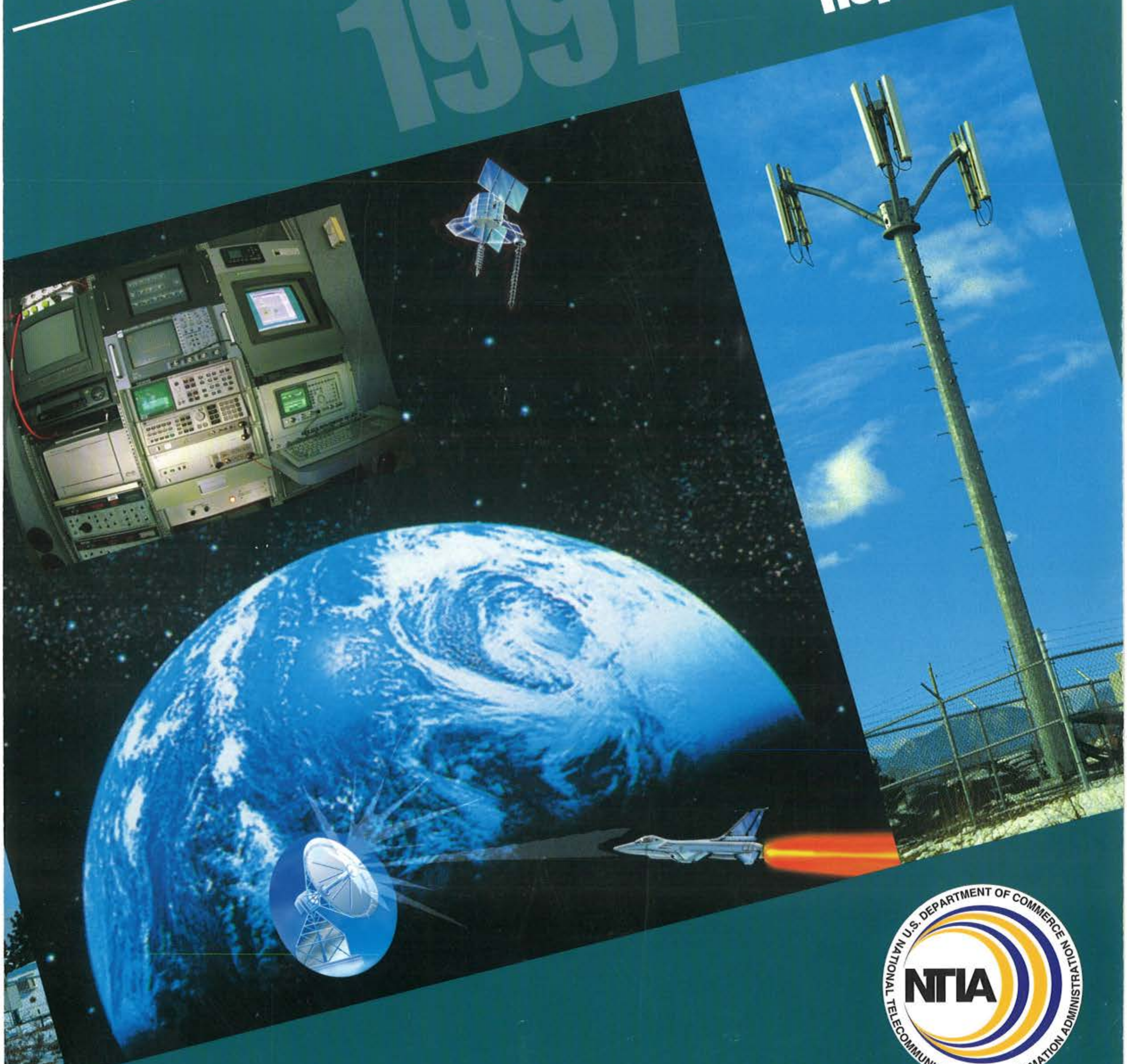
Institute for Telecommunication Sciences

1997 Technical Progress Report



U.S. DEPARTMENT OF COMMERCE
NTIA
NATIONAL TELECOMMUNICATIONS & INFORMATION ADMINISTRATION

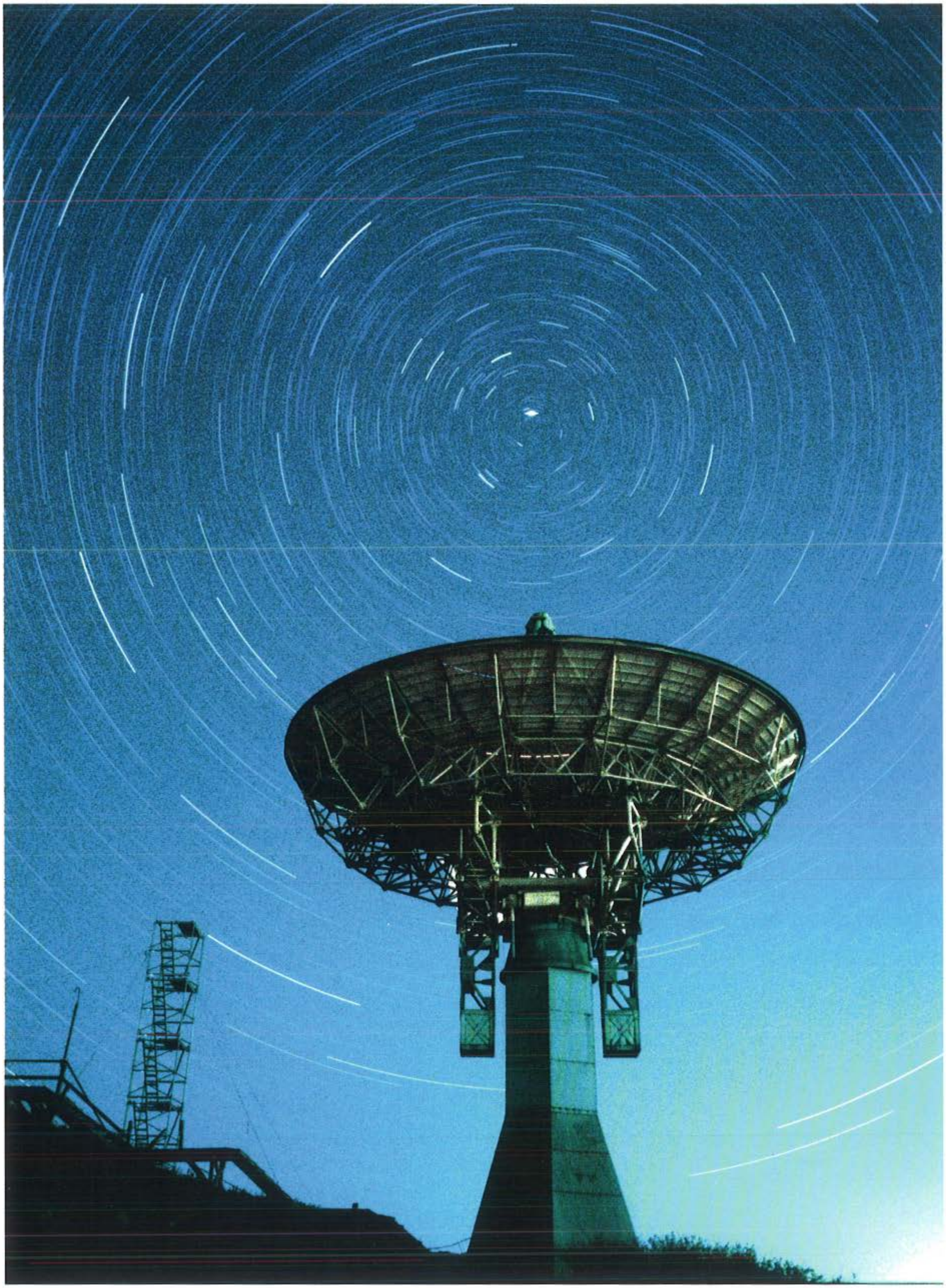
Institute for Telecommunication Sciences

1997 Technical Progress Report

U.S. Department of Commerce
William M. Daley, 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



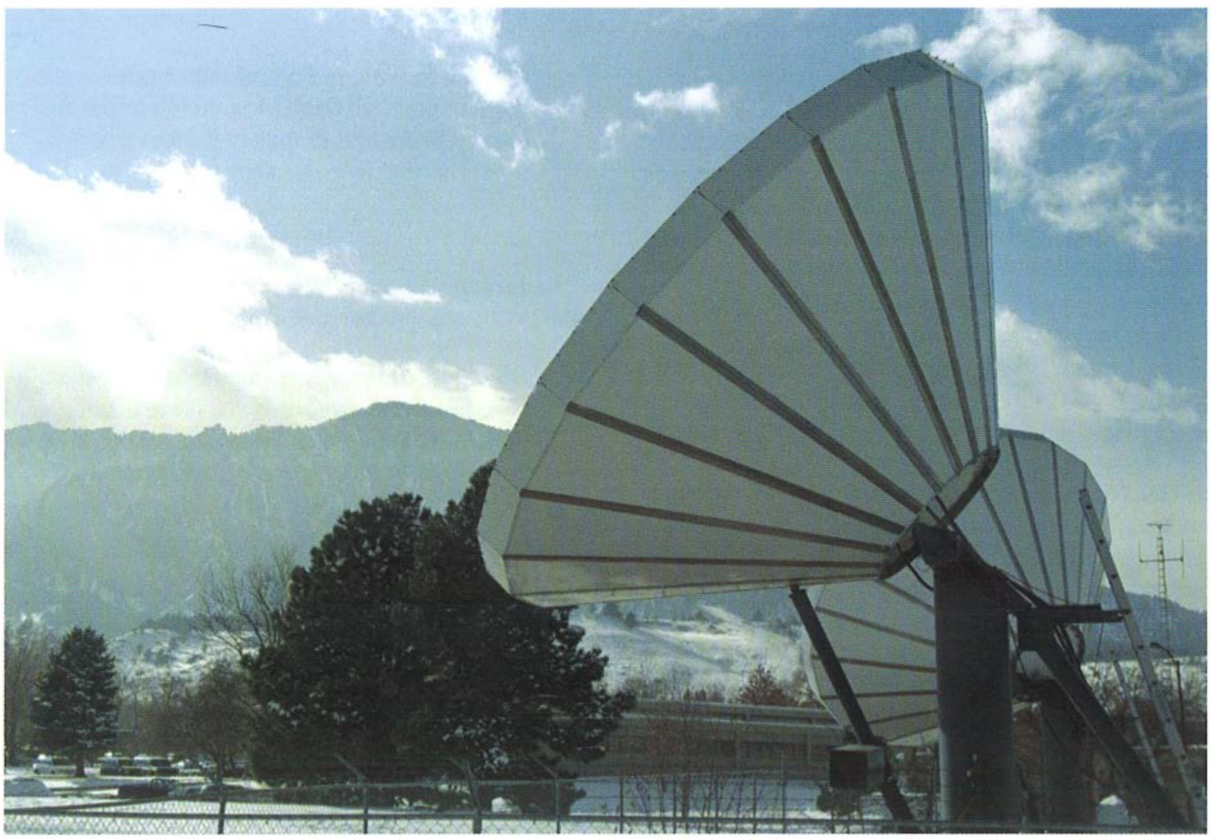
A 60-ft-diameter dish antenna at the Table Mountain radio quiet zone, north of Boulder, Colorado (photograph by F.H. Sanders).

The ITS Mission

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

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

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



Antenna used to communicate with a geosynchronous satellite (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 1997 fiscal year consisted of $4.3 million of direct funding from the Department of Commerce and approximately $6.7 million for work sponsored by other Federal Government agencies and U.S. industry.

History

ITS began in the 1940s as the Interservice Radio Propagation Laboratory, which later became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards of the Department of Commerce. In 1965, CRPL became part of the Environmental Science Services Administration and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, the telecommunications function of ITSA was transferred into the newly formed Office of Telecommunications (OT). Finally, under the President's Reorganization Act #1 of 1977, OT and the Office of Telecommunications Policy merged to form NTIA. Since that time, ITS has performed telecommunications research and provided technical engineering support to NTIA and to other Federal agencies on a reimbursable basis. Over the last decade, ITS has pursued cooperative research with U.S. industry under the provisions of the Federal Technology Transfer Act of 1986.

Activities

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

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

Benefits

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

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

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

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

Outputs

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

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

- Standards, Guidelines, and Procedures: Contributions to and development of national and international standards in such areas as network interconnection and interoperation, performance evaluation, and information protection.

- Research Results: Mathematical models for electromagnetic wave propagation, noise, and interference characterization.

- Expert Services: Training courses and workshops to communicate technology advances and applications to industry and Government users.

Organization

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

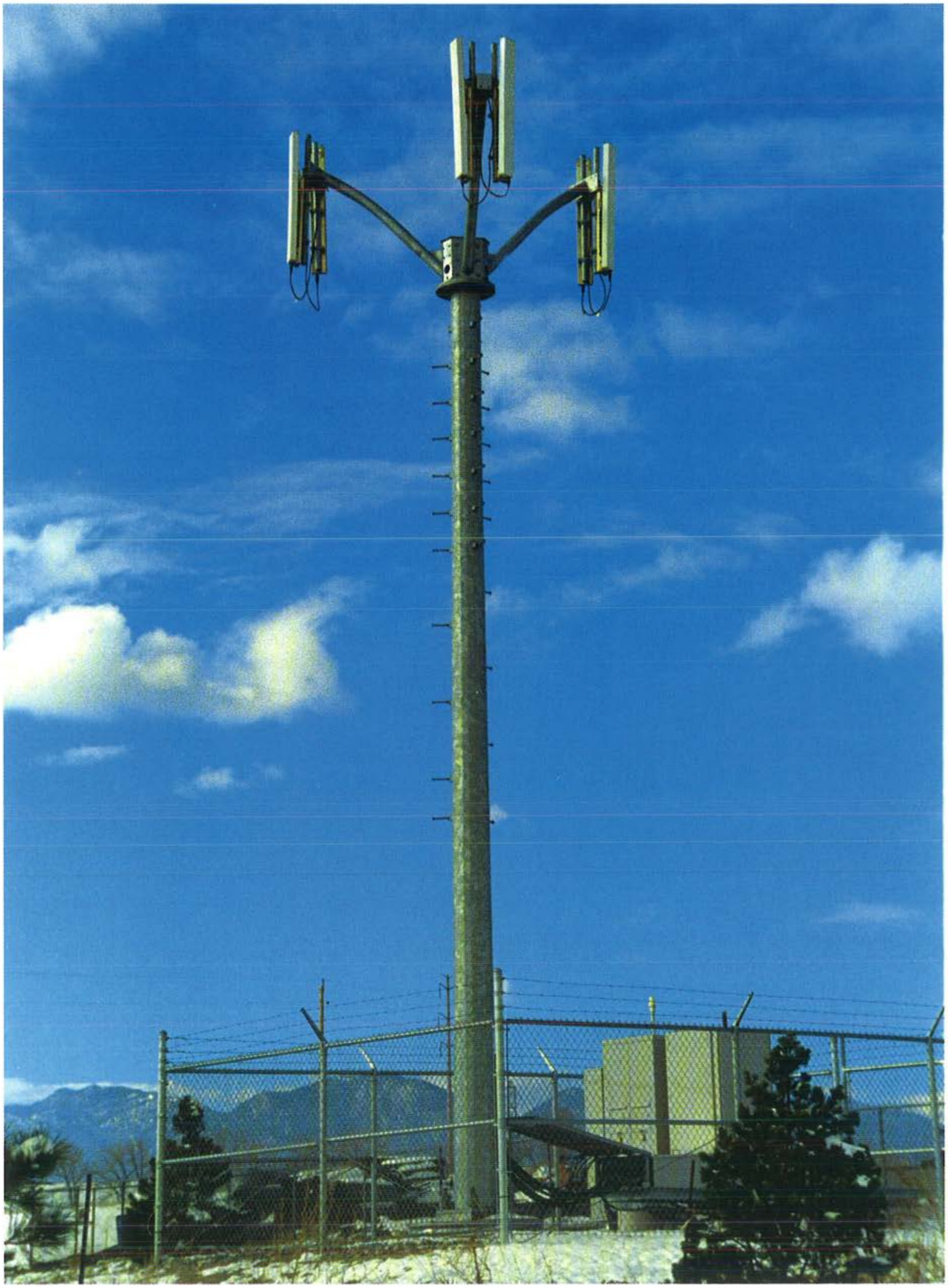
The ITS Executive Office manages administrative matters. The Executive Office also manages the Institute's budget and program-planning functions and interacts with various administrative offices within other parts of the Department of Commerce to meet its payroll, procurement, personnel, facilities management,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

Sponsors

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

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

Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides scientific research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 1997 that have significance for both the public and private sector.



The infrastructure of the wireless revolution: one of 14,000 new sites added by the cellular/PCS industry in the past year (photograph by F.H. Sanders).

Spectrum Planning and Assessment

NTIA is responsible for managing the Federal Government's use of the radio spectrum and is the President's advisor on telecommunications. These responsibilities include establishing policies on spectrum assignment, allocation, and use. ITS supports these activities by performing spectrum measurements and studies directed toward 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. The Institute's spectrum analyses are directed toward ensuring that increasingly crowded radio spectrum is used for maximum benefit, thus 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 bodies significantly affect spectrum allocations and use 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

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 the Department of Transportation (DOT) and NTIA.

Technology and Spectrum

The Institute performs forecasting of technology developments that will significantly affect the demand for spectrum services and the ability of the spectrum to satisfy that demand. Projects are funded by NTIA.

Radio Spectrum Measurements

The Institute performs usage measurements across a wide range of radio frequencies and geographic locations 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 EMC characteristics. Projects are funded by DOD and NTIA.

Radio Frequency Interference Monitoring System

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

ITU-R Activities

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

Domestic Spectrum Analysis

Outputs

- Technical support for NTIA DTV policies and studies on alternative DTV station allocations.
- Continued tracking of spectrum requirements for the fixed services.
- Assessment of the future of spectrum management.

FY 1997 (like so many of its immediate predecessors) was a year of big changes for the U.S. radio spectrum. The broadcast television industry now has orders for conversion to digital television (DTV). Auctions have become a routine method of distributing radio licenses. One spectrum auction was even considered a failure, in that the bidding resulted in much less money than expected. Spectrum policy makers continue to examine improved ways to manage the spectrum, so that frequency bands can be found for dozens of new radio services and applications. ITS has helped make these changes happen through research and analysis intended to assist U.S. policy makers in choosing the best possible domestic frequency management policies and decisions.

In the early part of the year, the Federal Communications Commission (FCC) issued a series of rules and proposed rules that will substantially change the nature of broadcast television. In particular, television will change over a several-year period from its current analog NTSC signal to a set of digital signal formats, including high-definition television and multiple channels of standard-definition television. This is a very significant change that represents a culmination of many years of work by ITS and many other Government agencies and corporations. ITS research in past years has helped to provide basic propagation loss models that formed the core of the FCC's coverage and rechannelization proposals. ITS' past research has also contributed to technical details on multipath delay (needed to establish the feasibility of proposed DTV digital modulations) and methods to compare the performance of the various digital compression techniques for DTV video and sound. The FCC proposal also included the use of four old television channels to provide spectrum for new public safety services, as recommended by the Public Safety Wireless Advisory Committee, in which ITS participated actively last year.

ITS continued to assist DTV spectrum policy makers in two major areas. First, ITS helped NTIA develop policy positions concerning DTV; NTIA advocated these positions to the FCC during the various DTV public hearings. ITS developed policy alternatives and provided technical analysis of policies proposed by NTIA. ITS and NTIA carried on extensive discussions over several months concerning the technical feasibility of alternative methods of relocating and rechannelizing existing television transmitters, including various co-sited multichannel configurations and the role of low-power television and multiple simulcast transmitters.

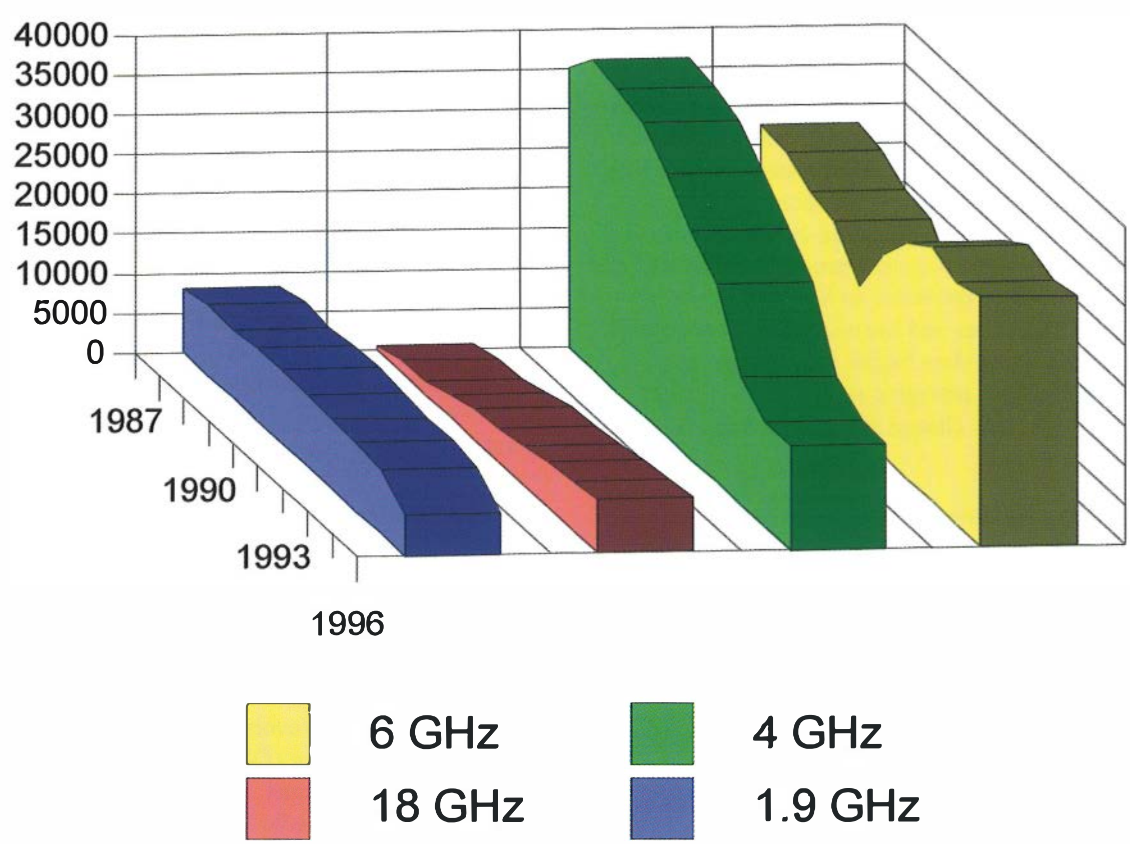
The process of rechannelizing all of the 1,500 existing television transmitters in an optimum way is an extremely complex and interactive process. ITS has been developing a computer tool for optimizing such processes. This tool is based on software developed by the FCC for this purpose and used by the FCC to develop their proposed DTV allocation plan. It uses a process called "simulated annealing" to examine a very large number of alternative configurations—converging to a near optimum configuration according to a selected "cost function." In the case of DTV, the cost function is based on co-channel and adjacent-channel separation distances. Initial ITS studies have looked at a set of alternative siting constraints for more than 200 television stations in the northeastern part of the United States. This optimization tool should also be valuable for the study of similar sets of any mobile/cellular/personal communications services (PCS) sites and other systems.

ITS continues to provide support for NTIA's spectrum management functions by providing an ongoing market analysis of the fixed services. This is an important function because the fixed services (especially point-to-point microwave links) are potentially subject to replacement by optical fiber links. Thus, the large amount of spectrum currently used by the fixed services may be (or may not be) a candidate for conversion to new wireless or satellite services. The Figure shows a 10-year history of licenses in several of the heavily used fixed bands.

The details of each band are different. The 1.9-GHz band contains private/commercial microwave users, who are now moving out to make room for new PCS users. The 4-GHz band was the mainstay of the old AT&T microwave network. It has been mostly replaced with fiber; coordination in this band with satellite downlinks is also problematic. The 6-GHz band is another old AT&T band. Many old links have been replaced with fiber, but many new links have been added recently to interconnect rapidly growing cellular telephone networks. The 18-GHz band is growing steadily to support a mixture of cellular and private microwave uses, especially in short-range urban applications where the small antenna size is an advantage. The growth of the 38-GHz band (not shown) is uncertain. As a result of the new privatized area-based regulatory philosophy, there seems to be no national information available.

ITS is preparing a report that will update a 5-year-old summary of the fixed services, including predictions on growth for each of 30 microwave bands.

The rapid change in spectrum-based services is stressing the frequency management capabilities of Government regulators, leading to spectrum shortages that have delayed the introduction of new services. ITS is working with NTIA counterparts to develop new spectrum management policies that can respond more rapidly, flexibly, and beneficially to changing technology and demand. A major effort this year has involved discussions of alternative spectrum policies, directed toward the preparation of a report on spectrum management. This report will stress the need for flexibility, auctions, market forces, and continued involvement in international spectrum management.



Number of licenses in selected point-to-point microwave bands (1987-1996).

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Technology and Spectrum

Outputs

- Projections of growth in market share of wireless integrated circuits.
- Spectrum utilization trends versus calendar year.
- Impact assessment of digital radio receivers on the management of the Federal radio spectrum.
- Characterization of potential adjacent channel interference problems that may occur when unlicensed mobile radios operate in frequency bands adjacent to Federal spectrum users.

The Institute performs technology forecasting on developments that will significantly affect the demand for spectrum services and the ability of the radio spectrum to satisfy that demand. Congressional and industry interest in providing additional radio spectrum for private sector development of emerging wireless telecommunications technologies (particularly mobile and low-power fixed-site applications) is an important policy consideration. Developers and policy makers interested in how to implement low-power broadcast and two-way land-mobile communications are finding higher radio frequencies suitable to support emerging services. The factors responsible for this change in perception are presented below.

The ongoing evolution of microwave monolithic integrated circuits (MMIC's) continues to improve circuit packaging (size reduction) techniques, function integration (consolidation of many circuit functions into a single integrated circuit), efficiency (voltage and current supply requirements), refinement of processing and fabrication techniques (increased manufacturing yields and lower unit cost), and maximum operating radio frequency. These improvements enhance the ability of developers to mass produce MMIC-based land mobile and portable communications products at an attractive price and to offer services where co-channel interference and congestion are minimal. This is evidenced by Figure 1, which shows the growth in market share of digital wireless integrated circuits.

Current paradigms of mobile communications technology are favoring short range communications

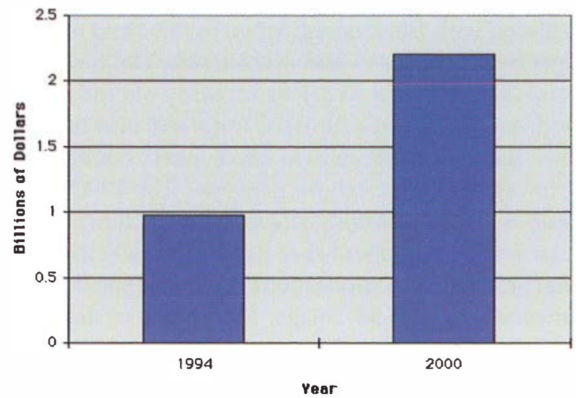

Figure 1. Digital wireless integrated circuit market share.

between mobile users and base station network access points. Decreasing the size of individual radio coverage regions, while simultaneously increasing the aggregate number of regions serving a fixed geographic area, yields large increases in available system capacity, as evidenced by the cellular and personal communications services industries. Spectrum congestion at lower frequencies discourages the assignment and use of broadband services. New services and applications are requiring wide bandwidths and must, by necessity, be relegated to sparsely occupied higher frequency bands. Higher operating frequencies are well-suited for short range communications, and are necessary to support the wide bandwidths and high data rates inherent to video and graphics transmission. As wireless applications continue to evolve towards a denser radio infrastructure, shorter path lengths, and wider message bandwidths, spectrum utilization will continue to move to higher operating frequencies (Figure 2).

Wireless technology is evolving to the point where digital signal processing (DSP) is being incorporated into radio receiver designs. DSP digitizes the received signal at the radio frequency (RF) or intermediate frequency (IF). By digitizing at the RF or IF, many of the traditional analog functions of the radio receiver are being replaced with software or digital hardware. A general study of the theory, concepts, and practical hardware limitations of these radio receivers has already been completed (Wepman and Hoffman, 1996; see Publications Cited; p. 103). Current efforts focus on identifying

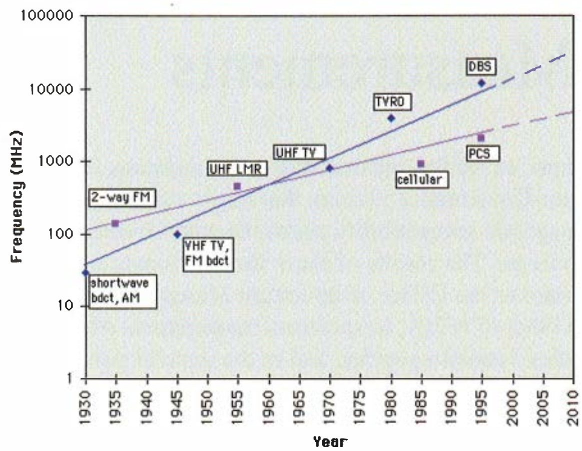

Figure 2. Frequency utilization and assignment of wireless technologies versus year of introduction (broadcast - blue and land mobile -pink).

and acquiring representative digital receivers and conducting electromagnetic compatibility (EMC) testing on them in a noise- and interference-laden environment. The purpose of this study is to further investigate the impact of these radio receivers on the management of the Federal radio spectrum. These systems will have to go through the process of spectrum certification to be implemented and used by Governmental agencies. The process of spectrum certification includes an EMC analysis. By measuring the performance of the receiver in a noise and interfering environment and by knowing the architecture of the receiver (in particular the center frequency and bandwidth to be digitized, the front end filtering before digitization, the sampling rate, and the digital filtering and processing), a better understanding of how to approach EMC analyses for spectrum certification can be obtained.

The Institute also assesses various radio modulation techniques that promise to improve the efficiency of use of the radio spectrum. One technique of interest is constant envelope modulation. Constant envelope digital modulations, such as minimum-shift keying (MSK), have a number of advantages when used in battery-operated mobile radios. For example, they can be used with power efficient nonlinear power amplifiers (PA), they are robust in a fading channel, and they can be designed to meet stringent adjacent channel interference (ACI) requirements. Constant envelope modulations such as MSK, however, are not as efficient, in terms of bits/Hz, as commonly used variable envelope modulations such as quadrature phase-shift keying (QPSK). As a result, system designers are considering variable envelope modulations, such as differential QPSK (DQPSK) with pulse-shape filtering, when more spectral efficiency is needed. DQPSK is robust in a fading channel, and with the proper filtering can meet stringent ACI requirements. To achieve the minimum ACI with variable envelope modulations, however, PA's must be operated linearly with reduced power efficiency when compared to nonlinear operation. To extend battery life, manufacturers often choose to run the PA with some degree of nonlinearity. The PA nonlinearity increases the ACI of variable envelope modulations, thereby pitting spectral efficiency against power efficiency.

Engineers at ITS are studying the nonlinear behavior of a three-stage, 2-GHz, integrated circuit PA and its effects on spectral and power efficiency for variable envelope modulations. A nonlinear amplifier model based on measured amplifier characteristics was developed and used in simulations to determine the relationship between ACI, battery current, and bit error rate. The goal is to develop an understanding of potential ACI problems that may occur when unlicensed mobile radios operate, for example, in bands adjacent to Federal spectrum users. Figure 3 shows simulated power spectral density for 48.6 kb/s π/4 DQPSK modulation and an assumed channel width of 30 kHz. The signal is distorted by the PA model operating at two different bias levels: -2.0 and -2.5 V. Note that as the bias voltage is decreased, the ACI increases; however, the battery current (and hence the battery power consumed) for the -2.5-V bias is about 75% that of the PA operating with a -2.0-V bias.

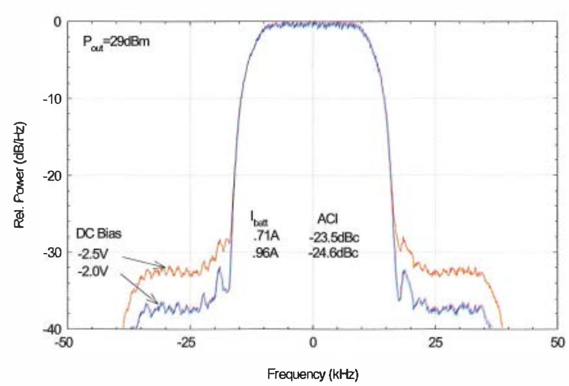

Figure 3. Power spectral density of a simulated π/4DQPSK signal. The transmitter amplifier is a 2-GHz Class AB PCS power amplifier.

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Radio Spectrum Measurements

Outputs

- Results of channel-by-channel usage statistics and maximum, minimum, and average spectrum occupancy levels before, during, and after the 1996 Summer Olympic Games
- Results of Los Angeles and San Francisco, California broadband spectrum occupancy survey measurements
- Measurements of emissions from a microwave-powered lighting device, and possible impact of those emissions on navigation systems in adjacent spectrum bands.

As part of the ongoing NTIA mission to manage Federal spectrum and assess current and future trends in spectrum use, ITS performs broadband spectrum occupancy measurements at selected locations, as well as measurements of emissions from non-Government systems that might cause electromagnetic compatibility problems with Government systems. The results of these measurements are provided to the Office of Spectrum Management (OSM) of NTIA, to spectrum management offices in other Federal agencies, and to the general public as NTIA reports. Spectrum surveys and emission measurements on individual devices 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. Emission measurements on non-Government devices are used to determine whether or not compatibility problems can be expected between those systems and Government systems.

Data from last year's channel occupancy measurements in Atlanta, Georgia, were analyzed (Figure 1),

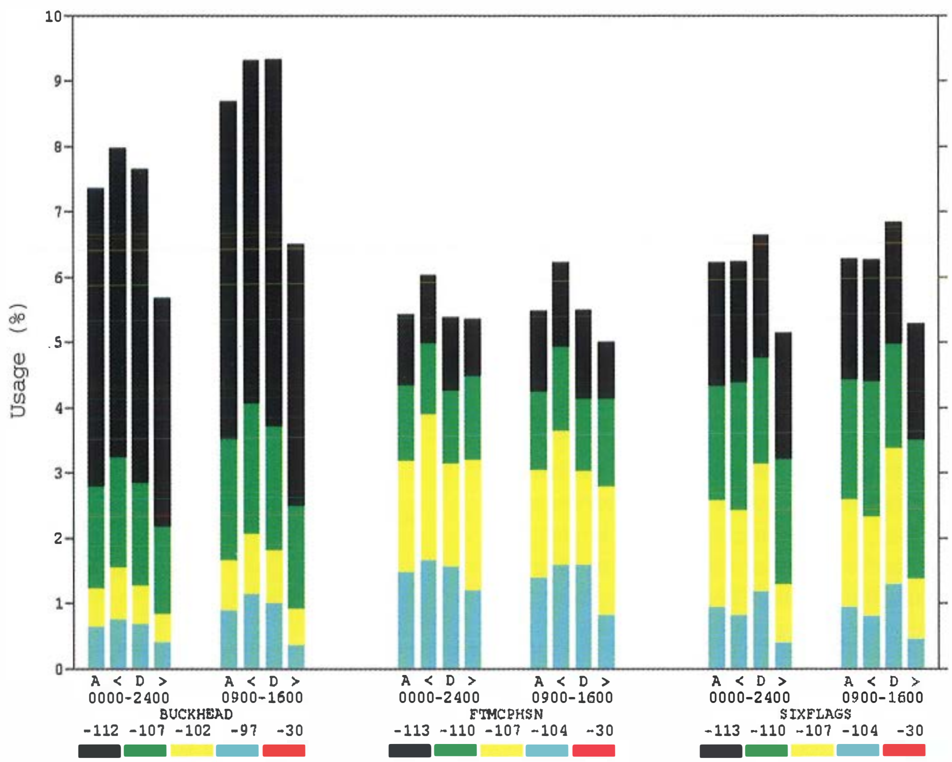

Figure 1. Land mobile radio channel usage data from the Olympic Games measurements, showing relative effect of the Games on band usage at three measurement locations named Buckhead, Ft. McPherson, and Six Flags. Usage statistics are shown for each site for all measurements (A), for the week prior to the Games (<), for the period during the Games (D) and for the period after the Games (>). The usage color bars are keyed to usage measurement threshold levels in decibels relative to a milliwatt (dBm) at each of the three sites.

and the NTIA Report on those results will be available in FY 98. Data analysis was performed to determine relative levels of spectrum use in mobile radio bands before, during, and after a major event that was expected to produce unusually high levels of demand for mobile communication systems. The report provides measured data that can be used in determining the amount of extra mobile radio spectrum needed for crisis events.

In 1997, data from earlier spectrum survey measurements in Los Angeles and San Francisco, California, were analyzed, and NTIA Reports have been written that present the results of those measurements. These will be the third and fourth reports in a series; earlier reports were written for spectrum occupancy measurements at Denver, Colorado, and San Diego, California.

Measurements of emissions from a microwave-powered lighting device were performed to determine the impact of those emissions on Government-operated navigation systems such as the global positioning system (Figure 2). Spectrum measurements, emission patterns, and time waveforms were measured. One of the lighting devices was operated in close proximity to a number of navigation receivers, and receiver operation was monitored for adverse effects. Preliminary results of the measurements indicate that radiated emissions from these lighting devices will not pose a threat to the use of navigation systems in adjacent spectrum bands.

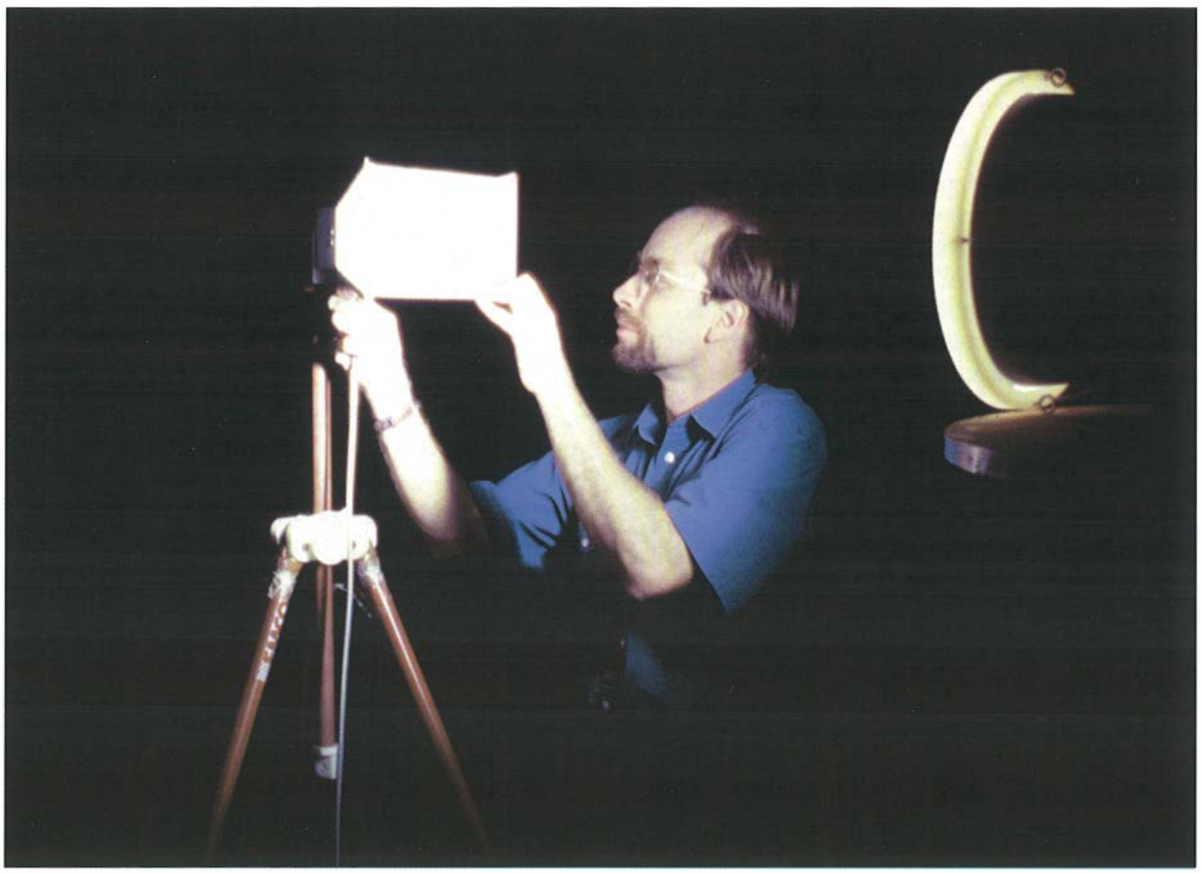

Figure 2. Emission spectrum measurements in progress on a microwave-powered light (light is on the right). These lights will find increasing use in hangars, factories, and warehouses, and thus it is important to know what their impact on spectrum occupancy will be (photograph by F.H. Sanders).

Recent Publications

F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, 1997, "Broadband spectrum survey at Los Angeles, California," NTIA Report 97-336, May 1997.

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Spectral Assessment of Government Systems

Outputs

- EMC measurements and tests between new earth-orbiting radar designs and existing long-range air-traffic control and defense radars.
- Interference measurements, tests, and analysis to resolve an ongoing interference problem between Government radars and an Earth station.
- Tests and measurements on narrowband maritime mobile radio systems.
- Emission spectrum measurements on Government radars to determine potential for EMC problems with intelligent transportation systems.

As more users and new services attempt to use existing spectrum, and as interference problems involving incompatibilities between existing radio systems occur, there is a continuing, critical national need to determine the sources of existing and potential electromagnetic compatibility (EMC) conflicts that involve Government radio systems. There also exists a critical national need to evaluate EMC problems between new and existing Federal radio systems, and it is very important to determine the potential for EMC problems in newly designed systems, before they are built and deployed. ITS provides electromagnetic measurement and analysis capabilities that meet these needs.

In 1997, ITS and the NTIA Office of Spectrum Management (OSM) jointly performed a series of tests and measurements to determine the emission parameters that would ensure electromagnetic compatibility between newly proposed National Aeronautics and Space Administration (NASA) earth-orbiting radars and existing air-traffic control (ATC) and defense radars (see the Figure). The tests were required because the new NASA radars would be designed to share a spectrum band with existing radars that are used for ATC and air-defense identification. Although the terrestrial radars carry out essential missions, the NASA radars also are critical, as they are intended to support NASA remote-sensing missions well into the next century. In addition, the NASA deployment is planned to be concurrent with deployment of a new generation of the terrestrial radars. Since no other spectrum is available for the NASA radars, they must share spectrum with the terrestrial radars. To determine the technical requirements for spectrum sharing between these terrestrial and spaceborne radar systems, ITS designed and operated a test transmitter that emulated the emissions from the proposed space radars, and transmitted those signals into a new-generation air traffic control radar in the Baltimore, Maryland, area. Using a conventional set of operating parameters, the emulated signals produced significant degradation of the terrestrial radar functions, including total failure of the radar. However, additional ITS/OSM test results showed that compatibility could be achieved with certain limits placed on the spaceborne radar pulse parameters. Those limits were determined by ITS/ OSM tests, and are now being incorporated into the design of the NASA spaceborne radar transmitters.

ITS and OSM also worked jointly with the U.S. Navy to resolve an ongoing interference problem between Government radars and a private-sector Earth station in Bath, Maine. The Earth station had been built in close proximity to a location where the Navy performs tests of high-power air-search and air-defense radars, and the Navy radars operate in a spectrum band that is adjacent to the Earth station band. Although the Government radars met all applicable emission criteria, both in the radar band and in the adjacent Earth station band (that is, the Navy radar emissions in the Earth station band fell below the limit imposed by the NTIA radar spectrum engineering criteria; RSEC), the Earth station nevertheless experienced interference that adversely affected the operator's business. This was an excellent example of the fact that EMC problems can occur between radio systems even when both systems meet all applicable technical criteria for radiation limits. The ITS/OSM/Navy measurements and tests pinpointed the causative factors in the interference problem. One of the proposed solutions is expected to be applied at this location in early 1998. This problem was somewhat different from past problems of a similar nature that have involved ITS, because the Earth station was handling entirely digital data. Further work at ITS is planned in FY 98 to study the mechanisms of interference between radars and digital data links and develop effective mitigation procedures for when such interference occurs.

Measurements being performed while the ITS radio spectrum measurement system is transmitting simulated spaceborne radar signals into an air-traffic control radar (photograph by F.H. Sanders).

ITS and OSM personnel worked jointly on a set of measurements on maritime mobile radio systems in Savannah, Georgia, and New Orleans, Louisiana. These measurements were designed to ensure compatible operation of those systems with other mobile systems. Because these narrowband systems will eventually replace older, wideband systems in the maritime mobile bands, ITS/OSM have been tasked with determining, in advance, what EMC issues may occur as these narrowband systems are deployed. In Savannah and New Orleans, ongoing interference problems were analyzed to determine the underlying causes, and to further determine the extent to which similar interference problems may occur in other locations as these systems are more widely deployed. It was determined that the interference in Savannah and New Orleans was caused by intermodulation between transmitters, and that the potential for this source of interference will increase at other locations as the number of maritime channels is eventually doubled.

In support of two other projects, one with the Federal Highway Administration and the other with the American Automobile Manufacturer's Association, ITS personnel performed many measurements of maximum incident field strength at roadway locations in the United States. These measurements were performed to determine the EMC features that will be necessary in the design of future intelligent transportation systems, and in future electronic packages built into automobiles. The information will help ensure successful operation of those systems in the vicinity of high-power radio transmitters. Because radar units typically produce the highest peak power levels, most of the measurements for these projects were performed in the vicinity of high-power radar units. In addition to peak power levels, time waveform information such as pulse width, pulse repetition rate, and antenna beam scanning characteristics were also measured and recorded. The result of these measurements will be enhanced EMC between existing high-power emitters and future automobile designs and intelligent transportation systems in the highway environment.

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Radio Frequency Interference Monitoring System

Outputs

- Integrated, total system design, including vehicle, hardware, and software solutions for spectrum measurements.
- Electronic hardware design, documentation, description, and drawings.
- Measurement control system design, development, description, and flowcharts.
- Technical papers addressing software techniques for, and physical analysis of, radio frequency measurements, including patent application.

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 radio frequency interference monitoring system (RFIMS), they selected ITS to design and build them.

This three-phase project—which included (1) analyzing FAA requirements and designing and developing a custom radio spectrum measurement system; (2) building and testing a prototype mobile system; and (3) integrating and testing production mobile systems—is now at the beginning of phase 3.

The design for the first of the eleven RFIMS vans (the prototype), with all of its interconnected hardware, software, and on-line help was tested and accepted by the FAA in mid-September (Figure 1).

The vehicle is a standard, four-wheel-drive E-350 van that meets the Department of Transportation's limitations for height and weight. An on-board generator, air-conditioner, heater, and three equipment racks have been added. Figure 2 shows the efficient layout of the interior of the van with the integrated electronics package (IEP) monitoring equipment mounted in three 6-ft racks.

The IEP combines ITS-designed and commercially available hardware into an integrated set of radio measurement and test equipment with the capability of both specialized measurements and general spectrum monitoring. The IEP consists of the measurement antenna package, the tower-top preselector, and the rack-mounted equipment. The antenna package includes several antennas. 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.

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 measurement algorithms that cannot be implemented without automated control. In both cases, a measurement control system is required for consistent measurements and data recording. ITS has produced the measurement control system that will control the measurement system and record all data sets on the system—the measurement data, as well as all states of all equipment—thus ensuring repeatability and comparability. The system is able to operate in automatic mode (via local computer) or manual mode (via the instrument front panel controls.) All of the RFIMS hardware and software algorithms were tested and verified by ITS prior to delivery to the FAA.

One of the software algorithms written by ITS engineers measures air-traffic control radar beacons. For this algorithm, the software team has applied for a patent. The algorithm allows the FAA a savings of approximately one million dollars. Prior to the development of this algorithm, expensive pulse-separation hardware had to be used, or the radar had to be turned off in order to make the necessary measurements. Such alternatives are costly and disruptive to the nation's airports, creating a safety concern, since radar operations had to be interrupted.

ITS' innovative, nondisruptive, safety-conscious technique now measures both emission patterns simultaneously and plots them separately using conventional test equipment under computer control.

Figure 1. RFIMS van at an FAA navigation beacon facility. RFIMS van used four-wheel drive capability to negotiate deep mud and bring the measurement system to this location (photograph by F.H. Sanders).

Figure 2. The interior of the RFIMS van, showing the layout of the integrated electronics package monitoring equipment mounted in three 6-ft racks (photograph by F.H. Sanders).

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ITU-R Activities

Outputs

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

The International Telecommunication Union-Radiocommunication Sector (ITU-R) is the 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 both in this country and 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 international radio system standards.

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. 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 for 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 members 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 group 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.

ITS is involved in the development of short-path propagation models that will be incorporated in a propagation recommendation of ITU-R Study Group 3. The short paths are up to about 1 km in length and four typical situations are depicted in Figure 1. The antenna for base station 1 (BS1) is mounted above roof-top level and propagation from this base station is mainly over the roof-tops to the mobile stations (MS). A typical nonline-of-sight case (link BS1-MS1) is described by Figure 2. The relevant parameters for this situation are:

h_r height of buildings,
w street width,
b building separation,
h_b base station antenna height,
h_m mobile station antenna height,
l length of the path covered by buildings,
φ street orientation with respect to the direct path,
d distance of BS to MS.

This frequently occurs in residential/rural environments for all cell types and is predominant for small macrocells in urban/suburban low-rise environments.

Base station 2 (BS2) is mounted below roof-top level and defines a micro- or pico-cellular environment. In these cell types, propagation is mainly within street canyons for both line-of-sight (LOS) and NLOS. Figure 3 depicts the situation for a typical microcellular NLOS case (link BS2-MS3). The

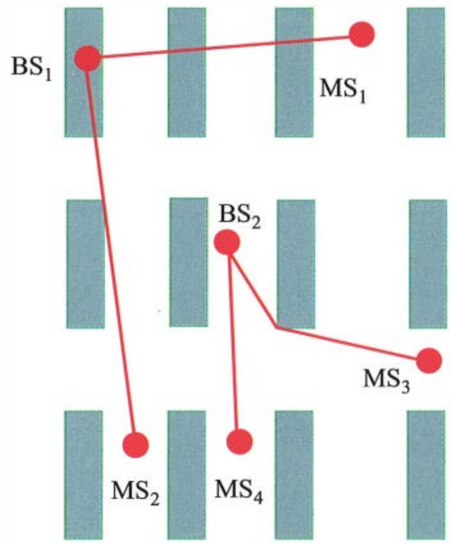

Figure 1. Top view of the four short-path propagation scenarios for typical urban base station (BS) to mobile station (MS) situations.

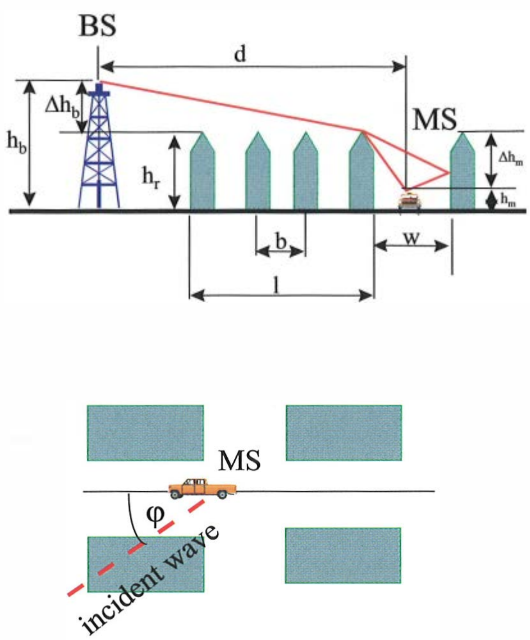

Figure 2. Model parameters as shown in a side view of the nonline-of-sight scenario from a high base station (BS) to a low mobile station (MS) and top view of the incident angle from the MS to the BS.

relevant parameters for this situation are:

w_1 street width at the position of BS,
w_2 street width at the position of MS,
x_1 distance BS to street crossing,
x_2 distance MS to street crossing, and
α corner angle.

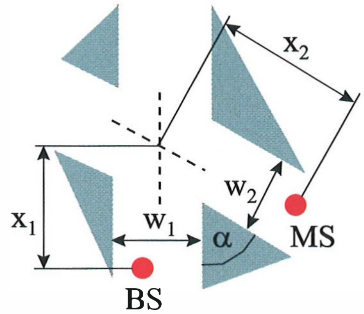

Figure 3. Model parameters as shown in a top view of the non-line-of-sight scenario from a low base station (BS) to a low mobile station (MS).

This case is the predominant effect in urban high-rise environments for all cell types and occurs frequently in micro- and pico-cells in urban low-rise environments. A two-dimensional analysis of the area around the mobile unit is required to determine all parameters for this case. The paths BS1-MS2 and BS2-MS4 occur in LOS situations. The same models can be applied for both BS antenna configurations.

For site-specific calculations in urban areas, different types of data may be used. The most exact information can be derived from high-resolution data where information consists of:

- building structures
- relative and absolute building heights, and
- vegetation information.

As an example of the types of models in development, the well-known basic transmission loss for an LOS case can be characterized by two slopes and a single breakpoint. An approximate upper bound is given by

$$L_{LOS,u} = L_b + \begin{cases} 20\log_{10}(\frac{d}{R_b}), & d \le R_b \\ 40\log_{10}(\frac{d}{R_b}), & d > R_b \end{cases}$$

where R_b is the breakpoint in the bound and is given by

$$R_b \approx \frac{4 h_b h_m}{\lambda}$$

The remaining models will be given in the new recommendation.

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ITS engineers staff a display of audio and video quality measurement technologies at the 1997 National Association of Broadcasters Conference in Las Vegas, Nevada (photograph by W. Hughes).

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), the Institute of Electrical and Electronics Engineers (IEEE), and others. The technical standards and recommendations developed in these forums are blueprints for technology evolution and can influence billions of dollars in telecommunications research and development investments worldwide.

Areas of Emphasis

Video Quality Standards Development:

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

Audio Quality Standards Development

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

Broadband Networks

The Institute contributes to the development and effective use of broadband integrated services digital network, asynchronous transfer mode, and advanced Internet technologies through laboratory measurements and technical contributions to national and international performance standards committees. Projects are funded by NTIA and NCS.

Telecommunication Terminology Standards

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

Wireless Standards Support

The Institute contributes to the development of industry standards for personal communications services and provides objective testing and evaluation of the associated technologies. Projects are funded by NTIA 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 land mobile radio and high-frequency radio systems. Projects are funded by NCS.

ITU-T Standardization Activities

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

Video Quality Standards Development

Outputs

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

Digital compression and transmission techniques offer an economical means of implementing video communication services in emerging national and global information infrastructures. However, these techniques affect received video quality in complex ways. The quality of compressed digital video systems cannot be evaluated using the static test patterns and waveform reproduction measures traditionally used in assessing analog video systems. ITS engineers have addressed this problem through the development and standardization of a fundamentally new methodology for video quality assessment.

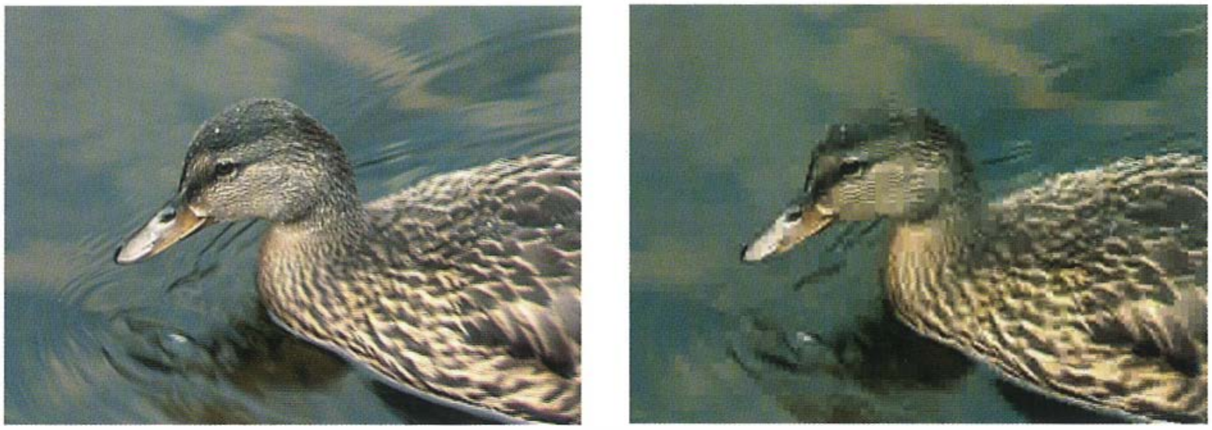
The ITS-developed methodology employs natural video scenes (rather than artificial test patterns) as input material, and captures the observable effects of a wide range of impairments using *perception-based* video quality parameters. These parameters have been selected for their correlation with the subjective assessments of human viewer panels. The ITS-developed parameters are specified in American National Standards Institute (ANSI) T1.801.03-1996 (ANSI, 1996; see Publications Cited, p. 103). These parameters can be used to characterize both spatial and temporal distortions in the output video. Supporting material is presented in ANSI Standards T1.801-01 and T1A1.801-02, which are based largely on ITS contributions. T1A1.801-02 provides a reference for terms and definitions used in the other 801 series standards, while T1.801-01 specifies a set of video test scenes that may be used in subjective and objective video quality testing.

During FY 97, ITS engineers continued to refine and apply the ANSI standard video quality metrics to facilitate their consideration in international standardization. The Figure presents video images from a recent cooperative effort with the National Institute of Standards and Technology that involved measuring the subjective and objective quality of Motion Picture Expert's Group (MPEG) coded video. MPEG coding is being used for digital delivery of most high-end video streams, including high-definition television (HDTV). An original source frame before MPEG coding is represented by (a) in Figure 1, while (b) is the corresponding image after MPEG coding and decoding at 1.8 Mbits/s. The fine detail in the duck's head has been smeared[1] and block distortion[2] is evident in the duck's body and the water. The operation of two objective video quality parameters is illustrated in Figure 2. These parameters simultaneously measure the perceptual effects of blurred edges (shown in green) and added edges (shown in red).

Successful objective video quality models that track subjective assessments normally involve computation and combination of at least four video quality parameters: two parameters that measure the perceptual effects of lost and added motion and two parameters that measure the perceptual effects of lost and added edges. These two parameters (and the corresponding motion parameters) can be measured simultaneously using ITS-developed laboratory test equipment. ITS had developed a laboratory implementation as well as field-portable demonstration versions of the ITS objective video quality measurements. For more information, see *http://its.bldrdoc.gov/n3/video/*

1. Smearing is defined in ANSI T1.801.02-1996 as "A localized distortion over a sub-region of the received image, characterized by reduced sharpness of edges and spatial detail."

2. Block distortion is defined in ANSI T1.801.02-1996 as "Distortion of an image characterized by the appearance of an underlying block encoding structure."



(a) (b)

Figure 1. Source video image, (a) before MPEG coding and (b) after MPEG coding and decoding.

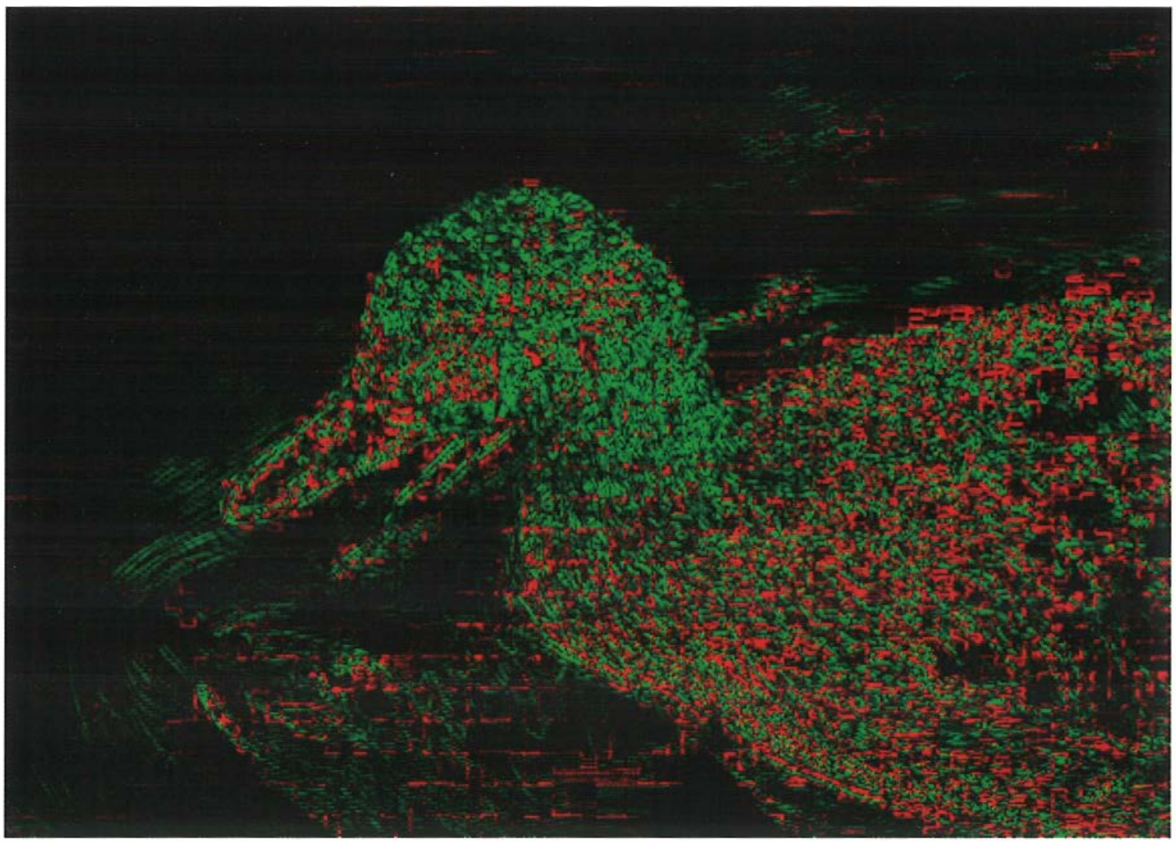


Figure 2. Objective parameters to measure smearing (green) and block distortion (red).

Recent Publications

S. Wolf, "Measuring the end-to-end performance of digital video systems," *IEEE Trans. Broadcast.*, Vol. 43, No. 3, pp. 320-328, Sep. 1997.

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Audio Quality Standards Development

Outputs

- Objective audio quality assessment algorithms.
- Prototype audio quality test instruments.
- Results of subjective listening experiments.
- Reports to standards organizations and other groups.

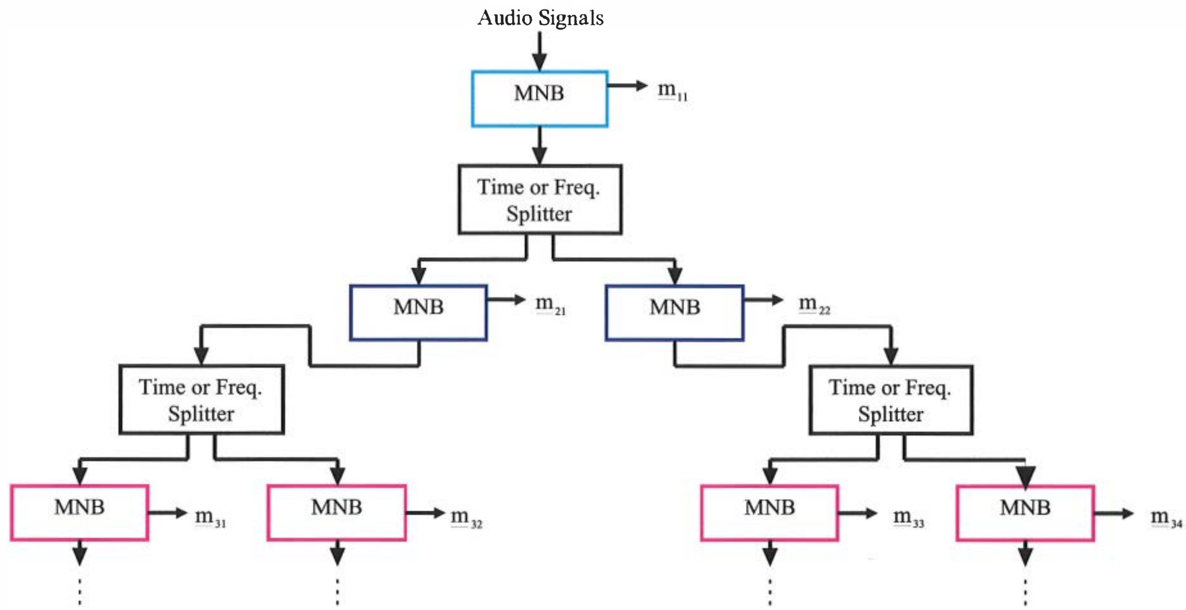
Technology advances have greatly expanded the available options for encoding and transmitting audio signals–and complicated the assessment of delivered audio quality. With advanced digital signal processing, toll-quality speech can now be transmitted or stored at bit rates as low as 8 kbit/s. Fully intelligible, lower quality speech can be transmitted or stored at a bit rate of 2.4 kbit/s. High-quality audio signals, such as music and entertainment soundtracks, can be encoded at rates as low as 64 kbit/s per channel. However, compressed audio signals are much more vulnerable to transmission impairments than signals encoded by simple waveform reproduction. Advanced transmission techniques such as asynchronous transfer mode create complex, nonlinear impairments whose effects on compressed audio signals are not well understood. Higher capacity (and signal quality) will be associated with higher equipment and service costs.

These technology advances and associated economic trade-offs have created important new measurement issues. Equipment manufacturers, service providers, and users all need an audio quality assessment method that works no matter how a signal has been encoded and transmitted. Not surprisingly, traditional waveform reproduction measures developed for wired 4-kHz analog telephony are ineffective in assessing the listener-perceived quality of today's digital speech and audio systems.

The most fundamental and accurate measures of audio quality are the subjective responses of users. These responses can be obtained by conducting subjective listening experiments, but the time and cost of such experiments is often difficult to justify. In its Audio Quality Standards Development program, the Institute is working to overcome this problem by developing practical alternatives to controlled subjective listening experiments: digital signal-processing algorithms that objectively and accurately estimate perceived audio quality as determined in such experiments. Quality estimates obtained using candidate objective measures are compared with corresponding listening experiment results to ensure that the selected algorithms accurately reflect human perception over a wide range of encoding techniques and channel conditions.

The ITS approach to the development of objective audio quality assessment algorithms is *perception based*. The basic premise of the perception-based approach is that audio signals can be transformed into a perceptual domain in which 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. The perceptual transformation used at ITS incorporates a psychoacoustic frequency scale and a model for nonlinear loudness growth. Once audio signals have been transformed into the perceptual domain, they must be compared in a way that mimics human judgment. Using the results of subjective listening experiments, ITS has determined that listeners adapt and react differently to spectral deviations that span different time and frequency scales. Following from this result, staff members developed a novel analysis technique to measure and remove spectral deviations at multiple scales using time-measuring and frequency-measuring normalizing blocks. To best emulate listeners' patterns of adaptation and reaction to spectral deviations, the measuring normalizing blocks are combined so that analysis proceeds from larger scales to smaller scales as illustrated in the Figure. ITS has applied for a patent on this innovative audio quality measurement technology.

During FY 97, ITS staff members applied these perception-based audio quality assessment techniques in advancing the development of audio performance standards in American National Standards Institute (ANSI)-accredited standards Working Group T1A1.7 (Signal Processing and Network Performance for Voiceband Services). A proposed standard specifying the ITS-developed audio quality



Example block diagram for a combination of measuring normalizing blocks (MNB's).

metrics is being developed in that group. The Institute is also contributing 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 non-linear distortions in voice transmission. Results were also presented in the Federal Telecommunications Standards Committee's Multimedia Telecommunication Performance Measurements Subcommittee, which ITS leads.

During FY 97, ITS also applied its perception-based audio quality assessment tools in evaluating cellular telephone transmission impairments under a cooperative research and development agreement with an industry partner. ITS designed, conducted, and analyzed a listening experiment in which several recorded signals with selected impairments were subjectively evaluated. ITS also applied its objective audio quality assessment algorithms to the corresponding digital voice signals. It is expected that this work will lead to the development of commercial products that use the Institute's objective audio quality assessment algorithms.

ITS staff members disseminated objective audio quality assessment results to industry, Government, and academia through several technical publications and presentations during FY 97. Staff members also demonstrated the ITS-developed prototype audio quality test instruments to industry, Government, and standards committee representatives. These prototype test 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 tools are available for use in cooperative laboratory or field test experiments.

Recent Publications

S. Voran, "Estimation of perceived speech quality using measuring normalizing blocks," In *Proc. 1997 IEEE Workshop on Speech Coding for Telecommunications*, Pocono Manor, PA, Sep. 1997, pp. 83-84.

S. Voran, "Listener ratings of speech passbands," In *Proc. 1997 IEEE Workshop on Speech Coding for Telecommunications*, Pocono Manor, PA, Sep. 1997, pp. 81-82.

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Broadband Networks

Outputs

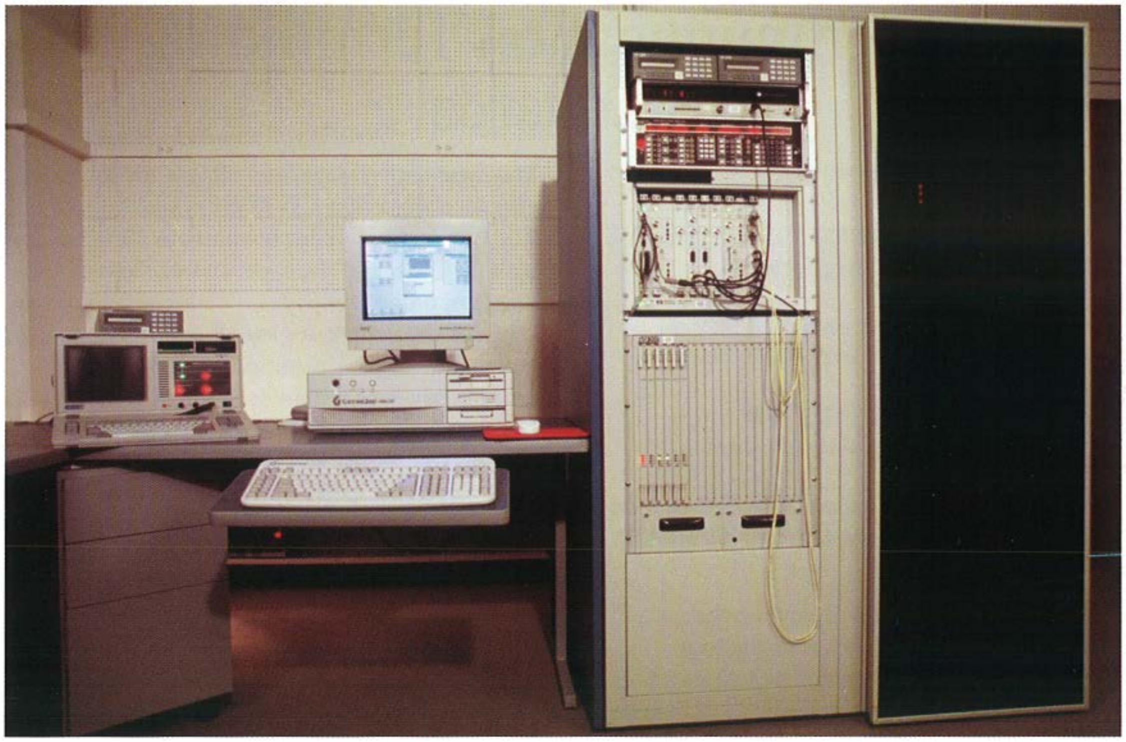
- Emulation and performance measurement tools for B-ISDN/ATM.
- Contributions to national and international performance standards committees.
- Draft national and international standards on Internet performance.

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 realizing the Global Information Infrastructure (GII) envisioned by industry and Government planners. However, these technologies have transmission performance characteristics fundamentally different from those observed in traditional isochronous networks, and their successful deployment will require complex traffic control and resource management mechanisms that are not fully defined. B-ISDN/ATM interworking with related data communication technologies, such as frame relay and transmission control protocol/Internet protocol (TCP/IP), is important but is not completely understood. The Institute's Broadband Networks program contributes to the resolution of these issues and the successful deployment of B-ISDN/ATM and related technologies through network performance measurement studies and associated standardization activities.

In FY 97, ITS placed a principal emphasis in the Broadband Networks project on the development of performance specification standards for Internet-based data communication services. These services are expected to be widely used in the GII and will provide a major proportion of the early ATM network traffic. To establish a technical basis and appropriate liaisons for this work, ITS staff members attended and provided invited presentations and demonstrations at meetings of three industry organizations with relevant responsibilities: the Cross-Industry Work Team, the Internet Engineering Task Force, and the North American Network Operators Group (NANOG). These organizations focus, respectively, on national and global information infrastructure (NII/GII), Internet technical standards, and Internet operational issues. They represent a substantial portion of the U.S. Internet and related NII/GII planning communities—the NANOG presentation alone addressed over 350 participants.

Using information gleaned from these and other outreach activities, ITS developed a project proposal for Internet performance standardization and presented the proposal to the American National Standards Institute (ANSI)-accredited T1 (Telecommunications) Committee's Technical Subcommittee T1A1 (Performance and Signal Processing). The proposal was adopted by T1A1's Working Group on Digital Networks and Services (T1A1.3) and stimulated related Internet initiatives in each of the other three T1A1 Working Groups. T1A1.3 expects to complete an American National Standard on IP service performance by the end of 1998. Working Group T1A1.2 (Network Survivability Performance) plans to develop a new T1 technical report on reliability and survivability aspects of interactions between the Internet and the public switched telecommunications network (PSTN) by the end of 1998. This activity is expected to be of interest to the Federal Communications Commission-chartered Network Reliability and Interoperability Council, which is examining reports of PSTN congestion caused by Internet use. Working Group T1A1.5 (Multimedia Communications Coding and Performance) plans to develop a new American National Standard on reference connections for Internet multimedia service performance characterization by early 1999. The initial focus of the T1A1.5 work will be on video teleconferencing and video telephony. Working Group T1A1.7 (Signal Processing and Network Performance for Voiceband Services) will investigate voice and voiceband data performance over IP-based networks interconnected with the PSTN, and plans to develop two related T1 technical reports. The first will define performance metrics and the second will define statistical tools for end-to-end performance measurement. An Institute staff member serves as Technical Editor for the T1A1.3 IP service performance standard. ITS expects to contribute to the other T1A1 Internet performance initiatives as well.

ITS presented a skeleton outline for the proposed Internet performance standard at the May 1997



Broadband network emulator system at ITS (photograph by D.J. Atkinson).

T1A1.3 meeting. That contribution defines an approach to the standard's development that maximizes the use of relevant prior T1A1.3 work (e.g., performance standards for X.25 packet-switched services) while accommodating the significantly different characteristics of IP (e.g., its connectionless nature and facilities for "datagram" fragmentation and reassembly). The proposed outline was adopted and provided the framework for a second, more substantial ITS contribution that was accepted as the baseline for the proposed new standard. That standard is designed to be used by Internet service providers, equipment manufacturers, and end users in planning, provisioning, and evaluating IP-based data communication services. The draft standard specifies an Internet performance model and a set of IP packet transfer reference events that can be observed at defined measurement points (e.g., host and router interfaces); applies the specified events in defining a set of discrete IP packet transfer outcomes (lost, errored, misinserted, and successfully transferred packets); and specifies five performance parameters that will collectively describe the speed, accuracy, and dependability of IP packet transfer in Internet data communications. The draft standard also outlines a means of specifying and measuring IP service availability. The T1.5IP standard will provide a basis for characterizing the performance of services provided by higher-layer Internet protocols (e.g., TCP, FTP, Telnet, and the World Wide Web) and emerging new Internet applications such as streaming video and packet voice.

In related laboratory work, ITS integrated the Institute's Broadband Network Emulator (see the Figure) with its new Multimedia Subjective Test Facility and existing perception-based voice and video quality test instruments in order to determine the impacts of broadband network transmission and switching impairments on the user-perceived quality of multimedia services. One experimental use of this capability, planned for FY 98, will involve two subjects that will be asked to complete a task requiring cooperation via a telecommunications link (audio, video, or combined audio and video signals). During the session, various network facilities (e.g., ATM and TCP/IP) and levels of network impairment will be introduced to assess their impact on user-perceived quality and user effectiveness. Results will contribute to the specification of recommended broadband network performance levels in national and international standards committees.

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Telecommunication Terminology Standards

Outputs

- CD ROM of Federal Standard 1037C in HTML, .PDF, and word- processing formats.
- HTML-coded hypertext version of Federal Standard 1037C on the World Wide Web.
- U.S. Contributions to ISO/IEC-2382, *Information Technology—Vocabulary.*
- ANSDIT, *American National Standard Dictionary for Information Technology*, ANSI X3.172.

Advancements in technology depend on the use of agreed-upon terminology. Unless technology advances are recorded and communicated unambiguously, they may be misinterpreted, and their benefits may be compromised or lost. A common understanding of technical terminology is particularly important in the rapidly growing field of telecommunications, where the development and implementation of new technologies may require cooperation and mutual understanding among dozens—or even hundreds—of independent equipment and service providers. A common understanding of telecommunication terminology is also important in ensuring the marketability of U.S. telecommunication products and services in international trade. Telecommunications and information terminology standards developed under ITS leadership, with sponsorship of the National Communications System (NCS), effectively advance the aforementioned goals in Federal, national, and international fora.

The Institute's Federal standardization work benefits the Federal user community and the public at large by developing standardized vocabulary for—and thereby promoting advancement of—the National Information Infrastructure (NII). In prior work, ITS chaired the Federal Telecommunications Standards Committee (FTSC) Subcommittee in revising Federal Standard 1037B and developing its successor, Federal Standard 1037C, *Glossary of Telecommunication Terms.* This 5800-entry dictionary was published in hard copy in 1996 and in hypertext version in 1997. The hypertext version of the Standard resides on the World Wide Web at *http://glossary.its.bldrdoc.gov/fs-1037*

The hypertext version, as well as a .PDF version, is also accessible on a CD-ROM available from NCS. The CD-ROM includes browsers to allow access to both the .PDF and the hypertext versions of this Standard on several popular computer platforms. Users of the hypertext glossary can navigate quickly in a nonlinear (i.e., nonsequential) mode, by clicking on defined terms within definitions or 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 expanding access to the document to a worldwide audience. More than 20,000 users from the United States and a dozen foreign countries accessed this standard during the first 14 months it was available on the World Wide Web. ITS has been contacted with a request for authorization to translate the standard into Chinese.

In national fora, an ITS staff member serves as Chairman of the American National Standards Institute (ANSI)-accredited Technical Committee K5, which developed ANSDIT, *American National Standard Dictionary for Information Technology* (ANSI, 1996; see Publications Cited, p. 103). An ITS staff member also served as project editor for this 220-page glossary, published in FY 97 as ANSI X3.172.

In the international arena, an ITS staff member serves as convener of the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Joint Technical Committee 1/Subcommittee 1, Working Group 7, Vocabulary for Data Communications. Working Group 7 met twice during FY 97 to develop vocabulary for databases, electronic mail, and network management. An ITS representative serves as project editor for the English text of several parts of ISO/IEC-2382, *Information Technology—Vocabulary* (see Publications Cited, p. 103).

The goal in each committee is 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 standards fora, ITS promotes congruence 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; NSA, 1992; see Publications Cited, p. 103) provide a common language for communicating technology advances, promoting interoperability of equipment and systems, and ensuring the marketability of U.S. telecommunications products and services worldwide.

Development of a more compact, more readily accessible format for glossary standards.

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Wireless Standards Support

Outputs

- Study of the results of the JTC PCS technology field trials.
- Draft NTIA report based on the JTC PCS technology field trials.

Wireless technologies are being implemented in a wide variety of existing and emerging systems. Examples include land mobile radio; HF radio; broadcast radio and television; local and multichannel multipoint distribution service; wireless telephone systems (such as cellular and personal communications services, PCS, systems); paging; packet radio; wireless local area networks (WLAN's); wireless digital modems; and satellite-based systems. New technologies are being developed both for emerging services such as PCS and for traditional services such as broadcast television and radio. The need for wireless standards becomes increasingly important as new wireless systems and technologies proliferate. Without standards, interoperability is not possible. Users are faced with an overwhelming number of ad hoc, disjointed systems and services. This is both frustrating and costly to the wireless user as, potentially, a user must subscribe to several different services and purchase several different pieces of equipment to meet their needs. In the case of public safety communications, lack of interoperability can be detrimental to the health, safety, and welfare of the public. Because of the importance of wireless standards for the development of future wireless systems and technologies, the Institute is actively involved in supporting these standards. In particular, wireless standards support at the Institute in FY 97 was centered around PCS standards.

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 was a joint activity between committee T1 of the American National Standards Institute (ANSI) and the Telecommunications Industry Association (TIA). The work of the JTC resulted in the generation of draft standards for the following six PCS air-interface technologies:

1. IS-95-based code division multiple access (CDMA),
2. IS-136-based time division multiple access (TDMA),
3. personal access communication system (PACS),
4. PCS 1900,
5. Composite CDMA/TDMA, and
6. wideband CDMA.

Field trials for all of these technologies were performed at the US West Boulder Industry Test Bed in cooperation with the JTC. Work at the Institute in FY 97 included a study of the results of these field trials and the preparation of a draft NTIA report based on these trials.

While the composite CDMA/TDMA technology was tested in both a high-tier and low-tier configuration and the PACS technology was tested only in a low-tier configuration, the remaining technologies were all tested in a high-tier configuration. The same configuration (cell site layout, antenna type, and antenna orientation) was used for all of the systems tested as high-tier systems. Similarly, another configuration was used for the systems tested as low-tier systems. These configurations were fixed throughout the entire duration of the field trials and did not vary from one technology to another. This provided a common environment in which the tests could be conducted. It did not, however, allow the performance of each technology to be optimized.

Field testing for all six of the air interface technologies typically consisted of four general types: area coverage testing, handoff testing, interference testing, and voice quality testing. The area coverage testing included fundamental measurements of received signal strength (RSS) and error rate as a function of location. The types of parameters measured during handoff testing included the change in RSS before and after handoff, the change in error rates before and after handoff, the time between successive handoffs, the cell site sector in use as a function of location, the percentage of time that the network was in a particular handoff state, and the handoff state as a function of location. As an example, a histogram of the time between successive handoffs for one of the technologies is shown in Figure 1.

Interference testing typically consisted of co-channel and adjacent channel interference measurements. The goal of the interference measurements was to determine the error rate performance as a function of co-channel and adjacent channel carrier-to-interference ratios (C/I's). An example of downlink bit error rate (BER) as a function of adjacent channel C/I is shown in Figure 2.

For the JTC PCS technology field trials in general, two types of voice quality measurements were made: quasi-stationary measurements and handoff measurements. The quasi-stationary measurements were made at fixed locations on a grid within each cell site. At each fixed location, voice recordings of transmitted voice were made as the mobile unit traveled a specified distance. In addition to the voice recordings, various objective measures were recorded such as RSS and BER. Voice quality of the voice recordings was determined by both mean opinion score (MOS) and expert listener techniques. The MOS technique in determining voice quality entailed having a group of listeners rate the quality of voice recordings subjectively. For each voice recording, the results from all subjects in the group were then averaged to form the MOS. For the expert listener technique, a person was trained to emulate the responses of listener panels to the question "Would you consider this [voice recording] acceptable as portable service?" Figure 3 shows an example of MOS as a function of RSS for one of the PCS technologies.

For the voice quality handoff measurements, continuous voice recordings of transmitted voice were made as the mobile unit traveled along routes through handoff areas. In addition to the voice recordings, various objective measures were recorded (such as RSS and BER), as in the quasi-stationary measurements.

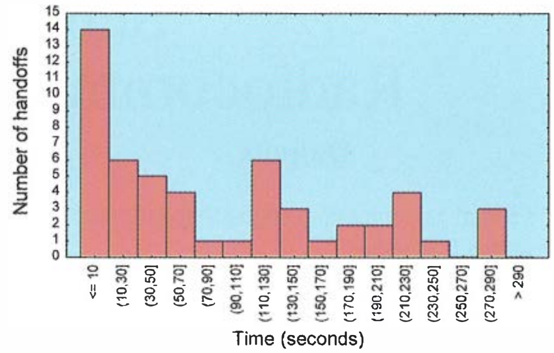

Figure 1. Histogram of time between successive handoffs for a PCS system during the JTC technology field trials.

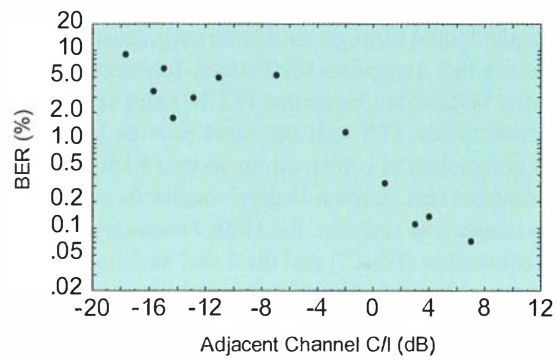

Figure 2. Average downlink BER vs. adjacent channel C/I for a PCS system during the JTC technology field trials.

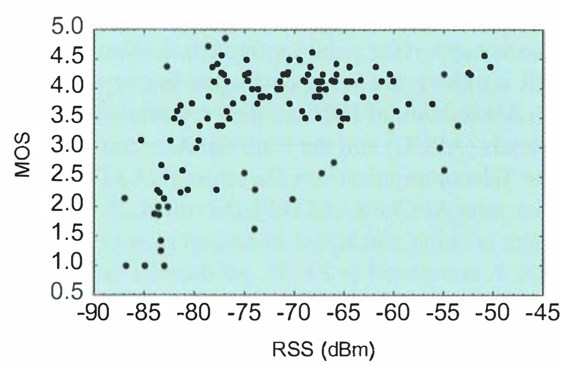

Figure 3. MOS vs. average RSS for a PCS system during the JTC technology field trials.

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Standards for Radiocommunication Systems

Outputs

- Federal Telecommunications Standards subcommittee leadership.
- APCO Project 25 task group leadership.
- Federal standards for HF and land mobile radio communications.

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 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 or Emergency Preparedness telecommunications, and law enforcement.

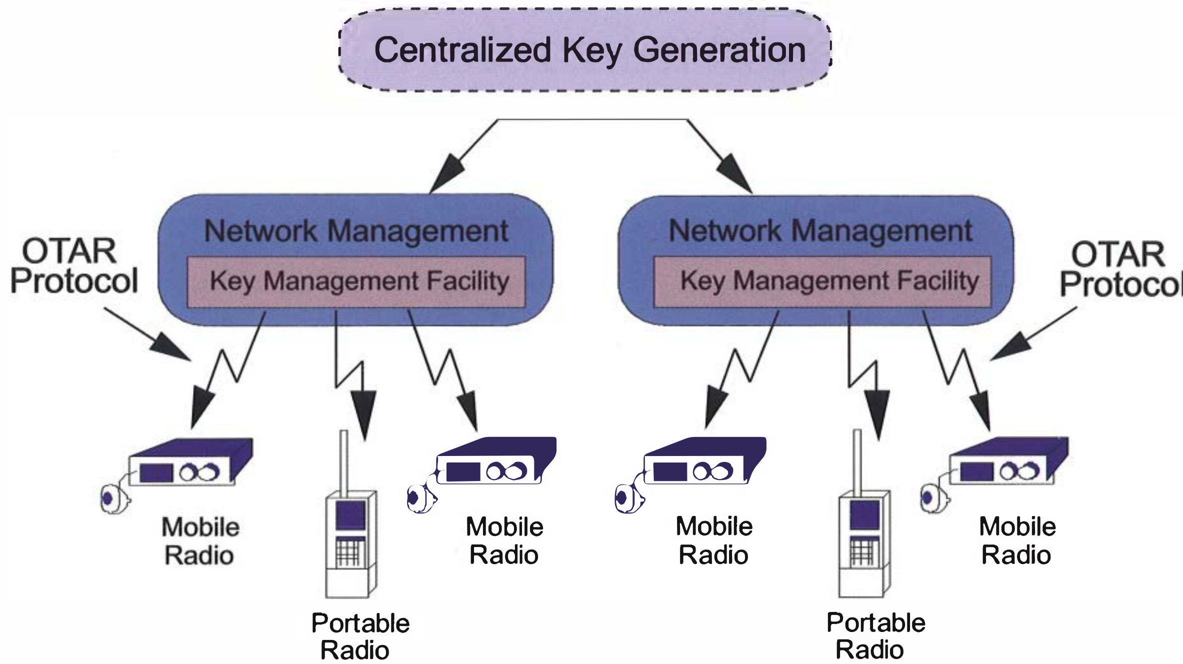
During FY 97, ITS continued to assist NCS and other Government agencies in developing interoperability standards for digital land mobile radio (LMR) systems supporting public safety applications. The LMR standards are being developed in conjunction with Association of Public-Safety Communications Officials (APCO) and the National Association of State Telecommunications Directors (NASTD) under joint APCO/NASTD/FED Project 25. The project is being conducted in several phases. Phase 1, completed in FY 96, produced a comprehensive set of standards for 12.5-kHz digital LMR systems. During FY 97, the Project 25 steering committee planned and initiated a phase 2 program aimed at developing technology and interoperability standards for more spectrally efficient narrowband digital LMR systems. The phase 2 standards will cover 6.25-kHz frequency-division multiple access radios, and may define time-division multiple access radios with equivalent channel efficiency. ITS supported NCS, Federal law enforcement agencies, and the National Security Agency (NSA) in planning phase 2, and is taking the lead in developing related information security (INFOSEC) standards.

An ITS staff member chairs the APCO/NASTD/FED Project 25 Encryption Task Group (ETG) and works closely with its members in developing Project 25 INFOSEC standards. ITS also participates in the related Telecommunications Industry Association (TIA) TR 8 Encryption Committee to ensure that TIA standards meet Government requirements. ITS participates in other TIA and Project 25 working groups to ensure that the total suite of Project 25 LMR interoperability standards meets Federal needs. One output from this program is Federal Telecommunications Recommendation 1024A, *Project 25 Radio Equipment.*

In its Project 25 ETG leadership role, ITS developed and coordinated industry standardization of an innovative technology for over-the-air rekeying (OTAR) of secure LMR systems. "Keys" are the variables that govern the operation of cryptographic algorithms. Security services such as confidentiality and authentication rely on cryptographic algorithms and keys. When either of these security services are provided, as they are in Project 25, the system must also provide a means of key management. Cryptographic key management encompasses every stage in the life cycle of a cryptographic key, including: generation, distribution, entry, use, storage, destruction, and archiving.

Once keys have been generated, they must be distributed to the cryptographic end units (e.g., mobile radios) that require keys for their cryptographic processes. The traditional means to distribute keys is through a manual process using a physical key loader or key fill device. This process requires that the physical device be transported to each radio. This is obviously inefficient—especially in systems with a large number of elements.

OTAR is a new, more efficient key-distribution method that allows keys to be distributed over the radio channel. The functionality of OTAR is quite simple. Key management facilities (KMF's) store all the keys for use in a system. This is depicted in the Figure. The keys may be generated at KMF's, or may be generated at some centralized facility and



Mobile radio key management system-level diagram.

passed to the KMF's as shown in the Figure. The keys used for traffic are called traffic encryption keys (TEK's). The KMF distributes TEK's over the air by encrypting them with a key encryption key (KEK), and then transmitting them to subscriber units in the system. The subscribers then decrypt the TEK's and store them for use among themselves. This process requires development of an architecture that allows the storage and management of keys in a radio, as well as a protocol for securely transferring and managing these keys over the air.

The OTAR protocol, defined in Telecommunications Industry Association TSB-102.AACA, provides the capability at the KMF to remotely add, modify, inventory, update, activate, and delete keys at a radio. It also provides the capability for the KMF to determine a particular radio's key management capabilities, to set the date and time at a radio, to change a radio's identification, and to zeroize all keys in a radio. The protocol also provides a unique capability that allows a group of keys (called a "keyset") to be managed as a single key, achieving greater efficiency in the key management process.

Institute staff also contributed to the development of HF communication standards (Federal Telecommunications Recommendations; FTR's) during FY 97. ITS staff members chaired the HFRS, co-chaired the Joint Department of Defense/Federal Working Group on next generation HF automatic link establishment (ALE) standards, co-chaired the Working Group's Technical Advisory Committee, and provided technical information, text, and data for several FTR's. ITS prepared two FTR's for publication by NCS during FY 97: FTR 1047/3: *HF Radio Automatic Message Delivery-Network Coordination and Management ALE Addressing and Registration* (NCS, in press) and FTR 1050: *HF Radio Baseline Parameters* (NCS, in press). These documents, coupled with previously Federal standards on HF communications developed under Institute staff leadership, comprise a comprehensive set of standards and recommendations for advanced HF systems.

During FY 97, an Institute staff member was elected chair of U.S. Working Party 9C, which is developing U.S. contributions to the International Telecommunication Union-Radiocommunications Sector (ITU-R) recommendations on HF communications systems. Technical contributions to the development of HF communication system FTR's make widespread use of the HF Communications System Test and Evaluation Facility described in the ITS Tools and Facilities section of this document.

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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 telecommunication 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 important to U.S. Government and industry organizations.

The Institute provides strong support to the U.S. Department of State in leading the U.S. Organization for the ITU-T. 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 4 (Telecommunications Management Networks and Network Maintenance), 6 (Outside Plant), 10 (Languages and General Software Aspects for Telecommunications Systems), 11 (Signaling Requirements and Protocols), 13 (General Network Aspects), and 15 (Transport Networks, Systems, and Equipment). Study Group 13 develops recommendations for advanced broadband networks using high-speed synchronous digital hierarchy (SDH), asynchronous transfer mode (ATM), and Internet systems; and is leading ITU-T efforts to define the Global Information Infrastructure (GII) envisioned by Government leaders and network planners worldwide.

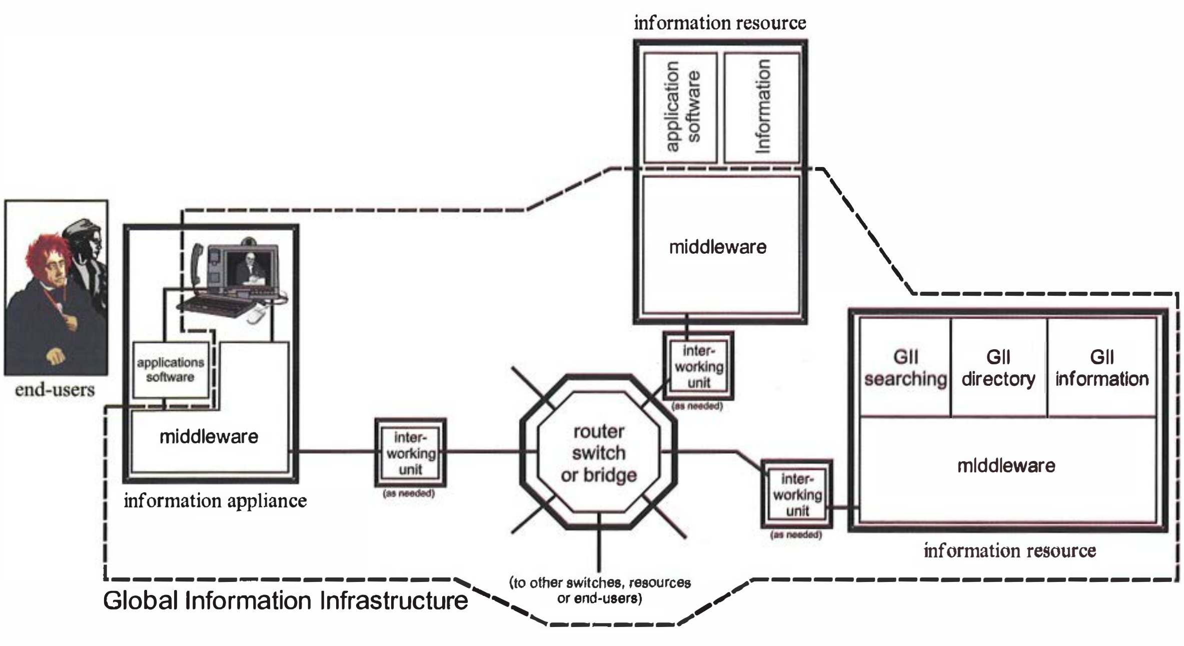
During FY 97, the Institute participated in the U.S. Delegation to the World Telecommunications Standardization Conference, held in October, and assisted the Department of State and ITAC in representing U.S. interests in several of the ITU-T Study Group meetings inaugurating the 1997-2000 study period. ITS headed the U.S. Delegations to the February and September 1997 meetings of ITU-T Study Group 13, at which over a dozen new and revised recommendations on broadband networks and multimedia services were approved. U.S. Delegates contributed to the development of several other ITU-T recommendations, including the first three documents in a new family of recommendations that will guide 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 Department of Commerce goals. During FY 97, Institute representatives (1) continued technical leadership of ITU-T Working Party 4/13 and the ITU-T Rapporteurs Groups for Questions 11, 13, and 22/12; (2) continued corresponding technical and managerial leadership roles 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 broadband integrated services digital network and asynchronous transfer mode (B-ISDN/ATM) services and the GII. The three Study Group 12 Rapporteurs Groups headed by ITS staff are responsible for developing international standards that define subjective and perception-based objective quality of service measures for speech transmission, audio/visual, and multimedia communication systems. Technical Subcommittee T1A1 develops national standards for performance and signal processing in emerging broadband networks. Technical Subcommittee T1S1 develops national standards for broadband network services, architecture, and signaling.

During FY 97, the Institute's ITU-T Study Group 13 activities contributed strongly to the organization and initial development of two new recommendations important to the evolving GII: Recommendation "GII.PERF" and Recommendation "I.35IP."

Recommendation GII.PERF will establish general principles and a framework for GII performance and will define specific interfaces, events, and criteria to be used in characterizing the many new functions the GII will offer (e.g., multiparty call processing, user authentication, address translation, format and media conversion, searching and browsing, and quality of service negotiation). This Recommendation is expected to be important in providing a common understanding of performance concepts among several industries whose technologies will comprise the GII (e.g., the telephone; computer; cable television; and wireless, satellite, and broadcasting industries). Recommendation I.35IP will define parameters for specifying and measuring the speed, accuracy, dependability, and availability of Internet protocol (IP) data packet transfer in public Internet services, which are expected to play an important role in GII. ITS participants are working to coordinate the development of I.35IP with the development of a corresponding American National Standard, T1.5IP, described under the Broadband Networks program (p. 24). This work is being coordinated with the Internet Engineering Task Force (IETF).

The Figure illustrates the boundaries being considered for GII performance description. The end-user interfaces for the GII are being defined to include some major components of user end systems in addition to the traditional telecommunication transmission and switching facilities. For example, the GII will include the hardware and "middleware" in GII "information appliances." GII *middleware* is defined to include network operating systems, web browsers, distributed database management tools, e-mail and file transfer clients, and the associated network servers. The GII will also include the hardware, the software, and the data supporting "information resource" functions, such as information searching, address translation, and directory assistance. The GII will not include application-specific software (e.g., word processing and spreadsheet programs) or the communicated information content itself. ITS continues to provide technical input to advance GII performance description, building on the approaches successfully applied in the I.350-series ITU-T recommendations. Success in this effort will require an extremely broad view of emerging technologies and the associated business drivers.



Performance boundary of the Global Information Infrastructure.

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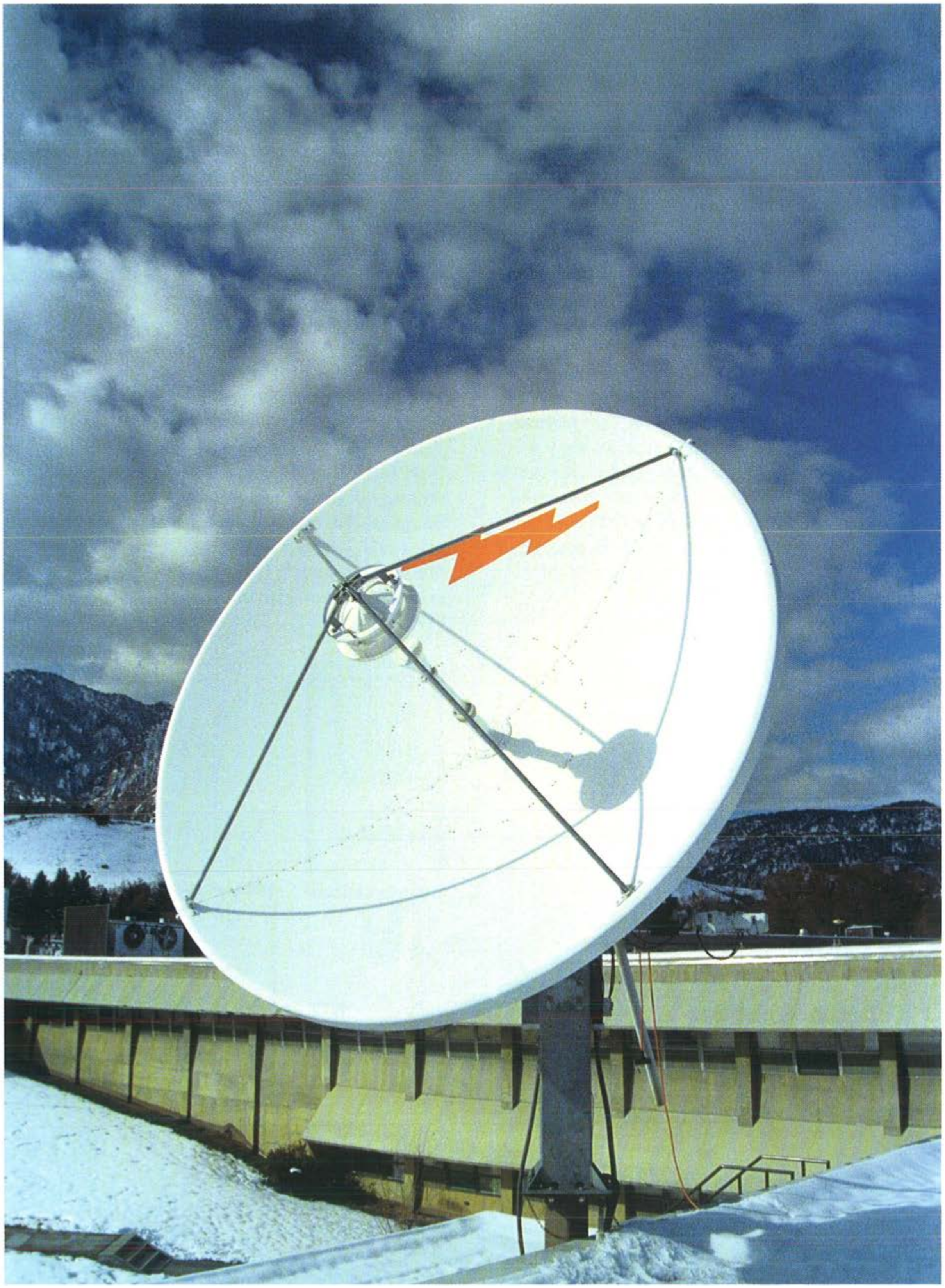


Integrated system planning frequently includes a satellite component. Earth station antennas like this one receive signals from satellites in geosynchronous orbit (Photograph by F.H. Sanders).

Telecommunication System Planning

A major element of the ITS mission is to assist other Federal agencies and private sector clients in planning advanced telecommunication systems to meet evolving operational needs. The Institute's telecommunication system planning assets include skilled personnel, extensive laboratory facilities, hardware and network-accessible software simulation capabilities, and mobile test equipment for radio wave propagation, area coverage, and network performance assessment. These assets are used in planning new systems ranging from individual communication links to wide area networks—some involving thousands of interconnected elements. Typical studies involve specification of user requirements, characterization of existing facilities, evaluation of applicable regulations (and other internal and external factors), and the assessment of relevant telecommunication technologies. Results are typically documented in recommended system configurations and implementation plans. The Institute's direct involvement in telecommunications research, performance assessment, and standards development ensures that its planning recommendations are effective and far-reaching.

Areas of Emphasis

Intelligent Transportation Systems Planning

The Institute performs electromagnetic compatibility analyses of intelligent transportation systems and subsystems, supports the Transportation Research Board and related communications committees, and provides electromagnetic testing of various systems (e.g., dedicated short-range communication systems used in automatic highway toll collection). Projects are funded by the Federal Highway Administration (FHWA).

Advanced System Planning

The Institute evaluates trunked radio system design alternatives and assesses system capacity and performance for various communications channel plans being considered for use in the railroad industry. Projects are funded by the Federal Railroad Administration.

Telecommunication Analysis Services

The Institute provides network-based public access to the latest ITS research results, engineering models, and databases supporting broad applications in wireless telecommunications system design and evaluation of broadcast, mobile, and radar systems. The project is funded by NTIA and by users of the services.

Augmented Global Positioning System

The Institute promotes cost-effective nationwide implementation of differential global positioning system (DGPS) service by recommending the optimum locations and operating parameters for DGPS reference stations. Projects are funded by the FHWA.

PCS Networks

The Institute promotes interoperability and improved performance of personal communications services through standards leadership and laboratory interference assessment studies. The project is funded by NTIA.

Wireless ATM

The Institute defines strategies for extending asynchronous transfer mode technologies to wireless network infrastructures to enhance coverage and user mobility. Projects are funded by the Department of Defense.

NCS Strategic Architecture

The Institute develops systematic procedures and technical information to support strategic planning and development of National Security or Emergency Preparedness telecommunications capabilities. Projects are funded by the National Communications System.

Intelligent Transportation Systems Planning

Outputs

- Electromagnetic compatibility analysis of the intelligent transportation system and subsystems.
- Support for intelligent transportation system committees for communications, spectrum, and electromagnetic compatibility.
- Electromagnetic compatibility testing of the dedicated short range communication systems for intelligent transportation systems.

Solving the transportation problem in the United States is becoming more critical as traffic congestion continues to increase. For financial and environmental reasons, it is no longer feasible to use the conventional approach of building more roads or expanding the number of lanes on existing highways. The continued increase in traffic congestion in the United States will result in a loss in productivity, 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 to monitor, guide, and control the operation of vehicles. Intelligent transportation systems can improve safety, reduce congestion, enhance mobility, minimize environmental impact, save energy, and promote economic productivity on the nation's transportation system. Maintaining safety on the nation's streets and highways will be an additional benefit of applying intelligent transportation systems to the traffic congestion problem. Intelligent transportation systems will allow travelers to plan their mode of transportation ahead of time, and make more informed choices about routes, time, and modes of travel. In addition, authorities will be able to manage transportation systems and control traffic more efficiently.

Examples of intelligent transportation systems applications include:

1. Rapid response to road accidents by emergency vehicles to restore traffic flow, traffic redirection away from the most congested routes by traffic management centers.

2. Traffic control at intersections and on street networks by intelligent controllers.

3. Ramp metering on freeways with traffic sensors, and reserved lanes for buses and high-occupancy vehicles.

4. Automatic in-transit commercial vehicle weigh-in and toll collection to eliminate stopping vehicles.

The electronic devices and equipment used for intelligent transportation systems, and the coupling of external signals and interference from external sources represent a complex interactive electromagnetic environment with emitters and receptors. There is a potential for interference problems to arise when radio communications equipment and other electronic devices are operated around intelligent transportation system-equipped vehicles. This could cause interference between intelligent transportation system equipment, the automotive electronic systems and the electronic equipment in the rest of the environment. Electromagnetic compatibility (EMC) must be achieved to prevent interference interactions.

EMC is the ability of electronic equipment to achieve a specified level of operability when operating in an uncontrolled environment. It is a primary factor in the performance, safety, and effective operation of intelligent transportation systems. It involves the orchestration and integration of system components in a fashion that will control interference coupling, which is a primary consideration in intelligent transportation system design.

Recent activities and accomplishments by the Institute to address the EMC of intelligent transportation systems include:

1. Analysis of the dedicated short-range communication system that determined the potential EMC problems with radars in the 5850- to 5925-MHz band.

2. Measurements of radar characteristics in the 5850- to 5925-MHz band to assist in characterizing the emissions in that frequency band.

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

4. An analysis of an AM subcarrier system for a proposed advanced traveler information system (ATIS).

The system would be used to disseminate information to travelers in the rural roadway environment. This analysis will support the design and field testing of the AM subcarrier evaluation effort for ATIS.

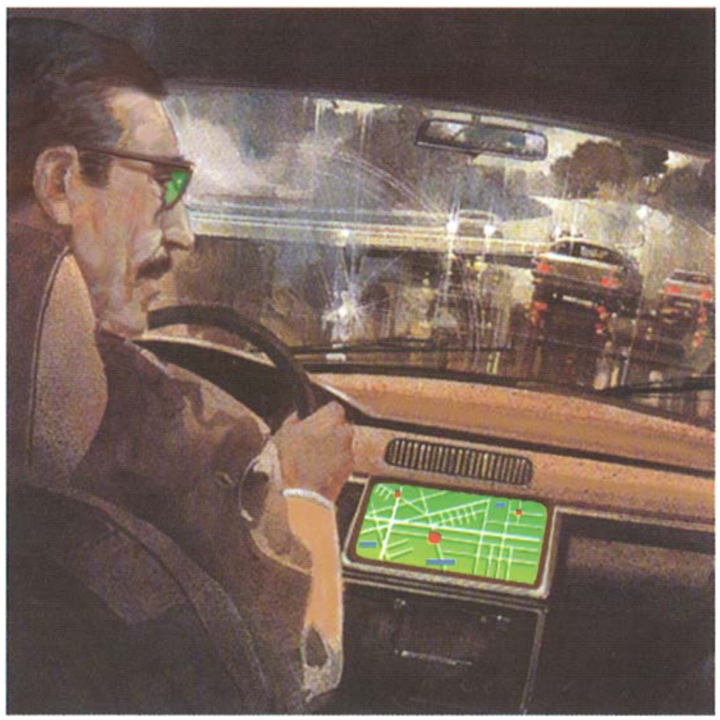
5. Ongoing support for intelligent transportation systems communications committees, including the High-speed Data Subcommittee, Intelligent Transportation Systems Telecommunications Committee, and the Transportation Research Board.

6. Development of a low and medium frequency propagation model to be used for analysis of the differential global positioning system signal for refinement of position accuracy and the AM subcarrier advanced traffic information system.

7. FM subcarrier coverage and performance prediction of selected areas in the United States. These predictions will be made for regions that differ dramatically in terrain and population density. These regions may implement FM subcarrier traveler information systems.

Future activities of the Institute will include: characterization of the electromagnetic environment, measurement of the electromagnetic environment, spectrum planning, propagation model development, determination of suitable new and emerging communications technology for intelligent transportation systems, prediction of radio coverage for communication systems, selection/establishment of an EMC requirement and testing standards for intelligent transportation systems, and creation of EMC test plans for the many different subsystems of intelligent transportation systems.

The Figure represents the ATIS concepts of in-vehicle information and route guidance for navigation with updated traffic and road condition information using an FM subcarrier system.



The ATIS concept of in-vehicle navigation and traffic update using an FM subcarrier system (illustration by J. Evans).

Recent Publications

N. DeMinco and C.L. Holloway, "Propagation modeling for ITS applications in the roadway Environment," *Intelligent Transportation Systems Journal*, Vol. 3, No. 4, pp. 287-331, Aug. 1997.

R.O. Debolt and N.DeMinco, "FM subcarrier corridor assessment for the intelligent transportation system," NTIA Report 97-335, Jan. 1997.

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Outputs

- Trunked repeater base station design alternatives.
- Assessment of system capacity as a function of proposed channel plans.

ITS is assisting the Federal Railroad Administration (FRA) by analyzing a study of a railroad industry proposed channel plan. This proposed channel plan would be used by the railroads to provide trunked radio services for their industry. This study is an outgrowth of the recent Federal Communications Commission spectrum refarming initiative and the requirement that existing users migrate to more spectrally efficient systems. In addition to evaluating the frequency reuse potential of trunk groups, self-interference at base stations and the methods and costs to mitigate the interference between co-sited transceivers are being investigated.

The study commenced with the evaluation of several combinations of trunked channel pairs exhibiting various channel spacings and transmit/receive frequency offsets. Both single (shared transmit and receive) antenna and dual (separate transmit and receive) antenna configurations are being considered. The combinations are evaluated based upon minimum requirements for transmitter emission masks and estimated receiver selectivity/sensitivity masks.

Figures 1 and 2 show block diagrams of multiple co-sited trunked repeaters. The engineering challenges arise from the close channel spacing and transmit/receive frequency offset requirements imposed by the frequency assignments available to the railroad industry in the VHF band (approximately 160 MHz). For example, for eight co-sited full-duplex repeaters, an overall transmission channel bandwidth of 537.5 KHz is required for both inbound and outbound paths (see the Table); the minimum frequency offset between any one transmitter frequency and an independent channel's receiver frequency is 195 kHz. Providing the necessary isolation to mitigate adjacent channel interference between co-sited repeaters is not a trivial task. Reducing the number of co-sited radio repeaters relaxes these constraints, but the system capacity is reduced, as shown in Figure 3. These are the trade-offs that must be identified and quantified, so that the railroad industry can make informed decisions related to the planning and design of their industry's radio communications infrastructure.

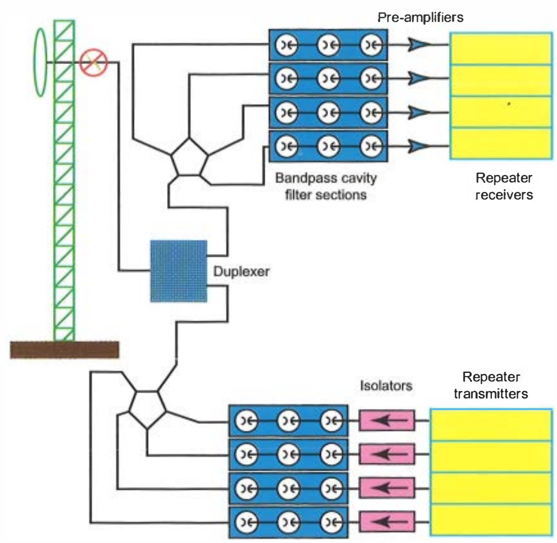

Figure 1. Block diagram of co-sited repeaters using single antenna/duplexer arrangement.

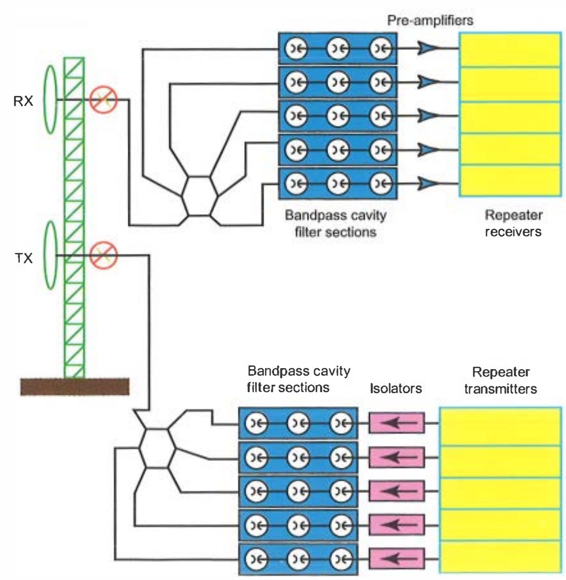

Figure 2. Block diagram of co-sited repeaters using separate antennas for combining transmitters and multicoupled receivers.

Aggregate Channel Bandwidth and Minimum Adjacent Transmit/Receive Frequency Separation versus Number of Co-sited Repeaters.

No. of kHz Channels (spaced every 75kHz)	Aggregate Transmission Bandwidth (kHz)	Minimum Transmit-to-Adjacent Receive Channel Frequency Separation (kHz)
1	12.5	—
2	87.5	645
3	162.5	570
4	237.5	495
5	312.5	420
6	387.5	345
7	462.5	270
8	537.5	195

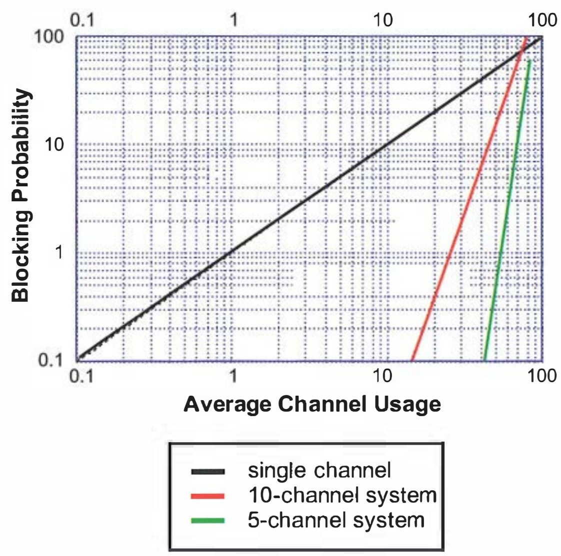

Figure 3. Percent probability of user being denied access to trunked radio system. As channel use is increased, the probability of any one user being denied access to the system also increases, for a fixed number of trunk channels. As the number of trunk channels increases, the probability of blocking decreases for a fixed channel occupancy.

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Telecommunications Analysis Services

Outputs

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

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

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 is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and DTV). 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 used to develop these scenarios. Results of analyses show those areas of new interference and the population and households within those areas. Figure 1 shows the result of a study for a proposed digital station in San Francisco, California. In addition to determining the contribution to interference from other stations to a selected station, the model can give the amount of interference a selected station gives to other stations. This allows users to make modifications to their stations and determine the effect these modifications have on their station's interference to other surrounding stations. In addition to creating a plot similar to that shown in Figure 1, the program creates a table that shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates.

TA Services continues to develop models in the GIS environment for personal communications services (PCS) and local multipoint distribution service (LMDS). A GIS efficiently captures, stores, updates, manipulates, analyzes, and displays all forms of geographically referenced information. The use of GIS has grown substantially over the past several years and it is now common for business, Government, and academia to employ GIS in many and diverse applications. As a result, databases necessary for telecommunication system analysis are now becoming available in forms easily imported into the GIS environment. These include databases of 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/LMDS modeling.

As the frequency of an application increases, the level of detail required to adequately describe the path also increases. At PCS and LMDS frequencies, it is increasingly important to know the location of trees and buildings as well as other terrain obstructions. At these higher frequencies, it also becomes important to know what kind of vegetation a signal is penetrating. As ray tracing becomes practical in GIS models, it will become important to know the shape and materials used in buildings. Information on building heights and vegetation is not commonly available. Some city and county Governments are beginning to enhance their GIS databases to include this data, and this trend is expected to continue. Software is available and under development that allows a user to import digital stereo photographs or other remote-sensing data taken from aircraft at relatively low altitudes or even spacecraft. If this data is of sufficient quality, it can be used to create three-dimensional surfaces for the GIS with accuracies on the order of 1 m or less. This will greatly reduce the cost of developing databases with the accuracies necessary to ensure reliable analysis results.

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

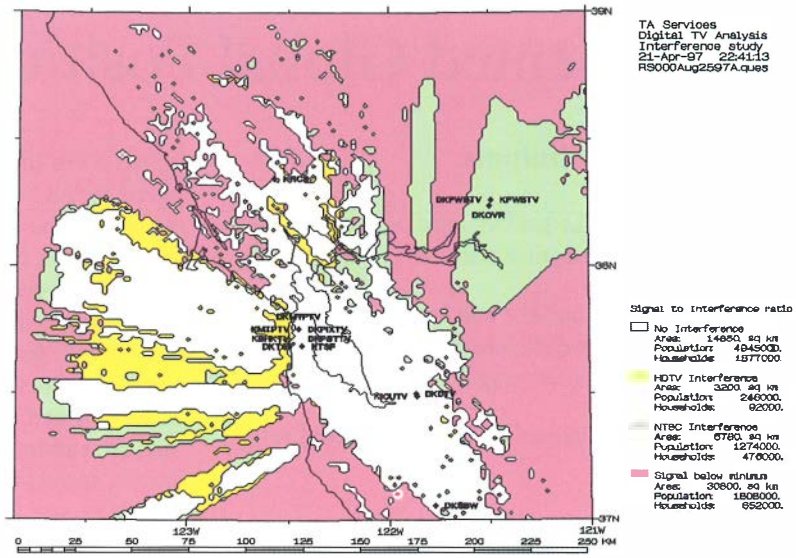

Figure 1. Interference analysis for a proposed digital television station in San Francisco, California.

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 by 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. The user can then give the pattern a name and store it in a personal catalog for future use.

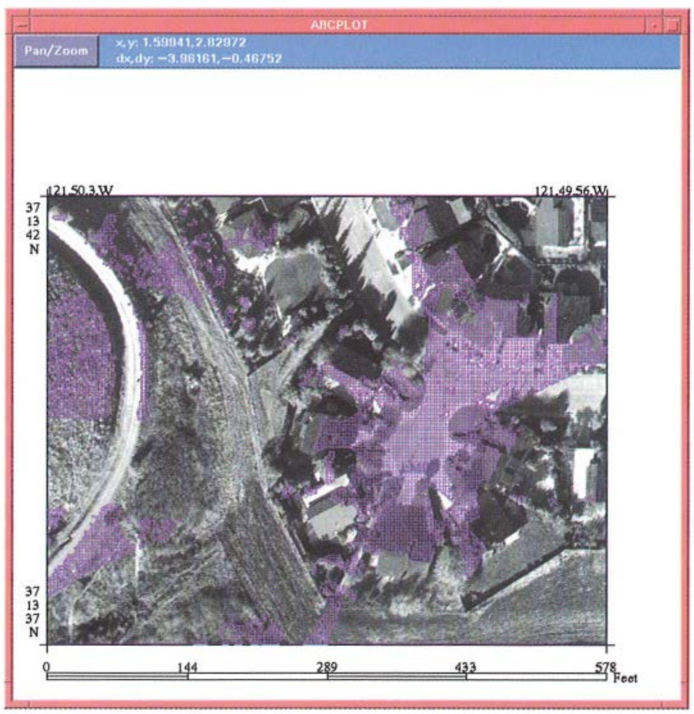

Figure 2. Line-of-sight region around a residential PCS/LMDS transmitter.

Analysis scenarios created by a user consist of a set of transmitters, antennas, and models chosen to produce propagation results for a region of interest. Models include a line-of-sight (LOS) model, a road-guided path loss model, and a diffraction model. The program allows the user to vary receiver heights as well as turn on and off the contribution of any transmitter to the overall coverage. 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 can also select contours and the colors of each contour in all subsequent output result displays. Figure 2 shows the nearby LOS coverage of a PCS/LMDS transmitter located on a street corner. The shaded areas are those areas that are line-of-sight to the transmitter.

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

SPS accuracy of 100 m does not meet most civilian navigation and positioning requirements. Various augmentations to GPS are used to provide increased accuracy and integrity of the SPS signal. One form of augmentation, differential GPS (DGPS), can provide 1- to 10-m accuracy for dynamic applications and better than 1-m accuracy for static users. In the 1995 NTIA Report, "A technical report to the Secretary of Transportation on a national approach to augmented GPS Services," ITS recommended implementation of a radio beacon system, operating in the 300-kHz band, modeled after the U.S. Coast Guard's (USCG) local area DGPS, to provide nationwide coverage of DGPS for surface applications (DeBolt et al., 1995; see Publications Cited, p. 103). The Institute has completed a study, sponsored by the Federal Highway Administration, to determine the optimum location and operating parameters of the DGPS reference stations required to provide this civil navigation and positioning service to all surface users across the nation. The use of this service will have an enormous impact on a diverse set of uses including ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, emergency location and rescue operations, and many others that have not yet been identified.

This new service will be known as the nationwide differential global positioning system. The foundation of this system is the DGPS reference stations currently operating or planned by the USCG and the U.S. Army Corps of Engineers; this system provides coverage of the radiobeacon DGPS signal for coastal areas, harbors, and inland waterways. This existing capability provides the DGPS signal over a majority of the nation (Figure 1).

ITS added to this foundation in three stages, to provide nationwide coverage of the DGPS signal. In the first stage, DGPS reference stations were positioned 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 provides a cost-effective method of implementing nationwide coverage of the DGPS signal. Since the GWEN sites are at fixed locations, complete nationwide signal coverage could not be achieved with only these sites. The second stage required locating additional reference stations at geographical locations that would fill gaps in the coverage. A total of 15 GWEN sites and 7 additional sites were required to complete the nationwide signal coverage (Figure 2). In the third stage, an additional 16 DGPS reference stations were added to achieve redundant signal coverage, providing at least two DGPS radiobeacon signals at all locations; this greatly increased the availability of this navigation and positioning service.

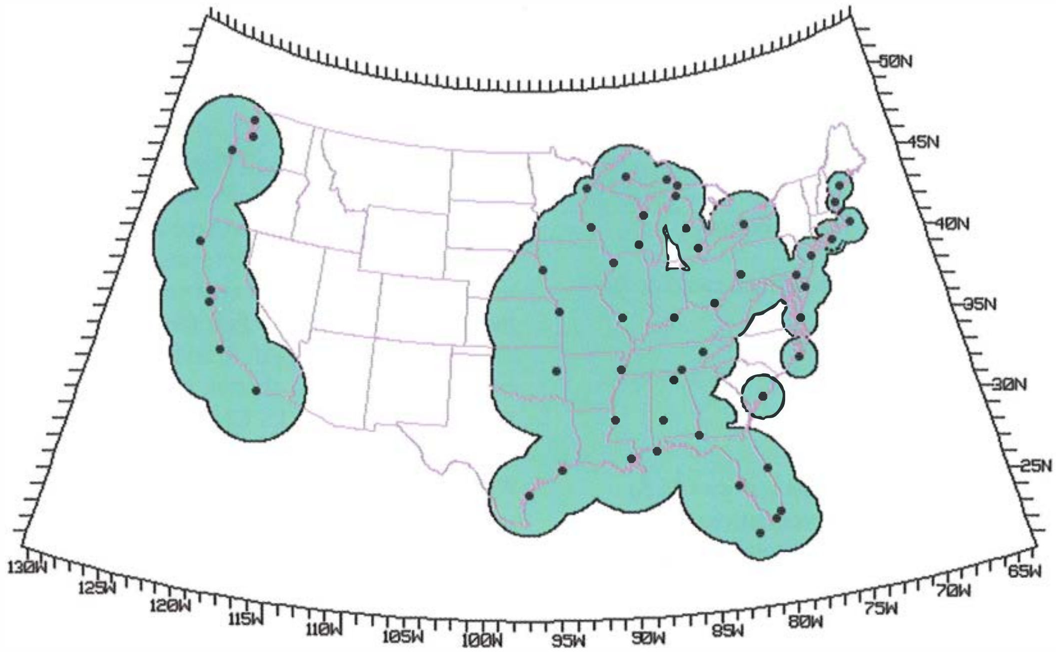

Figure 1. Predicted signal coverage for the existing DGPS used by the USCG and U.S. Army Corps of Engineers.

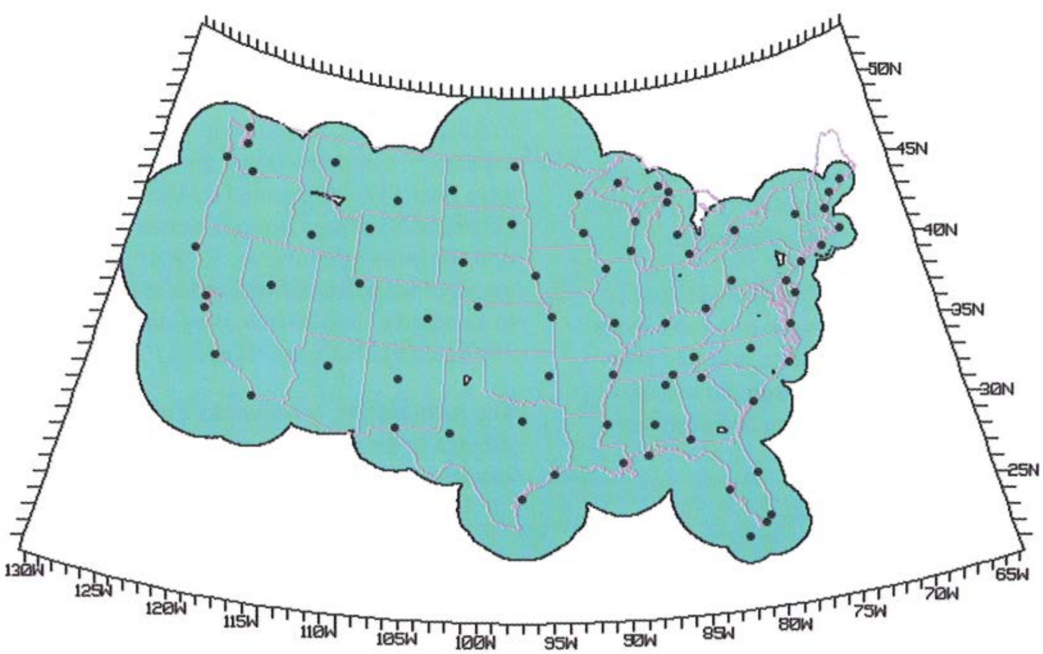

Figure 2. Predicted DGPS signal coverage with 22 additional sites.

Recent Publications

J.R. Hoffman, J.J. Lemmon, and R.L. Ketchum, "Field strength measurements of DGPS and FAA beacons in the 285 to 325 kHz band," NTIA Report 97-337, Jun. 1997.

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PCS Networks

Outputs

- Chairmanship of the MMITS Forum.
- Contributions to software-defined radio architecture specifications.
- Planning and design of the wireless networks test bed.

Digital personal communications service (PCS) offers substantial advantages over conventional analog cellular service in mobile and other wireless applications. However, PCS is being implemented using three different access technologies in the United States: code-division multiple access (CDMA) and two distinct time-division multiple access (TDMA) technologies. The three technologies have fundamentally different spectrum usage characteristics and are not interoperable at the air interface. As a result, three different handsets could be required to access the full range of available PCS services. There are further incompatibilities between PCS and emerging mobile satellite services. In its Wireless Networks program, ITS is working with equipment and service providers and other Federal agencies to enhance the interoperability of PCS and other advanced digital wireless technologies.

During FY 97, ITS contributed strongly to the founding and initial technical work of a joint industry/Government forum organized to promote wireless network interoperability through the use of innovative digital signal-processing and software-defined radio techniques. That group, called the Modular Multifunction Information Transfer System (MMITS) Forum, attracted broad international interest and now includes participants from many commercial and U.S. Government entities. An ITS staff member was elected to chair the MMITS Forum during its formative period, and led the group in establishing a formal charter, an organization, and work methods. The ITS Chair also established strong liaison relationships with standards development organizations and other relevant fora.

The MMITS Forum set as its initial goal the development of a software-defined radio system architecture that would enable a single radio terminal or base station to support several different access technologies. An ITS staff member played a lead role in developing this target architecture and served as Technical Editor for the architecture specification. The specification includes a functional description that reduces the handheld user terminal to a few common modules, as shown in Figure 1. This high-level functional model was later mapped into an applications programming interface model for the handheld device, as shown in Figure 2. With ITS' assistance, these functional and structural models were formally documented by the MMITS Forum's Technical Working Group. The resulting specification, Technical Report No. 1, "Architecture and elements of software defined radio systems as related to standards," was approved by the Forum in July of 1997 (see Publications Cited, p. 103).

The Institute's PCS Networks Program also contributes to the development of wireless network specifications in established industry standards com-

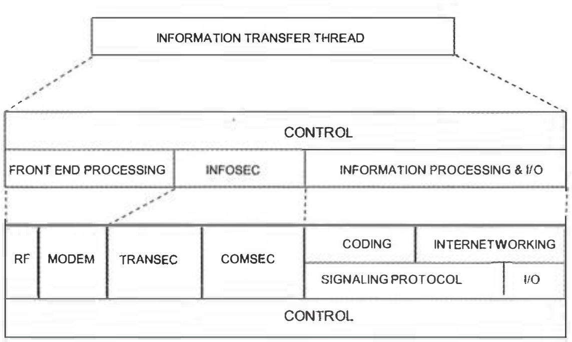

Figure 1. Software-defined radio high-level function model.

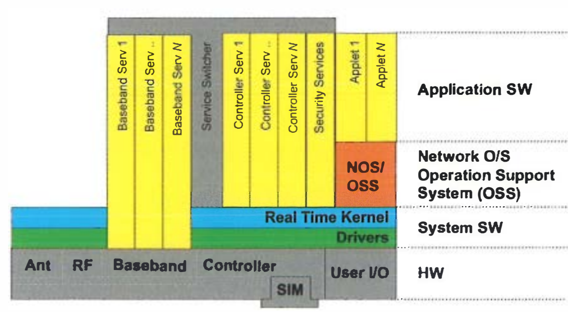

Figure 2. Handheld multiple service model.

mittees. During FY 97, ITS provided a contribution on PCS 1900 interference simulation to the Telecommunications Industry Association TR 46.2.1 Working Group, which deals with interference among licensed PCS systems operating in the 1800-MHz band. To support further contributions to this work, Institute staff members developed the design for a wireless networks test bed (Figure 3) that should provide an efficient, accurate means of assessing the effects of inter- and intrasystem interference on the performance of PCS and other digital wireless services. Results will be used to optimize the performance and capacity of wireless systems sharing bandwidth under high traffic conditions.

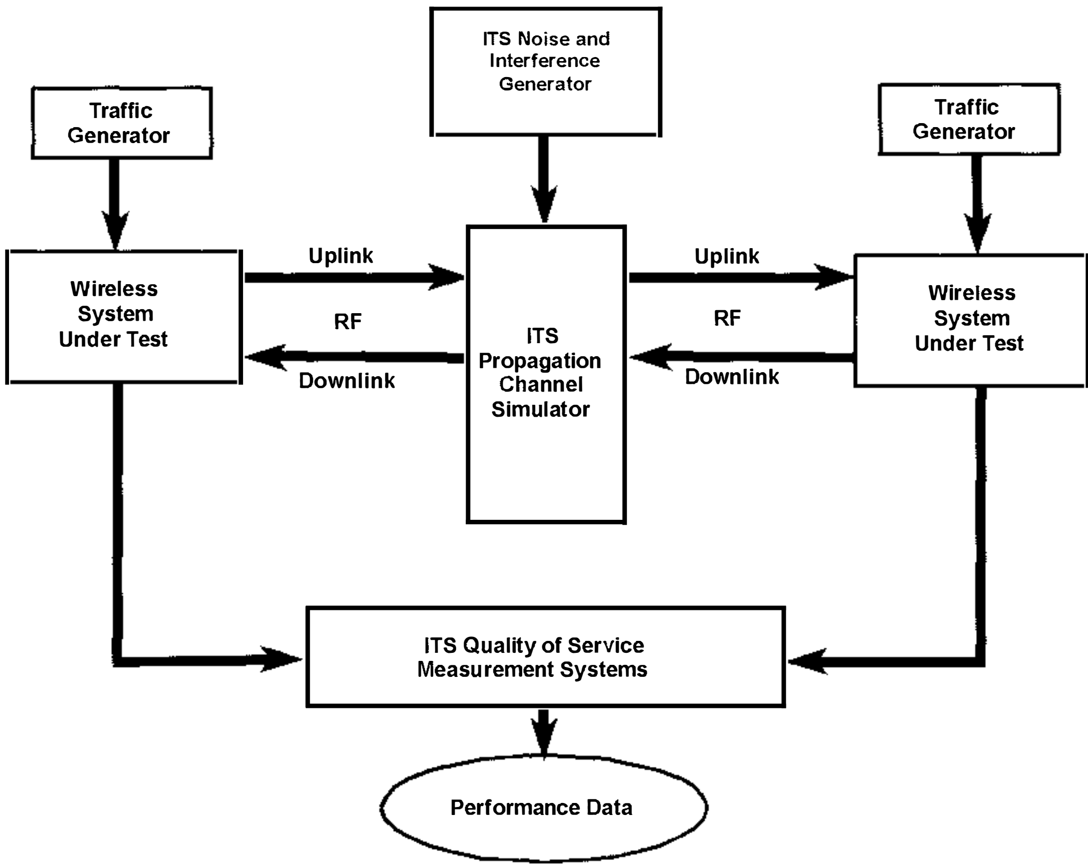

Figure 3. Wireless networks test bed.

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Wireless ATM

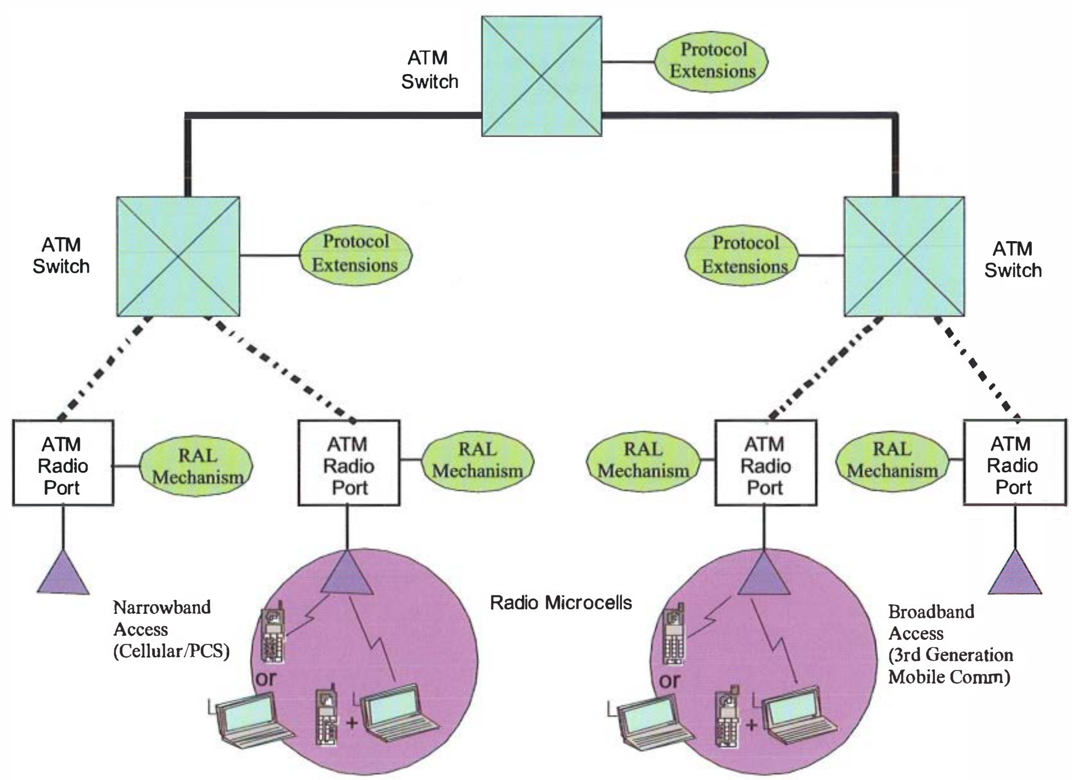
Outputs

- Analysis of wireless ATM issues and technologies.
- Survey of mobile communication technologies.

Asynchronous transfer mode (ATM) technologies are expected to provide the foundation for future broadband and multimedia communications on a worldwide basis. However, ATM has been developed primarily for use over fiber optic and other high-quality wired transmission media. During FY 97, ITS undertook a study aimed at defining the technical challenges and potential benefits of extending ATM to wireless infrastructures that could enhance service coverage and provide full mobility to users. Specifically, the study addressed: (1) the efficient integration of proposed wireless systems, such as personal communications service (PCS), with ATM-based networks; (2) mobility management issues for wireless ATM; (3) wireless ATM security issues; and (4) use of ATM-based networks for the fixed wireless system infrastructure.

Standards committees are currently specifying ATM-based broadband integrated services digital networks (B-ISDN's) to accept and efficiently transport all types of offered traffic. At the same time, the quality of service (QOS) needs of various user applications are being defined and factored into ATM network designs. There is a challenge in satisfying both the network efficiency and QOS goals, since they are inherently conflicting. When a wireless segment of ATM is added to this situation, end-to-end network performance and QOS issues become more complex.

A mobile ATM network is represented schematically in the Figure. In such a network, there are specification issues related to the radio access layer (RAL) mechanisms that will allow radio systems to interoperate with the fixed ATM infrastructure, and the protocol extensions to the fixed ATM infrastructure that will enable it to support terminal mobility. A signifi-



Wireless ATM network architecture.

cant area of required RAL research identified involves the high-speed physical layer: 20-Mb/s multiaccess radios that can overcome multipath reception from stationary and moving objects are not currently available. Protocol extensions were also identified as a difficult problem. For example, a QOS solution for wireless ATM will have to provide statistical service guarantees, which may require additional source declaration parameters (such as some measure of the degree of mobility). Further research and standardization activities should determine if the ability of the network and terminal to renegotiate virtual connection parameters during the course of a connection provides the key to robust operation in this environment.

As the Figure shows, wireless ATM network planning also involves consideration of existing and evolving standards for mobile communications (e.g., cellular radio and PCS). With several million users worldwide already using narrowband cellular/PCS technology (including 50 million in the United States alone), cellular/PCS technology is destined to play a major role in the telecommunications network of the future. Efforts aimed at extending mobile systems to broader bandwidths and providing a richer variety of services has been undertaken and is motivating planners to plot an evolutionary course to advanced systems that will satisfy the demanding (and dynamic) requirements of the future. The evolutionary steps are defined in a series of technology "generations" as shown in the Table below.

Although some experts predict that one cellular/PCS technology will ultimately "win out" and dominate the U.S. market, others are not so sure. Wireless ATM will likely need to operate in a diverse technology environment for many years to come.

Generations of Mobile Communications

First Generation
(Past)

Mobile telephone service: carphone

Analog cellular technology

Macrocellular systems

Second Generation
(Now)

Digital voice and messaging/data services

Fixed wireless loop

Digital cellular technology plus intelligent network emergence

Third Generation
(Year 2000)

Integrated high-quality audio and data

Narrowband and broadband multimedia services plus intelligent network integration

Broader bandwidth efficient radio transmission; LAN/WAN; information compression

Higher frequency spectrum utilization: LAN/WAN

Intelligent network plus network management integration

Fourth Generation
(Year 2010)

Telepresencing

Education, training, and dynamic information access

Wireless-wireline and broadband transparency

Knowledge-based network operations

Unified service network

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NCS Strategic Architecture

Outputs

- NS/EP Telecommunications Strategic Planning Guide.
- Application to mobile and relocatable wireless services.

The National Communications Systems (NCS) is responsible for planning and implementing initiatives to enhance National Security or Emergency Preparedness (NS/EP) telecommunications under a wide range of operational scenarios. To fulfill this responsibility effectively, NCS must have a systematic process for defining comprehensive NS/EP telecommunications needs, evaluating relevant technologies, and specifying an NS/EP telecommunications infrastructure that economically applies the selected technologies in meeting the defined needs. During FY 97, ITS undertook a project designed to assist NCS in defining and demonstrating such a process. Key project results were documented in a technical report that provides a model and initial content for development of the *NCS NS/EP strategic architecture*—a comprehensive operational, technical, and physical system specification of essential NS/EP communications capabilities.

It is anticipated that the NS/EP strategic architecture will assist NCS in identifying infrastructure enhancements with maximum NS/EP benefit, and in undertaking technology application, standardization, and development initiatives that will cost-effectively achieve these enhancements. The strategic architecture will promote cooperative planning among NCS member organizations by articulating a common vision of future NS/EP capabilities, and will provide a benchmark with which alternative NCS program initiatives and resource allocation alternatives can be evaluated. The strategic architecture will provide the specific, quantitative information that Federal communications managers and engineers need to select and economically implement communications systems that meet NS/EP requirements. Examples of such information are expected service coverage areas; service and equipment functionality, performance, cost, and pertinent industry standards and implementation agreements.

Figure 1 summarizes the Strategic Architecture development process. The process addresses each of the three basic steps in traditional strategic telecommunications planning: definition of user requirements (in the operational architecture); characterization of relevant technology solutions (in the technical architecture); and specification of the best technology solutions for the defined requirements (in the systems architecture). The recommended process differs from existing practice in that the user requirements and technology characterization steps occur concurrently and interactively. This approach realizes the synergy between technology advances and user requirements, and better accommodates the rapid pace of technology evolution.

The process also includes, as an explicit fourth step, the definition of NCS (or other) initiatives required to implement the chosen solutions. The solutions and corresponding initiatives fall into three broad categories from an NCS NS/EP planning perspective. First, the chosen solution may be simply to use an available system or service. In that case, the initiative required is to motivate such use through Federal standards, Federal Telecommunications Recommendations, or other publications—or through outreach activities such as NS/EP planning workshops. Second, the chosen solution may require enhancements to an existing or evolving technology—for example, the addition of priority access capability to a new wireless service being specified in a national or international standards committee. In that case, NCS or other Federal agency representatives may need to participate in the specification process—for example, for documenting Federal requirements and proposed enhancements in standards contributions. Finally, the chosen solution may be to develop a new, NS/EP-specific facility (e.g., a transportable emergency communications system). In that case, the initiatives required may include the specification and procurement of the new facility.

The ITS study also provided a trial application of the recommended process in defining NS/EP requirements and technologies for mobile and relocatable wireless communication services. A wide range of wireless services were characterized at a high level. Both current and near-term capabilities of these services were addressed. Summary information was provided for well-established services, such as

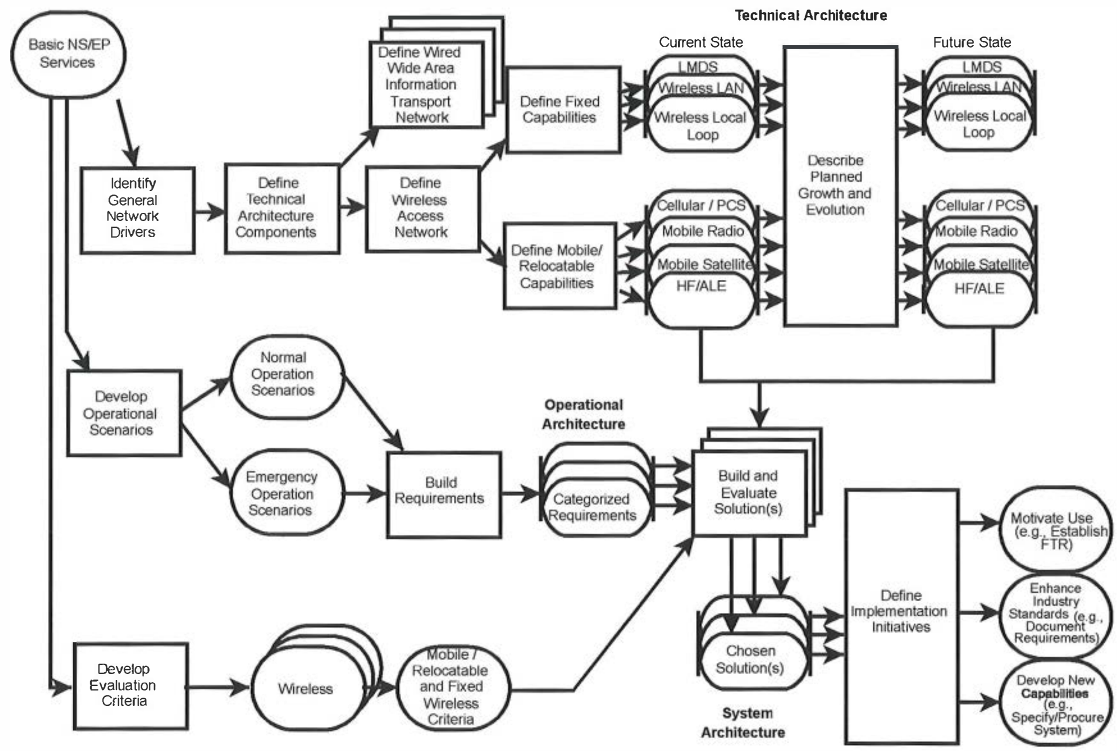

Figure 1. Development process for the NCS strategic architecture.

cellular, land mobile radio, and high frequency radio services, as well as emerging personal communications and mobile satellite services. A particular focus in the study was on personal communications services (PCS) and the several competing technologies that support them. Three distinct PCS technologies are being implemented in the United States: code-division multiple access (CDMA) and two distinct time-division multiple access (TDMA) technologies. The study evaluated these emerging technologies from an area coverage point of view. As an example, Figure 2 displays the areas where the different license holders have committed to use CDMA technology. Each technology offers the prospect of nationwide coverage within 2-3 years.

One of the most important issues the study identified is the general lack of interoperability among many wireless services. As an example, the three PCS technologies have fundamentally different protocols and spectrum usage characteristics, and are not interoperable at the air interface. Preliminary results of the study suggest that adaptive multiprotocol terminals may be the most practical way of solving the resulting interoperability problems. Hardware-based precursors of such adaptive, multiprotocol terminals already exist. However, a much more powerful, flexible, and cost-effective means of achieving such adaptivity is becoming available through advances in software-defined radio and digital signal-processing techniques. Eventually, software-defined radios may provide users with the ultimate ability to roam within a global wireless "network of networks"—and to seamlessly communicate in a multitude of diverse and dynamic technology environments.

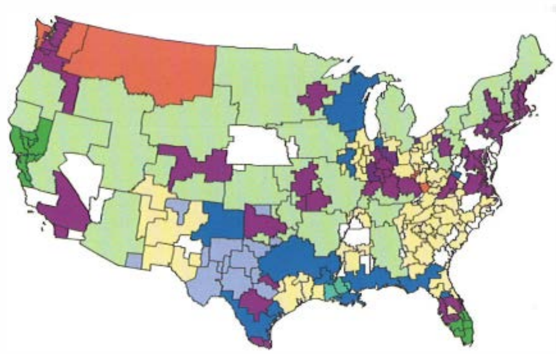

Figure 2. Coverage map for licencees committed to code-division multiple access technology.

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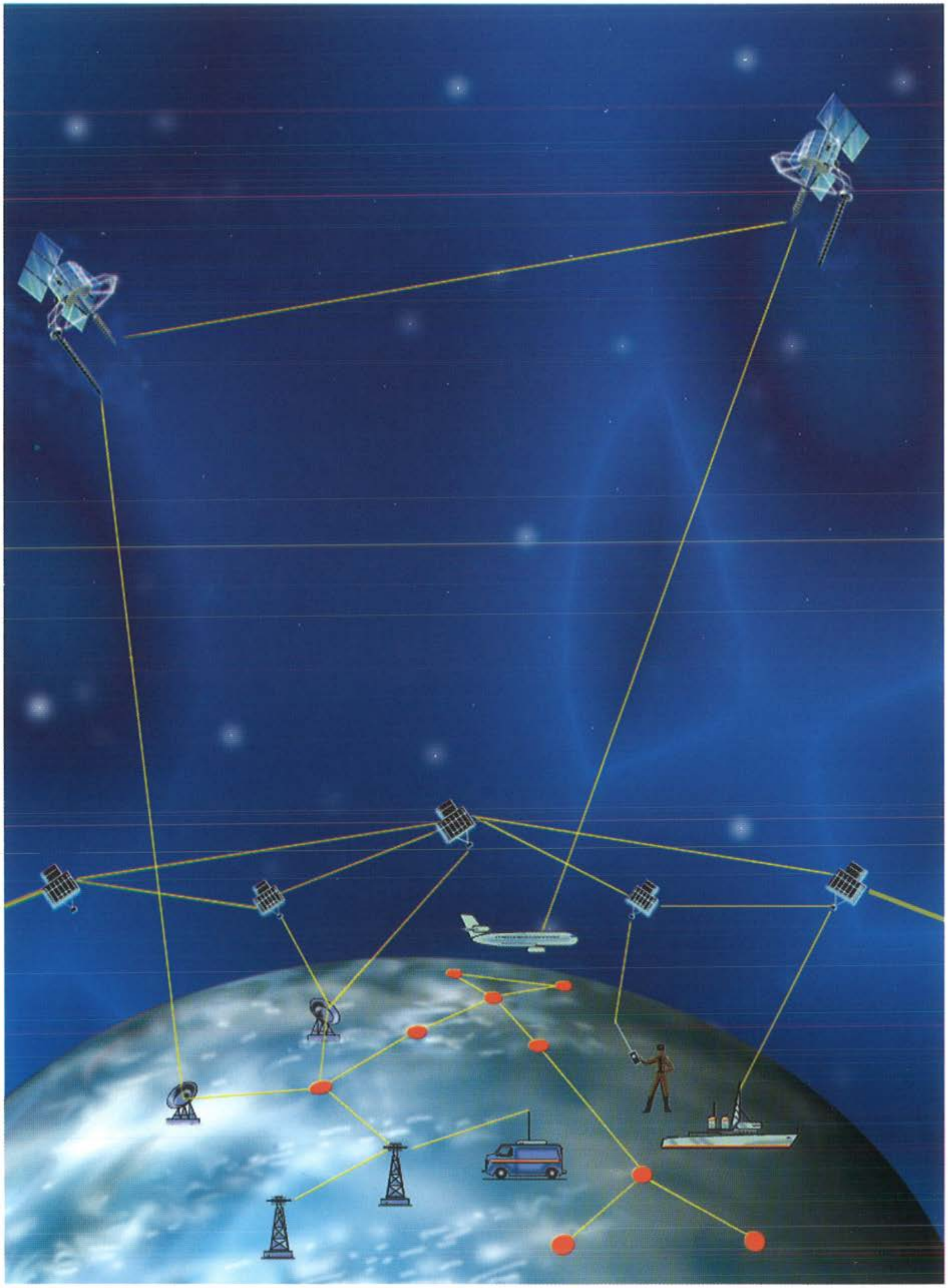


Interoperabiliy among telecommunications systems requires performance assessment of various systems and system elements designed to carry data, voice, video, and multimedia information (illustration by J. Evans).

Telecommunication System Performance Assessment

Telecommunication performance can be expressed, by a user, as a specification or requirement or, by a provider, as a characterization of a particular system and its elements. The Institute contributes to performance description from both perspectives by developing a variety of assessment tools and applying them in characterizing a wide range of telecommunication systems and networks. Assessment tools developed by the Institute include automated analysis techniques, used during the design of a system for predicting performance in any specified environment; and test and measurement systems, used for evaluating the performance of prototype and operational systems.

These hardware and software tools are used to assess the performance of individual transmission links or entire networks that may carry a variety of data, voice, video, and multimedia information. The transmission media evaluated include terrestrial radio and satellite links, wire and cable, and optical fiber. Asynchronous transfer mode (ATM) and other advanced switching facilities are evaluated as well.

Specific ITS activities during FY 97 included improvements in the Jammer Effectiveness Model (JEM) to expand the range of scenarios where it is useful, satellite system performance measurements designed to enhance satellite/terrestrial system interoperability, improvements in the methods used to test HF radios, and enhancements to a compact disk-based interactive handbook that gives users readily understandable technical information on the application and performance of multimedia communication systems.

Areas of Emphasis

Radio System Design and Performance Software

The Institute applies its Windows-based Jammer Effectiveness Model in assessing radar and communication system interference under a wide range of electronic warfare scenarios. Projects are funded by the U.S. Army National Ground Intelligence Center.

Satellite Studies

The Institute conducts measurements of satellite-based voice, video, and data communication applications and uses results to promote interoperability and performance standards for advanced satellite communication systems. Project are funded by NTIA and the National Security Agency.

Advanced HF Testing and Evaluation

The Institute applies its automated HF radio laboratory test bed and state-of-the-art HF channel simulators in assessing the performance of military and amateur radio modems and protocols. Projects are funded by the National Communications System (NCS).

Multimedia Performance Handbook

The Institute develops practical information and procedures to assist users in planning, acquiring, and testing multimedia communication systems, and publishes these results in an interactive multimedia compact disk. Projects are funded by NCS.

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.
- Jammer Effectiveness Model compatibility with Windows 95.

The Jammer Effectiveness Model (JEM) allows the user to perform both communication systems analysis and radar systems performance in a jamming environment. JEM runs as a Windows application and is user-friendly and menu-driven. This model can perform many different types of analysis and is a very flexible analysis tool because it is highly structured and modular in design. The radar analysis capability is obtained by creating a separate version of JEM with the appropriate models for radar calculations.

The JEM version developed as a communications analysis model is primarily used 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 that are either airborne or ground-based. The jammer versus network scenario can also handle multiple jammers.

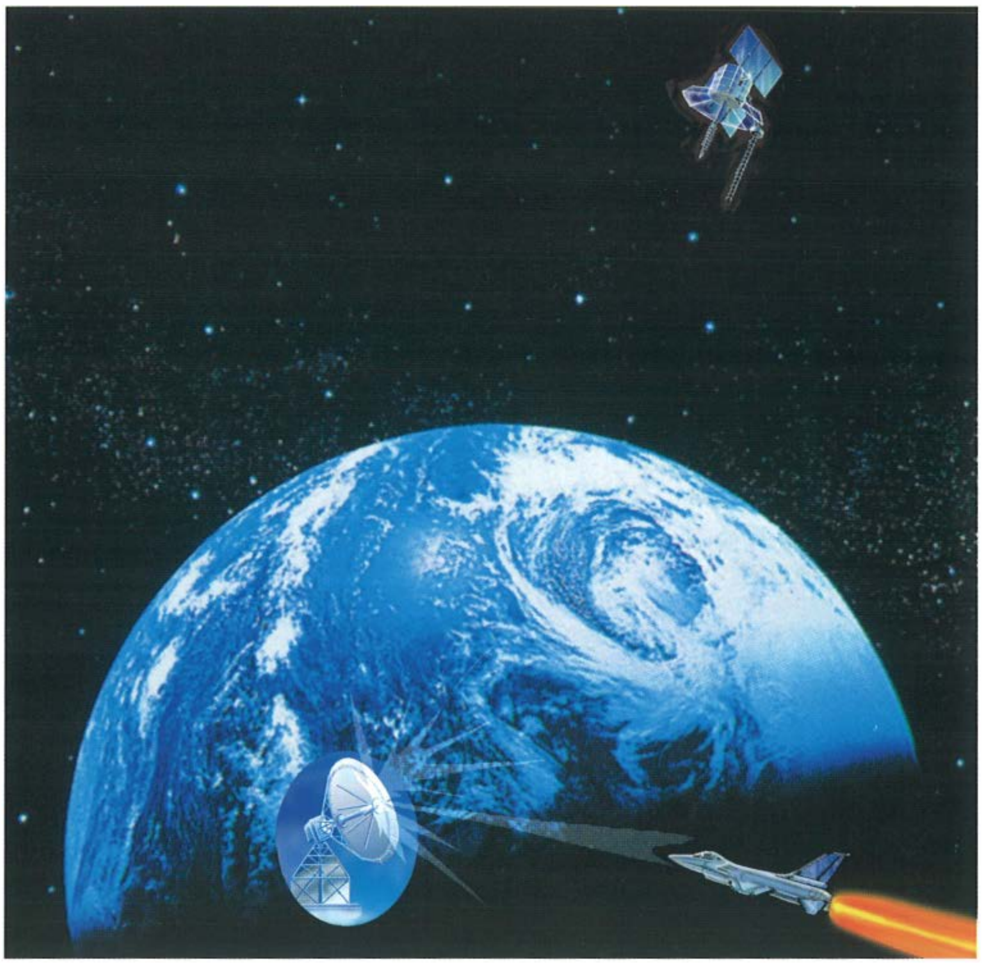
The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. The valid frequency range of the communication version of JEM currently is from 2 MHz to 300 GHz and includes complete analysis capability for both the jamming and the jammer versus network model scenarios. The valid frequency range of the radar version of JEM currently is from 30 MHz to 20 GHz.

Data entry in the JEM is simplified by the use of user-friendly menus and options. Databases are created as a result of this data entry and saved as scenario descriptions. 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 scenario types are used as an aid in the evaluation and design of 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 run several different types of analyses on the data without having to re-enter it.

The radar version of JEM that is currently under development will allow radar analysis for different combinations of radars and jammers that are on the ground or carried by airborne stations. Two analyses can be performed: evaluation of the performance 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 can either be collocated with the jammer or separated from the jammer. A second scenario involves the jamming of a synthetic aperture radar on an airborne platform from either an airborne or ground-based jammer platform. The three-dimensional geometry of these radar scenarios 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 is also the maximum range versus azimuth angle at which the radar detects the target. The Figure illustrates an airborne jammer attempting to jam an Earth-to-satellite communication link.



An airborne jammer attempting to jam an Earth-to-satellite communication link (illustration by J. Evans).

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Satellite Studies

Outputs

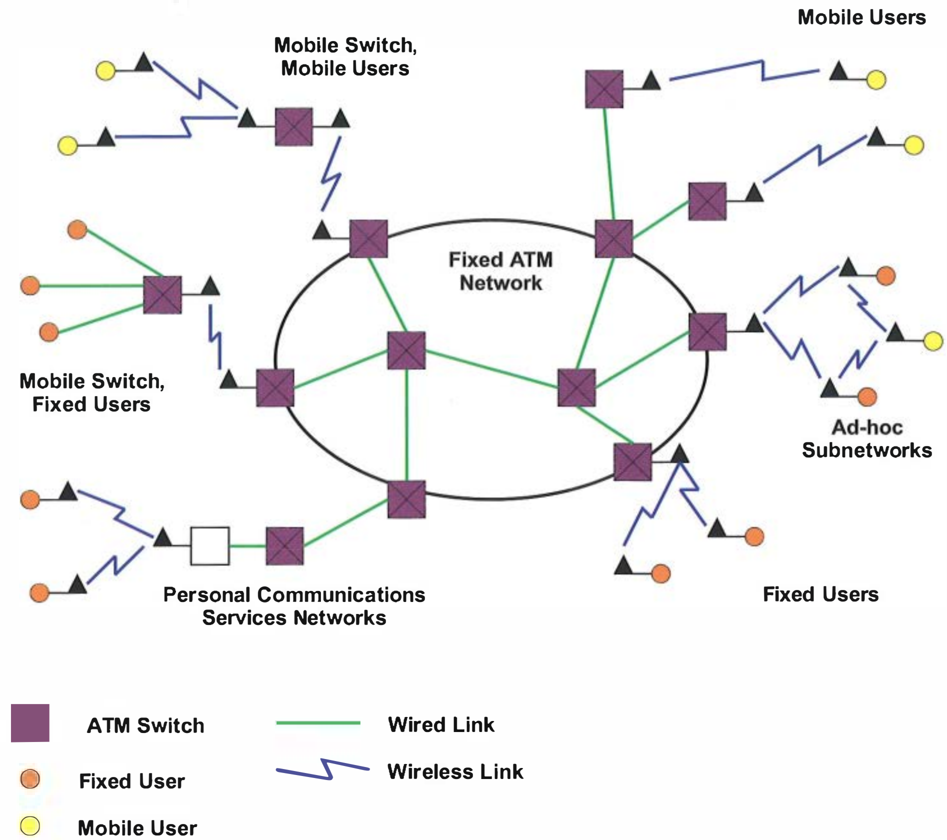
- Satellite performance measurement and analysis.
- Participation in standards development.

Communications satellites have been viewed both as backups to more powerful terrestrial communication networks and as indispensable primary communication facilities in their own right. This dichotomy arose because the traditional satellites had capabilities (e.g., broad area coverage, support for mobility) that made them ideally suited for certain applications, but also had limitations (e.g., delay and low space segment power) that restricted their use in others. Recent technology advances promise to eliminate many of the traditional limitations of satellites and expand greatly their scope of application. The early communications satellites were repeaters placed at very high altitudes, usually in geostationary earth orbit (GEO). Their terrestrial coverage areas were very broad, and typically were not adaptable. Today, advanced GEO satellites have on-board switching capabilities and use electronically steerable spot beams. In the near future there will be low earth orbit, medium earth orbit, and highly elliptical orbit satellite constellations with intersatellite links that can cover nearly all points on the Earth's surface. These technology advances will greatly enhance the value of satellites, but will also complicate their integration with terrestrial infrastructures. The Institute's Satellite Studies program contributes to satellite technology enhancement and interoperability with terrestrial facilities through experimental measurements and related technical contributions to national and international standards committees.

In prior years, ITS developed and conducted a series of experiments using the National Aeronautics and Space Administration's (NASA's) Advanced Communications Technology Satellite (ACTS). These experiments, which used a small network of ACTS Earth stations, provided substantial insight on the performance of advanced GEO satellites in supporting a variety of commercially available applications. Results developed during FY 97 showed that the quality of desktop conferencing, local area network (LAN) bridging, and voice communications was not significantly affected by the delay and error characteristics of the digital satellite links. However, the satellite network did not perform as well as terrestrial facilities in supporting TCP/IP (transmission control protocol / Internet protocol) based Internet applications without special enhancements.

Technical standards provide a powerful means of improving interoperability between satellite and related terrestrial systems. ITS provides contributions to such standards using the results of experimental work and knowledge of Government user requirements. During FY 97, ITS staff members worked closely with a National Security Agency (NSA) representative in specifying a reference configuration for wireless asynchronous transfer mode (WATM) in the ATM Forum (ATM Forum, 1997). The reference configuration was required to encompass a wide range of wireless scenarios, including the fixed network infrastructure, fixed and mobile LAN's, microcellular personal communications services (PCS), and others as shown in the Figure. Although not shown explicitly in this simplified diagram, as a result of NSA and ITS efforts, satellite links can be included in all of the areas. This result ensures that satellite/terrestrial system interoperability will be "built-in" at the very foundation of many standards that will implement ATM over wireless, and satellite, links. This result will facilitate the use of satellites in ATM-based infrastructures.

To extend these benefits, and to harmonize the work of different standards development organizations, ITS staff also participated actively in the newly formed Telecommunications Industry Association (TIA) Satellite Communications Division (TR-34) and in U.S. International Telecommunication Union-Radiocommunication Sector (ITU-R) Working Party 4B during FY 97. The TIA group is developing the radio (wireless) access layer specification for the ATM Forum's WATM Group. ITS has been involved with the development of this specification to ensure that Government requirements are met (*Some Government User Requirements for Wireless/ Satellite Communications*, Presentation to the TIA Satellite Communications Division, Communications and Interoperability Section, Jul. 1997). One source for wireless/satellite system requirements is the Federal Wireless Users Forum, where capabilities needed to ensure system-level interoperability



Simplified diagram of the Wireless ATM reference configuration from ATM Forum Contribution 97-0174. Satellite links can be included in each of the areas shown.

have been identified. For example, the common air interface (CAI) for cellular/microcellular should be sufficiently similar to the CAI for satellites that one terminal can be used for both interfaces. Another requirement, for some Government applications, is that ATM cells not be segmented when passed over a wireless or satellite link. This ensures the effective use of end-to-end encryption.

Working Party 4B of the ITU-R is developing two Recommendations that will define performance requirements for satellite-based ATM services. ITS made a presentation at a Special Rappateur's Meeting of Working Party 4B of the ITU-R that identified improvements needed in a draft recommendation regarding quality of service (QOS) parameters for ATM over satellite systems ("Recommendations for Revision and Addition to ITU-R Draft Recommendation S.atm," Presentation to U.S. Working Party 4B of the ITU-R, Jul. 1997). These improvements are based on the QOS parameters for terrestrial ATM systems defined earlier (under ITS leadership) in ITU-T Recommendation I.356. Other inputs presented to Working Party 4B included the proposal that the reference models being used by ITU-R for satellite systems be the same as, or consistent with, the reference configurations approved by the Wireless ATM Group of the ATM Forum.

It is clear that more information regarding the performance of satellite systems—specifically, the effects of impairments at the physical and link layers on voice and video quality—is needed to support these standards development activities. During FY 97, ITS staff began planning experiments designed to meet that need. These experiments, to be conducted during FY 98, will apply the ITS-developed voice and video quality assessment systems in assessing both fixed and mobile satellite services. A video quality measurement system capable of assessing the quality of a communication link with geographically separated endpoints is being developed.

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Advanced HF Testing and Evaluation

Outputs

- Automated laboratory test bed for evaluating HF modems and protocols.
- HF modem/protocol performance test results.
- Compact disk sets for ALE interoperability and performance testing.
- Anonymous FTP access to HF test documentation and software.

HF radio is currently experiencing a revival in popularity, due in part to technological advances such as automatic link establishment (ALE) computer-controlled radios. ITS has been in the vanguard of HF technology advances in several areas, including modeling, testing, and evaluation. ITS has recently applied its HF modem/protocol test bed to assess the performance of commercially available HF data transmission equipment. Using two digital signal processing-based, computer-controlled narrowband HF channel simulators, engineers subjected target HF modems and protocols to a wide range of controllable and repeatable channel conditions. The simulators allow test conditions to be varied with little or no equipment reconfiguration, while the test control computer permits extensive, unattended testing.

Test results developed in the HF modem/protocol test bed are particularly valuable to the National Communications System (NCS) and other Federal agencies responsible for emergency communications planning. Government communications managers depend on the large number of established HF radio operators (including amateurs) to supplement their own resources in many emergency situations. To assess the ability of commercial HF radio products to support such operations, ITS evaluated the performance of a number of low-cost HF modems and protocols during FY 97. The target HF technologies were tested under two sets of simulated conditions—CCIR Good and CCIR Poor—while the signal-to-noise ratio (SNR) was varied from +20 dB to 0 dB (Figure 1). Older protocols (such as AMTOR and PACTOR) provided relatively low throughput over the tested range of conditions, although they are still useful in transmitting small, low-priority text messages. Newer protocols (such as CLOVER and PACTOR2) employing advanced digital signal-processing circuitry and adaptive modulation schemes provided throughputs up to an order of magnitude greater than their predecessors. These advanced protocols also continued to pass data under signal conditions that caused the older protocols to fail.

ITS continues to provide support to the High Frequency Industry Association and other Government agencies in extending the ALE test capabilities during FY 97. ITS has developed an HF radio protocol model under the sponsorship of NCS. The ALE protocol model, based on the ITS-developed Federal Standard 1045A, *Telecommunications HF Radio Automatic Link Establishment*, (NCS, 1993) was used to create two innovative, effective, and economical ALE radio test products—the ALE Clean and Degraded Tones audio compact disk (CD) sets. The Clean Tones set, published in FY 96, provides 65 tracks of precise calibration tones and a number of ALE-specific audio signals on a single CD. Documentation is provided on a companion floppy disk. The Degraded Tones set, published during FY 97, comprises 12 audio CD's and a CD-ROM. Each audio CD provides several tracks of calibration tones and 25 tracks containing 100 ALE calls created under a variety of simulated channel conditions. Four discs contain Gaussian noise with SNR's from 0.0 dB through -2.5 dB. Another four discs are subjected to CCIR Good conditions with SNR's varying from 0.5 dB through 8.5 dB, while the remaining four discs are subjected to CCIR Poor conditions with SNR's varying from 1.0 dB through 11.0 dB. The CD-ROM contains related documentation and the program *alecall*, which was used to create the sounds recorded on the audio CD's. This information and software are available by FTP through the Internet at *ftp://ftp.its.bldrdoc.gov/pub/ale-cd*. Both ALE CD sets are now available to the public through NIST Special Databases. Information is available at *http://www.nist.gov/srd.*

The Clean Tones set can be used to test protocol implementations and to assess equipment interoperability. The Degraded Tones set can be used to assess radio system compliance with probability-of-linking statistics specified in Federal Standard 1045A. Use of these CD sets to test the functionality and performance of ALE hardware under simulated "live" conditions is shown in Figure 2.

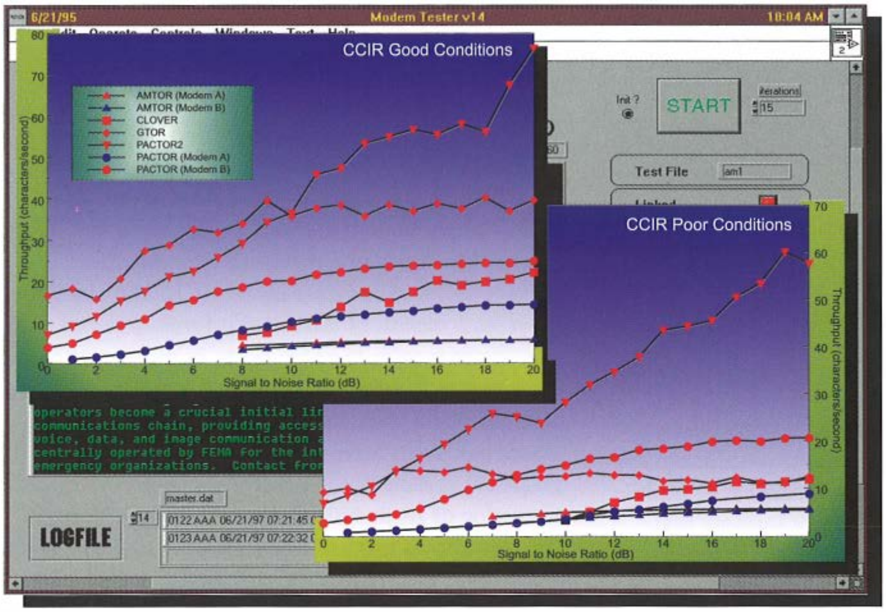

Figure 1. Results of low-cost HF modem/protocol performance testing.

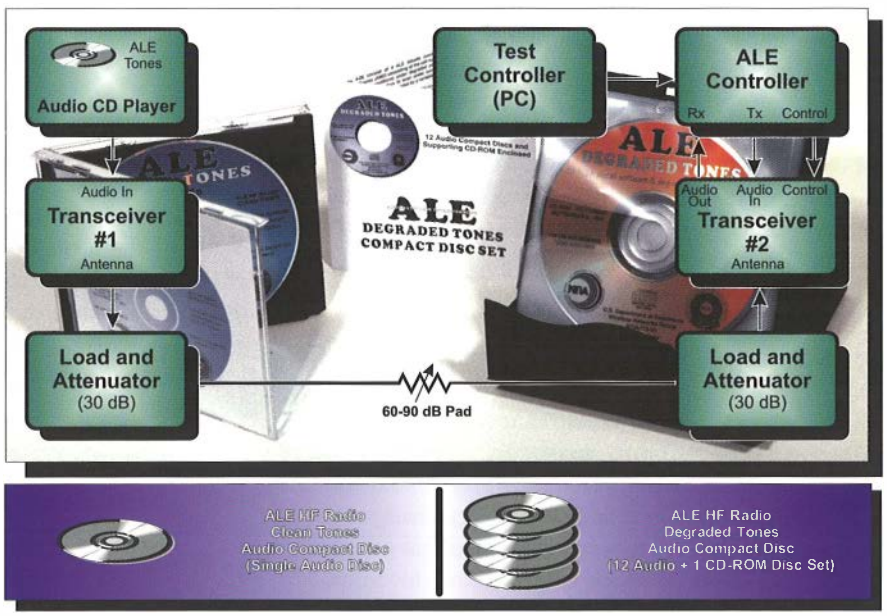

Figure 2. Setup for one-way radio testing using ALE audio compact disk.

Recent Publications

T. Riley, D. Bodson, S. Rieman and T. Sparkman, "A comparison of HF digital protocols," *QST*, Vol. 80, No. 7, pp 32-39, Jul. 1996. Republished in *Packet: Speed, More Speed and Applications*, American Radio Relay League: Newington, CT, pp. 2-7 through 2-11.

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Multimedia Performance Handbook

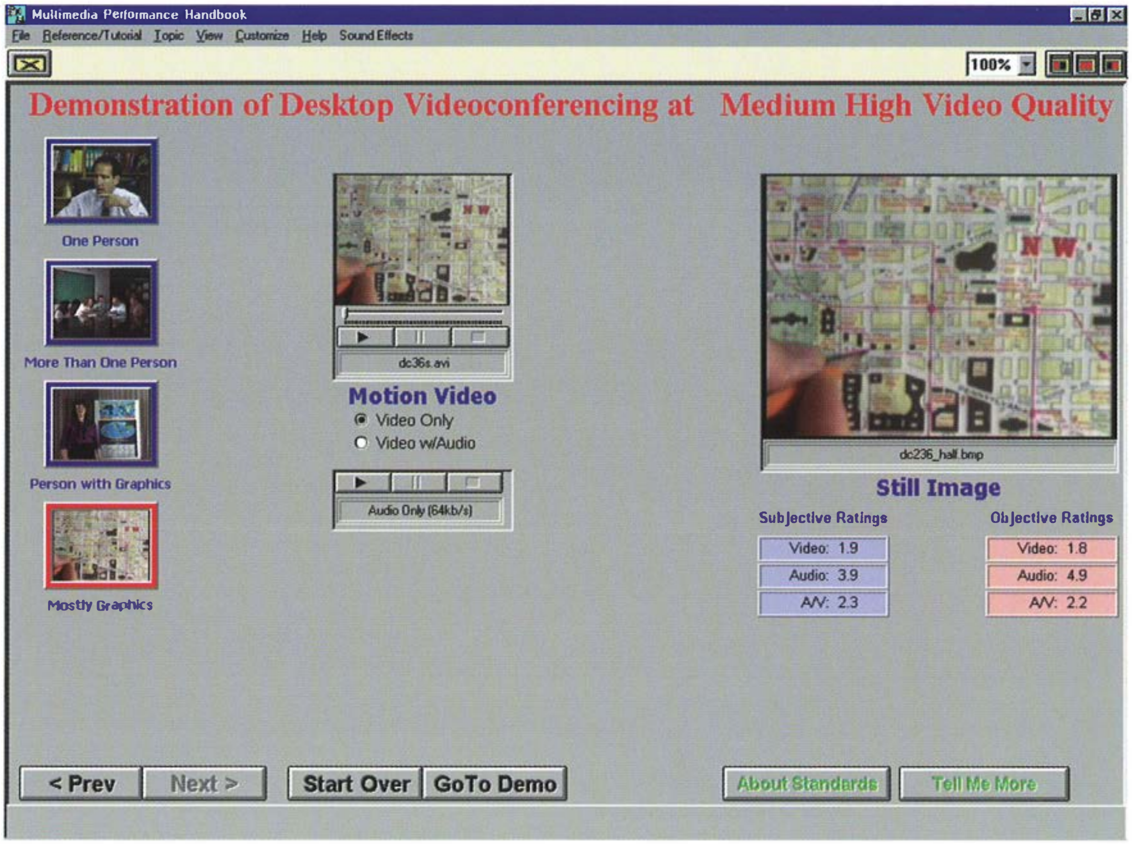
Outputs

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

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

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

Version 2.0 of the Handbook implements a new specification "applet" (a small application program) that assists users in establishing multimedia performance requirements. The applet enables users to experience interactively the likely performance of particular VTC configurations. For example, after entering the specification applet and choosing the videoconferencing application, the user can choose either desktop videoconferencing or conference room videoconferencing as the multimedia context. Assuming the former choice is made, the user is next asked to choose the class of video content for which performance examples will be given. The user might choose to see all four classes of video content available for the desktop videoconferencing application. On the next page, the user can choose the quality level of the videoconferencing system: low, medium, medium high, high, or source quality. Figure 1 shows an example screen where the user has chosen "medium high" video quality. The user can then see and hear examples of the performance to be expected for the selected combination of content and system quality level. The media options provided include motion video (with and without audio), audio only, and a still image frame (at half and full resolution). Numerical quality ratings (derived from ITS-developed industry performance standards) are provided to enable the user to relate the media examples to subjective and objective performance assessment scores. At each step along this interactive process, information is provided in several ways to help the user make these choices. "Tell Me More" buttons are available on each page and hyperlinks are abundant.



Example screen from the NCS Multimedia Performance Handbook.

This and other version 2.0 applets make extensive use of real audio and video clips, derived from commonly available multimedia communications systems and equipment, in illustrating performance impairments and demonstrating their effects on particular source material. This feature gives users a realistic view of product performance before any product is procured.

Development of the Handbook was an exciting, though demanding, task. The development team used several commercially available programming tools to produce the large quantity of custom audio, video, and image data included in the document. A standard hyperlinked text browser was used to provide access to the thousands of lines of tutorial and reference information. Applets and the overall user interface were created using Microsoft Visual Basic 4.0 supplemented by special-purpose library packages. Creation of the audio and video data was the most time-intensive task. Each audio or video clip was recorded by the development team and then digitized in formats that could be played by the set of standard multimedia players included with the computer operating system. During the recording process, each source clip was processed through a number of different real or emulated coding systems to allow the effects of such coders on user perception to be illustrated. Upon the release of version 2.0 of the Handbook, the development team had produced over 450 mb of digitized audio, video, and image data. Over 371 mb of this data was digitized video!

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

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ITS staff members preparing a system for noise measurements (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 the behavior of radio waves 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. 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); Integrator Corporation; the American Automobile Manufacturers Association; Industrial Technology, Inc.; and Hewlett-Packard Co (HP).

Millimeter-wave Research

The Institute conducts research on the millimeter-wave radio propagation channel. The results enable industry to develop and deploy local multipoint distribution services systems. Projects are funded by NTIA and HP.

Wireless Propagation Research

The Institute conducts research involving the radio propagation channels that will be employed in new wireless communication technologies such as personal communications services. This knowledge will aid Government and industry as these systems are developed and deployed. Projects are funded by NTIA, US WEST, 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 researches the effect of the radio propagation channel on radar applications, thus allowing simulation of the total system and radar performance prediction. The project is funded by the U.S. Air Force.

Radar Target Identification

The Institute conducts research related to automatic target recognition by radar systems. The project is funded by the U.S. Air Force.

Electromagnetic Compatibility Research

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

Man-made Noise Measurements

The Institute performs measurements to define the RF noise environment that is experienced by communication systems. The project is funded by NTIA and the National Oceanic and Atmospheric Administration.

Cooperative Research with Industry

Outputs

- A propagation model to predict line-of-sight coverage of PCS and LMDS signals.
- A model for the OFDM radio propagation channel that will facilitate analysis of radio links.
- Measurements defining the electromagnetic environment in which vehicular electronics will be required to operate.

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

ITS participates in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. ITS has participated for a number of years in CRADA's with private sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with Bell South Enterprises; Telesis Technology Laboratories (TTL); US WEST Advanced Technologies (US WEST); Bell Atlantic Mobile Systems; GTE Laboratories Inc.; US WEST New Vector Group; General Electric Company; Motorola Inc.; Hewlett-Packard Company (HP); Integrator Corporation; Industrial Technology, Inc.; 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 CRADA's. As part of a CRADA with US WEST, ITS served as a neutral independent observer as the Joint Technical Committee on Wireless Access (JTC) conducted field trials of six proposed PCS air-interface standards in the Boulder Industry Test Bed. The results of these six separate field trials have been compiled and will be published as an NTIA report in FY 98.

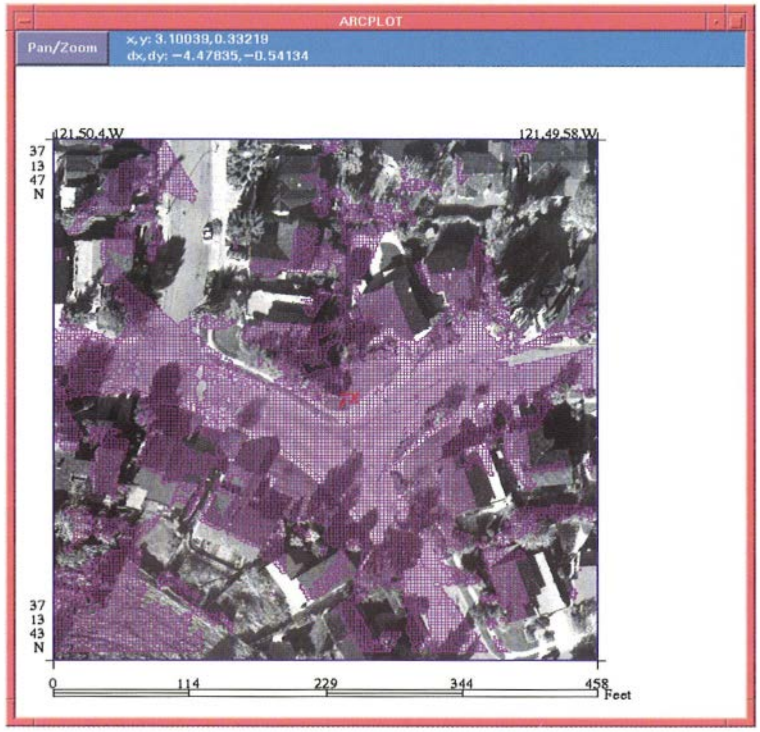
ITS is conducting a CRADA with AAMA to collect field data that will define the electromagnetic environment at specific locations in the United States. As electronic devices proliferate, it becomes important for the motor vehicle industry to have knowledge of the electromagnetic environment in which vehicular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

ITS has developed a PCS/local multipoint distribution services (LMDS) propagation model, within a geographic information system, to predict line-of-sight coverage of the PCS/LMDS signals. Use of the model requires input of a digital elevation model (DEM), for the area of interest, to provide a three-dimensional terrain and land cover map of the area. As part of a CRADA with HP, a DEM was generated from aerial photography to produce a three-dimensional map (see the Figure). In this Figure, the line-of-sight coverage for a PCS signal is shown in red. The PCS antenna is mounted on a light pole at the street corner in the center of the figure.

Under a CRADA with Integrator Corporation, ITS used a digital terrain database with the PCS/LMDS model to produce signal coverage patterns for rural communities, to investigate the feasibility of broadband wireless network technology as the basis for a rural community communications infrastructure. Also under this CRADA, ITS developed a model for the orthogonal frequency division multiplexing (OFDM) radio link that will facilitate analysis of the radio link in this application.

ITS has been a premier laboratory in millimeter-wave research for two decades. Now ITS is applying this unique expertise while conducting research into radio propagation considerations for LMDS. ITS has

CRADA's with TTL and HP for LMDS research. Under the current agreements, ITS has developed propagation models for the LMDS channel, conducted field measurements to characterize radio frequency propagation of an LMDS system, and developed a three-dimensional signal coverage map of the area of interest for LMDS transmission. The field measurements use an innovative impulse response measurement system called a digital sampling channel probe. This system allows the measurement of the complex-valued radio channel impulse response, and is ideally suited for making outdoor impulse response measurements.



Three-dimensional line-of-sight coverage model for a PCS base station.

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.

A CRADA with GTE Laboratories produced an objective video quality model for MPEG (Motion Picture Expert's Group)-coded video. This work was documented in a summary paper entitled "Objective and subjective measures of MPEG video quality" and accepted for publication by The Society for Motion Picture and Television Engineers. Under a CRADA with Industrial Technology, Inc., a manufacturer of telecommunications test equipment, ITS developed algorithms for assessing telephony speech quality.

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

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

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Recent Publications

R. Dalke, G. Hufford, and R. Ketchum, "A digital simulation model for local multipoint and multichannel multipoint distribution services," NTIA Report 97-340, Aug. 1997.

P. Papazian, G.A. Hufford, R. Achatz, and R. Hoffman "Study of the local multipoint distribution service radio channel," *IEEE Trans. Broadcast.*, Vol. 43, No. 2, pp. 174-184, Jun. 1997.

P. Papazian and G.A. Hufford, "Time variability and depolarization of the LMDS radio channel," In *Proc. 1997 Wireless Communications Conf.*, Aug. 11-13, 1997, Boulder, Colorado, pp 8-11.

Millimeter-wave Research

Outputs

- LMDS 30-GHz area coverage and time variability study.
- Measurement of signal attenuation by vegetation.
- Millimeter-wave propagation models.

In the past few years, consideration has been given to the allocation of frequencies in the extremely high frequency band so that wireless video, voice, and data services can be made commercially available to consumers. The potential availability of spectrum for these "wireless" services, known as local multipoint distribution services (LMDS), 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. 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 molecular 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 (see Recent Publications, below). This study included field measurements at 28.8 and 30.3 GHz, as well as 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, basic transmission loss, signal depolarization, and the effects of variations in receiver height on area coverage for an LMDS broadcast cell. Area coverage results are given in Figure 1. On this plot, the probability of coverage for a suburban neighborhood is plotted versus the allowable basic transmission loss. Additional results for signal depolarization are plotted in Figure 2. In this figure, the cross-polarization discrimination for a 28.8-GHz signal at different attenuation levels and the best fit linear approximation to the data is plotted. In this case, signal attenuation is caused by vegetation. It was found that the depolarization by vegetation is an order of magnitude greater than the depolarization caused by nonspherical raindrops at the same attenuation levels as predicted using CCIR models. Figure 3 describes the time variability of measured data when the signal was propagating through foliage. In this Figure, several examples of data with different k-factors plotted on Rayleigh paper are shown. Presently, ITS is continuing study on the time variability of signals attenuated by vegetation in the LMDS band. The experiment setup used for this study involved a 1-km line-of-sight link established through deciduous trees (Figure 4). The arrow in the Figure shows the transmitter van.

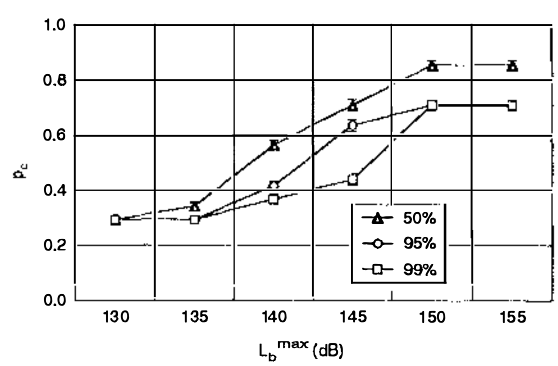

Figure 1. Area coverage probability estimate verses L_b^{max} for 50%, 95%, and 99% availability levels for a suburban cell in Northglenn, Colorado using a 12.5-m transmitter.

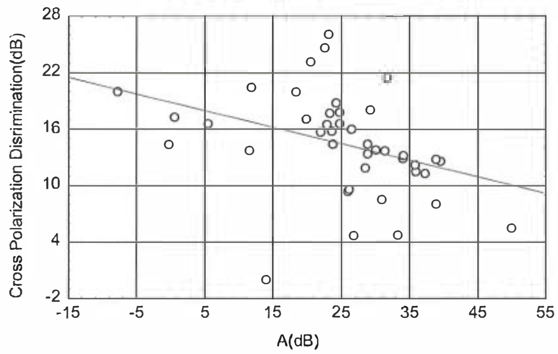

Figure 2. Cross-polarization discrimination verses attenuation, 0.5-km cells using 12.5-m transmitters in Northglenn, Colorado.

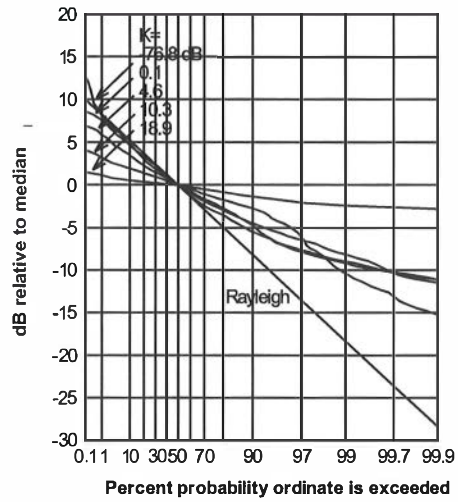

Figure 3. Selected examples of measured data for various k factors plotted on Rayleigh paper.

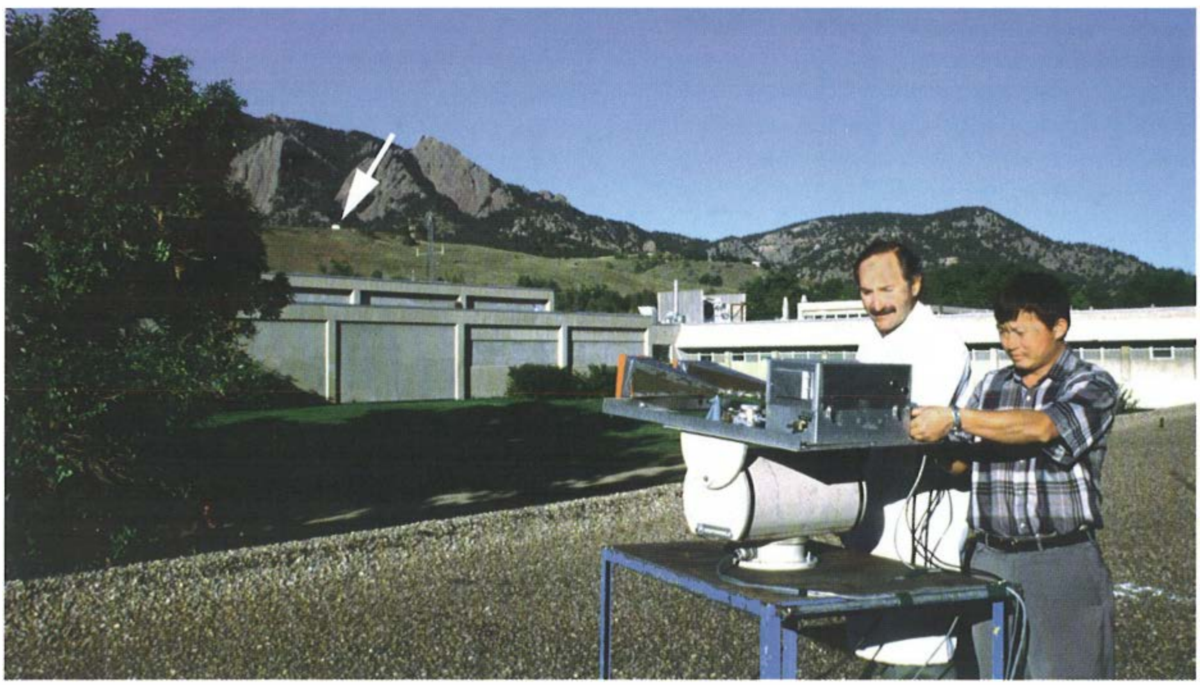

Figure 4. Dual-polarized 28.8 GHz receiver used for th LMDS vegetation study. The arrow indicates the transmitter van at a 1-km line-of-sight link (photograph by F.H. Sanders).

Recent Publications

P. Papazian, G.A. Hufford, R. Achatz, and R. Hoffman "Study of the local multipoint distribution service radio channel," *IEEE Trans. Broadcast.*, Vol. 43, No. 2, Jun. 1997, pp. 174-184.

P. Papazian and G.A. Hufford, "Time variability and depolarization of the LMDS radio channel," In *Proc. 1997 Wireless Communications Conf.*, August 11-13, Boulder, CO.

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Wireless Propagation Research

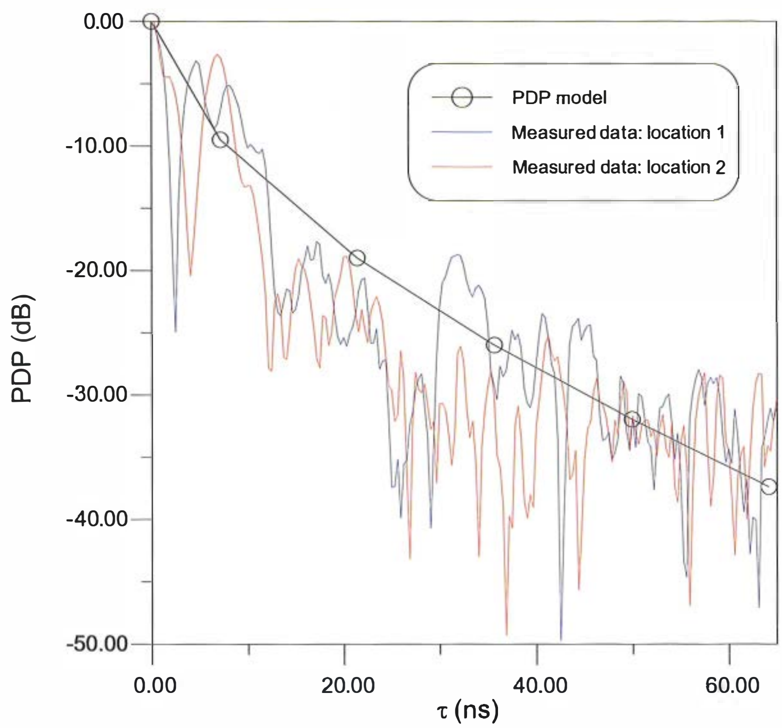
Outputs

- Indoor channel modeling.
- Predicting the impulse response for an indoor propagation channel.
- Predicting delay spread of the multipath channel.
- Smart antenna performance.

The Institute is involved in several research efforts related to wireless communication applications and research. This effort supports new wireless technology development and helps U.S. industry compete in the worldwide telecommunications market place. This work includes: (1) developing measurement systems for assessing different multipath environments, (2) developing models to predict impulse response and delay spread for different propagation channels, and (3) investigating the potential benefit of the use of smart antennas for communication systems.

ITS has developed measurement systems to study different types of propagation environments. Two types of impulse response measurement channel probes—one analog and one digital sampling—are presently being used. The analog probe is capable of high bandwidths (500-Mbits/s chip rate) with a resolution of 2 ns, and an output of 1 impulse every 10 ms. This system is ideal for indoor measurements or situations where high resolution is required. The Figure shows results of the measured impulse response obtained from this impulse response measurement probe. It has been used with carrier frequencies as high as 60 GHz. The digital sampling channel probe can have bandwidths as high as 200 MHz and can measure the channel impulse response as often as once every 5 μs. It is ideally suited for rapidly changing channels and is easily configured to various parameter values since most of the receiver is implemented in software.

Measurement systems for the 27.5- to 29.5-GHz local multipoint distribution service (LMDS) radio channel were developed to study the characteristics of the LMDS channel in FY 97. ITS also developed



Comparison of the power delay profile model to measurements.

measurement systems to study the man-made noise environment for different radio frequency bands.

The Institute has developed a geometric optics (or ray-tracing) model and a finite-difference time-domain (FDTD) model for calculating the impulse response of an indoor radio propagation channel. While both the FDTD and the ray-tracing techniques are very accurate, they can be very time consuming. The Institute is presently developing a simplified model for calculating the impulse response and delay spread for the indoor channel. The model can be expressed by the simple expressions:

$$IP(t_o) = 1 \quad \Rightarrow \quad t_o = 0$$

$$IP(t_n) = \frac{1}{4}\frac{\alpha^n}{n^2} \quad \Rightarrow \quad t_n = \frac{l_c}{c}(2n-1) \quad \text{for } n \neq 0$$

where α and lc are parameters that are functions of 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 energy absorbed into objects within the room. The Figure shows a comparison of this model to measured data. Since this model is based upon simple assumptions, the characteristics of the power delay profile can be calculated in a matter of seconds.

The Institute assesses the advantages of antenna arrays and smart antennas for wireless communication systems. Recently, the Institute has worked with US West Advanced Technologies, Inc. on investigating antenna diversity of antenna arrays. In this study, ITS compared angle and space diversity in different mobile radio environments. A summary of this work in shown in the Table, where the results show a 7.5- to 8.5-dB improvement in fading for the urban environment. However, a 2.5-dB improvement for space diversity in the rural setting was shown, and no improvement in angle diversity was demonstrated.

In a related effort, ITS is establishing an adaptive test bed. The test bed uses an 8-channel RF system with IF digitization. This system will allow participants to evaluate phased array algorithms designed to increase cellular system capacity and reduce cell site and mobile transmit power requirements.

Angle and Space Diversity Comparisons in Different Mobile Radio Environments

Location	**Diversity Type**	**Fading Improvement (dB)**	
		(15° beam antenna)	**(30° beam antenna)**
Urban	Angle (1% probability)	8.5	7.5
Urban	Space (1% probability)	7.5	7.0
Urban	Angle (10% probability)	4.0	2.5
Urban	Space (10% probability)	4.0	2.5
Rural	Angle (1% probability)	0.0	2.5
Rural	Space (1% probability)	2.5	1.0
Rural	Angle (10% probability)	0.0	0.0
Rural	Space (10% probability)	1.0	2.0

Recent Publications

P. Papazian, G.A. Hufford, R. Achatz, and R. Hoffman "Study of the local multipoint distribution service radio channel," *IEEE Trans. Broadcast.*, Vol. 43, No. 2, Jun. 1997, pp. 174-184.

C.L. Holloway, M.G. Cotton, and P. McKenna, "A simplified model for calculating the decay rate of the impulse response for an indoor propagation channel," In *Proc. 1997 Wireless Communications Conf.*, August 11-13, Boulder, Colorado.

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Wireless System Modeling and Simulation

Outputs

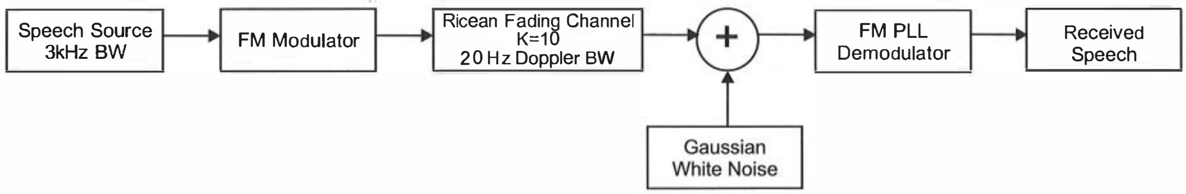
- System simulation (modems, channel, and noise) software modules.
- Predicted speech performance as a function of channel conditions, including SNR.
- Tested channel model.

ITS has been conducting research of wireless systems for many years. Past efforts include radio, television, and radar channel propagation; 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.

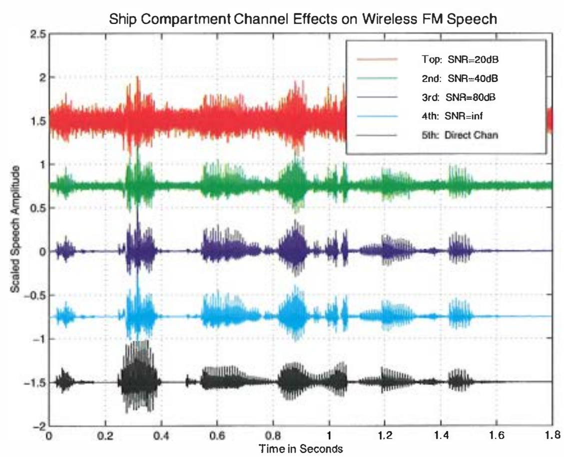
ITS has investigated the effects of multipath fading, noise sources, and cochannel interference on performance of land mobile radio, wireless private branch exchange, global system for mobile communications, IS54/136 personal communciations services (PCS), wireless local area networks, and ionospheric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

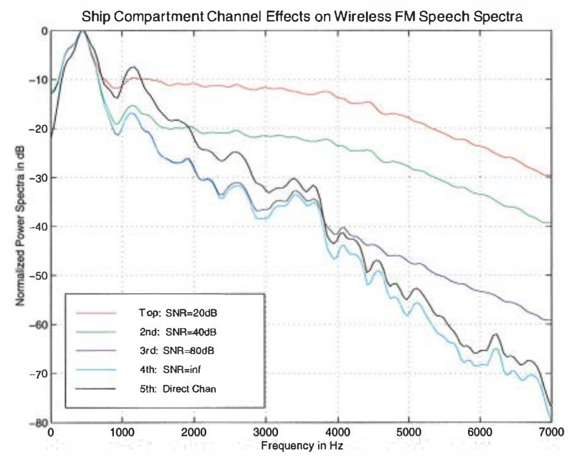
In the most recent efforts, ITS has investigated the effects of dispersive, time-varying, multipath fading and noise sources on performance of wireless frequency-modulated (FM) systems operating in the 400-MHz region inside ship steel compartments. The initial objective of this research was to model this noisy, dispersive operating environment as a communication channel. The channel model was used in simulating the existing FM wireless system operating intra- and intercompartment to predict speech performance. After studying the physics of the possible propagation paths in the environment, the initial channel model was represented by a time-varying Ricean model. This represents an environment with random multipath components arriving at different angles that are superimposed on a stationary dominant direct path signal. It is time-varying to represent changes in the propagation path due to orientation of the operator's body and motion in the compartments by personnel and equipment. Once the environment has been properly modeled, it can be used to predict the performance of proposed new digital wireless modems operating in the same environment.

The Figure (a) depicts the current wireless FM system that was simulated to estimate speech performance, compare simulated speech performance with the current operational system, and validate the channel model. The channel model has two primary parameters. One is the ratio (K) of the deterministic signal power of the direct path and the variance of the multipath. The other parameter is the Doppler bandwidth due to motion in the compartments. These were varied during our investigation and set at K=10 and a 20-Hz Doppler bandwidth for the results shown in the Figure (b) and (c). An IEEE standard male speech was selected as the test source and rolled off with a 3-kHz bandwidth. The spoken words are: "If dark came they would lose her" and the corresponding received waveforms can be observed in the Figure (b) along with channel degradation for several cases. The speech quality associated with the waveforms in the Figure (b) varies from "very good" for the direct channel with no noise (bottom waveform) to "very poor" and barely intelligible for the top waveform when the fading channel with a 20-dB signal-to-noise ratio (SNR) was employed. The Figure (c) shows the estimated speech power spectra corresponding to the waveforms in the Figure (b). The loss of fricative power in the 3000- to 4000-Hz range is particularly noticeable as the SNR decreases much below 60 dB where the additive white Gaussian noise swamps out the speech power.



(a)





(b) (c)

Performance of wireless FM communicating inside steel ship compartments for a variety of channel conditions: (a) simulation block diagram of FM system, (b) received speech waveforms, and (c) power spectra of received speech waveforms.

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HF Channel Modeling and Simulation

Outputs

- Software implementation of the ITS wideband HF channel model.
- Real-time wideband/narrowband HF channel simulations.
- Contributions to international HF radio standards committees.
- IEE and NTIA publications.

Spread spectrum technologies and new digital signal-processing techniques are enabling the development of advanced high-frequency (HF) communication systems that operate over very wide bandwidths (on the order of 1 MHz). These advanced systems offer substantial benefits in throughput, spectrum efficiency, and interference immunity, but their successful deployment will require resolution of many technical uncertainties. Channel simulation provides an accurate, repeatable means of evaluating the performance of such systems without incurring the time delays and costs of field testing.

A channel model that accurately describes the real-world conditions encountered on communication links is required for the development of a channel simulator. Until recently, HF channel simulators were based on the Watterson channel model, developed (by ITS) circa 1970. That model is restricted to narrow bandwidths (on the order of a few kHz), and is also limited in its ability to describe propagation in nondispersive channel conditions.

In recent years, the Institute has developed a wideband channel model that overcomes many of these limitations. The new model is accurate not only for narrowband technology, but also over bandwidths of 1 MHz or more. It has been validated with measured data and has been implemented in a real time, wideband HF channel simulator that can be interfaced directly with operational radio equipment. The model includes the channel transfer function, describing the characteristics of ionospheric skywave propagation, and a model of wideband HF noise and interference.

In January of 1997, Institute engineers submitted a U.S. contribution to International Telecommunication Union-Radiocommunication Sector (ITU-R) Working Group 9C that proposes the ITS-developed wideband HF channel model for adoption as an ITU-R recommendation. As outlined in the contribution, the new recommendation would specify the new HF propagation and noise and interference models as well as a functional architecture for implementing those models in real-time channel simulation equipment.

The Institute also completed a software implementation of the wideband HF channel model during FY 97. This alternative implementation will allow wider dissemination of the model and should promote its international acceptance. Results of a typical application of the software model are shown in Figures 1 and 2. The modeled channel is a three-path wideband HF channel. One path is the ordinary mode and the other two are extraordinary modes for 1-hop F-layer returns representing a quiet 126-km path in California in the winter season. The scatter function depicted in Figure 1 shows the ability of the spectral average results to distinguish between separate paths. Two major divisions of energy are evident. The contour plot of Figure 2 clearly indicates the presence of three paths, as the contours in the upper middle of the figure show two sections with distinctly different slopes.

ITS also set out to implement the new HF channel model in an inexpensive single board digital signal-processing instrument during FY 97. This effort not only supports the Institute's contribution to the ITU-R, but will allow the model to be implemented in commercial test equipment. A principal application of such equipment will be in testing narrowband HF modems. The new model will provide more accurate results than the Watterson model in such tests because of its enhanced ability to represent delay spread characteristics. The new narrowband HF channel simulator operates on a common digital signal-processing board in a personal computer.

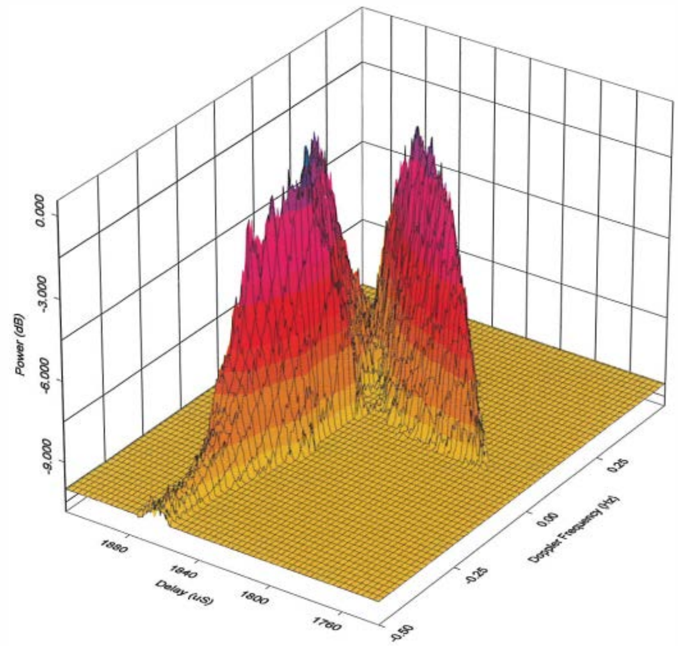

Figure 1. Scatter function for a three-path wideband HF channel (software simulation).

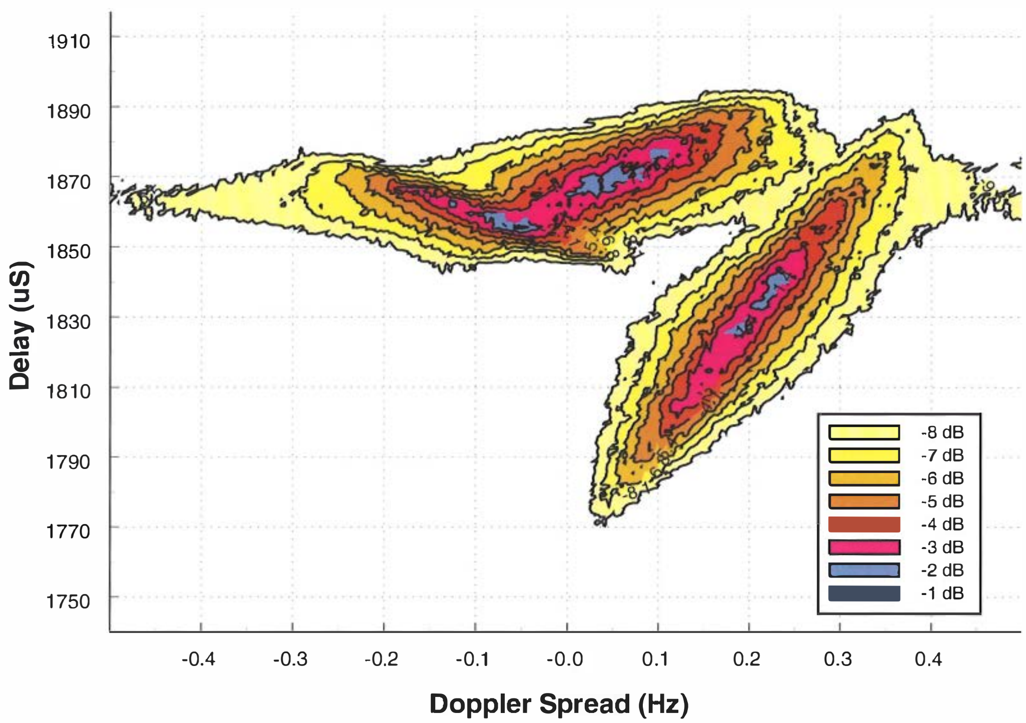

Figure 2. Scatter function contour plot for a three-path wideband HF channel (software simulation).

Recent Publications

C. Behm, "A narrowband HF channel simulator with delay spread," In *Proc. HF Radio Systems and Techniques Conf.*, IEE Conf. Pub No. 441, Jul. 7-10, 1997.

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Advanced Radar Research

Outputs

- Investigation of the feasibility of new radar systems.
- Assessment of system performance.
- 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 system development, feasibility, simulation, and algorithm development. In the past year our efforts concentrated on ground-penetrating radars, meteorological radar for determining wind speed and turbulence, and wavelet algorithms for radar data compression.

Military, civilian, and commercial identities are faced with a need to image underground objects at depths ranging from a few centimeters to several meters. The Institute is involved in research efforts to determine the propagation characteristics for electromagnetic waves in different soils for various moisture levels. Figure 1 shows preliminary results of the attenuation constant for a soil composed of 90% sand, 7% clay, and 3% silt for various moisture levels. These results indicate that if a wide bandwidth pulse is launched into this type of soil, severe distortion in the pulse will occur for high moisture levels as a result of the large attenuation of the high-frequency energy.

The atmospheric science community has a need for fast and accurate estimates of the wind speed and turbulence of the air mass in the lower boundary layer for clear air conditions. Over the past couple of years, the Institute has been working with the National Center for Atmospheric Research to develop a 915-MHz radar system for monitoring the lower boundary layer. In this work we have developed theoretical scattering models that have allowed for the development of algorithms for determining both wind speed and turbulence. Figure 2 shows estimated wind speed and turbulence (rms wind variability) values obtained from these algorithms using the 915-MHz radar system. These algorithms allow for frequent and accurate measurement data needed for meteorologic parameters.

In automatic target recognition (ATR) applications using synthetic aperture radar (SAR), compressing data sets enables faster and less costly target decisions, as well as smaller storage requirements. Lossy

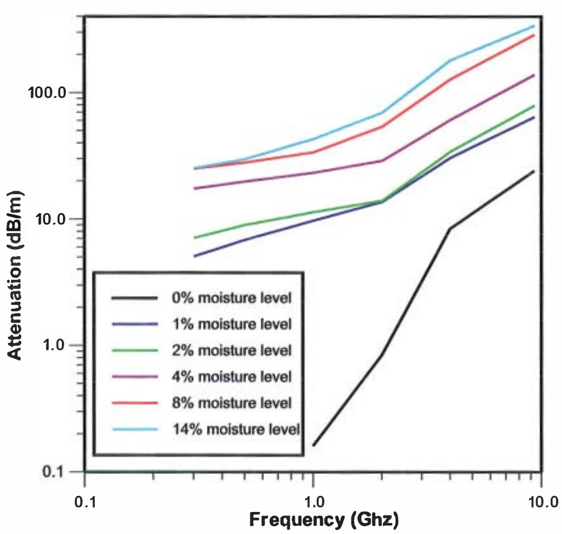

Figure 1. The attenuation constant for a soil composed of 90% sand, 7% clay, and 3% silt for various moisture levels.

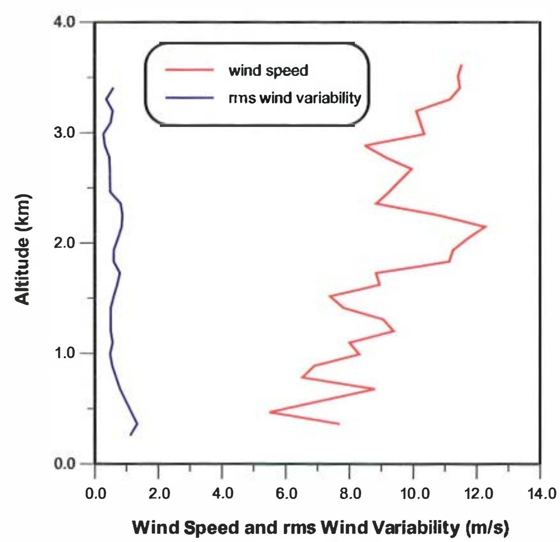

Figure 2. Wind speed and turbulence (rms wind variability) values obtained from these algorithms using the 915-MHz radar system.

compression of SAR images using wavelet transforms causes degradation of ATR performance that depends on the compression ratio and the choice of wavelet filter. In this research the Institute has investigated and developed distortion measures for assessment of wavelet compression effects on SAR images. The end objective is to select those measures that relate most directly to ATR performance. Windowed measures were developed that relate to ATR feature size. These were the most sensitive to distortion, and they provide an effective method for assessing tradeoff between compression and distortion. Figure 3 shows the compression ratio as a function of the threshold used in discarding wavelet coefficients. Figure 4 shows the distortion of an image's peak signal-to-noise ratio (PSNR) and entropy as a function of wavelet compression (measured by the threshold percentage). Notice that both the PSNR and the entropy decrease with increasing compression. While wavelet compression can reduce the data set, it is crucial to realize that target recognition can be degraded. Thus, wavelet compression is only useful if target recognition capabilities are not unduly degraded.

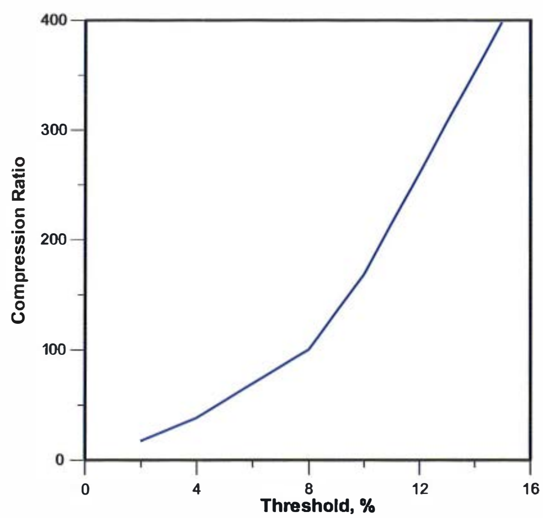

Figure 3. Compression ratio as a function of threshold percent.

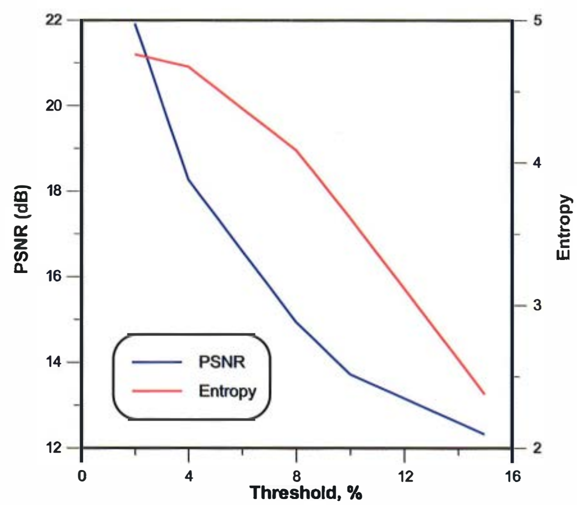

Figure 4. Peak signal-to-noise ration (PSNR) and entropy as a function of threshold percent.

Recent Publications

C.L. Holloway, R.J. Doviak, S.A. Cohn, R.J. Lataitis, and J.S. Van Baelen, "Cross correlations and cross spectra for spaced antenna wind profilers 2: Algorithms to estimate wind and turbulence," *Radio Science*, Vol. 32, No. 3, pp. 967-982, May-Jun. 1997.

E.A. Quincy, R.B. Stafford, C.L. Holloway, M.G. Cotton, and A.S. Ali, "Distortion measures for wavelet compression of SAR images in ATR," In *Proc. 1997 IEEE Pacific Rim Conf. Communication, Computers and Signal Processing Vol. 1*, Victoria, B.C., Canada, Aug. 1997, pp. 310-317.

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Radar Target Identification

Outputs

- Automatic feature-picking algorithm and software module.
- Automatic feature optimization algorithm and software module.
- Trainable target identification software module with probability of correct classification and declaration.

The Department of Defense (DOD) is developing automatic/aided target recognition (ATR) systems for high resolution radar (HRR) sensors. ITS has decades of experience in developing and optimizing feature sets for classification of a variety of data and is assisting the DOD in their effort. The DOD provided HRR range profile data obtained by measurements and synthetic model responses for a variety of targets; this data was used to develop an ATR system.

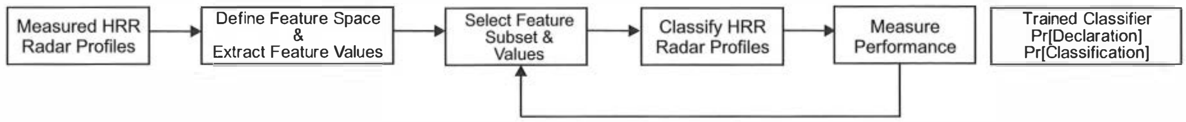
Maximum classifier performance is realized only with a minimal, optimum set of objective features extracted from the data. Minimizing feature sets also minimize storage, processing requirements, and decision times for the ATR system. This is extremely important to systems that may fly at supersonic speeds. Exhaustive evaluation of all possible combinations of features is required to yield the optimal set but is computationally prohibitive due to the potentially large search space.

Most common methods of feature selection involve some suboptimum criterion associated with the feature space that allows design goals to be achieved. Our method maximizes the average probability of correct classification of the target data while employing a bottom-up algorithm for adding new features to the set. Extracted feature values are used to train a Bayes classifier with one set of target data and classify the same set and other new sets of data. Probability of correct classification may be improved by not declaring a classification for every target response, but instead averaging over multiple responses to improving the classification probability at the expense of lowering the declaration probability.

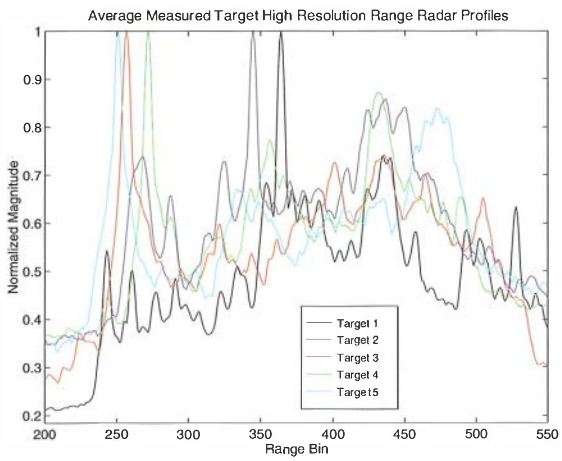
The Figure (a) depicts the development process used by ITS in feature optimization and training the ATR classifier. One of the major efforts in this process was defining the feature space such that new targets could be added to the classification set without having to define or add new features, thus enabling automatic retraining of the ATR system when new targets are added. Each target was described by a large number of measured responses differing significantly in a random fashion.

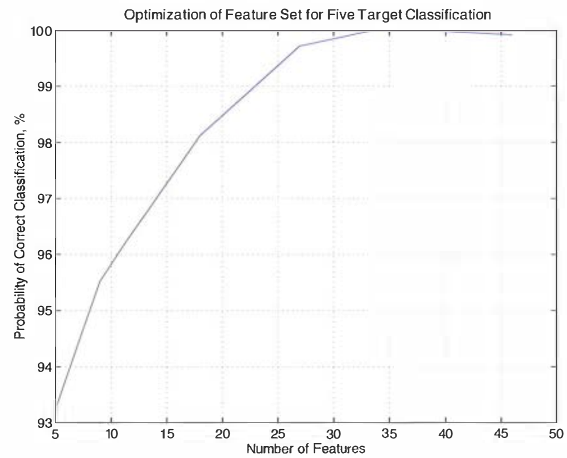
The Figure (b) describes the complexity and confusion between targets of the average range profiles for the five targets. The challenge is that these targets must be correctly classified with very high reliability even though a single target response may be greatly confused, by a human, with other target responses.

The Figure (c) demonstrates the performance of the ATR system as features are added in the optimization process; it shows that the probability of correct classification increases from 0.93 when one feature per target is used to 1.00 when 34 features are optimally employed. Adding too many features may decrease performance as it did here for more than 37 optimal features. These results were obtained when classifying the same set of data as used in training. Similar results were obtained when training on one set of data and classifying another data set from the same five classes. However, peak performance decreased to 0.958 probability of correct classification with the 34 optimal features when the classification was declared with each target response.



(a)





(b) (c)

Dependence of target identification classifier performance on number of optimized features for measured data: (a) feature optimization flow chart, (b) average radar responses used in training classifier, and (c) probability of correct classification for a five target set.

Recent Publications

E.A. Quincy, R.B. Stafford, C.L. Holloway, M.G. Cotton, and A.S. Ali, "Distortion measures for wavelet compression of SAR images in ATR," In *Proc. 1997 IEEE Pacific Rim Conf. Communication, Computers and Signal Processing Vol. 1*, Victoria, B.C., Canada, Aug. 1997, pp. 310-317.

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Electromagnetic Compatibility Research

Outputs

- System performance.
- Immunity and emission compliance.
- System interference and susceptibility.

To compete in the new global economy, manufacturers of electronic and telecommunication devices must be able to market their products worldwide. Such marketing is contingent upon meeting both domestic and international regulations and requirements. Indeed, products must meet both emission and immunity requirements to obtain access to some of the world's most lucrative markets. The Institute is involved in several research efforts in the areas of electromagnetic compatibility (EMC) and electromagnetic interference (EMI).

Anechoic and semi-anechoic chambers provide an accurate and convenient environment for EMC/EMI testing and are important cost-effective tools for achieving EMC/EMI compliance. The Institute has developed models for predicting the performance of these test facilities. In one of these models we have been able to predict the decay rate of energy inside these test facilities. Figure 1 shows a comparison between this model and measured data for an anechoic chamber. We have also developed models for analyzing different types of electromagnetic absorbing material used in these test facilities.

The crucial step in designing an EMC/EMI test chamber is the proper choice of the RF absorbing material used to line the walls of the chamber. As a consequence of the different nature of the required tests, the performance of the RF absorber material lining the walls is specified differently in each test application. The Institute has developed guidelines for choosing an absorber for these different chamber applications (see the Table). These guidelines are presented for the purpose of aiding individuals in choosing the proper type of absorbing structure.

The Institute has recently developed a model that aids in examining the amount of energy that pc-boards (commonly found in most communication and electronic products) emit. This model will aid designers in meeting Federal Communications Commission emission requirements. Figure 2 shows results of a quantity L_{GR} (ground plane inductance) that is related to pc-board emissions. The smaller this quantity, the smaller the emissions. These results show that if the height of the board is made small, the emissions can be greatly reduced.

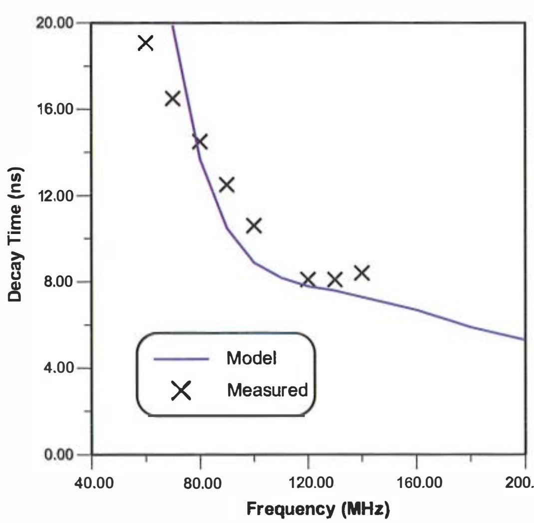

Figure 1. Comparison between experimental and calculated decay time of a chamber.

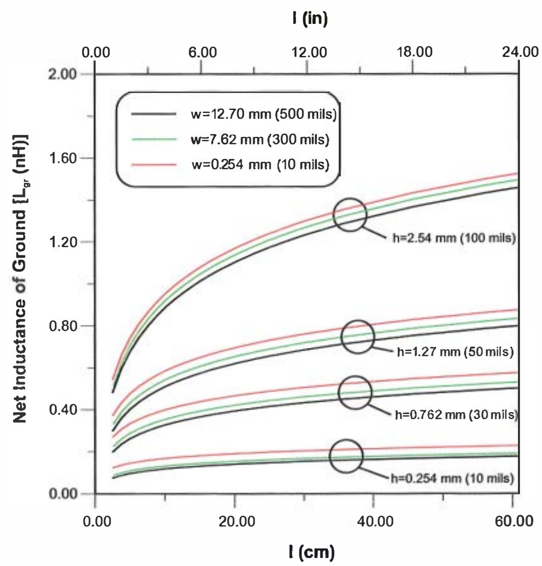

Figure 2. The parameter that is related to pc-board emission as a function of pc-board dimensions.

General Guidelines for Absorber Reflectivity

Chamber Application	Criteria for Absorber Reflectivity
Military-Standard	-6 dB normal incidence for 20-250 MHz -10 dB normal incidence above 250 MHz
Immunity	-18 dB normal incidence for 80-100 MHz
Emission	
3-m chambers	-18 dB normal incidence for 30-1000 MHz -12 dB at 45° for 30-1000 MHz
10-m chambers	-20 dB normal incidence for 30-1000 MHz -15 dB at 45° for 30-1000 MHz

The Institute is working jointly with personnel from the NTIA Office of Spectrum Management to perform measurements on electromagnetic emissions from microwave-driven lighting devices. These lighting devices, which are more efficient than conventional light sources such as fluorescent lamps, may find wide application in lighting for warehouses, factories, and aircraft hangers. The ITS measurements have been performed to determine the extent to which the deployment of these lighting devices may cause electromagnetic compatibility problems in the microwave spectrum. The ITS-generated data includes emission spectra, time waveforms, and spatial emission patterns of the lighting devices. In related work, the Institute has recently completed a project which analyzed and measured the emissions of a new highly energy-efficient light bulb composed of a plasma excited by RF fields.

Other EMC issues that the Institute is investigating include intelligent transportation systems for the 5850- to 5925-MHz band and the characterization of man-made noise for various frequency bands. Details on these topics can be found in Intelligent Transportation Systems Planning (p. 36) and Man-made Noise Measurements (p. 78).

Recent Publications

R.A. Dalke, R.J. Achatz, Y. Lo, P.B. Papazian, and G.A. Hufford, "Measurement and analysis of man-made noise in VHF and UHF bands," In *Proc. 1997 Wireless Communications Conf.*, Boulder, Colorado, Aug. 1997, pp. 229-231.

C.L. Holloway, R.R. Delyser, R.F. German, P. McKenna, and M. Kanda, "Comparison of electromagnetic absorber used in anechoic and semi-anechoic chambers for emissions and immunity testing of digital devices," *IEEE Trans. Electromagn. Compat.*, Vol. 39, No. 1, pp. 33-47, Feb. 1997.

C.L. Holloway and G. Hufford, "Internal inductance and conductor loss associated with the ground plane of a microstrip line," *IEEE Trans. Electromagn. Compat.*, Vol., 39, No. 2, pp. 73-78, May 1997.

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Man-made Noise Measurements

Outputs

- Man-made noise measurement techniques.
- Median man-made noise power estimates.
- Statistical man-made noise models.

Wireless communication system performance is degraded by the addition of man-made noise to the received signal. Sources of man-made noise include automobile ignition systems, electric motors, power systems, and a wide variety of electronic equipment such as computers and microwave ovens (Figure 1). In the 1970s researchers at ITS presented methods, based on years of measurements, for predicting man-made noise power and noise amplitude-statistics for rural, business, and residential areas. These methods have been widely used by industry and are described in CCIR Report 258-5 (CCIR, 1990; see Publications Cited, p. 103).

Recently researchers have conjectured that the CCIR methods for estimating man-made noise power levels may have been made inaccurate by technological advances. For example newer automobile ignition systems radiate less noise but noise-generating electronic products such as computers and microwave ovens have become ubiquitous. Thus, measurement and modeling of man-made noise is timely for understanding the environment in which current wireless communication systems operate.

ITS has recently measured and analyzed man-made noise at 137 MHz in the very high frequency (VHF) radio band. The results from this work will be used in the design of a satellite broadcast system for weather images. The purpose of this effort was to compare contemporary average noise power values to those reported by the CCIR and to model the distribution of noise voltage amplitudes.

The man-made noise was measured with a custom-built, wide dynamic-range receiver installed in a

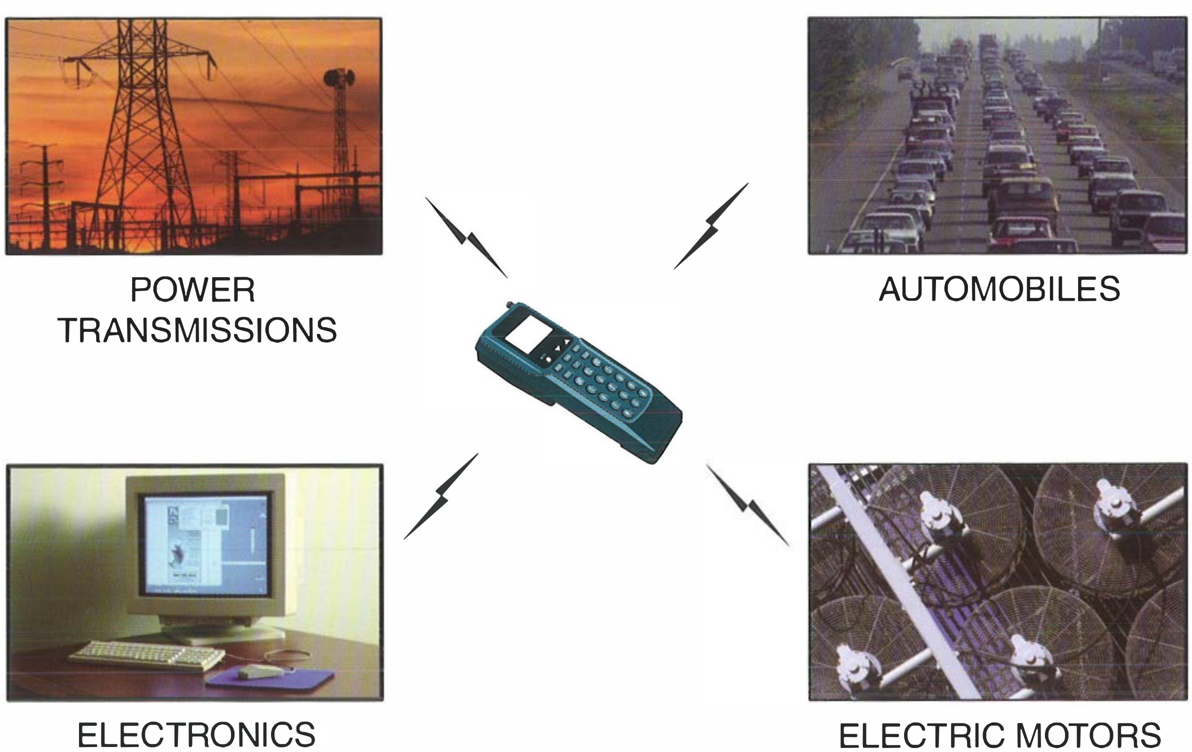

Figure 1. Sources of man-made noise.

van. Hundreds of hours of measurements were collected at various business, residential, and rural sites. First-order noise power statistics were obtained by digitizing 60,000 noise power samples every 2 min. The digitized samples were stored in a histogram that counted the number of samples at each power level.

Cumulative distributions functions (CDF) of the received noise power samples were constructed from the stored histograms. Median, mean, and peak noise powers from each CDF were plotted on one graph to summarize a long period of measurements. Figure 2 is a summary of 24 hours of continuous 2-min measurements at a suburban office park located near an interstate highway. Man-made noise power is represented in decibels exceeding the Gaussian noise power in the same bandwidth. Diurnal variation of the noise power is evident from the contrast of median noise power during the early morning hours to that of the mid-day hours. The hour-to-hour variation of the median noise power is small and within-the-hour variation of the median noise power is negligible. This last finding, negligible within-the-hour variation, significantly impacts communication link availability estimates and is one of the striking contrasts from measurements made in the 1970s.

The measurements over all sites show that residential median noise power is likely to have dropped from 1970s levels. Rural median noise power appears not to have changed appreciably. Downtown business median noise power levels have stayed consistent over the years; however, measurements in business areas outside downtown show that the median noise power is comparable to the more benign residential environment.

The impact of man-made noise on wireless communication systems using digital signal-processing techniques, such as source coding, error correction, interleaving, and equalization, is predicted analytically or through simulation. Accurate man-made noise models are essential for either method. Noise narrower than the measurement bandwidth of 30 KHz was rarely observed and not modeled. Noise wider than the measurement bandwidth was successfully modeled as one or more multivariate random processes added to complex Gaussian noise.

The results from measuring and modeling VHF noise show that the noise estimates based on CCIR reports are likely to be inaccurate, as predicted. In the future we will measure and model noise in other bands, as well. Measurement and modeling, for example, in the emerging technology bands such as the industrial, scientific, and medical bands, 2-GHz personal communications services band, and the proposed 5-GHz National Information Infrastructure band would be very useful to engineers designing tomorrow's wireless communication systems.

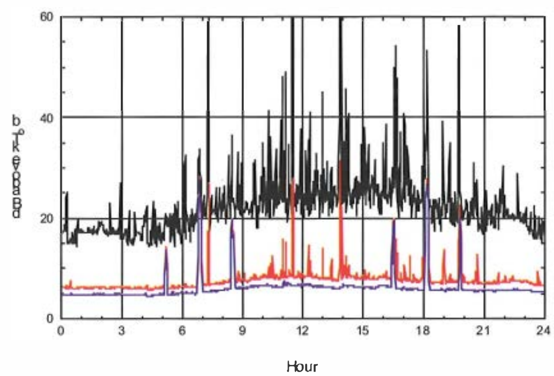

Figure 2. Median (blue), mean (red), and peak (black) noise power during a 24-hr measurement period near an office park.

Recent Publications

R. Dalke, R. Achatz, Y. Lo, P. Papazian, and G. Hufford, "Measurement and analysis of man-made noise in VHF and UHF bands," In *Proc. 1997 Wireless Comm. Conf.*, Boulder, Co., Aug. 1997, pp. 229-233.

For more information, contact:
Robert J. Achatz
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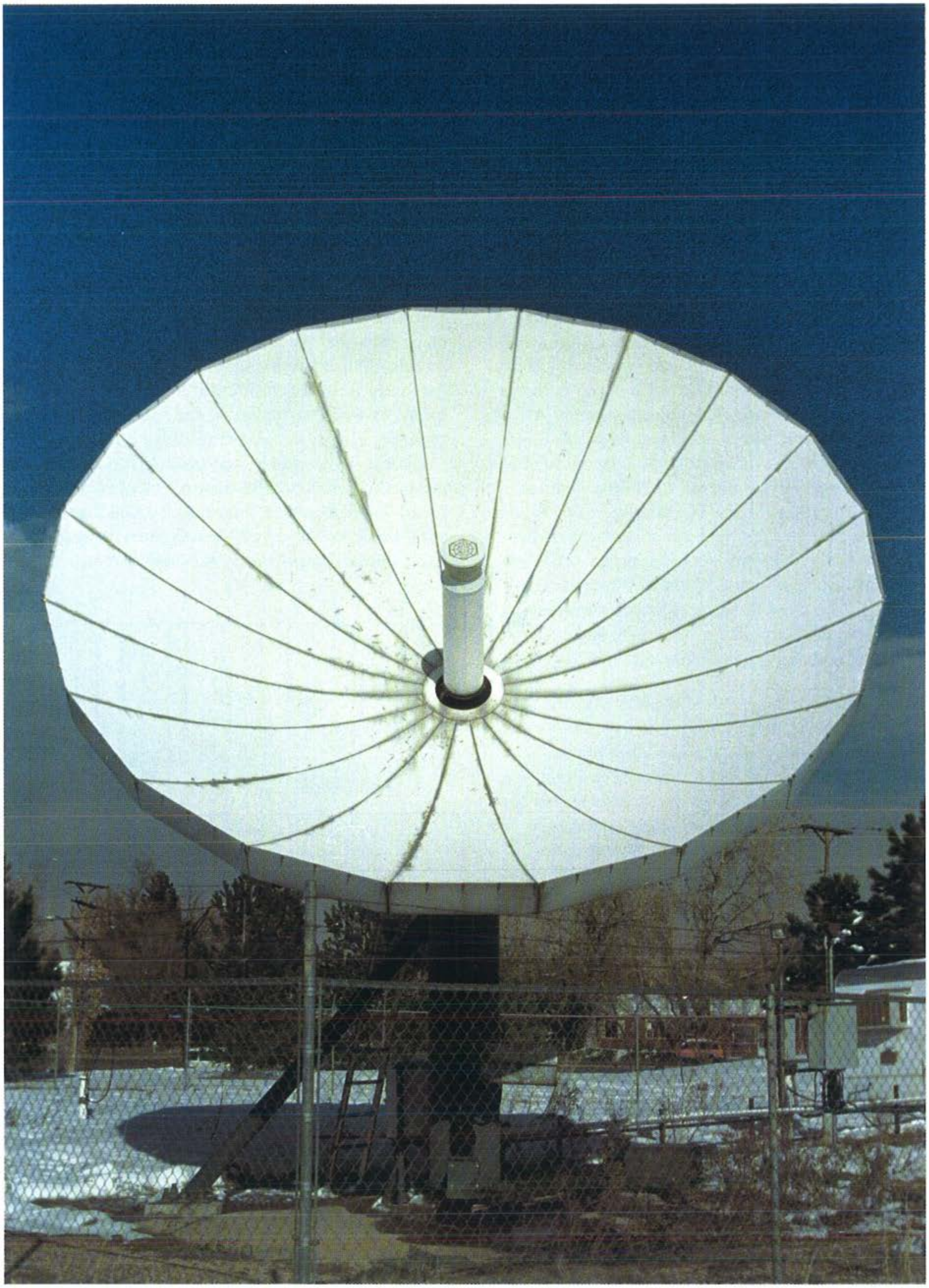
e-mail rachatz@its.bldrdoc.gov



Antenna for geosynchronous satellite communication (photograph by F.H. Sanders).

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-Mb/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 and reproduction of audio signals. The laboratory also supports subjective and objective analyses of audio signals. Subjective analyses are conducted in acoustically isolated and treated rooms that conform with international recommendations for subjective listening and viewing experiments. Two such rooms are available in the laboratory. Participants hear digital audio recordings through headphones or loudspeakers and use electronic pens and screens to record their responses. Workstations equipped with 16-bit digital-to-analog converters control the reproduction of test material and the collection of responses.

Audio Quality Laboratory equipment includes digital audio tape recorders, compact disk players, digital audio encoders and decoders, a spectrum analyzer, signal generators, level meters, mixers, amplifiers, processors, speakers, and microphones. 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 Communication 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 of HF communications systems related to National Security or Emergency Preparedness telecommunications. The facility also is 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. ITS has also developed a computer model to simulate the effect of different TCP/IP parameters when sending e-mail over HF radio links under different ionospheric conditions. This will aide in determining optimum settings for emergency HF usage.

Integrated Networks Test Bed

This facility provides integrated services digital network-switching and emulation capabilities, and a wide range of facilities to support broadband network testing. 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 Internet Services

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

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

- Anonymous FTP distribution of some ITS-developed software programs: Available at *ftp.its.bldrdoc.gov*

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

ITS Local Area Network

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

Client-server and peer-to-peer intranetworking services link together UNIX servers and workstations, X-terminals, Macintosh computers, and personal computers using Windows NT and Windows 95. This open-systems environment uses the transmission control protocol/Internet protocol (TCP/IP) suite with Network File System and Session Message Block protocol services on all platforms. For more detailed information regarding ITS information services or network technology, please contact Darren L. Smith, Network Manager at (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- to 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 Radio Propagation 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 capability up to 96 GHz. Impulse response measurement capability at 30 GHz has been enhanced with the addition of a fully digital wideband recording system.

During the past year ITS increased its channel measurement capability with the addition of a VME computer-based system. This system will enable real-time processing of the channel data using onboard digital signal processing as well as increased data throughput. This increased capability will allow continuous recordings of the mobile radio channel to be made. This data can then be used to simulate and model radio systems using a recording of the radio channel. The system will also be used for an advanced antenna test facility being constructed on the Boulder, Colorado campus. This system will employ an 8-channel digital system for evaluating signal-processing algorithms for phased array antennas.

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 designed, built, and currently 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's), 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, industrial, scientific, and medical devices, broadcast signals, and special-purpose transmitter systems can be measured. For a complete description of the RSMS, see Appendix A of NTIA Report 97-334 (see ITS Publications in FY 1997, p. 89).

Table Mountain Radio Quiet Zone

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

Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provide the latest engineering models and research data developed by ITS to industry and other Government agencies. TA Services is interactive and is becoming Web-based. It is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 3-arc-seconds (90 m) resolution for much of the world and 5-min resolution data for the entire world; the 1990 census data; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (arcinfo). Other Government databases and reports are available through a bulletin board service available to all users of TA Services as they are developed. TA Services has developed models that predict communication system coverage, and interference for many broadcast applications. New models in the GIS environment for personal communications services (PCS) and local multipoint distribution services (LMDS) have been developed; (see Telecommunications Analysis Services, p. 40). The following is a brief description of some programs available through TA Services.

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

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

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

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

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

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

SHADOW - Plots the radio line-of-sight (LOS) regions around a specified location in the United States using digitized topographic data. It shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.

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

CSPM - Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the Figure on p. 87. Plotted outputs can either be faxed directly to the user or plotted in brilliant colors on clear plastic to a specified scale for overlaying on geopolitical maps. This is the most detailed of the signal calculation programs available and uses ITS' 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.

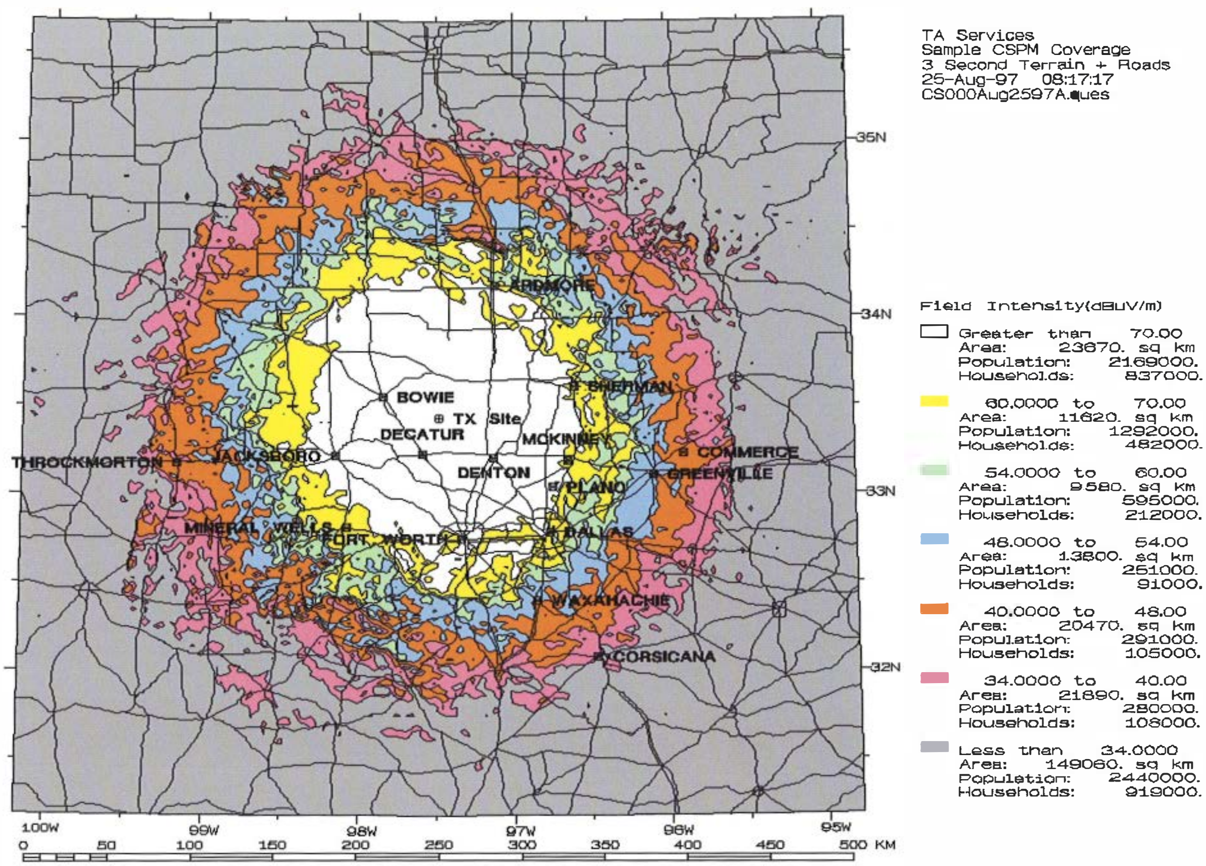
Video Quality Laboratory

The ITS Video Quality Laboratory contains objective and subjective measurement facilities that are used to develop and test automated techniques for assessing the quality of video and image data. The video quality studies conducted in this laboratory support national and international standardization and associated Government and industry technology assessment needs. The objective measurement facilities include (1) several high-performance workstations that are used for prototyping and testing the video and image parameters; (2) an ensemble of switcher-connected broadcast quality cameras, video recorders, video monitors, video capture and display equipment, video signal generators, and video coders/decoders (codecs); (3) an 80-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. The objective quality measurement software, written in C++, can perform pixel-accurate and field-accurate processing of sampled input and output video streams in accordance with ANSI T1.801.03-1996 (*Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment*). The subjective measurement facilities include two sound-proof audio-visual testing rooms and an ITU-R Recommendation BT.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 are 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 the end-to-end quality of 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.

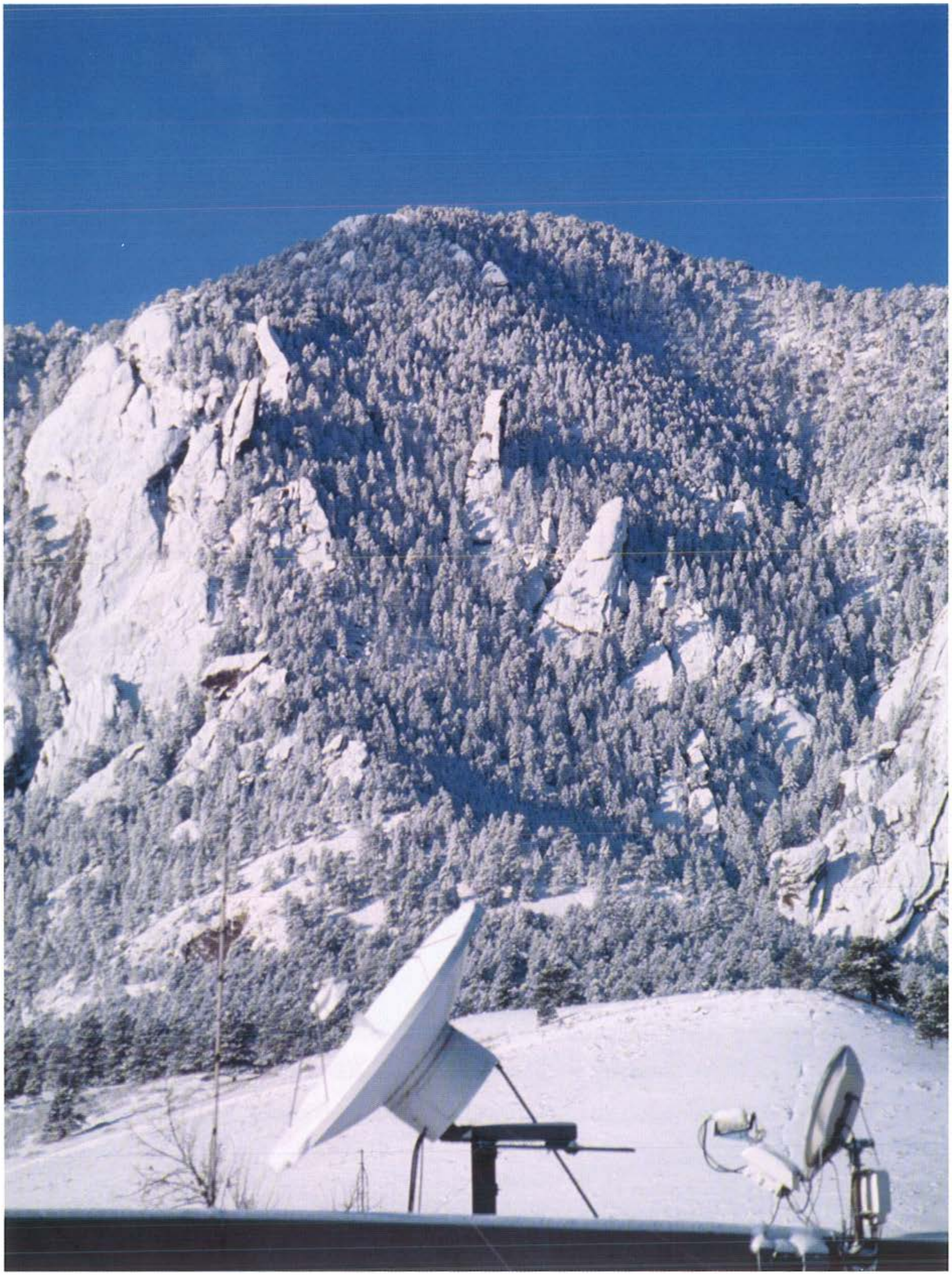
Wireless Link Simulation Laboratory

The Wireless Link Simulation 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 and spectrum requirements via simulation. Typically, predicted speech and image quality are determined as a function of signal-to-noise ratio, carrier-to-interference ratio, and bit error ratio for a selected radio system and channel. Real-time link bit error generator models are available for each simulation used to study the effects of the link conditions on various sources and may also be employed as a link model in wireless network simulation. These capabilities are useful in determining predicted performance of proposed wireless systems and standards and are used to determine design and deployment specifications for these systems.

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



Example of a transmitter coverage using CSPM (see Telecommunications Analysis Services, pp. 40 and 86).



The C/Ku band antenna (left) and Advanced Communications Satellite Technology antenna (right) are used for performance testing of satellite systems and the voice, video, and data services they transport (photograph by D.J. Atkinson).

ITS Projects in FY 1997

American Automobile 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 (303) 497-3411
e-mail sdavidson@its.bldrdoc.gov

Wireless Interoperability of Asynchronous Transfer Mode - Investigate current domestic and international standardization activities relative to wireless asynchronous transfer mode applications, and develop a structured plan for satisfying their 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 - 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 the intelligent transportation systems. Perform measurements for an electromagnetic compatibility analysis which will determine the levels of radio frequency radiation that will be coupled from an Earth station operating in the 5875- to 5925-MHz band to a location that would be typical of a highway environment. Perform an EMC analysis for dedicated short-range communications systems in the 5850- to 5925-MHz band.
Project Leaders: Robert J. Matheson (303) 497-3293, Nicholas DeMinco (303) 497-3660, Frank H. Sanders (303) 497-5727, and Roger Dalke (303) 497-3109
e-mail matheson@its.bldrdoc.gov, ndeminco@ its.bldrdoc.gov, fsanders@ its.bldrdoc.gov, and rdalke@its.bldrdoc.gov

Implementation of a Nationwide Global Positioning System Service - Evaluate the performance of a Ground Wave Emergency Network transmitter site and provide continued support for the implementation of a nationwide DGPS service.
Project Leader: John J. Lemmon 9303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Federal Railroad Administration

Telecommunications Study - Review and comment on the railroad's next generation telecommunications system design and demonstration projects to be used on positive control systems and advise the Federal Railroad Administration on telecommunication issues.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail eldon@its.bldrdoc.gov

Hewlett-Packard Company

Local Multipoint Distribution Service Model Development - Develop computer models to predict excess path loss for the local multipoint distribution system signal.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Industrial Technology, Inc.

Calibration and Verification Listening Test - Conduct a subjective test that will result in data that will be used to calibrate and verify the operation of a cellular telephone test instrument that is currently under development.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail sv@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

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

Development of the *Multimedia Performance 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

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) 497-3307
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

***Multimedia Performance Handbook:* Desktop Video Teleconferencing Testing** -Produce preliminary performance information concerning a typical desktop video teleconferencing system. Produce content for the *Multimedia Performance Handbook* and contribute to national and international standards bodies.
Project Leader: Coleen T. Jones (303) 497-3764
cjones@its.bldrdoc.gov

Operation and Maintenance Engineering Services - Provide technical support to NCS on performance and interoperation of Government telecommunication assets for National Security or Emergency Preparedness telecommunications purposes.
Project Leaders: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@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 - Provide technical support to the research and development aspects of performance and interoperation of Government telecommunication assets for National Security or Emergency Preparedness telecommunication purposes.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Strategic Architecture and Standards Support - Develop a strategic architecture for NCS National Security or Emergency Preparedness telecommunications; develop national and international wireless communication standards.
Project Leader: Richard E. Skerjanec (303) 497-3157
e-mail rskerjanec@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

Perception Noise Models for Advanced Television Systems - Collect subjective data to be used in the development of objective video quality models for measuring the perceptual effects of noise in advanced television systems.
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

National Oceanic and Atmospheric Administration

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

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

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

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 for the Global Information Infrastructure - Investigate the possibility of applying ITS- developed quality of service measurement technology to the evolving NII and GII, especially their Internet aspects.
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 - Participate in technical working groups to define the basic architectural needs and contribute to the technical architecture report for the Modular Multifunction Information Transfer System.
Project Leader: Richard E. Skerjanec (303) 497-3157
e-mail rskerjanec@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: Robert J. Achatz (303) 497-3498
e-mail rachatz@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-ISDN's). 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-ISDN's.
Project Leader: William A. Kissick (303) 497-7410
e-mail billk@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

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

Spectrum Utilization 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

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

U.S. Air Force

Layered Medium Investigation - Investigate transmission and reflection coefficients for a variety of soils, at the frequencies of interest for ground penetration radar systems.
Project Leader: Christopher L. Holloway (303) 497-6184
e-mail cholloway@its.bldrdoc.gov

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

Wideband HF Simulator Enhancements - Make enhancements to the WBHF simulator and use the WBHF simulator evaluate a WBHF modem.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

U.S. Army

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

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. Navy

FM Trunked Radio Simulation and Performance Prediction - Assist in benchmarking the current shipboard mobile FM-VHF trunked radio system performance. This performance prediction can be used to predict future performance of potential digital PCS candidate systems.
Project Leader: Edmund A. Quincy (303) 497-5471
e-mail equincy@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: Jeffrey A. Wepman (410) 415-5541
e-mail jwepman@its.bldrdoc.gov

This antenna at the ITS facility in Boulder, Colorado is used for development and testing of radio signal measurement equipment (photograph by D.J. Atkinson).

ITS Publications in FY 1997

NTIA Publications

R.A. Dalke, G.A. Hufford, and R.L. Ketchum, "A digital simulation model for local multipoint and multichannel multipoint distribution services," NTIA Report 97-340, Jul. 1997.

The Institute for Telecommunication Sciences has developed a computer simulation model that can be used to predict coverage and quality of service for proposed terrestrial communication systems that broadcast digital television such as local multipoint distribution services and multichannel multipoint distribution services. The model includes a variety of digital modulation schemes that have been proposed for these services. The model also contains a nonlinear amplifier that allows the user to evaluate the effects of intermodulation distortion on performance. In addition to a simple additive white Gaussian noise channel, three different propagation channels are included: a simple two-ray channel; and two more complex channels based on measurements of broadband signals in various geographic environments. A description of the simulation model as well as examples of applications are given in this report.

R.A. Dalke, R.J. Achatz, C.L. Holloway, G.A. Hufford, and E.A. Quincy, "Link analysis for the LRPT digital weather satellite system," NTIA Report 97-341, Sep. 1997.

The National Oceanic and Atmospheric Administration, the European Space Agency, and the European Organization for the Exploitation of Meteorological Satellites are designing a weather satellite system that will broadcast digital weather images at VHF. As a part of that effort, the Institute for Telecommunication Sciences has analyzed the VHF digital communications link. The results of the link analysis are described in this report. This analysis is based on published literature and models that describe propagation effects such as ionospheric scintillation and man-made noise, and are applicable to VHF digital communications. The analysis includes the estimation of the required link margins for coded binary and quaternary phase-shift modulation methods.

R.O. DeBolt and N. DeMinco, "FM Subcarrier corridor assessment for the intelligent transportation system," NTIA Report 97-335, Jan. 1997.

This report documents the assessment of FM subcarrier performance for Intelligent Transportation Systems (ITS) applications in three areas of interest in the United States. These areas are: 1) The I-95 corridor from Richmond, Virginia to Portland, Maine; 2) The Midwest corridor from Gary, Indiana to Chicago, Illinois and Milwaukee, Wisconsin along interstates I-80, I-90, and I-94; and 3) The Atlanta, Georgia metropolitan area. This study indicates that subcarrier systems on carefully chosen FM stations can provide good performance for ITS applications.

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

An interference model applicable to wireless technologies is presented in this report. Specifically, a generic methodology for cellular system self-interference modeling was developed, then applied to two proposed personal communications services (PCS) technologies: the Global System for Mobile-based PCS 1900, and IS-95-based code division multiple access. Resulting system-specific models are discussed in detail, and are used to produce output noise and interference waveforms suitable for implementation in a real-time hardware channel simulator, or as a component of a higher-level software simulation. Example outputs are given for simulations of both technologies, with corresponding statistical analyses of the noise and interference waveform properties. Models described in this report are particularly well-suited for independent PCS system evaluation by other Federal agencies, system manufacturers, and service providers.

J.R. Hoffman, J.J. Lemmon, and R.L. Ketchum, "Field strength measurements of DGPF and FAA beacons in the 285- to 325-kHz band," NTIA Report 97-337, Jun. 1997.

Signal strength measurements in the 285- to 325-kHz band were conducted on eight U.S. Coast Guard differential global positioning system beacons along the Gulf and West Coast, and on a Federal Aviation Administration beacon in Bennett, Colorado. Data were acquired continually en route between sites and tagged with geographical position. Field strength of each individual signal was plotted against distance from the transmitter. Cumulative distributions and histograms of deviation from the least squares fit were also plotted. Results of the measurements were used as model inputs and to compare results to model predictions.

F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at Los Angeles, California," NTIA Report 97-336, May 1997.

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA funds the Institute for Telecommunication Sciences Radio Spectrum Measurement System to collect data for spectrum utilization assessments. This report details such a data collection effort spanning all of the spectrum from 108 MHz to 19.7 GHz in the metropolitan area of Los Angeles, California during March, April, and May 1995.

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

The National Telecommunications and Information Administration (NTIA) is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement System to collect data for spectrum utilization assessments. This report details such a data collection effort spanning all of the spectrum from 108 MHz to 19.7 GHz in the metropolitan area of San Diego, California during February and March of 1995.

Outside Publications

R.J. Achatz, "Modeling and simulation of a OFDM radio link," In *Proc. 1997 Wireless Communications Conf.*, Boulder, CO, Aug. 1997, pp. 234-239.

This paper describes how a fixed orthogonal frequency division multiplexing (OFDM) radio link operating in a frequency-selective channel has been modeled in a software simulation environment. This model will all communications engineers to optimize OFDM radio link parameters. The following model parameters are adjustable: 1) number of bits per symbol; 2) number of symbols per OFDM block; 3) number of guard samples; 4) number of virtual carriers; 5) square root raised cosine excess bandwidth; 6) multipath amplitude, phase, and delay; 7) frequency shift; and 8) amplifier back-off. Example results showing OFDM radio link performance in a two-ray multipath channel are discussed.

C.J. Behm, "A narrowband high frequency channel simulator with delay spread," In *Proc. IEE HF Radio Systems and Techniques Conf.*, Jul. 1997, pp. 388-391.

No abstract available.

R.K. Chambliss, "Automatic measurement of RF spectrum from an operating radar," In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

Using LabVIEW and GPIB control, an off the shelf spectrum analyzer is used to measure radar emission spectrum without interrupting service. Computer control provides a intuitive interface while increasing the reliability and accuracy of measurements by controlling the spectrum analyzer, tracking RF pre-selector, and front-end attenuation.

R.A. Dalke, R.J. Achatz, Y. Lo, P.B. Papazian, and G.A. Hufford, "Measurement and analysis of man-made noise in VHF and UHF bands," In *Proc. 1997 Wireless Communications Conf.*, Boulder, CO, Aug. 1997, pp. 229-231.

Recently, the Institute for Telecommunication Sciences measured man-made noise in portions of the VHF and UHF bands. This paper provides a brief overview of the measurement and analysis methods used and examples of the results. The VHF measurements were made as part of a link analysis for the broadcast of digital satellite weather images at 137 MHz. The motivation for these measurements was that published man-made noise statistics (e.g., [2]) are probably outdated because they are based on noise measurements made over two decades ago. Since that time, technological advances have changed man-made noise emissions. For example, automotive emissions have been reduced, while emissions from other sources such as unregulated electronic devices (e.g., computers and microwave ovens) and other electrical equipment such as electric motors have probably increased significantly. In addition to the VHF measurement results, we present an example of measured noise statistics at 2460 MHz. At this frequency, dominant noise sources are thought to be microwave ovens. The data we obtained show that there are significant changes in the character of man-made noise which should be considered in the design and implementation of radio systems. Also, additional measurements are necessary to characterize adequately VHF and UHF man-made noise in high technology environments such as modern urban and suburban areas.

S. Davidson, " Using LabVIEW to save a complete measurement," In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

In developing a file system to save measurement data, the questions go beyond what type of file to save (e.g., binary, ASCII, or datalog.) The file system is an integral part of the system's ability to analyze, certify, and rerun the measurement. You also need to ask: What am I going to do with the data? Do I need to display or analyze the file data at a later time? Do I need to duplicate the test exactly or simply repeat it? Do I need to convert the data to other formats? How do I add testing and analysis comments? How do I design for efficiency and maintain flexibility? Besides the measurement data, what other data or information needs to be saved? How can other systems read my data? This paper presents my insight and solutions to these questions.

N. DeMinco, C.L. Holloway, "Propagation modeling for ITS applications in the roadway environment," *ITS Journal*, Vol. 3, No. 4, pp. 287-331, 1997.

It is expected that the Intelligent Transportation Systems (ITS) of the future will involve communication between vehicles and the roadside. In designing these communication systems it is imperative that one has a sound and a detailed understanding of radio-wave propagation in both short-distance roadside and complicated urban environments. In this paper we discuss the type of propagation models that are needed for ITS designers to predict system performance. This paper has approached this problem by examining the radio-wave propagation in the roadway environment over the range of distances and at frequencies that will have the potential to meet the needs of ITS. The requirements of the individual functions of ITS were taken into consideration in addition to what portions of the radio frequency spectrum will be available.

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, MA, 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, "Commerce agencies participate in satellite videoed teletalk," *Commerce People*, Sep./Oct. 1996, p. 17.

No abstract available.

J.A. Hoffmeyer and D. Bodson, "Use of advanced HF physical, link, and network simulators in the standards development process," in *Proc. IEE Colloquium on Frequency Selection and Management Techniques for HF Communications*, Feb. 1996,

No abstract available.

J.A. Hoffmeyer, M. Cummings, D. Bodson, S. Blust, R. Skerjanec, "Standards development for open architecture wireless systems," In *Proc. 9th Internat. Conf. Wireless Communications*, Vol. 2, Calgary, Alberta Canada, Jul. 1997, pp. 644-665.

In the United States and elsewhere in the world, a plethora of wireless standards and technologies have been developed to provide a wide spectrum of wireless products and services. These wireless technologies are applicable to commercial wireless (e.g., personal communications services (PCS) and cellular services), and Government applications (defense and Civil). Clearly, there are advantages to having choices among the diverse systems and services. However, there is also a negative aspect, the lack of interoperability between the various technologies employed in the systems and services.

In order to address these interoperability and compatibility issues, a new forum has been created, the Modular, Multifunction Information Transfer System (MMITS) Forum. This forum is an organization whose objective is to facilitate the identification and development of an open system framework architecture that promotes the use of open standards and interfaces for a family of worldwide, modular, multifunction, communications systems.

This paper first describes the issues and requirements as seen from the perspectives of several classes of users of wireless systems and services. The mission, objectives, and goals of the MMITS Forum are then described with respect to these issues and requirements. Initial technical results in the form of high level functional architectures and specifications are discussed. The paper concludes with an overview of the work plan of the MMITS Forum.

C.L. Holloway, M.G. Cotton, P. McKenna, " A simplified model for calculating the decay rate of the impulse response for an indoor propagation channel," In *Proc. 1997 Wireless Communications Conf.*, Boulder, CO, Aug. 1997.

In this paper we introduce a simplified model for calculating the decay rate of the power delay profile (or impulse response) for indoor wireless radio propagation channels. Results from this model are compared to results obtained from measured impulse response data. We also show comparisons to a finite-difference time-domain (FDTD) model of the power delay profile.

C.L. Holloway, R.R. Delyser, R.F. German, P. McKenna, and M. Kanda, "Comparison of electromagnetic absorber used in anechoic and semi-anechoic chambers for emissions and immunity testing of digital devices," *IEEE Trans. Electromagn. Compat.*, Vol. 39, No. 1, pp. 33-47, Feb. 1997.

The absorber used in anechoic and semi-anechoic chambers employed for emissions and immunity testing of digital devices is examined. Using reflectivities obtained by the method of homogenization, the advantages and disadvantages of urethane pyramids, twisted-pyramids, wedges, as well as ferrite tiles, ferrite grids, and "hybrid" combinations of urethanes and ferrites are determined. General reflectivity guidelines are also presented for comparing absorber used for the electromagnetic compatibility (EMC) testing of digital devices from 30-1000 MHz.

C.L. Holloway, R.R. Delyser, and E.F. Kuester, "Field penetration corrections for the characteristic impedance of planar structures," In *Proc. IEEE 1997 Internat. Symp. Ant. Propag.,* Montreal, Canada, Jul. 1997.

In previous work, it was demonstrated that with an asymptotic technique, the fields inside a conducting strip can be accurately formulated. In this paper, we present closed-form corrections (due to field penetration) for the characteristic impedances of planar structures based on this accurate representation of the fields inside the conducting strip.

C.L. Holloway, R.J. Doviak, and S.A. Cohn, "Cross correlations of fields scattered by horizontally anisotropic refractive index irregularities," *Radio Science*, Vol. 32, No. 5, pp. 1911-1920, 1997

In this paper we present an analytic expression for the cross-correlation function of signals received by spaced antennas for scattering from an atmosphere with horizontally and/or vertically anisotropic scattering irregularities. We demonstrate that our expression is equivalent to the one Briggs obtained through heuristic arguments; we also show how the parameters in Briggs' expression are related to parameters that describe 1) the orientation, shape, and size of the scattering irregularities; 2) the turbulent flow; and 3) the radar. Finally, we introduce an alternative approach (different from Briggs' Full Correlation Analysis, FCA) for estimating horizontal winds and turbulence.

C.L. Holloway, R.J. Doviak, S.A. Cohn, R.J. Lataitis, and J.S. Baelen, "Cross correlations and cross spectra for spaced antenna wind profilers 2. Algorithms to estimate wind and turbulence," *Radio Science*, Vol. 32, No. 3, pp. 967-982, May-Jun. 1997.

In part 1 of this paper we developed analytic relationships linking the cross correlation and cross spectrum of the echoes from a spaced antenna system to the properties of a horizontally isotropic scattering medium (e.g., clear-air refractive index irregularities) and the background flow (e.g., laminar or isotropic turbulent flow). Using these analytic expressions, in the present paper, part 2, we construct algorithms (for both the time domain and frequency domain) for extracting unbiased wind and turbulence estimates. We derive a condition under which one can ignore turbulence when computing winds from the time delay to the peak of the cross-correlation functions. We show profiles of the horizontal wind and turbulence based on these algorithms using data from the unique 33-cm wavelength spaced antenna wind profiler developed by the National Center for Atmospheric Research.

C.L. Holloway and G. Hufford, "Internal inductance and conductor loss associated with the ground plane of a microstrip line," *IEEE Trans. Electromagn. Compat.*, Vol. 39, No. 2, pp. 73-78, May 1997.

In previous work a closed-form expression for the current density on the ground plane of a microstrip line was presented. In this paper, we show how this formula for the current density is used to derive an expression for the internal inductance associated with the ground plane. Results are presented for different geometries that illustrate when the internal inductance of the ground becomes comparable to the external inductance of the microstrip line. We also illustrate that the integrals needed for the internal inductance calculation can be used to develop an expression for the conductor loss associated with the ground.

C.L. Holloway and M. Johansson, "Effective electromagnetic material properties for alternating wedges and hollow pyramidal absorbers," In *Proc. IEEE 1997 Internat. Symp. Ant. Propag.* Montreal, Canada, Jul. 1997.

In this paper, we present expressions for the effective material properties of electromagnetic absorbers constructed in the shapes of alternating wedges and hollow pyramids. These expressions can be used to efficiently calculate the reflection coefficient of these two absorbing structures.

C.L. Holloway, P. McKenna, and D.A. Steffen, "Finite-difference time-domain modeling for field predictions inside rooms, In *Proc. IEEE 1997 Internat. Symp. Electromagn. Compat.*, Austin, TX, Aug. 1997.

In this paper we present a three-dimensional model based on the finite-difference time-domain (FDTD) technique that is used to analyze and design absorber lined EMC/EMI chambers. The FDTD is implemented in a manner such that the frequency-dependent material properties are taken into account. Comparisons of measured and predicted normalized site-attenuation are presented.

C.L. Holloway, P.L. Perini, R.R. Delyser, and K.C. Allen, "Analysis of composite walls and their effects on short path propagation modeling," *IEEE Trans. Veh. Technol.,* Vol. 46, No. 2, pp. 730-738, 1997.

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.E. Kub "Using LabVIEW to characterize the air traffic control radar beacon system," In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

> An algorithm is described that characterizes the Air Traffic Control Radar Beacon System (ATCRBS) antenna pattern. The computer-automated algorithm controls standard laboratory instruments and captures emissions from the ATCRBS to extract and plot two antenna pattern signals simultaneously. This system uses National Instruments (NI) LabVIEW software, a NI 488.2 General Purpose Interface Bus (GPIB) control board, and standard equipment (e.g., oscilloscope, spectrum analyzer). Extensive digital signal processing was used to adjust the instruments in real time for optimum results. This new algorithm eliminates the disruption of air traffic service caused by currently used ATCRBS measurement techniques and replaces alternative methods that cost over a million dollars in hardware.

J.F. Mastrangelo, J.J. Lemmon, L.E. Vogler, J.A. Hoffmeyer, L.E. Pratt, and C.J. Behm, " A new wideband high frequency channel simulation system," *IEEE Trans. Comm.*, Vol. 45, No. 1, pp. 26-34, Jan. 1997.

> This paper provides a technical overview of a high frequency (HF) channel simulation system that is applicable to either narrowband or wideband HF channels. Although narrowband models of the HF channel have existed for many years, they are applicable only to a limited set of actual narrowband channel conditions. The need for an HF channel model that is valid for both narrow and wide bandwidths over a more extensive range of channel conditions motivated the research reported in this paper. Wideband propagation, noise, and interference models have been developed and implemented in a real-time digital simulator that utilized state-of-the-art signal processing hardware with a throughput in excess of 1 mega samples/s. The simulator architecture has the flexibility to permit tits application to future simulator designs as faster signal processing components become available. The current simulation system can be used for simulating radio channels other than HF because the propagation, noise, and interference models are implemented in software. This flexibility results in a very powerful test instrument.

P.B. Papazian, G.A. Hufford, and R.J. Achatz, "Study of the local multipoint distribution service radio channel," *IEEE Trans. Broadcast.*, Vol. 43, No. 2, Jun. 1997, pp. 174-184

> This paper summarizes radiowave propagation impairments for local multipoint distribution services (LMDS) and reports measurement data for small cells. Results include area coverage estimates over a range of basic transmission losses for 0.5-, 1.0- and 2.0- km suburban cells with foliated trees. Multipath, signal attenuation, depolarization, and cell to cell coverage also are discussed. Data indicates a high probability of non-line-of-sight paths due to trees which can cause signal attenuation and signal variability when wind is present. Signal variability was studied using k factors and compared to the Rician cumulative distribution function. Depolarization caused by vegetation and other signal scatterers was found to be an order of magnitude greater than rain-induced depolarization. A simple tapped delay line model is presented to describe multipath for three channel states.

P.B. Papazian and G.A. Hufford, "Time variability and depolarization of the local multipoint distribution service radio channel," In *Proc. 1997 Wireless Communications Conf.*, Boulder, CO, Aug. 1997, pp. 8-11.

> This paper summarizes 28.8-GHz radiowave propagation measurements made for the local multipoint distribution services (LMDS) radio channel. Time variability and depolarization of the LMDS channel in a suburban environment was analyzed and possible propagation mechanisms are discussed. The signal variability was measured using k-factors and was compared to the Nakagami-Rice cumulative distribution function. Depolarization caused by vegetation and other signal scatterers was found to be an order of magnitude greater than rain-induced depolarization.

E.A. Quincy, R.B. Stafford, C.L. Holloway, M.G. Cotton, and A.S. Ali, "Distortion measures for wavelet compression of SAR images in ATR," In *Proc. 1997 IEEE Pacific Rim Conf. Communication, Computers and Signal Processing*, Vol. 1, Victoria, B.C., Canada, Aug. 1997, pp. 310-317.

> This research investigates and develops distortion measures for assessment of wavelet com-

pression effects on synthetic aperture radar (SAR) images. The end objective is to select those measures that relate most directly to automatic target recognition (ATR) performance. Windowed measures were developed that relate to ATR feature size. These were the most sensitive to distortion, and they provide an effective method for assessing tradeoff between compression and distortion.

B. Ramsey, The radio frequency monitoring system: A comprehensive RF emission measurement solutions," In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

A radio frequency (RF) measurement system was designed and implemented using LabVIEW and GPIB control software. The system performs fully automated and manually configured radio frequency spectrum and time-domain measurements using commercial test equipment. The system performs automatic RF calibration and contains an independent file system that records system parameters with the measured data.

T.J. Riley, "A comparison of HF radio digital protocols," In *Proc. IEE HF Radio Systems and Techniques Conf.*, Jul. 1997, pp. 206-210.

No abstract available.

T. Riley, D. Bodson, S. Rieman and T. Sparkman, "A comparison of HF digital protocols," *QST*, Vol. 80, No. 7, pp. 32-39, Jul. 1996. Republished in *Packet: Speed, More Speed and Applications*, American Radio Relay League: Newington, CT, 2-7 through 2-11.

Many over-the-air tests have been conducted on various modem/protocol combinations designed specifically for high-frequency (HF) radio links. Due to the varying conditions of the atmospheric propagation path, the over-the-air performances of the modem/protocol combinations cannot be compared with any reasonable degree of justification. The Institute for Telecommunication Sciences (ITS) has developed an automated test bed to test modems and their protocols in a controlled laboratory setting. Using this test bed, ITS subjected a number of protocols to a repeatable set of simulated propagation paths over a wide range of signal-to-noise ratios (SNR's). Five protocols (AMTOR, CLOVER, G-TOR, PACTOR and PACTOR2) were tested. Two narrowband, Watterson model HF propagation channel simulators created the ionospheric propagation conditions for each test. Two degraded conditions were used: CCIR Good and CCIR Poor. Data file transfers were performed at various SNR's for each of the five protocols in their automatic-repeat-request mode. When a file was transferred error-free, the test was considered successful. The throughput, a measure of the data transfer rate, was measured for each protocol under both simulated ionospheric conditions.

T.G. Sparkman, "Radio frequency measurement system Calibration using LabVIEW" In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

When making radio frequency (RF) measurements, the contributions introduced by the measurement system's own gains and losses, which change across the frequency spectrum, must be removed from the measured data. This paper describes a method of determining the measurement system gain so that it can be removed from the raw RF signal data to obtain final data.

T.G. Sparkman, "Improving user interface design for technical software," In *Proc. NI Week Conf.*, Austin, TX, Aug. 1997.

Effective interface design is essential in a highly technical software environment, especially in cases where the user is presented with many controls and indicators. A clear and intuitive interface design leaves no doubt in the mind of the users as to the steps they need to perform to complete a given task. This paper presents strategies to improve user interfaces.

S.D. Voran, "Listener ratings of speech passbands," In *Proc. 1997 IEEE Workshop on Speech Coding for Telecommunications*, Pocono Manor, PA, Sep. 1997, pp. 81-82.

We describe a listening experiment that measures the perceived speech quality of 19 speech passbands using 8 talkers and 28 listeners. Results are compared with the traditional wideband and narrowband telephony passbands. Based on our findings we identify several passbands that show particular promise for those who wish to select new speech coding passbands that maximize perceived speech quality under bit-rate constraints.

S.D. Voran, "Estimation of perceived speech quality using measuring normalizing blocks," In *Proc. 1997 IEEE Workshop on Speech Coding for Telecommunications*, Pocono Manor, PA, Sep. 1997, pp. 83-84.

> We describe a new approach to the estimation of perceived speech quality. The approach uses a simple, but effective, perceptual transformation to emulate hearing and a hierarchy of Measuring Normalizing Blocks (MNB's) to emulate auditory judgment. The resulting estimates were correlated with the results of seven subjective listening tests. Together, these seven tests include 182, 4-kHz bandwidth speech codecs, transmission systems, and reference conditions, with bit-rates ranging from 2.4 to 64 kbps. When compared with six other estimators, the MNB approach offers significant improvements in many cases, particularly at lower bit-rates, and when bit errors or frame erasures are present.

S. Wolf, "Measuring end-to-end performance of digital video systems," *IEEE Trans. Broadcast.*, Vol. 43, No. 3, pp. 320-328, Sep. 1997.

> Significant research and development efforts by industry and government laboratories were brought to fruition in 1996 with the approval of American National Standard (ANSI) T1.801.03 entitled "American National Standard for Telecommunications - Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment." This standard provides a set of objective parameters that have consistently demonstrated high correlation levels with subjective evaluations of digital video impairments. The parameters are technology-independent and may be used to measure the performance of a wide range of digital video compression, storage, and transmission systems. This paper presents an overview of the ANSI T1.801.03 parameters and summarizes other relevant standards activities and contributions.

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Abbreviations/Acronyms

AAMA	American Automobile Manufacturers Association
ACI	adjacent channel interference
ACTS	Advanced Communications Technology Satellite
ALE	automatic link establishment
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials
ATC	air traffic control
ATM	asynchronous transfer mode
ATR	automatic target recognition
B-ISDN	broadband integrated services digital network
BER	bit error ratio
CAI	common air interface
CCIR	International Radio Consultative Committee
CDMA	code-division multiple access
CD	compact disk
CD-ROM	compact disk read-only memory
CDF	cumulative distributions functions
C/I	carrier-to-intermodulation ratio
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	compact radio spectrum measurement system
DEM	digital evaluation model
DGPS	differential global positioning system
DOD	Department of Defense
DOT	Department of Transportation
DQPSk	differential quadrature phase-shift keying
DSP	digital signal processing
DTV	digital television
EHF	extremely high frequency
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ETG	Encryption Task Group
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FM	frequency modulated
FRA	Federal Railroad Administration
FTR	Federal Telecommunications Recommendation
FTSC	Federal Telecommunications Standards Committee
FTSP	Federal Telecommunications Standards Program
FTTA	Federal Technology Transfer Act
GEO	geostationary earth orbit
GII	Global Information Infrastructure
GIS	geographic information systems
GPS	global positioning system
GWEN	Ground Wave Emergency Network
HDTV	high-definition television
HF	high frequency
HFRS	High Frequency Radio Subcommittee
HP	Hewlett-Packard Company
HRR	high-resolution radar
IEEE	Institute of Electrical and Electronics Engineers
IEP	integrated electronics package
IETF	Internet Engineering Task Force
IF	intermediate frequency
IP	Internet protocol
ISDN	integrated services digital network
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
KMF	key management facility
LAN	local area network
LMDS	local multipoint distribution service
LMR	land mobile radio
LMRS	Land Mobile Radio Subcommittee
LOS	line-of-sight
MMIC	microwave monolithic integrated circuits
MMITS	Modular Multifunction Information Transfer System
MOS	mean opinion score
MPEG	Motion Picture Expert's Group
MSK	minimum-shift keying
NANOG	North American Network Operators Group
NASA	National Aeronautics and Space Administration
NASTD	National Association of State Telecommunications Directors
NCS	National Communications System
NII	National Information Infrastructure
NIST	National Institute of Standards and Technology
NLOS	nonline-of-sight
NS/EP	National Security or Emergency Preparedness
NSA	National Security Agency
NTIA	National Telecommunications and Information Administration
OFDM	orthogonal frequency division multiplexing
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTAR	over-the-air-rekeying
PCS	personal communications services
PA	power amplifier
PACS	personal access communication system
PPS	precise positioning service
PSNR	peak signal-to-noise ratio
PSTN	public switched telecommunications network
QOS	quality of service
QPSK	quadrature phase-shift keying
RAL	radio access layer
RDBMS	relational database management system
RF	radio frequency
RFIMS	radio frequency interference monitoring system
RSEC	radar spectrum engineering criteria
RSMS	radio spectrum measurement system
RSS	received signal strength
SAR	synthetic aperture radar
SDH	synchronous digital hierarchy
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
TEK	traffic encryption keys
TIA	Telecommunications Industry Association
TTL	Telesis Technology Laboratories
USCG	U.S. Coast Guard
US WEST	US West Advanced Technologies, Inc.
VHF	very high frequency
WATM	wireless asynchronous transfer mode
WLAN	wireless local area network

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