of special cases, such as metallic rooms and anechoic chambers at fre-

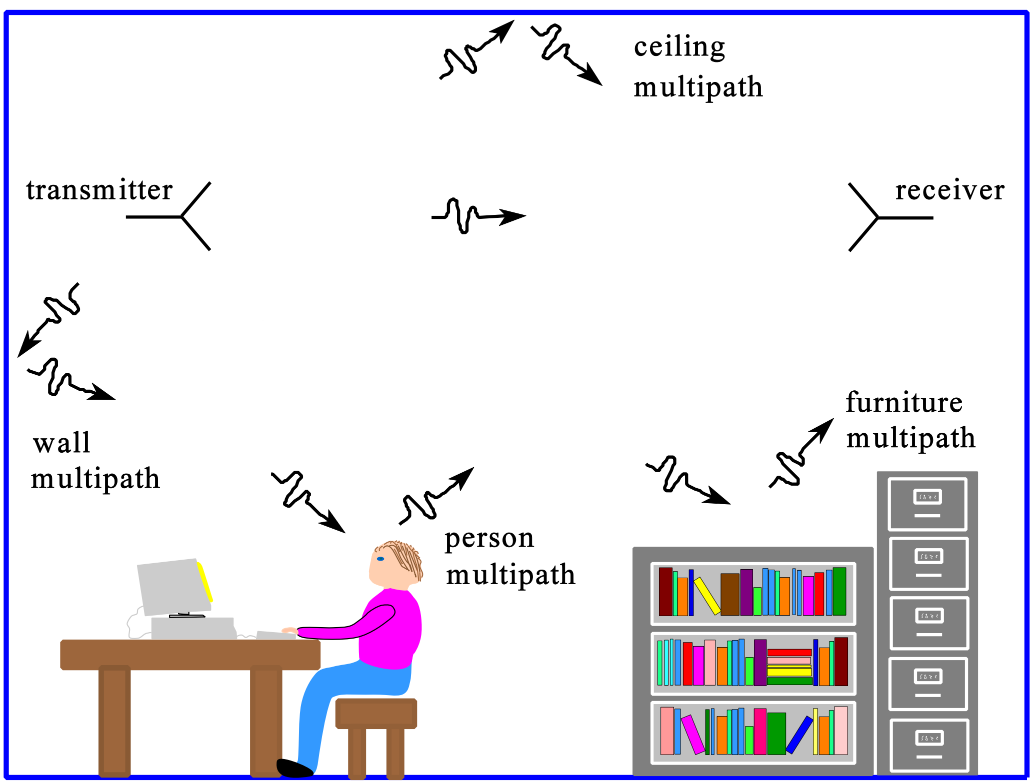


Figure 1. Illustration of multipath for an indoor propagation channel.

quencies below 80 MHz. The output of this model can be used easily as a channel model in radio system software simulation. Figure 2 shows the magnitude of the impulse response at one location in a room with a length of 12 m, a width of 8 m, and a height of 6 m.

The Institute also is investigating the use of a three-dimensional finite difference time domain (3D-FDTD) approximation to Maxwell's Curl Equations to determine the impulse response of the indoor channel. The advantage of this approach is that it is very accurate, and objects in the rooms can be incorporated easily. The disadvantage, however, is that this approach can be computationally intensive, requiring large amounts of computer memory and time. Different approaches for eliminating some of these pitfalls are currently under investigation.

While both the FDTD and the ray-tracing techniques are accurate, they can be very time-consuming. The Institute presently is developing a simplified model for calculating the impulse response and delay spread for the indoor channel. For years, the acoustic community has been estimating the decay rates (or reverberation time) of acoustic cavities in rooms, and recently these concepts have been used to analyze electromagnetic anechoic test chambers. By extending this work, it is possible to show that the average impulse response of a room can be given by very simple expressions. The parameters in this expression are the volume of the room, the surface area of the room, the amount of energy absorbed into the walls, the energy loss through doors and windows, and the energy absorbed into objects within the room. Once the impulse response is obtained, the delay spread can be calculated easily.

Preliminary results from this model are shown in Figures 2 and 3. Figure 2 compares the impulse response from the model to results obtained from MIRG; Figure 3 compares the results from this model to measured data. The advantage of this model is that it is based upon simple assumptions, such that the impulse response and delay spread can be calculated in a matter of seconds on a personal computer.

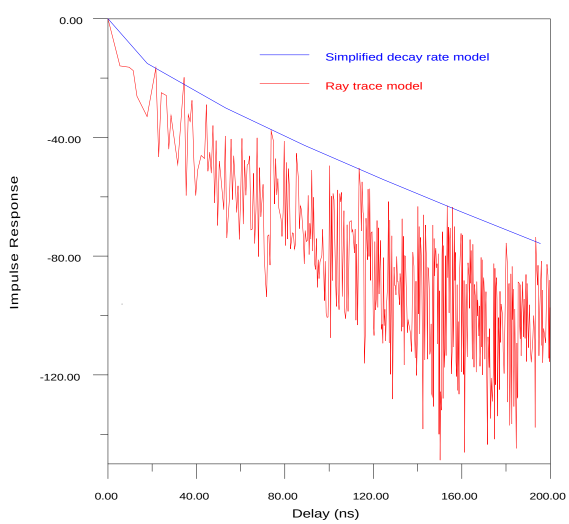


Figure 2. Comparison of the impulse response obtained from the mobile impulse response generator to the simplified decay rate model.

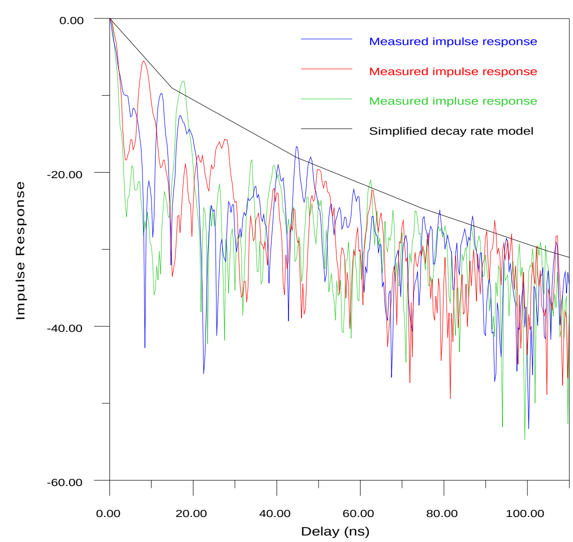


Figure 3. Comparison of the impulse response obtained from measurements to the simplified decay rate model.

Recent Publications

C.L. Holloway and E.F. Kuester, "Modeling semi-anechoic electromagnetic measurement chambers," *IEEE Trans. Electromagnetic Compatibility*, vol. 38, no. 1, pp. 79-84, 1996.

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

Outputs

- System simulation (modems, channel, and noise) software modules.
- Predicted bit error rate performance as a function of signal-to-noise ratio.
- Predicted speech and image quality using compression as a function of bit error rate and signal-to-noise ratio.

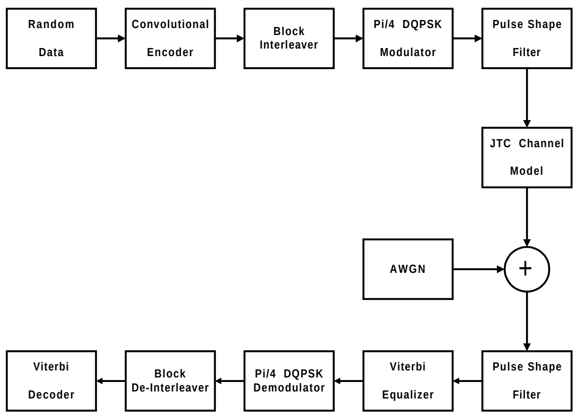
ITS has been conducting research of wireless systems for many years. Past efforts include radio, television, and radar channel propagation and impulse response measurement and modeling; software simulation of the channel for system performance prediction; hardware simulation of the channel for system hardware testing; and network performance prediction. Recent efforts have predicted system performance through software simulations of the system and channel for a variety of channels, modems, processing techniques, and sources. Channels include ionospheric, outdoor macrocell and microcell, and indoor microcell environments. Processing techniques such as compression, encryption, equalization, and channel coding have been used.

ITS has investigated the effects of multipath fading, noise sources, and cochannel interference on performance of land mobile radio, wireless private branch exchange, global system for mobile communications, IS54/136 personal communications services (PCS), wireless local area networks, and ionospheric high-frequency systems. Three types of channel distortion were used in the simulations: (1) time-varying multipath, (2) additive noise, and (3) cochannel interference. Sources include data, pulse-code modulation and voice-encoded speech, fax, uncompressed and discrete cosine transform (DCT)-compressed images, and automatic link establishment signals. Performance is described by bit error rate (BER), frame error rate, eye diagrams, in-phase/quadrature diagrams, character error rate, speech quality, and image quality.

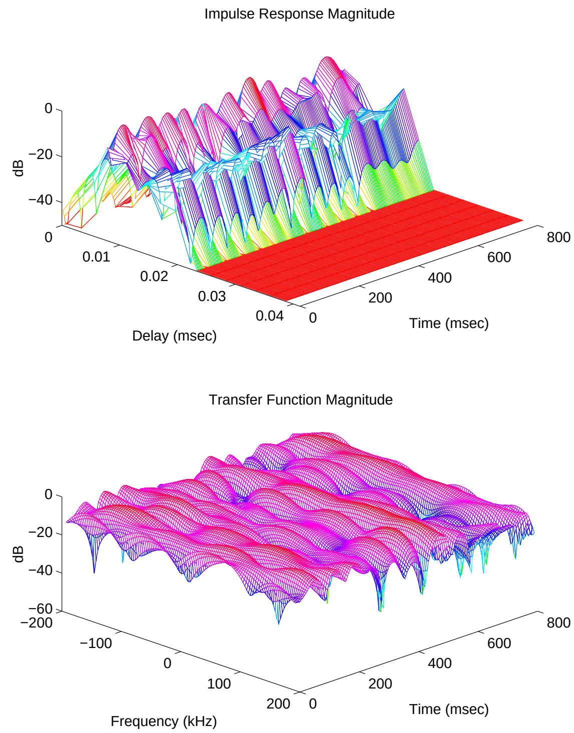
Implementation of the digital PCS standard IS54/136 is described in Figure (a) and was simulated to be operating at pedestrian speeds in an urban/suburban low-rise building and antenna environment described by Figure (b). These time-division multiple access (TDMA) systems are designed for the 1900-MHz frequency band and can operate in the bandwidth of a 30-kHz advanced mobile phone service (AMPS) channel. Compressed speech and image sources were transmitted by the B/4 DQPSK modem through a channel model derived from the Joint Technical Committee (JTC) air-interface standards that were proposed for PCS. The system employed a convolutional channel encoder and block interleaver, and a Viterbi equalizer and decoder. Figures (c) and (d) illustrate the predicted performance of this system.

Figure (b) describes the JTC channel C model characteristics in the time and frequency domain. It exhibits Doppler fading along the time axis (maximum Doppler frequency of 9.6 kHz) caused by the pedestrian velocity of 1.5 m/s and frequency-selective fading. Fading along the frequency axis corresponds to the coherence bandwidth of 106 kHz associated with the delay spread of 1500 ns specified in the 6 tap model. Doppler and frequency-selective fading and baud rate contribute to burst errors in the system. In addition, uncorrelated errors are caused by additive white Gaussian noise (AWGN). The fading effects of the channel are the primary error source beyond 20-dB signal-to-noise ratio (SNR) where the performance is channel limited.

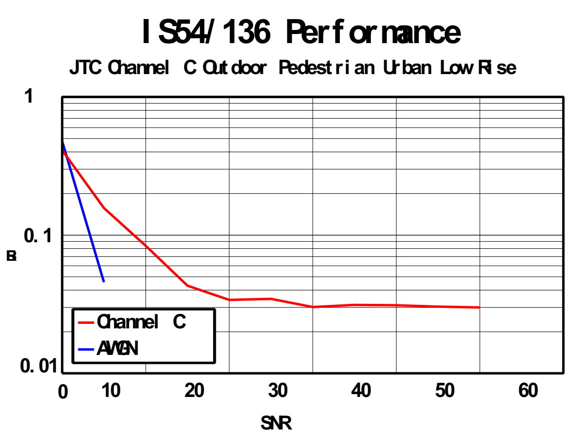
Figure (c) demonstrates the channel-limiting effect on the BER performance. The AWGN curve shows how rapidly performance would improve if there were only random noise causing bit errors. Transmission of voice-coded speech through channel C at 30 dB SNR resulted in distortion corresponding to a quality class of 2.5 out of 5. This channel model is intended to represent worst case conditions for this environment. A topographic map image compressed and transmitted using the DCT coefficients resulted in a quality class of 3 out of 5 at 30 dB SNR. The resulting received image after decompression is shown in Figure (d). Block errors are observed due to channel fading, causing error burst lengths exceeding the correction capability of the channel coding. Predicted performance of wireless systems is used to compare proposed wireless standards, determine design specifications, and select deployment parameters of military and commercial systems.



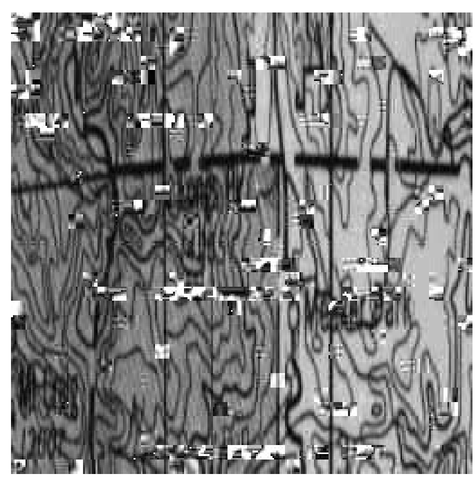
(a)



(b)



(c)



(d)

Performance of IS54/I36 PCS communicating over a JTC channel C model for worst conditions in an urban/suburban low-rise, low antenna environment: (a) simulation block diagram, (b) channel characteristics, (c) bit error performance, and (d) received image with a signal-to-noise ratio of 30 dB using discrete cosine transform compression.

Recent Publications

E.A. Quincy, R.J. Achatz, and M.Terada, "IS54/136 PCS performance prediction for standard JTC channels," in *Proc. Wireless 1996 8th Internat. Conf.*, Calgary, Alberta, 1996, pp. 43-57.

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

HF Channel Modeling and Simulation

Outputs

- Real-time wideband HF channel simulator.
- Radio Science and IEEE Transactions publications.
- Contributions to international HF standardization.

Channel simulators have long been accepted as an effective means for evaluating radio system performance. Advantages of using channel simulators in radio testing include repeatability, convenience, stationarity, availability, control of channel conditions, and relatively low cost. ITS has played a leading role in the development of simulators for HF communication channels for many years. In recent years, this work has been focused on the simulation of wideband (up to 1 MHz) HF channels. This work supports the development of national and international HF radio standards and the testing of prototype spread-spectrum HF radio equipment.

During FY 96, the Institute's wideband HF channel-modeling and simulation program had four primary goals. The first goal was to enhance the existing ITS-developed wideband HF channel simulator to permit the simulation of atmospheric, Gaussian, and impulsive noise. A commercially available waveform generator was integrated with the existing simulator to provide these new capabilities. The waveform generator is programmable, and thus has the flexibility to emulate realistic HF noise environments—including the complex environments specified in noise models developed in prior ITS work.

The second goal was to disseminate key program results in technical publications. Staff members submitted a technical paper describing the wideband HF noise and interference model to the journal *Radio Science*. A second paper, which provides a comprehensive summary of the Institute's research in wideband HF channel modeling and simulation, was accepted for publication in the *IEEE Transactions on Communications*. Several other technical papers, addressing particular aspects of wideband HF channel characterization, were initiated and will be submitted for publication early in FY 97.

The third goal of the FY 96 HF Channel Modeling and Simulation program was to make technical contributions to the development of international standards on HF communications. An existing International Radio Consultative Committee (CCIR) Report and associated International Telecommunication Union-Radiocommunication Sector (ITU-R) recommendation describe HF ionospheric channel simulators and their use (CCIR, 1990). The HF channel model specified in the CCIR Report was developed from a database consisting of 36 min of information collected on a single day on a single, 1300-km mid-latitude path under quiet ionospheric conditions. The valid bandwidths of the model were 2.5 kHz, 8 kHz, and 12 kHz for the three sample periods observed. The model assumes that delay dispersion is negligible. Although this narrowband model has been implemented widely and has proven to be quite useful, an enhanced model that accommodates wider bandwidths, additional propagation conditions, and more accurate representation of noise and interference is needed to properly assess advanced HF equipment. In FY 96, Institute engineers submitted a proposed U.S. contribution that defines such an enhanced model to U.S. ITU-R Working Party 9C. The contribution specifies (1) a new propagation model that emulates HF propagation conditions for either narrowband (a few kHz) or wideband (hundreds of kHz) channels; (2) an accurate noise and interference model for most operational HF environments; and (3) an architecture to implement those models in a real-time simulator. This contribution was approved by the U.S. Working Party and will be submitted to the corresponding international ITU-R Working Party at its January 1997 meeting.

A final goal of the HF Channel Modeling and Simulation program was to apply the Institute's wideband HF channel simulator in testing high-speed wideband HF modems. The simulator was used in the preliminary evaluation of a direct sequence spread-spectrum modem being developed for the Department of Defense. The test results showed that the high-speed modem could operate effectively over ionospheric paths; this supported a decision to advance the Department of Defense's research and development program towards full implementation. A block diagram and front panel photograph of the ITS-developed wideband HF simulator are provided in Figures 1 and 2, respectively.

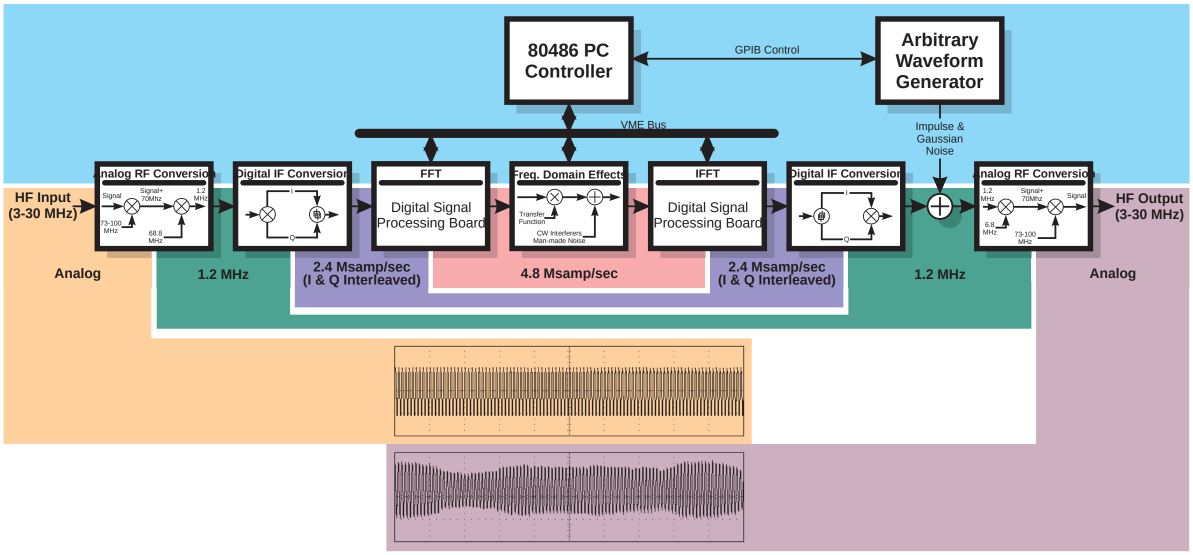


Figure 1. Block diagram of the wideband HF channel simulator.

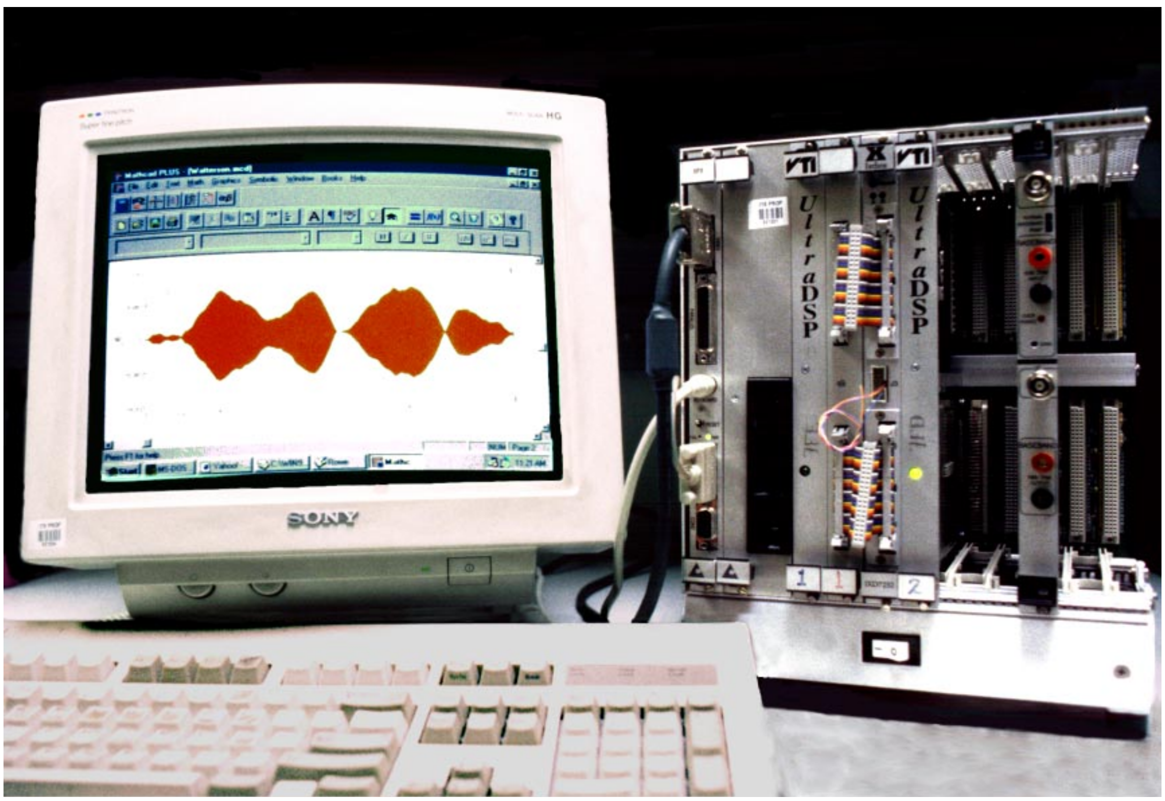


Figure 2. Hardware for the wideband HF channel simulator (photograph by F.H. Sanders).

For more information, contact:
James A. Hoffmeyer
(303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Advanced Radar Research

Outputs

- Performance prediction of radar systems.
- Development of radar algorithms for a wide array of applications.
- Radar simulation test bed for various systems.

The Institute is involved in research related to radar systems simulation and algorithm development. In this effort we are developing a radar simulation and performance prediction test bed (Figure 1). This test bed allows the radar system, the propagation channel, and the scattering object to be modeled, which then allows for performance prediction and algorithm development. Such a test bed is general enough to handle a wide array of radar applications. This past year our efforts concentrated on military radars used for target identification, and meteorological radars for determining wind speed.

There is a need in the military to identify a radar target (e.g., a ground vehicle, a ship, or an aircraft) from the target's scattered radar signature. The performance of signal/image-processing algorithms used to form radar target identification depends upon the radio propagation effects such as time-varying multipath, dispersion, noise, and attenuation. These propagation effects can seriously degrade the radar signature and significantly influence the target identification process. The Institute is investigating the use of minimum mean-square-error (MMSE)-equalizing filters on radar signatures to mitigate the effects of multipath and noise.

Figure 2 shows a typical multipath and noise environment that a radar is confronted with when trying to identify a ground vehicle. By knowing the statistical characteristics of the multipath channel, the MMSE filter can be used to recover the ground vehicle radar signature in a noisy, multipath environment. Figure 3 illustrates the improvement in the

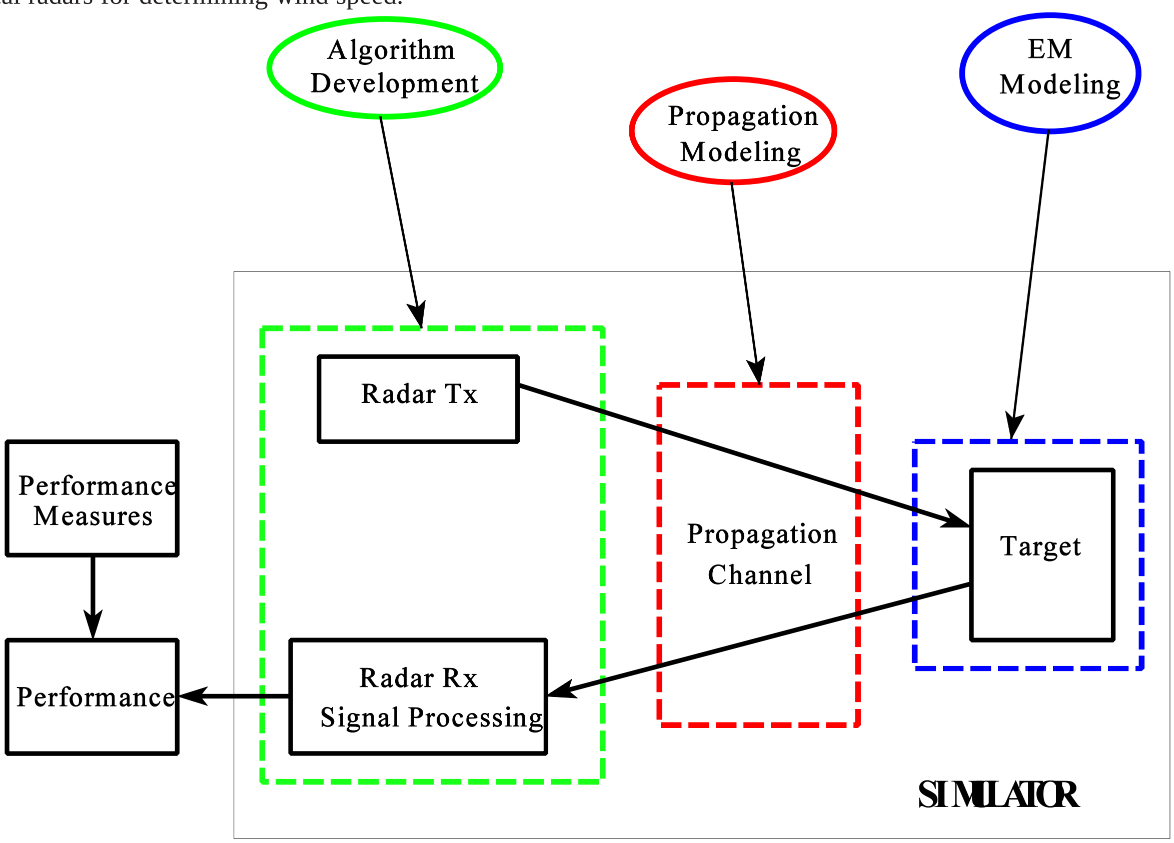


Figure 1. Radar simulation and performance prediction test bed.

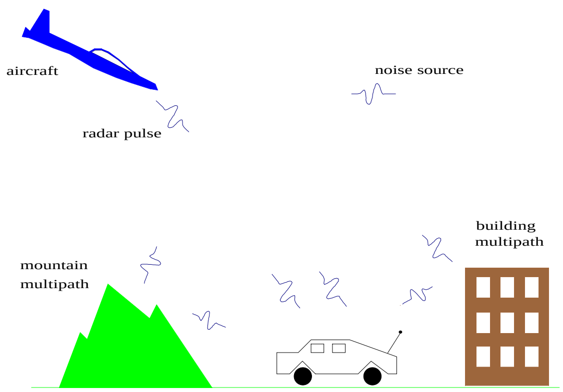


Figure 2. Radar target in a multipath environment.

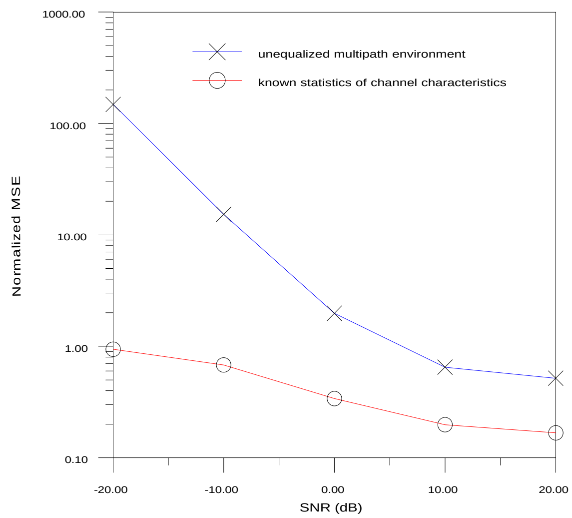


Figure 3 Normalized mean-square-error equalizer performance comparison.

radar signature if a MMSE equalizer filter is used for a two-path Rayleigh channel. Plotted in this figure is the mean-square-error (MSE), which is a comparison between the idealized radar signature (the signature of just the ground vehicle with no noise or multipath effects) to the realistic signature (the signature of the ground vehicle with noise and multipath effects). Small values of MSE indicate that the noise and multipath effects are mitigated, and the identification process is greatly enhanced.

In large-scale climate modeling, it is important to know the three-dimensional speed of the air mass in the lower boundary layer (from the surface to a height of 5 km). The wind speeds are used as initial starting points for these climate models. At the Institute we have been working with the National Center for Atmospheric Research to develop theoretical scattering models for the atmosphere in the lower boundary layer. These models have allowed us to develop a 915-MHz radar system and algorithms for determining these boundary-layer winds. The system is presently being field tested and preliminary results look promising. These algorithms that were developed have the potential to yield frequent and accurate measurement data needed in the boundary layer for other important meteorologic parameters (such as momentum and temperature flux estimates).

Recent Publications

E.A. Quincy, R.A. Dalke, R.J. Achatz, C.L. Holloway, and P.M. McKenna, “Radar target image resolution enhancement via propagation channel equalization,” in *Proc. SPIE Radar Processing, Technology, and Application*, vol. 2845, Denver, Colorado, 1996, pp. 49-55.

R.J. Doviak, R.J. Lataitis, and C.L. Holloway, “Cross correlation and cross spectra in spaced antenna wind profilers part I: theoretical analysis,” *Radio Science*, vol 38, no. 1, pp. 79-84, 1996.

C.L. Holloway, R.J. Doviak, S.A. Cohn, and R.J. Lataitis, “Algorithms to retrieve wind from spaced-antenna wind profilers,” in *Proc. 27th Internat. Conf. Radar Meteorology*, Vail, Colorado, 1995, pp. 323-325.

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

ITS staff member using the ITS multimedia subjective testing facility.

ITS Tools and Facilities

Advanced Communications Technology Satellite Test Facility

The ITS Advanced Communications Technology Satellite (ACTS) test facility consists of a complete ACTS earth station (ES), provided through a Memorandum of Understanding with the National Aeronautics and Space Administration (NASA), and associated digital interface and test equipment. The experimental Ka-band ES is capable of 1.8-Mbit/s integrated services digital network (ISDN) communications and provides full-mesh connectivity with other ACTS ES's. The digital interface equipment includes a narrowband ISDN switch, narrowband ISDN interfaces and terminal adaptors, an ATM switch, and associated ATM network interfaces. The test equipment includes two data communication test sets and three voice quality assessment systems. The data communication test sets are UNIX work stations that implement ITS-developed, standard data communication performance measures. Associated satellite clocks allow precision time stamping of performance-significant events. The voice quality assessment systems consist of desktop and laptop personal computers and digital signal-processing boards controlled by ITS-developed software that implements innovative perception-based quality measurements. The ACTS test facility is available for Government, industry, and university use as approved 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, subjective and objective analyses, and reproduction of audio signals. Subjective analyses are conducted in an acoustically isolated and treated room that conforms with international recommendations for subjective listening and viewing tests. Test participants hear test material through headphones or loudspeakers and use an electronic pen to record their responses on a small screen. Workstations equipped with 16-bit digital-to-analog converters control the reproduction of test material and the collection of responses.

Also available in the Audio Quality Laboratory are digital audio tape recorders, compact disk players, digital audio encoders and decoders, a spectrum analyzer, signal generators, level meters, mixers, amplifiers, and microphones. Together, this equipment allows ITS staff and cooperative research partners to determine the impact of various coding and transmission systems on the perceived quality of audio signals. This equipment also allows staff to develop and test objective measurements of the perceived quality of audio signals. The Audio Quality Laboratory is connected with the Video Quality and Digital Networks Laboratories. These connections enable integrated testing of multimedia communication systems that transport audio, video, and data communications.

Digital Sampling Channel Probe

ITS, in a joint effort with Telesis Technology Laboratory, has developed and patented an innovative digital sampling channel probe (DSCP). The probe, consisting of both a transmitter and receiver, is used to make complex impulse response measurements of outdoor communication channels and in turn to determine the wideband propagation characteristics. Such measurements are used for modeling and simulation. Unlike the analog sliding correlator equivalent, the DSCP is capable of impulse response acquisitions within the period of 1 pseudorandom noise code word length (typically 51 µs). Used extensively for channel characterization of cellular and personal communications services, the probe typically has 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 µs. Bandwidths as large as 50 MHz also have been used. Currently, the probe has a dual channel capability, making it possible to measure simultaneously two different pseudorandom noise codes on different carrier frequencies, with different antenna polarizations, or with different antenna spacings. By using synchronized timing, it can measure absolute time-of-flight from transmitter to receiver. In addition, it has the capability to acquire multiple impulse responses in succession and thus determine Doppler spread at high vehicle speeds. The present system has a noise figure of 7 dB and when used with an automatic gain control is capable of measuring signals within a range of power seen in cellular sites characterized by severe multipath and shadow fading. Concurrent acquisition of a global positioning system has given the system the capability of marking the data with speed and location.

New DSCP systems currently are under development. These include a VME system with rapid acquisition for extended periods of time and real-time processing of impulses. A wide bandwidth system (1 GHz null-to-null) also is under development and is particularly suited for indoor measurements where high resolution is required. Future plans include expanding the probe to more channels for use in measurements helpful in analyzing the potential benefits of adaptive antenna arrays. For further information, see the description at the following web site address: *http://www.its.bldrdoc.gov/pub/chprobe/chprobe.html*.

HF Communications System Test and Evaluation Facility

The primary components of the ITS HF Communications System Test and Evaluation Facility are (1) audio compact disk (CD) equipment and software for testing HF radio automatic link establishment (ALE) interoperability; (2) HF network simulators; (3) HF channel and modem software simulators; and (4) narrowband and wideband HF real-time hardware channel simulators. This facility focuses on performance and interoperability testing, particularly on testing HF communications systems related to National Security Emergency Preparedness. The facility also is particularly useful in conducting the proof-of-concept testing that is a critical part of the standards development process.

The audio CD equipment and associated software are used to test ALE protocols and techniques for adaptive HF radios as defined in Federal Standard 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 Federal Standard 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 Federal Standard 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 network simulators are a pair of tools that includes a discrete event simulation model for HF ALE radio networks, and a network protocol simulator. The discrete event simulation model is a computer program used to determine the effects of periodic sounding on network operation. The network protocol simulator is a real-time digital signal processor that simulates HF ALE radio network operation. This latter simulator is very useful for the evaluation of advanced HF networking protocols.

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 chose the proper mix of newly developed advanced 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 and a wideband channel simulator. The latter simulator was developed recently at ITS and has a unique capability for simulating the channel conditions encountered on HF communication links in order 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 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, satellites links, and other systems.

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. The most recent addition is 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 and Video Quality Laboratories (described separately in this section). Future applications of this group of integrated laboratories will support the development of performance standards pertaining to multimedia communications.

ITS Local Area Network

ITS maintains a state-of-the-art local area network (LAN) to provide public information services via the Internet, and also to support intranetworking services and laboratory interconnection requirements. The ITS World Wide Web Home Page at *http://www.its.bldrdoc.gov/* features on-line publications and project and personnel information. The ITS anonymous FTP site at *ftp.its.bldrdoc.gov* also provides on-line reports and standards working group information. From these sites one can access special features such as the on-line *Glossary of Telecommunication Terms* (Federal Standard 1037C), or download a complete CD-ROM of HF automatic link establishment tones.

The LAN's 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. Nearly 200 devices are supported on the Ethernet. Connections also may be made to laboratory test beds featuring synchronous optical network/asynchronous transfer mode and 100Base-TX fast Ethernet facilities. This provides ITS with unique flexibility and quick turnaround time to respond to new programmatic needs.

Intranetworking services include both client-server and peer-to-peer support for 180 personal computers, UNIX workstations, X-terminals, Macintosh computers, and printers in an open-systems environment using the TCP/IP suite with Network File System (NFS) and Session Message Block (SMB) protocol services. The network is managed using the simple network management protocol (SNMP). For more detailed information regarding ITS information services or network technology, please contact Darren L. Smith, Network Manager, (303) 497-3960 or e-mail dsmith@its.bldrdoc.gov.

Laboratory Atmospheric Simulator

ITS has a unique atmospheric simulator facility to measure the radio refractive index of moist air. A computer-controlled environmental chamber, resonator, and millimeter-wave vector network analyzer provide highly accurate measurements of attenuation and phase delay in the 10-220 GHz frequency range. The simulator permits the pressure to be varied over six orders of magnitude (0.001-103 millibars), the relative humidity to be varied between 0 and 100%, and the temperature to be varied between 270 and 320 K. The simulator provides a means of conducting millimeter-wave propagation experiments in a controlled environment that can represent atmospheric heights from the earth's surface to 120 km. This latter height provides a realistic basis for experiments that are representative of satellite heights for most applications. This tool is available for use by private parties on a reimbursable basis.

Microwave Line-of-Sight and Troposcatter Channel Probes

ITS has constructed hardware channel probes to measure multipath on both line-of-sight and troposcatter communication links. Multipath is a radio communication channel impairment in which two or more replicas of a transmitted signal are received at slightly different times as a result of reflections, scattering, or atmospheric refraction in the channel. Multipath changes dynamically and can substantially deteriorate radio performance. The ITS channel probes measure multipath by injecting an RF signal, modulated by a digital pseudorandom sequence, into the channel and cross-correlating the received sequence with a replica of the transmitted one.

Mobile Millimeter-wave Measurement Facility

ITS maintains two measurement vehicles capable of radio channel characterization over a wide frequency range. Both vehicles are equipped with on-board power, telescoping masts, azimuth elevation controllers, and global positioning systems with dead-reckoning backup. A suite of measurement equipment also is available for use in these vehicles. This includes wideband systems for measuring radio channel impulse response at 900 MHz, 1.8 GHz, and 30.3 GHz, as well as additional narrowband measurement capabilities up to 96 GHz. Most recently, these facilities have been used for characterizing radio channel impulse response and Doppler spectrums for cellular radio at 915 MHz, and proposed personal communications services at 1.8 GHz. Millimeter-wave measurements also have been made over a 1-GHz bandwidth centered at 30.3 GHz to characterize proposed local multipoint distribution service radio channels. These vehicles and equipment allow ITS to provide industry with site-specific measurements to support the development of new radio communication technologies.

Radio Spectrum Measurement Systems

ITS has built and operates a number of spectrum measurement systems. The radio spectrum measurement system (RSMS), ITS' primary system, provides a vehicularly mounted, self-contained capability for measurements between 1 MHz and 19.7 GHz. ITS also has available several suitcase-deployable systems, called compact radio spectrum measurement systems (CRSMS), which can be used across the same frequency range. The RSMS and CRSMS incorporate a combination of commercially available hardware, hardware custom-built 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 equipment racks, and storage space. CRSMS capabilities include the same software as the RSMS, but typically include only as much hardware as is required to perform a particular measurement. Local arrangements must be made for CRSMS shelter and power.

RSMS and CRSMS use extensive computer control for measurements. RSMS and CRSMS measurements can be performed in fully automatic, semiautomatic, and fully manual modes. Mobile radios, fixed communication links, radars, ISM devices, broadcast signals, and special-purpose transmitter systems can be measured. For a complete description of the RSMS, see Appendix A of F.H. Sanders, et al. (1996; see ITS Publications in FY 1996).

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 increases, the average level of electromagnetic energy across the spectrum will 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 computer-based, and 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 is currently developing models in the GIS environment for personal communications services (PCS). 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.

RAPIT - Provides on-line access to the latest in VHF/UHF propagation models. It can calculate basic transmission loss and other engineering information, such as received signal levels over irregular terrain for the design or analysis of broadcast and mobile radio systems. These program options allow a user to review the effects that input parameters, such as antenna height, have on the received signal.

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. Plotted outputs either can 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’ 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. It shows 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.

Video Quality Laboratory

The ITS Video Quality Laboratory is used to develop and test automated techniques for assessing the quality of video and image data. The laboratory contains both objective and subjective measurement facilities. 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, video monitors, image capture and display equipment, video signal generators, and video coders/decoders (codecs); (3) a 40-GB read/write optical jukebox for storing digitized images; and (4) real-time personal computer-based systems that can perform video quality measurements in the field. In FY 96, significant improvements were added to the video quality measurement software (written in C++) to support expanding video quality studies in national and international standards bodies and associated Government and industry technology assessment needs. These improvements include field-accurate video processing (as opposed to frame processing, used in the prior system); improved spatial and temporal registration of input and output images; and accurate precalibration of the sampled images. The subjective measurement facilities include two sound-proof audio-visual testing rooms (added in FY 96) and an ITU-R Recommendation 500 viewing room. These subjective facilities provide a means for validating objective video and image parameters implemented in computer-based measurement systems. The audio-visual testing rooms will be used for assessing interactive multimedia communications equipment and services. The video quality laboratory hardware and software have been designed specifically to address the difficult problem of assessing digital video systems. For example, video codecs are used in conjunction with network error simulators to generate impaired digital video for objective and subjective quality testing.

Wireless Link Simulation Laboratory

This laboratory at ITS simulates wireless systems and channels to predict performance for data, compressed or uncompressed speech and images, and fax sources. 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 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. 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 also may 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 are used to determine design and deployment specifications for these systems.

PC/DOS-based and UNIX-based link software simulation packages and a generic channel simulator software package are available to perform wireless simulations, predict performance, 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 television monitor are available for storing and demonstrating speech, images, and video images. 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 also is available for testing transmitters and receivers.

ITS Projects in FY 1996

American Automotive Manufacturer's Association

Roadway RF Environment Measurements - Perform measurements of the roadway RF environment in the vicinity of high-power transmitters.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Department of Defense

Channel Modeling Support for Personal Communications Services - Assist in providing access to channel measurements for review, validating Dr. Bello's generic channel simulator models, and promulgating these personal communications services models in standards bodies.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

Standards Development for Asynchronous Transfer Mode - Assist the National Security Agency in developing standards for interfaces and operation of the global grid.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@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 data services with STU-111 applications in the proposed TR41.6 unlicensed personal communications services standards.
Project Leader: Steven M. Davidson
e-mail sdavidson@its.bldrdoc.gov

Wireless Interoperability of Asynchronous Transfer Mode - Investigate current domestic and international standardization activities related to wireless asynchronous transfer mode applications. Develop a structured plan to satisfy the National Security Agency's security, performance, and interoperability needs.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail vpietrasiewicz@its.bldrdoc.gov

Federal Aviation Administration

Analysis for the Radio Frequency Interference Monitoring Systems Program - Analyze requirements for and develop a custom radio spectrum measurement system. Integrate and test prototype mobile systems.
Project Leader: Patricia J. Longstaff (303) 497-3568
e-mail plongstaff@its.bldrdoc.gov

Federal Highway Administration

Electromagnetic Compatibility of the Intelligent Transportation System - Provide support to the intelligent transportation system program as it applies advanced technology for safety and throughput. Develop communication systems that will provide information to travelers, their vehicles, and the infrastructure. Support development of standards and identify spectrum issues as they relate to electromagnetic compatibility of intelligent transportation systems. Perform measurements of the highest electromagnetic fields and general background fields in the roadway environment from 30 MHz to 18 GHz in the San Diego, California area. Independently evaluate the performance of the AM subcarrier traveler information system.
Project Leaders: Robert J. Matheson (303) 497-3293, Nicholas DeMinco (303) 497-3660, Frank H. Sanders (303) 497-5727, and John J. Lemmon (303) 497-3414
e-mail matheson@its.bldrdoc.gov, ndeminco@ its.bldrdoc.gov, fsanders@ its.bldrdoc.gov, and jlemmon@its.bldrdoc.gov

Feasibility Study of Global Positioning System Augmentation for Intelligent Transportation Systems - Examine the feasibility of using augmented global positioning systems to support intelligent transportation systems.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Federal Railroad Administration

Telecommunications Study - Review and comment on the ability of a new railroad telecommunications system to provide safety features desired by the Federal Railroad Administration.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail eldon@its.bldrdoc.gov

General Electric

Emission Measurements of an RF-driven Lighting Device - Measure radio emissions of a newly developed lighting device. Characterize the RF emissions produced by the device; these data will be used by the Federal Communications Commission to introduce such devices into the commercial market.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Hewlett-Packard Company

Local Multipoint Distribution Services Signal Coverage - Develop signal coverage plots of the 28- to 30-GHz local multipoint distribution service radio channel in Fremont, California.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Measurements and Model Development for Local Multipoint Distribution Services - Provide knowledge on radio propagation in the 28- to 30-GHz band through measuring the local multipoint distribution service propagation channel within existing cellular transmitter sites. Develop channel models to be used for system simulation.
Project Leader: Peter P. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Integrator Corporation

Wireless Signal Coverage for Rural Communities - Use a terrain database with the personal communications services model to produce signal coverage patterns for three rural communities. Develop a model for the orthogonal frequency division multiplexing radio link that will facilitate analysis of the radio link.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@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 sv@its.bldrdoc.gov

American National Standard Institute Vocabulary Development - Provide expert technical support in the revision of the ANSDIT, *American National Standards Dictionary for Information Technology*, and in participation in the U.S.-member body of American National Standard Institute to develop U.S. technical contributions to ISO/IEC-2382, Information Technology—Vocabulary, within ISO/IEC JTC 1 /SC 1.
Project Leader: Evelyn M. Gray (303) 497-3107
e-mail evie@its.bldrdoc.gov

Broadband Digital Telecommunications - Test and verify broadband multimedia quality measurements. Contribute results to national and international standards organizations.
Project Leader: Coleen T. Jones (303) 497-3764
e-mail cjones@its.bldrdoc.gov

Compact Disk for Interoperability Testing of HF Automatic Link Establishment Radios - Develop an audio CD that will provide a precise duplication of the HF radio automatic link establishment (ALE) tones that represent standardized calls used for communications between ALE-equipped HF radios.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Development of the Multimedia Handbook - Develop a multimedia handbook in conjunction with the Multimedia Performance Measurements Subcommittee of the Federal Telecommunications Standards Committee. Present technical contributions to standards fora.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail webster@its.bldrdoc.gov

HF Modem Performance and Interoperability Testing - Conduct performance and interoperability testing on HF modems to enhance the ITS HF test bed.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

HF and Wireless Standards Development - Provide technical support for evaluating and extending current telecommunications technology with respect to requirements for National Security Emergency Preparedness communications.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Hypertext Version of Federal Standard 1037C - Provide expert technical support in developing this revised standard and making it electronically available. This document provides Federal departments and agencies a comprehensive source of definitions of terms used in telecommunications and related fields.
Project Leader: Evelyn M. Gray (303) 497-3107
e-mail evie@its.bldrdoc.gov

Integrated Voice/Video/Data Performance Measurement - Provide expert technical support for integrated voice/video/data measurement and standardization.
Project Leader: David J. Atkinson (303) 497-5281
e-mail dj@its.bldrdoc.gov

Interoperability and Performance Assessment of Multimedia Information Systems - Support the development of an interoperability and performance reference model for multimedia information systems (MMIS); track the development of MMIS standards and products, nationally and internationally.
Project Leader: William R. Hughes (303) 497-3728
e-mail whughes@its.bldrdoc.gov

Interoperability Standards for Land Mobile Radio - Assist in the development of interoperability standards for the next generation of digital land mobile radios, particularly in the area of security. This information will be used for radios and standards related to public safety applications.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@its.bldrdoc.gov

Modeling, Simulation, and Testing of Asynchronous Transfer Mode over Wireless Telecommunications - Assess proposed asynchronous transfer mode service over current and future wireless telecommunication technologies.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

National Security Emergency Preparedness Communications via Satellite - Determine qualitative and quantitative performance of satellite communications used in tests of National Security Emergency Preparedness situations.
Project Leader: William A. Kissick (303) 497-7410
e-mail billk@its.bldrdoc.gov

Operation and Maintenance Engineering Services - Provide technical support to NCS on performance and interoperation of Government telecommunication assets for National Security Emergency Preparedness purposes.
Project Leaders: James A. Hoffmeyer (303) 497-3140 and A. Glenn Hanson (303) 497-5449
e-mail jhoffmeyer@its.bldrdoc.gov and ghanson@its.bldrdoc.gov

Protocol Testing for the HF Radio Network - Develop an HF radio automatic link establishment network protocol simulator capability into the existing suite of test equipment.
Project Leader: Larry M. Brewster (303) 497-5953
e-mail lbrewster@its.bldrdoc.gov

Research and Development Engineering Services - Test the performance of HF radio modem products that implement packet HF protocols. Provide technical support to the research and development aspects of performance and interoperation of Government telecommunication assets for National Security Emergency Preparedness purposes.
Project Leaders: James A. Hoffmeyer (303) 497-3140 and A. Glenn Hanson (303) 497-5953
e-mail jhoffmeyer@its.bldrdoc.gov and ghanson@its.bldrdoc.gov

Testing and Evaluation Related to HF Standards Development - Assist in developing Federal standards for telecommunications.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Wideband HF Channel Simulator for the Extended Interoperability Test Facility - Obtain and integrate an upgraded, portable wideband HF channel simulator capability into existing equipment.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

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

National Institute of Standards and Technology

Communication Standards for the 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 vpietrasiewicz@its.bldrdoc.gov

National Oceanic and Atmospheric Administration

NOAA Weather Satellite System Analysis- Provide analysis of VHF satellite-to-ground link propagation channels and environments that introduce attenuation, noise, and possibly multipath and fading. Characterize attenuation, link budget, and noise, with multipath and fading cases reflected in the attenuation, link budget, and bit error ratios.
Project Leader: Roger A. Dalke (303) 497-3109
e-mail rdalke@its.bldrdoc.gov

NTIA

Audio Quality Standards Development - 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 sv@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 Radio 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

Broadband Wireless Standards - Provide leadership and technical contributions to national and international wireless standards development that enhances domestic competitiveness, improves foreign trade opportunities, and facilitates 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 eldon@its.bldrdoc.gov

Broadcasting Studies - Provide engineering support to the Executive Branch to select the best alternatives for efficient use of the broadcasting spectrum. Analyze and develop alternatives for the National Television System Committee and high-definition television/advanced television spectrum sharing.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail eldon@its.bldrdoc.gov

Digital Networks Performance - Maintain, develop, and enhance digital network performance measurement software and perform integrated multimedia performance measurement experiments. Develop performance-related content and new functionality for a World Wide Web version of the NTIA *Multimedia Performance Handbook*.
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 neal@its.bldrdoc.gov

Personal Communications Services Networks - Implement a wireless network modeling, simulation, and testing facility for personal communications services (PCS) system-specific noise and interference models tailored for implementation in a real-time hardware channel simulator, and PCS network-level simulations that use statistical data from the noise and interference model outputs.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Personal Communications Services Radio Systems - 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: Jeffrey A. Wepman (410) 415-5541
e-mail jwepman@its.bldrdoc.gov

Radio Spectrum Measurement System Engineering Enhancements - 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. Such 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

Satellites and Integrated Services Digital Networks - Identify needs and recommend solutions for interoperation of advanced satellite and broadband terrestrial networks that use asynchronous transfer mode (ATM) to provide broadband integrated services digital networks (B-ISDNs). Evaluate the application of perception-based metrics for multimedia systems and services applied to advanced satellite networks. Participate in standards organizations concerned with the use of ATM on satellite networks and the performance and interoperability of advanced satellite and terrestrial B-ISDNs.
Project Leader: Raymond D. Jennings (303) 497-3233
e-mail rjennings@its.bldrdoc.gov

Spectrum Efficiency Studies - Develop the general principles for efficient use and management of the spectrum, and resolve specific issues related to spectrum efficiency.
Project Leader: Robert J. Matheson (303) 497-3293
e-mail matheson@its.bldrdoc.gov

Spectrum Engineering Models - Develop and implement spectrum engineering models necessary to effectively manage the Government's use of the radio spectrum.
Project Leader: Robert J. Matheson (303) 497-3293
e-mail matheson@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 the 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

Naval Research Laboratory

Electromagnetic Compatibility Study - Perform an electromagnetic compatibility analysis to determine the levels of RF radiation that will be coupled from a proposed earth station to an existing NRL earth station; compare those levels to the thresholds of interference for the NRL earth station.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Operational Support Office

Wideband HF Simulator Enhancements and Use for the Evaluation of Wideband HF Modems - Enhance the wideband HF simulator and use it to test a wideband HF modem. Develop a report detailing the results of the test.
Project Leader: Christopher Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Telesis Technologies Laboratory

Model Development and Consulting for Local Multipoint Distribution Services - Develop a simulation model for local multipoint distribution services operating at frequencies in the extremely high frequency band. Provide technical consulting at field trials in Palm Springs, California.
Project Leader: Roger A. Dalke (303) 497-3109
e-mail rdalke@its.bldrdoc.gov

U.S. Army

HF Radio System Simulation - Evaluate predicted performance (including a variety of channel conditions, sources, modulations, and jamming) of proposed Army HF electronic warfare systems using software simulation.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

Independent Evaluation of the Reserve Component Automated System - Establish and conduct a comprehensive evaluation program for the Reserve Component Automated System program. Independently evaluate testing methodology and results, and report on the findings.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail vpietrasiewicz@its.bldrdoc.gov

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

Technical Test of the Reserve Component Automated System - Provide technical testing and system engineering consulting during the development and fielding phases of the Reserve Component Automated System (RCAS). The RCAS is an automated information system including computers, software, and networks connecting over 5000 sites to improve operational readiness of the Army National Guard and Army Reserves.
Project Leader: Richard E. Skerjanec (303) 497-3157
e-mail rskerjanec@its.bldrdoc.gov

Test Support for the Army High Frequency Electronic Warfare System - Support the test and evaluation of HF electronic warfare systems for the U.S. Army Signals Warfare Directorate.
Project Leader: Patricia J. Longstaff (303) 497-3568
e-mail plongstaff@its.bldrdoc.gov

U.S. Information Agency

HF Propagation Model Studies - Provide Voice of America (VOA), radio broadcaster for USIA, with a validation of broadcast service quality predictions using reception reports from VOA monitors. Provide modeling of advanced graphics displays to present VOA's propagation and monitoring results.
Project Leader: Gregory R. Hand (303) 497-3375
e-mail ghand@its.bldrdoc.gov

US West

Boulder Industry Test Bed Support - Serve as an independent observer during field trials of candidate personal communications services air-interface standards.
Project Leader: Ronald Ketchum (303) 497-7600
e-mail rketchum@its.bldrdoc.gov

University Corporation for Atmospheric Research

Consultation on the National Center for Atmospheric Research Wind Profiler - Consult, advise, and conduct research on the spaced antenna wind profiler systems.
Project Leader: Christopher L. Holloway (303) 497-6184
e-mail cholloway@its.bldrdoc.gov

ITS Publications in FY 1996

NTIA Publications

D.J. Atkinson, "Exploring B-ISDN performance: selected experiments and results," NTIA Report 96-329, Apr. 1996.

> This report describes experiments conducted to explore the user-information transfer performance of the broadband integrated services digital network (B-ISDN), the emerging infrastructure for the global information age. These performance experiments include studying the effect of physical layer transmission performance on asynchronous transfer mode (ATM) cell transfer performance, ATM performance in relationship to network topology, and the impact of B-ISDN performance on video quality. A tool to help study these performance issues, a B-ISDN network emulator, is described, including its validation. The emulator incorporates a novel model for transmission impairments, enabling performance interactions among the B-ISDN protocol layers to be studied based on relevant International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) recommendations and American National Standards.

R. Dalke, G. Hufford, and R. Ketchum, "Radio propagation considerations for local multipoint distribution systems," NTIA Report 96-331, Aug. 1996.

> A local multipoint distribution system will essentially broadcast television signals (and perhaps more) to subscribers in small cells. It has been proposed to put such systems in the frequency band from 27.5 to 29.5 GHz where the wave length is only about 1 cm, and where equipment is not well established and propagation effects are not entirely known. In this report we discuss what is known about the expected behavior of the radio waves and we suggest areas that need more study.

C.L. Holloway, PL. Perini, R.R. Delyser, and K.C. Allen, "A study of the electromagnetic properties of concrete block walls for short path propagation modeling," NTIA Report 96-326, Nov. 1995.

> For short propagation paths, correctly representing reflections of electromagnetic energy from surfaces is critical for accurate signal level predictions. In this paper, the method of homogenization is used to determine the effective material properties of composite material commonly used in construction. The reflection and transmission coefficients for block walls and other types of materials calculated with these homogenized effective material properties are presented. The importance of accurately representing the reflections for signal level prediction models is also investigated. It is shown that a 5- to 10-dB error in received signal strength can occur if the composite walls are not handled appropriately. Such accurate predictions of signal propagation over short distance is applicable to microcellular personal communications services deployments in urban canyons as well as indoor wireless private branch exchanges and local area networks.

J.F. Mastrangelo and W.R. Rust, "Testing and evaluation of the subcarrier traffic information channel," NTIA Report 96-333, Sep. 1996.

> In support of the Federal Highway Administration of the United States Department of Transportation, the Institute for Telecommunication Sciences has completed a laboratory and field test program designed to independently evaluate the performance of an FM subcarrier-based traveler information broadcast system. This system was developed by the MITRE Corporation to investigate the use of FM subcarriers for the broadcast of traffic data to vehicles on highways. The testing and evaluation program measured the Subcarrier Traffic Information Channel (STIC) system performance both in the laboratory and when installed in the subcarrier channel of a commercial FM broadcast station. STIC performance was measured and evaluated in a variety of reception environments in order to assist in the future prediction of STIC coverage in areas of the United States that differ dramatically in terrain and population density.

T.G. Sparkman, D.R. Wortendyke, C. Riddle, and G.P. Smith, “Testing automatic link establishment high frequency radios using compact disc technology part 1: clean tones,” NTIA Report 96-327, Feb. 1996.

A method of high frequency (HF) radio interoperability testing in accordance with Federal Standards 1045A and 1046/1 is now available on a compact disc (CD) created by engineers at the National Telecommunications and Information Administration, Institute for Telecommunication Sciences. This report describes both the use of the CD and the software that created the sound files recorded on the CD. The sound files, which can be recreated by the program on a personal computer and played through a PC sound card, were recorded on a compact disc and packaged with the executable software for distribution to the public. The use of the CD for interoperability testing is explained, and tools are provided to simplify testing, such as data log sheets and additional utility software.

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

This report presents a summary of the available measurement information on the level and statistical characteristics of the background noise environment in the frequency range of 1-3 GHz. The frequency range covers the proposed frequencies for the new personal communications services. Natural and man-made unintentional radiations are covered, both the general overall background noise and noise from individual sources. The urban noise environment in this frequency range is due primarily to automotive ignition systems. The noise is non-Gaussian in character, but not highly impulsive.

J.A. Wepman and J.R. Hoffman, “RF and IF digitization in radio receivers: theory, concepts, and examples,” NTIA Report 96-328, Mar. 1996.

Hardware development of analog-to-digital converters (ADC’s) and digital signal processors, including specialized integrated circuits, has advanced rapidly within the last few years. These advances have paved the way for development of radio receivers using digitization at the IF and in some cases at the RF. Applications for these receivers are expected to increase rapidly in areas such as cellular mobile, satellite, and personal communications services (PCS) systems. The constraints placed on these receivers due to hardware limitations of these devices are investigated in this paper. Some examples of state-of-the-art ADC’s, signal processors, and specialized integrated circuits are listed. Various quantization techniques, nonlinear compression devices, postdigitization algorithms for improving dynamic range, sampling downconverters, and specialized integrated circuits are discussed as they are expected to be useful in the development of these types of receivers. Several examples of radio receivers employing digitization at the IF and RF are also presented.

Other Publications

S.A. Cohn, J.K. Smith, C. Martin, and C.L. Holloway, “Spaced antenna profiler wind measurement: implementation,” in *Proc. 27th Internat. Conf. Radar Meteorology*, Vail, Colorado, 1995, pp. 326-328.

To infer winds, spaced antenna radars calculate the motion and evolution of the diffraction pattern associated with atmospheric scatterers in the radar resolution volume. Doviak et al. (1994) provide a theory for the cross-correlations and cross-spectra of signals from spaced radar antennas and suggest several analysis techniques by which the horizontal wind can be determined. These techniques were developed to allow for temporal decorrelation of the scattering medium diffraction pattern. The wind component is found along baselines formed by pairs of antennas, and the theory related the spatial spectrum of the atmospheric refractive index field to the cross-correlation in time-domain analysis and cross-spectrum in frequency domain analysis. A description of these algorithms is provided in Holloway et al. (1995, this volume) and we will refer to equations therein with the prefix “H.” Cohn and Chilson (1995) discuss potential advantages of spaced antenna wind profilers in the boundary layer. This paper describes implementation of these techniques and some preliminary results.

R. Dalke, G. Hufford, R. Ketchum, and K. Hugenberg, "Analysis of multipath and channel equalization for multichannel multipoint and local multipoint distribution services," in *Proc. 8th Internat. Conf. Wireless Communications*, vol. 2, Calgary, Alberta, 1996, pp. 333-346.

The Institute for Telecommunication Sciences (ITS) has developed computer simulation models which can be used to predict coverage and quality of service for proposed terrestrial communications systems that broadcast digital television such as Local Multipoint Distribution Systems (LMDS) and Multichannel Multipoint Distribution Systems (MMDS). An important consideration in the analysis of MMDS and LMDS is the efficacy of channel equalization of broadband signals subject to various multipath environments. To simulate multipath environments encountered by these systems, we have developed and implemented a statistical multipath propagation channel model which is based on measurements of the impulse response of broadcasts from operating television stations in a variety of environments (urban, suburban, and rural). The propagation channel model is a Gaussian process with the assumption that as a random process it is describable with only two parameters. A description of this model and results of simulations are presented in this paper.

R. Dalke, G. Hufford, R. Ketchum, and K. Hugenberg, "Digital simulation of radio propagation effects for terrestrial digital television broadcast services," in *Proc. 1996 Wireless Communications Conf.*, Boulder, Colorado, 1996, pp. 98-101.

Recently there has been considerable interest in the terrestrial broadcast of digital television using Multichannel Multipoint Distribution Services (MMDS) and Local Multipoint Distribution Services (LMDS). These services operate in the SHF and EHF bands and are subject to deleterious radio propagation effects such as attenuation and multipath. In addition, radio system effects (e.g., nonlinear amplifier characteristics) should also be considered for broadband millimeter wave systems. In response to this need, the Institute for Telecommunication Sciences (ITS) has developed computer simulation models which can be used to predict coverage and quality of service for such broadcast services [1]. Here we will give a brief description of the model and examples of simulation results.

N. DeMinco and J.A. Arnold, "What is an EMC program and why is it important to ITS" in *Proc. ITS America Sixth Annual Meet.*, vol. 2, Houston, Texas, 1996, pp. 1058-1065.

This paper discusses the role of electromagnetic compatibility (EMC) in Intelligent Transportation Systems (ITS). It is important that an EMC program be implemented early in ITS development to ensure compatibility of ITS equipment and subsystems with each other and their environment. The use of current standards would greatly reduce the cost and time needed to implement an EMC program plan for ITS. If such a program is not implemented, compatibility problems could arise and cause performance degradation or malfunction of the subsystems of ITS. This paper describes EMC as it relates to ITS and how an EMC program plan would be implemented. The application of existing standards to ITS is also discussed.

R J. Doviak, R.J. Lataitis, and C.L. Holloway, "Cross-correlation and cross-spectra in spaced antenna wind profilers part 1: theoretical analysis," *Radio Science*, vol. 31, no. 1, pp. 157-180, 1996.

The presented theory ties the properties of a turbulently advected scattering medium to the cross correlation and cross spectrum of signals in a general configuration of receiving and transmitting antennas. The correlation length of Bragg scatterers and antenna diameter are the significant parameters determining the diffraction pattern's correlation length. We examine how vertical anisotropy of the scattering medium affects the diffraction pattern's correlation length. We demonstrate that the cross spectrum can be formulated in terms of a pair of spectral sampling functions (a one-dimensional Doppler and a three-dimensional wavenumber function), and closed form solutions are obtained. We give the conditions under which the scattering medium's statistical properties can be represented by a Gaussian correlation or spectral model, and the distance over which the diffraction pattern simply advects without significant change. We show that the diffraction pattern of a pair of scatterers can translate at the speed of the scatterers, not twice their speed as is commonly thought.

J.G. Ferranto, “PCS 1900 interference simulation for personal communications services testing, evaluation, and modeling,” in *Proc. 5th IEEE Internat. Conf. Universal Personal Communications*, vol. 1, Cambridge, Massachusetts, 1996, pp. 225-230.

A generic methodology for personal communications services self-interference modeling is applied to the Global System for Mobile-based PCS 1900. The resulting system-specific model is discussed in detail, and is used to produce output noise and interference waveforms suitable for implementation in a real-time hardware channel simulator, or as a component of a link-level software simulation. Different deployment scenarios are then used to generate example PCS 1900 interference waveforms, along with corresponding statistical analyses of interference waveform properties. The model described in this paper is particularly well-suited for support of efficient PCS system evaluation.

E.M. Gray and D. Bodson, “Preserving due process in standards work,” *StandardView*, vol. 3, no. 4, pp. 130-139, Dec. 1995.

Due process refers to a legal concept and to the practice based on that concept. This paper begins with a brief review of the relevant legal and historical concepts, then more fully addresses the ways of preserving due process in the work of developing information-technology standards. The necessary and minimum procedures for preserving due process in standards working groups are identified. Connections are made between a) the defined elements of due process and b) the ways in which ANSI’s X3 and other standards working groups preserve due process in their work. With regard to accelerated procedures for standards development, the paper addresses briefly the need to balance timely standards development with due process. The paper identifies the advantages—to the standards user—of preserving due process in standards development.

J.A. Hoffmeyer and D. Bodson, “Present status and future development of U.S. Federal standards for HF communications,” in *Proc. IEE Colloquium on Frequency Selection and Management Techniques for HF Communications*, Savoy Place, London, 1996, pp. 19/1-19/5.

High frequency (HF) communications systems continue to be an important component of the suite of systems needed to meet both military and civil communications requirements. These military and civil applications of HF require the establishment of national and international interoperability and performance standards.

The United States has established a program for the development of a series of Federal HF Standards which are applicable to all United States Government departments and agencies. The National Communications System (NCS) is responsible for the development of Federal communications standards as part of its mission. The NCS responsibilities for National Security and Emergency Preparedness (NS/EP) functions for telecommunications systems include the responsibility for ensuring interoperability of a wide variety of telecommunications systems. The Institute for Telecommunication Sciences (ITS) is working jointly with the NCS in leading the development of Federal Standards that specify HF systems performance and interoperability requirements.

This paper summarized the status of existing U.S. HF Federal Standards, the current and future work in the development of additional U.S. Federal Standards, and identifies issues as the how these United States Federal HF standards relate to international standards activities within NATO and the International Telecommunication Union-Radiocommunication Sector.

J.A. Hoffmeyer and D. Bodson, “Use of advanced HF link and network simulators in the standards development process,” in *Proc. IEE Colloquium on Frequency Selection and Management Techniques for HF Communications*, Savoy Place, London, 1996, pp. 12/1-12/7.

Modeling and simulation are important components of present day HF radio communications standards development precess. This paper summarized work at the Institute for Telecommunication Sciences (ITS) under the direction and funding of the National Communications System (NCS) in the development of simulation tools useful in the HF standards development process in the United States. The simulation tools are introduced from the perspective of 1) the phase of the standards development process to which the tools may be applied and 2) the communication system layer to which they may be applicable. Particular emphasis in this paper is placed on the development of a new real-time HF channel simulator, the development of a compact disk-based automatic link establishment (ALE) tone simulator, and the development of a general purpose digital signal processor-based system for simulating HF network protocols.

C.L. Holloway, R.J. Doviak, S.A. Cohn, and R.J. Lataitis, “Retrieval of boundary layer turbulence using spaced antenna wind profilers,” in *Proc. 1996 Internat. Geoscience and Remote Sensing Symp.*, 1996, pp. 1914-1916.

In this paper, we present an algorithm for estimating turbulence (or wind variability) in the lower boundary layer for use with spaced-antenna systems.

C.L. Holloway, R.J. Doviak, S.A. Cohn, R.J. Lataitis, and J. Van Baelen, “‘Algorithms to retrieve wind from spaced-antenna wind profilers,” in *Proc. 27th Internat. Conf. Radar Meteorology*, Vail, Colorado, 1995, pp. 323-325.

In this paper, four algorithms for determining unbiased estimates of the wind from a spaced-antenna wind profiler are introduced.

C.L. Holloway and E.F. Kuester, “A quasi-closed form expression for the conductor loss of CPW lines, with an investigation of edge shape effects,” *IEEE Trans. Microwave Theory and Techniques*, vol. 43, no. 12, pp. 2695-2701, Dec. 1995.

In previous work, we used a matched asymptotic technique to investigate the fields near an edge of a finitely conducting strip with nonzero thickness. It was demonstrated that with this asymptotic solution of the fields, the power loss in the region local to the edge could be determined accurately. In this paper, we will show how the accurate representation of the power loss can be used to obtain a closed form expression for the attenuation constant due to conductor loss of coplanar waveguide (CPW) structures. This expression is valid for an arbitrarily shaped edge and any conductor thickness. Results obtained with this expression are compared to and closely agree with both experimental results and other techniques found in the literature. We also investigated conductors with different edge shapes (45 degree and 90 degree edges) to explore their effect on the attenuation constant (or loss) of CPW structures.

C.L. Holloway and E.F. Kuester, “Modeling semi-anechoic electromagnetic measurement chambers,” *IEEE Trans. Electromagnetic Compatibility*, vol. 38, no 1, pp. 79-84, Feb. 1996.

In previous work, we have developed a model to predict theoretically the low-frequency plane-wave reflection coefficient of an array of pyramid cone absorbers such as those used to line anechoic electromagnetic measurement chambers. In this paper, we apply this model in a geometrical optics approach to predict the electromagnetic field in a chamber lined with cone absorbers in the frequency range of 30-300 MHz. The results are compared with site attenuation measurements for two actual semi-anechoic chambers.

P. Papazian and G. Hufford, “Initial study of the local multipoint distribution service radio channel,” in *Proc. Wireless 1996 8th Internat. Conf.*, vol. 2, Calgary, Alberta, 1996, pp. 494-513.

A broadband millimeter wave study was completed to characterize the radio channel for local multipoint distribution services (LMDS) in Boulder, Colorado. The study determined characteristics for proposed 20-MHz channels centered at 30.3 GHz using two transmitter heights in a suburban environment in the winter. Distributions of signal loss, delay spread and frequency selective fading are presented. The median excess path loss for a 40-m transmitter height is 15 dB. Maximum delay spreads for this height are below 10 ns with a median value of less than 1 ns. Data was also collected to characterize a flat plate reflector proposed for use at 28.8 GHz. The measurement results indicate that vegetation causes significant propagation impairments for LMDS.

E.A. Quincy, R.J. Achatz, and M. Terada, “IS54/I36 PCS performance prediction for standard JTC channels,” in *Proc. Wireless 1996 8th Internat. Conf.*, vol. 1, Calgary, Alberta, 1996, pp. 43-57.

Several Joint Technical Committee (JTC) Air Interface Standards have been proposed for PCS. Standardized operational channel models were also developed by the JTC to provide a common operational environment in which to compare performance of these radio systems. We have investigated the performance of an IS54/I36-based PCS system operating over a range of signal-to-noise ratios (SNRs) using three of the urban channel models. Performance is given in terms of bit error rates (BER), compressed speech quality, and compressed image quality.

E.A. Quincy, R.A. Dalke, R.J. Achatz, C.L. Holloway, and P.M. McKenna, "Radar target image resolution enhancement via propagation channel equalization," in *Proc. SPIE Radar Processing, Technology, and Applications*, vol. 2845, Denver, Colorado, 1996, pp. 49-55.

The performance of signal/image processing algorithms used to form radar images and identify targets depends on propagation effects such as time-varying multipath, dispersion, attenuation, etc. In this paper, the effects of multipath propagation conditions that result from terrain or man-made environments and noise are modeled and simulated to determine their effects on radar target signatures. Here, we calculate the radar signatures for a ground vehicle subject to the deleterious effects of both multipath and additive noise. A minimum mean-square-error (MMSE) Wiener equalizing filter is developed and applied to the distorted radar target signatures. The mean-square-error (MSE) is calculated as a function of signal-to-noise ratio resolution. These techniques are particularly relevant for targets located in mountain or urban canyon environments.

Spaulding, A.D., 1995, "The roadway natural and man-made noise environment," *IVHS Journal*, vol. 2, no. 2, pp. 175-211.

This paper presents a summary of the available measurement information on the level and statistical characteristics of the background natural and man-made noise likely in highway and other high traffic density locations. The frequency ranges of around 100 MHz and 0.9 to 3 GHz are covered since these frequency ranges are those of current interest for "intelligent highway" telecommunication systems. The highway noise environment in these frequency ranges is due primarily to automotive ignition systems (and power lines at 100 MHz). The noise is non-Gaussian in character.

S. Voran, "Observations on auditory excitation and masking patterns," in *Proc. 1995 IEEE ASSP Workshop on Applications of Signal Processing to Audio and Acoustics*, New Paltz, New York, 1995.

Excitation patterns and masking patterns are used extensively in perceptual audio coders and quality assessment algorithms. Numerous algorithms for calculating these patterns have been proposed. This paper provides comparisons among the patterns generated by several of these algorithms. The comparisons are based on audio program material, rather than tones and noise. Explored areas include synthesis functions, spreading functions, masking indices, tonality measures, and the treatment of the absolute threshold of hearing. Several mathematical relations are provided to characterize observations in these areas. Patterns from simpler algorithms are considered as approximations to patterns from more complex algorithms, and the approximation error is characterized. Results may be useful to those who apply auditory excitation or masking patterns in their work.

Publications Cited*

CCIR, "HF ionospheric channel simulators," Report 549-3, International Telecommunication Union, Reports of the CCIR, 1990, Annex to Volume III, Fixed Service at Frequencies Below About 30 MHz., Geneva, 1990, pp. 47-59.

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, 1995.

E.J. Violette, R.H. Epseland, and K.C. Allen, "A diagnostic probe to investigate propagation at millimeter-wave lengths," 1983, NTIA Report 83-128, August 1983 (NTIS Order No. PB-104223).

*Publications cited in the report that are not Fiscal Year 1996 reports.

Abbreviations

AAMA	American Automobile Manufacturers Association
ACTS	Advanced Communications Technology Satellite
ADC	analog-to-digital converter
ALE	automatic link establishment
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials
ATCS	advanced train control system
ATIS	advanced traveler information system
ATM	asynchronous transfer mode
AWGN	additive white Gaussian noise
B-ISDN	broadband integrated services digital network
BER	bit error ratio
CCIR	International Radio Consultative Committee
CDMA	code-division multiple access
CD-ROM	compact disk read-only memory
C/I	carrier-to-intermodulation ratio
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	compact radio spectrum measurement system
DCT	discrete cosine transform
DGPS	differential global positioning system
DOD	Department of Defense
DOT	Department of Transportation
DPCM	differential pulse-code modulation
DSCP	digital sampling channel probe
EHF	extremely high frequency
EMC	electromagnetic compatibility
ETTM	electronic toll and traffic management
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDDI	fiber distributed data interface
FDTD	finite difference time domain
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FLEWUG	Federal Law Enforcement Wireless Users Group
FRA	Federal Railroad Administration
FTSC	Federal Telecommunications Standards Committee
FTSP	Federal Telecommunications Standards Program
FTTA	Federal Technology Transfer Act
GII	Global Information Infrastructure
GIS	geographic information systems
GPS	global positioning system
GSM	global system for mobile communications
GWEN	Ground Wave Emergency Network
HDTV	high-definition television
HF	high frequency
HFRS	High Frequency Radio Subcommittee

HIPERLAN	high performance radio local area network
IEEE	Institute of Electrical and Electronics Engineers
IP	internet protocol
ISI	Intersymbol interference
ISDN	integrated services digital network
ISM	industrial, scientific, and medical
ISO	International Organization for Standardization
ITAC	International Telecommunications Advisory Committee
ITS	Institute for Telecommunication Sciences
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
JEM	Jammer Effectiveness Model
LAN	local area network
LMDS	local multipoint distribution service
LMR	land mobile radio
LOS	line-of-sight
MIRG	mobile impulse response generator
MMITS	Modular Multifunction Information Transfer System
MMSE	minimum mean-square-error
MOS	mean opinion score
MPEG	Motion Picture Expert's Group
MSE	mean-square-error
NASA	National Aeronautics and Space Administration
NCS	National Communications System
NFM	Network Flow Model
NII	National Information Infrastructure
NIST	National Institute of Standards and Technology
NNPS	national navigation and positioning service
NS/EP	National Security Emergency Preparedness
NSA	National Security Agency
NTIA	National Telecommunications and Information Administration
OSM	Office of Spectrum Management
OT	Office of Telecommunications
PCS	personal communications services
PEACESAT	Pan-Pacific Education and Communications Experiment by Satellite
PPS	precise positioning service
PSNR	peak signal-to-noise ratio
PSWAC	Public Safety Wireless Advisory Committee
PTS	positive train separation
RCAS	Reserve Component Automation System
RDBMS	relational database management system
RFIMS	Radio Frequency Interference Monitoring System
RSEC	radar spectrum engineering criteria
RSMS	radio spectrum measurement system
SDH	synchronous digital hierarchy

SDR	software-defined radio
SFDR	spurious-free dynamic range
SNR	signal-to-noise ratio
SONET	synchronous optical network
SPS	standard positioning service
TA Services	Telecommunications Analysis Services
TCP	transmission control protocol
TDMA	time-division multiple access
TIA	Telecommunications Industry Association
TTL	Telesis Technology Laboratory
TWTA	traveling wave tube amplifier
USCG	U.S. Coast Guard
US WEST	US West Advanced Technologies, Inc.
WLAN	wireless local area network
WTSC	World Telecommunications Standardization Conference

Loaded onto a retired Navy landing craft, the ITS radio spectrum measurment system van is carried to a measurement site on Angel Island in the San Francisco Bay (photograph by F.H. Sanders).