Institute for Telecommunication Sciences

1995 Technical Progress Report

On the cover: *Green Mountain and Bear Peak provide a beautiful setting for the U.S. Department of Commerce's Boulder Laboratories in Boulder, Colorado (photograph by D. Atkinson).*

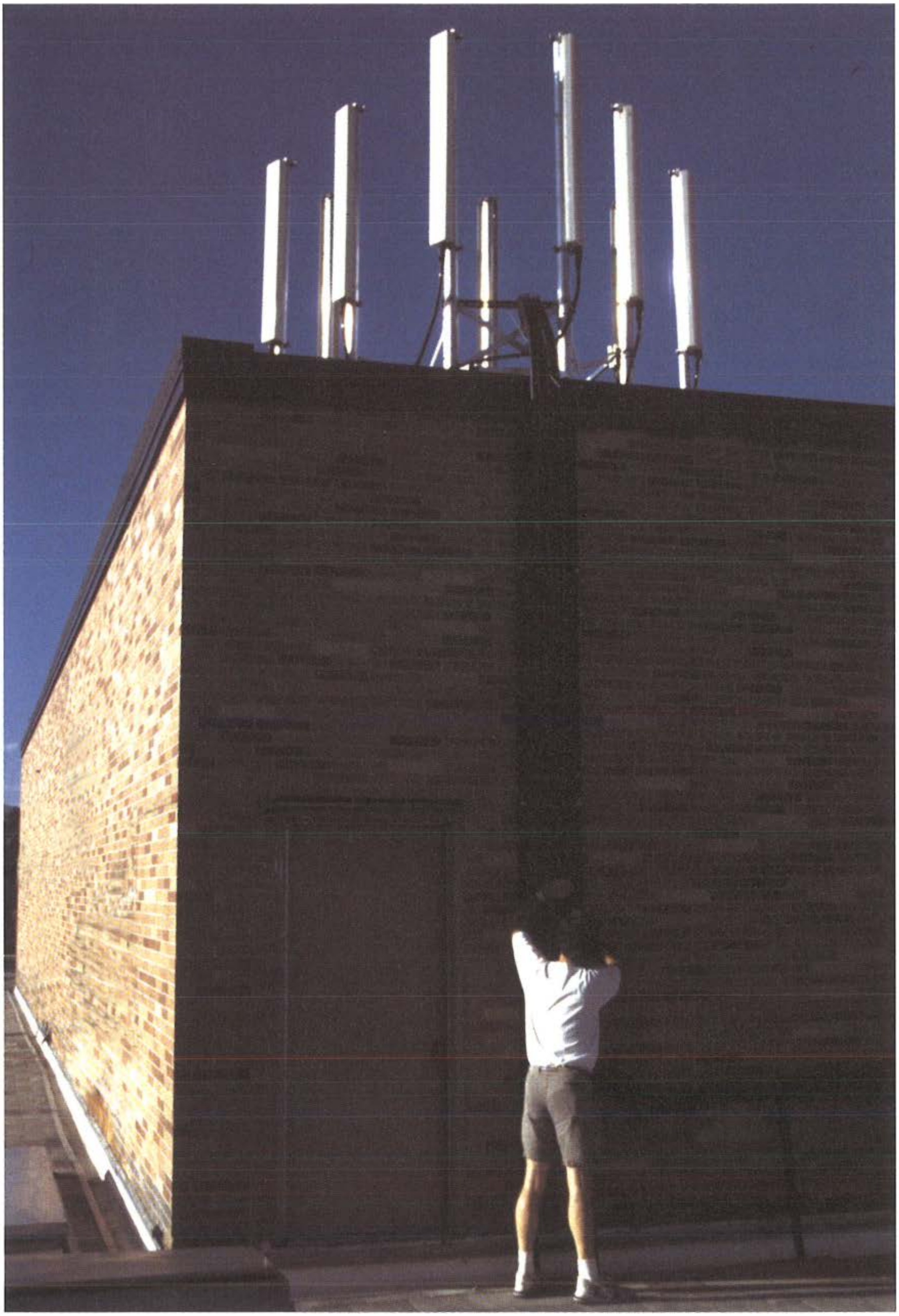
Institute for Telecommunication Sciences

1995 Technical Progress Report

U.S. Department of Commerce
Ronald H. Brown, 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



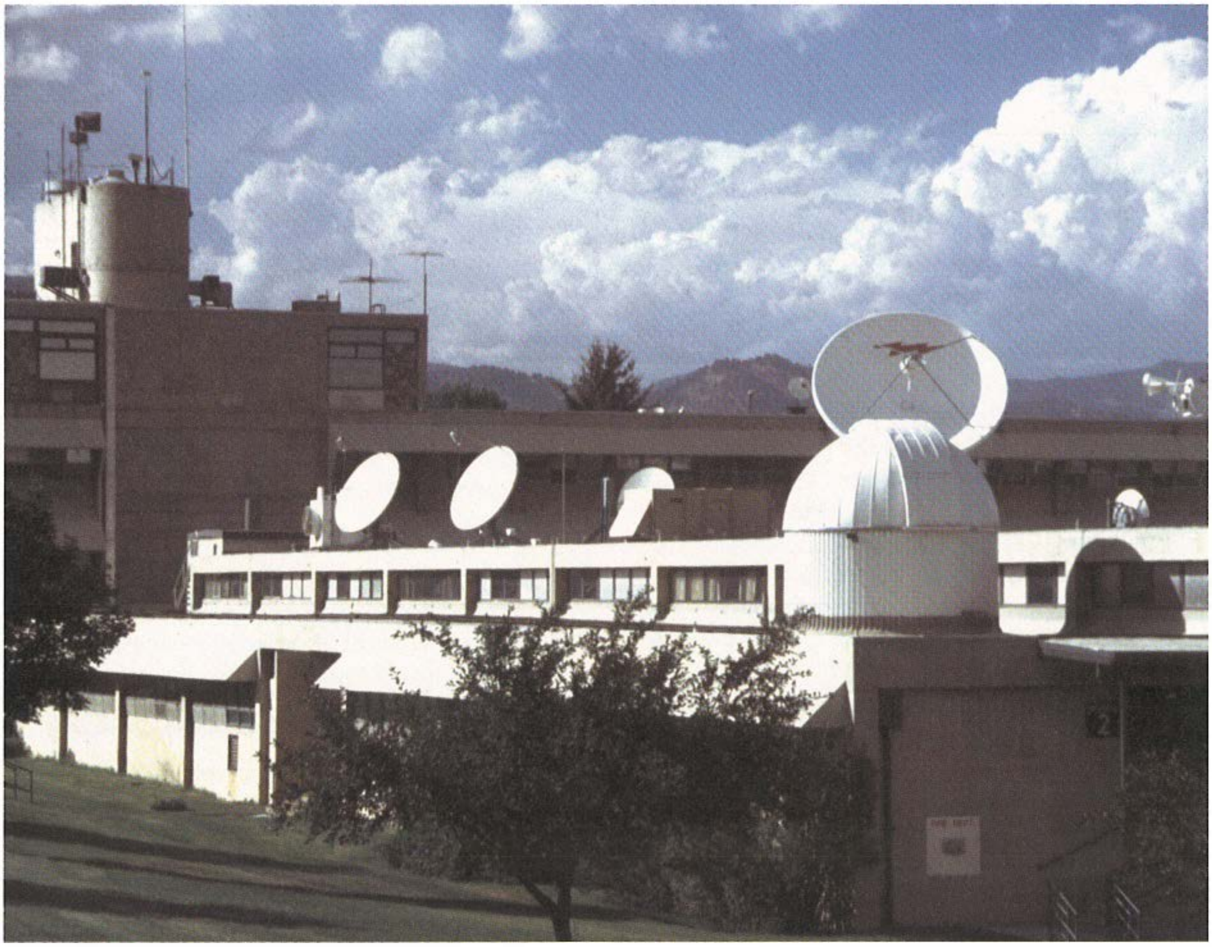
Prototype PCS antenna array deployed on a rooftop in conjunction with testing at ITS (photograph by F. Sanders).

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 telecommunication 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.



West view of ITS Boulder Laboratory in Boulder, Colorado (photograph by F. 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 approximately 100 permanent program staff. These employees bring substantial engineering and scientific backgrounds, skills, and experience to our technical programs. The majority of our employees (60%) are electronics engineers, while 6% are mathematicians, 2% are physicists, 3% are computer scientists, and 2% are computer programmers. ITS' support during the 1995 fiscal year consisted of $5.7 million of direct funding from the Department of Commerce and approximately $6.5 million for work sponsored by other Federal Government agencies and U.S. industry.

History

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

Activities

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

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

Benefits

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

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

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

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

Outputs

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

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

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

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

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

Organization

ITS is organized into two program divisions: Spectrum Research and Analysis, and Systems and Networks Research and Analysis. The Spectrum Division concentrates on analyses directed toward understanding radio wave behavior at various frequencies and determining methods to enhance spectrum use for predicting 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.

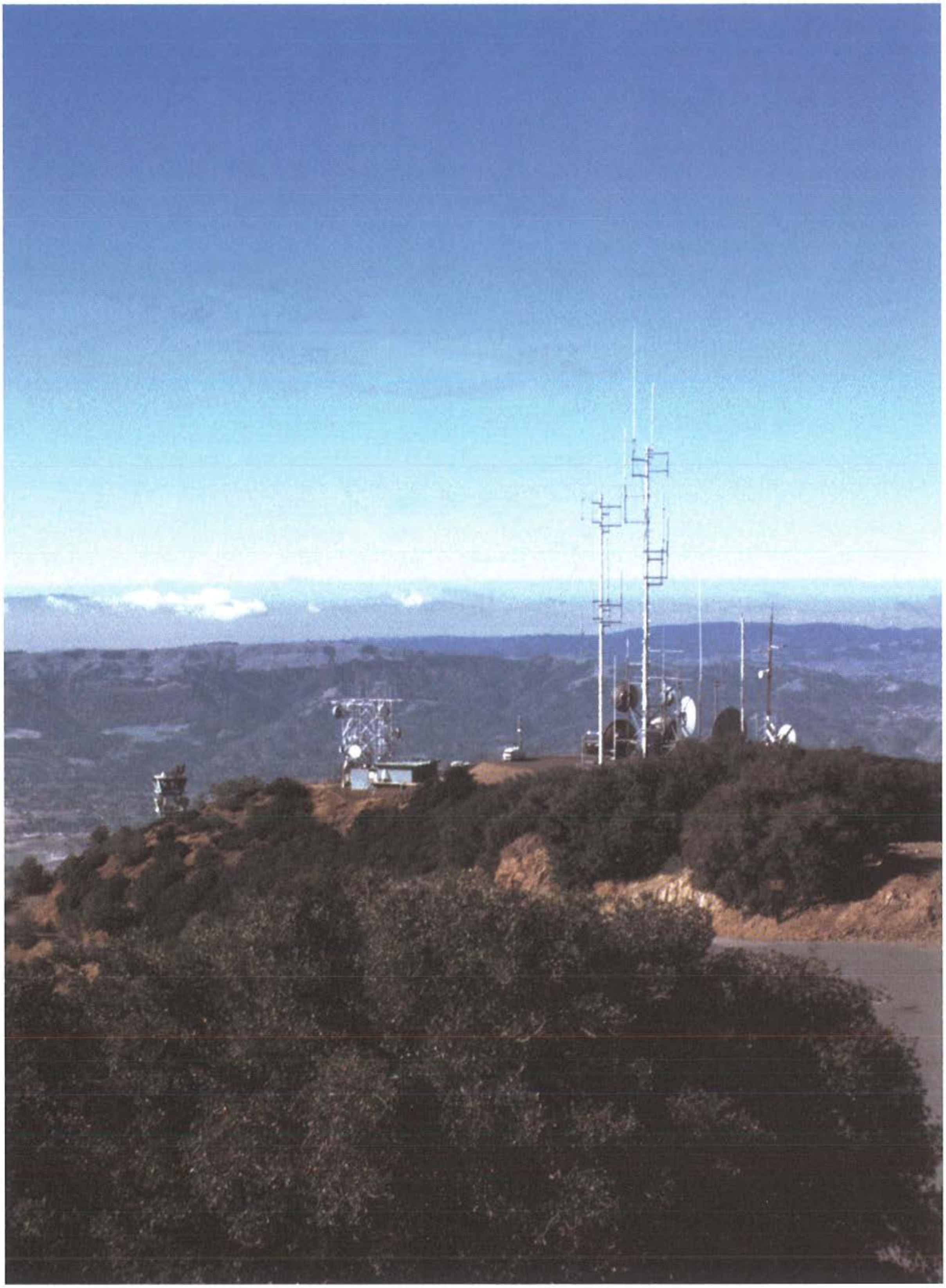
The ITS Executive Office manages administrative matters. The Executive Office also manages the Institute's budget and program planning functions and interacts with various administrative offices within other parts of the Department of Commerce to meet its payroll, procurement, personnel, facilities management,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

Sponsors

Activities at ITS 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 results 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 ITS' funding from other agencies. Other sponsors include the Department of Agriculture, the Department of Transportation, and the U.S. Information Agency.

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 this ensure the competitiveness of entrepreneurial ventures with larger national concerns.

Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that is not duplicated throughout many Federal agencies and industry. ITS provides scientific research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This progress report summarizes significant technical contributions made by ITS during fiscal year 1995 that have significance for both the public and private sector.



Radio spectrum measurement system at Mount Diablo, California making radar measurements in midst of broadcast, mobile radio, and microwave transmitters (photograph by R. Matheson).

Spectrum Planning and Assessment

NTIA is responsible for managing the radio spectrum allocated to the Federal Government. Part of NTIA's responsibility is to "... establish policies concerning spectrum assignment, allocation, and use, and provide the various departments and agencies with guidance to assure that their conduct of telecommunications activities is consistent with these policies." In support of these requirements, ITS conducts a variety of studies and field measurements directed toward ensuring efficient, effective, and equitable use of the radio spectrum. A primary objective of these analyses is to increase spectrum usefulness by developing ways to use presently congested portions of the spectrum more efficiently and to open up new portions of the spectrum for productive use.

In conjunction with these spectrum analyses, ITS supports NTIA's active role of developing and advocating the United States' position at various international spectrum allocation conferences. Decisions made at these conferences significantly affect the ways that the United States can use the radio frequency spectrum. U.S. positions at these conferences also help determine the ways that frequencies are used worldwide; this affects U.S. export market opportunities, as well as the compatibility and interoperability of global systems.

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

Areas of Emphasis:

ITU-R Activities

The Institute participates in the development of international rules on the use of the radio spectrum and standards for specific radio systems through active participation and chairmanships in the national and international working groups of the International Telecommunication Union-Radiocommunication Sector. Projects are funded by NTIA.

Domestic Spectrum Analysis

The Institute assists in the development of national policies on the radio spectrum through analyzing the current use of the radio spectrum, predicting future requirements for radio spectrum, and examining the expected application of innovative radio technologies. Projects are funded by the Department of Transportation (DOT) and NTIA.

Radio Spectrum Surveys

The Institute provides field measurements of radio spectrum use across a wide rage of frequencies, services, and geographic locations. This information is needed to interpret trends in spectrum crowding and to identify frequency bands that might be used for additional services. Projects are funded by the Department of Defense (DOD), DOT, and NTIA.

Spectral Assessment of Government Systems

The Institute provides technical measurements on specific radio systems needed to verify proper operation, identify and mitigate interference, and develop techniques for improving system capabilities. Projects are funded by DOD and NTIA.

ITU-R Activities

Outputs

- Input to technical standards development at radio conferences.
- U.S. representation in key ITU-R study groups.
- Coordination of U.S. positions on issues related to ITU-R Recommendations.

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

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

To meet the demand for international standards, the ITU-R has divided its work program into study groups that develop recommendations. As study groups meet infrequently (with some only meeting every 2 to 4 years), each study group is subdivided into working parties and task groups that provide a continuous forum for the development of recommendations on particular issues for the study group.

The ITU-R is comprised of eight study groups; the first two consider spectrum utilization and propagation issues and the latter study groups manage service-oriented issues (see the Table).

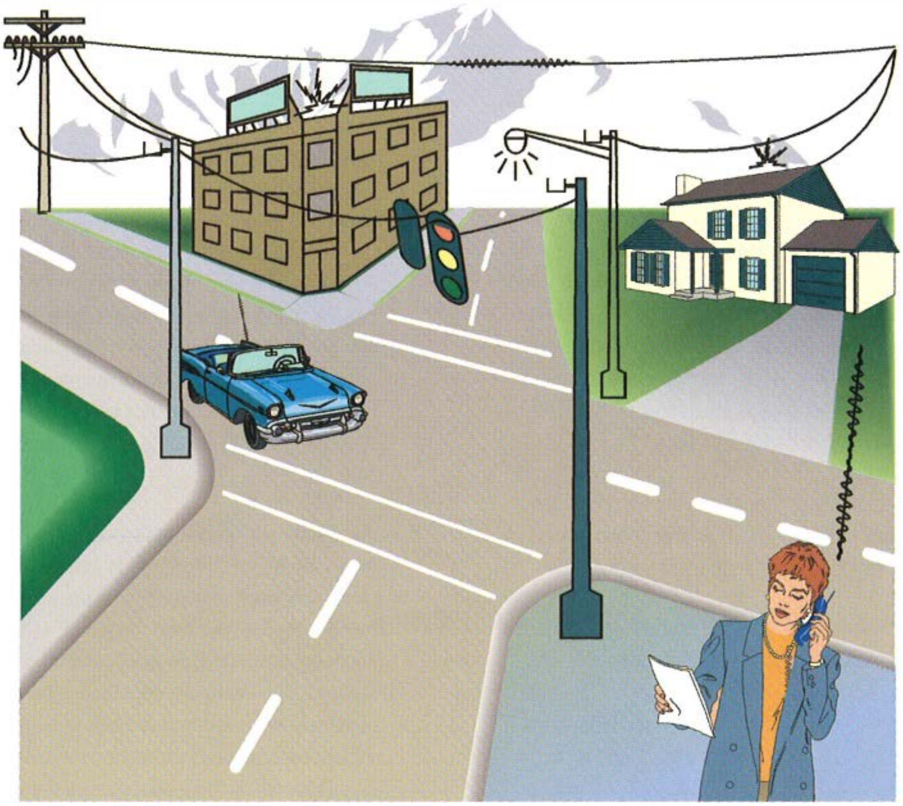
ITU Study Groups and Associated Areas of Concern

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

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

ITS is an active participant in both international and national committee work. One ITS staff member holds the office of international chairman of a working party and several ITS staff participate in the committee meetings of the international study group. 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. Institute personnel have supported the development of ITU-R recommendations for a global telecommunications system by advancing international mobile telecommunications 2000 (IMT-2000; formerly the future public land mobile telecommunication system). The goal of IMT-2000 is to provide mobile telecommunications anywhere and at anytime. An illustration of the implementation of IMT-2000 is shown in the Figure, where telecommunications services are being provided to pedestrians, to individuals within their homes and offices, and to individuals within their vehicles.

In FY 95, two ITS members of Study Group 1 (Spectrum Management) influenced issues on spectrum provisions for the emerging systems, criteria definition for sharing bands with other radio services, and frequency assignment methods. Two ITS members of Study Group 3 helped identify the appropriate radio propagation methods for short-path conditions, such as within buildings, in pedestrian malls, in residential neighborhoods, and on urban streets. This has lead to new models for radio propagation and signal coupling between offices within a building, between floors of a multistory building, and of signal penetration from outside to inside of buildings. Short-path models are emerging that are capable of predicting propagation loss as the signal is guided down city streets and as it propagates from a roof-top base station to a street-level mobile station located several buildings away. The new models are more precise in describing the specific site and environment than previous models have been. Another ITS staff member has been affiliated with Study Group 8 to define the system characteristics of the IMT-2000. A major focus of this effort has been to maximize the commonality between the various radio interfaces involved in order to simplify the task of building multimode mobile terminals covering more than one operating environment.



Typical upcoming shortpath communications links (graphic by A. Romero).

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Domestic Spectrum Analysis

Outputs

- NTIA report entitled "U.S. national spectrum requirements."
- Updated report on fixed service spectrum requirements.
- Studies and reports on federal mobile radio use.
- Studies and reports on mobile services for public safety.
- Liaison with statewide trunked system planning in Colorado.

The past few years have been exciting and tumultuous for spectrum management in the United States. This year, 235 MHz of spectrum were transferred from Federal control to commercial uses. In addition, an $8-billion auction of spectrum for personal communications services (PCS) was accomplished, solidly establishing marketplace economics as one tool for assigning frequencies.

ITS has continued to assist NTIA in technical studies, identifying and supporting possible changes in the way that the Federal Government manages spectrum. For several years NTIA has studied nationwide requirements for radio spectrum in the near future; results from this study were recently completed and widely distributed in a report entitled "U.S. national spectrum requirements." ITS' participation in this study included the sections on fixed radio services (mostly point-to-point microwave links). This study will be used as the basis for many future changes in U.S. frequency allocations.

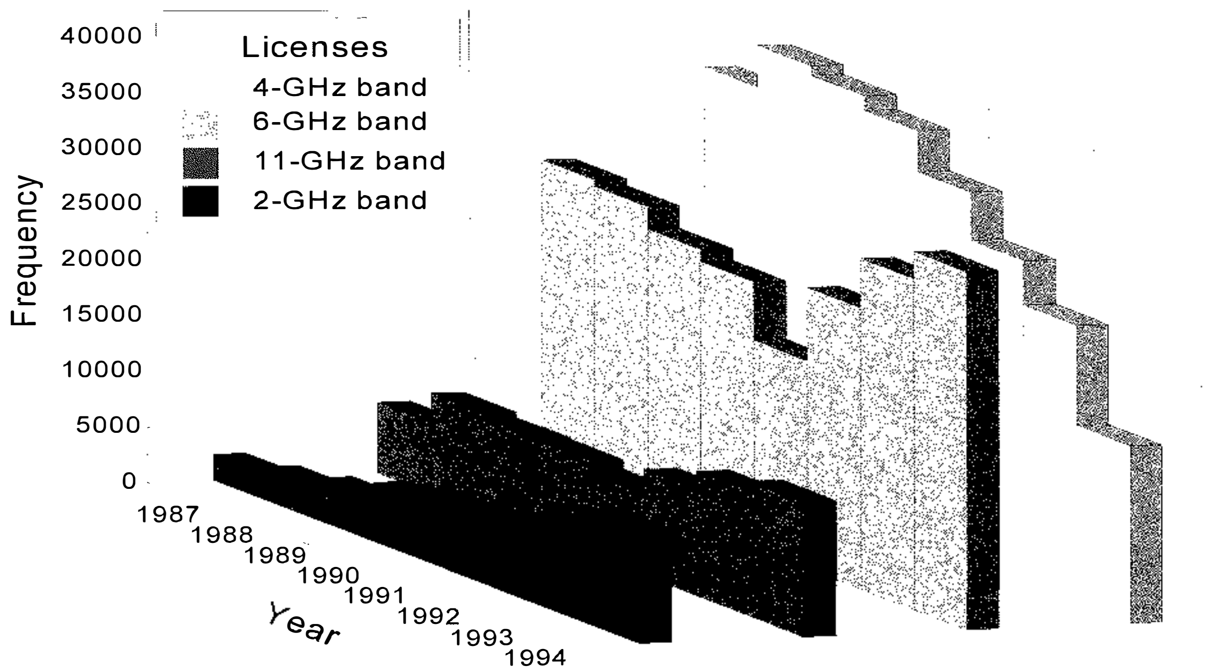
Throughout the study, ITS continued to gather new information on the latest fixed service trends and technologies. This additional material (including another three years of license statistics) was used to update an earlier report on fixed microwave use. Some surprising trends were noted in the license data from the past few years; the updated report contains new predictions of spectrum use over the next 5 years. A major surprise was the continued strong growth of microwave radios to support cellular telephone services (see the Figure); it was believed that optical fiber would displace many microwave services. Strong growth in the number of licenses was seen in the 6- and 11-GHz bands. Growth has continued even in the 2-GHz bands, which have been earmarked for imminent re-allocation to PCS use. On the other hand, use of the 4-GHz band (once the most heavily used band) has fallen dramatically.

Mobile radio in many forms continues to grow rapidly; finding the necessary frequency bands to support additional mobile services is a substantial problem for NTIA and the FCC. The FCC recently announced some new mobile radio rules in their "refarming" hearings. NTIA also has been adapting its rules on Federal mobile radio systems, and ITS has been assisting with technical support of those policies. ITS has performed studies on various technical and operational mobile radio alternatives of potential use in Federal radio systems. These mobile radio studies include:

1. The use of wide-area, shared, trunked radio systems in place of single-agency conventional mobile radios. ITS has paid close attention to the experience of the state of Colorado. Colorado is currently designing such a system for statewide use by most state agencies, some municipal and county governments, and possibly Federal agencies. Selected examples of other wide-area systems, including other states, common carriers, and commercial SMRs have been included in an NTIA Special Publication entitled "Land mobile spectrum planning options."
2. An analysis of the relative spectrum efficiency associated with certain types of band allocations. In particular, ITS examined mobile radio bands organized into separate sub-bands for mobile transmitters and base station transmitters, as compared to no band separation. This analysis showed minimum split-band spectrum efficiency improvements of 30-40%, in addition to substantial (but less quantifiable) advantages in frequency selection and site management.
3. Initial measurements and analysis of mobile band channel occupancy. These measurements were made by the radio spectrum measurement

system in San Diego, Los Angeles, and San Francisco, California and included all major Federal and non-Federal land mobile bands. One objective of these measurements is to obtain quantitative data on crowding in various land mobile radio bands and services, to gain insight on the degree of need for additional spectrum and the improvements that might be obtained from various technical options. The analysis is still at an early stage of development.

Finally, ITS has continued to help plan the spectrum required for the radio services incorporated in future intelligent transportation systems, in support of the Department of Transportation. This work is described more fully in Intelligent Transportation System Planning, page 36.



Frequency licenses in common carrier microwave bands, 1987-1994.

Recent NTIA Publications

Parlow, R.D., et al., 1995, "U.S. national spectrum requirements: projections and trends," NTIA Special Publication 94-31.

Parlow, R.D. et al., 1995, "Land mobile spectrum planning options," NTIA Special Publication 95-34.

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Radio Spectrum Surveys

Outputs

- Spectrum surveys that determine types and amounts of radio spectrum use up to 19.7 GHz in San Diego, Los Angeles, San Francisco, and Eureka, California, and Whiteman AFB, Missouri.
- Statistical measurements of communications channel use for bands between 30 and 900 MHz in San Diego, Los Angeles, and San Francisco, California.

In support of spectrum management tasks for the Department of Commerce and other Federal agencies, the ITS radio spectrum measurement system (RSMS) was used to perform broadband spectrum surveys for the NTIA Office of Spectrum Management (OSM) in San Diego, Los Angeles and San Francisco, California. RSMS spectrum surveys were also performed in support of the Commerce Department's Rural Information Infrastructure (RII) study with a survey in Eureka, California, and for the U.S. Air Force at Whiteman AFB, Missouri.

The California surveys for OSM incorporated two types of measurements in each city: general occupancy data that showed the aggregate activity across every spectral band between 100 MHz and 19.7 GHz, and statistical channel usage data for mobile communication bands between 30 and 900 MHz. The channel statistic measurements were omitted from the Eureka survey for the RII study. They were also omitted from the Whiteman survey, however general spectrum occupancy between 2 MHz and 19.7 GHz was measured. In Figure 1, the RSMS is shown during the San Diego survey at Point Loma.

RSMS measurement algorithms and parameters were selected to achieve maximum probability of intercept for the types of signals that occur in each spectral band. Measurements at a site typically last between 1 and 2 weeks. At the conclusion of mea-

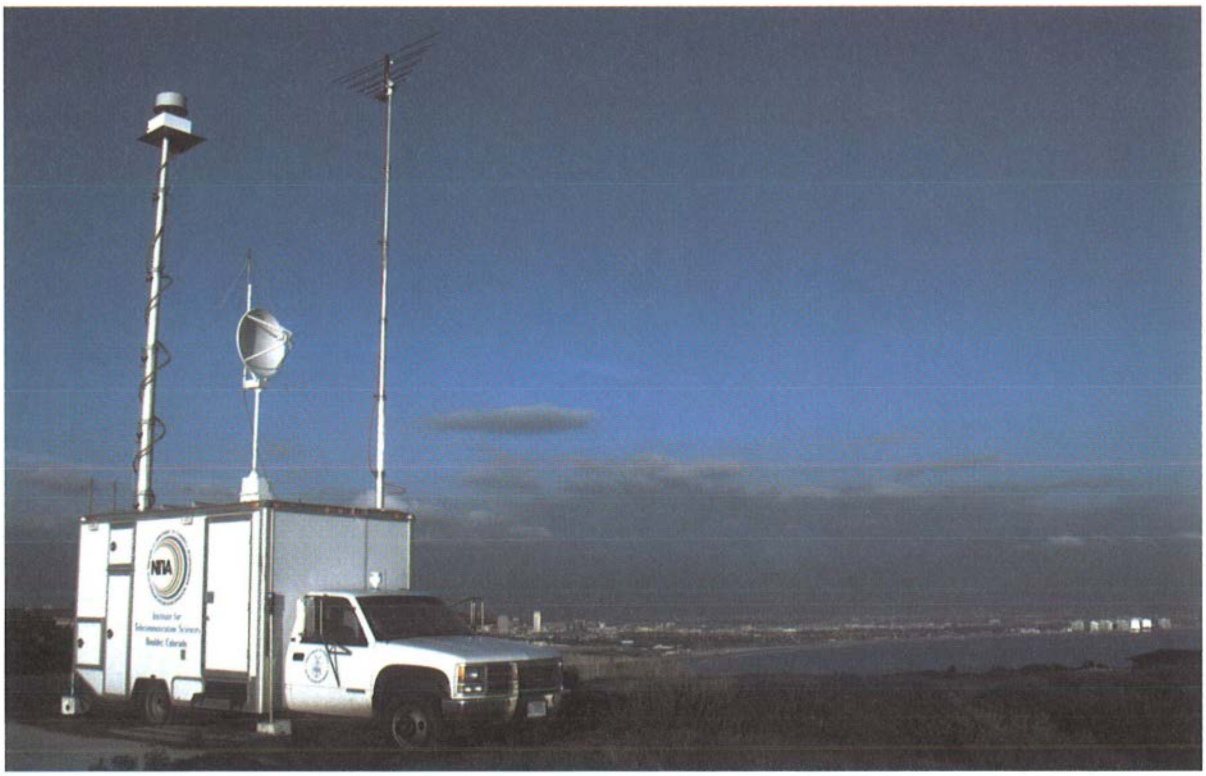

Figure 1. RSMS during a spectrum survey at Point Loma near San Diego, California (photograph by F. Sanders).

surements at a site, data are transported to the ITS Laboratory for accumulation ("cuming") into aggregate data blocks showing maximum, minimum, and average activity in each band during the survey period.

Figure 2 shows a typical cume result for a 2-week RSMS spectrum survey measurement in one of the survey bands. Results such as these are used by spectrum managers for several purposes. These include planning for the introduction of new systems and technologies, assessing compatibility of new systems with existing spectral use, and determining relative density of use in various bands.

The occupancy results of the California surveys will appear as NTIA reports in FY 96. The format will be similar to Sanders and Lawrence (1995), which reported results from a survey in Denver, Colorado. The results of the Eureka, California survey are presented in Allen, et al. (1995).

Statistical data on channel use for the California cities will be presented in reports separate from the occupancy data. It is expected that the channel statistics data will be used to determine the relative levels of crowding and efficiencies of spectral use in the mobile bands below 1 GHz.

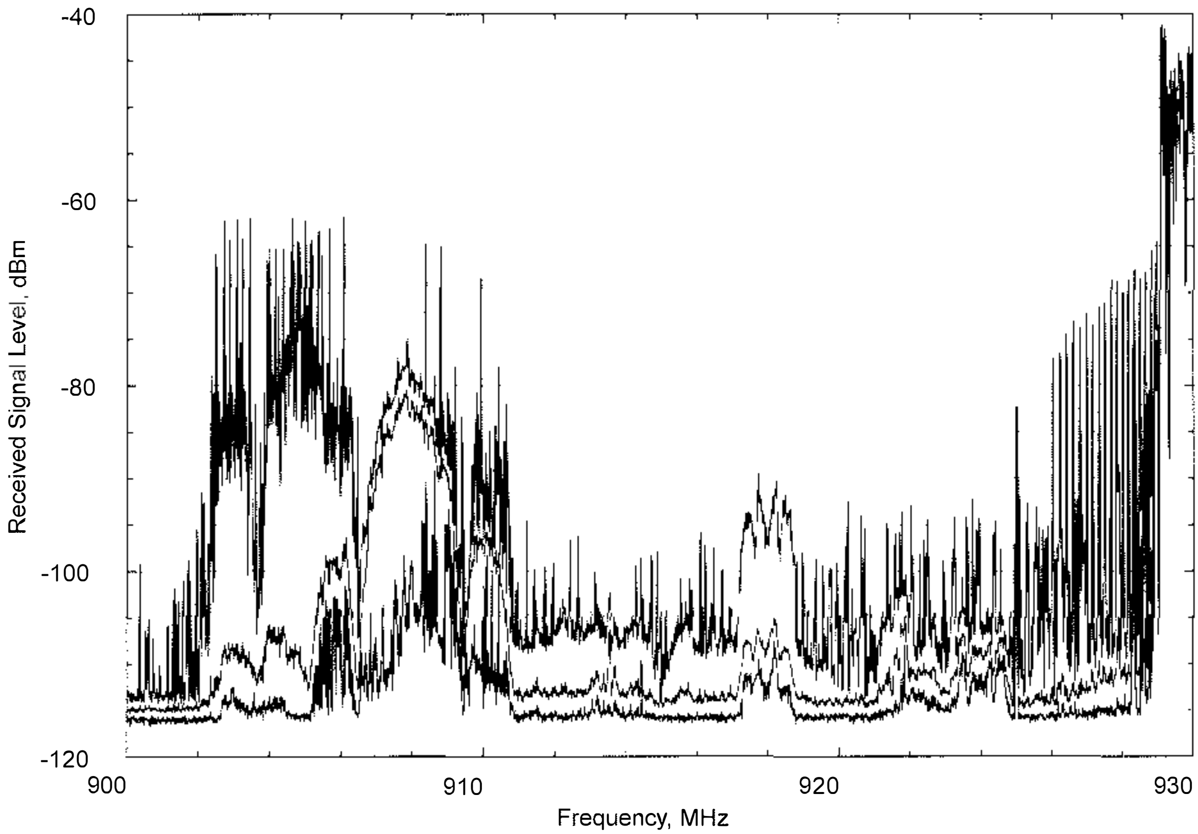

Figure 2. "Cumed" data in the 900- to 910-MHz portion of the spectrum, taken during an RSMS spectrum survey in California.

Recent NTIA Publications

Allen, K.C., et al., 1995, "Survey of Rural Information Infrastructure technologies," NTIA Special Publication 95-33.

Sanders, F.H. and V.S. Lawrence, 1995, "Broadband spectrum survey at Denver, Colorado," NTIA Report 95-321.

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Spectral Assessment of Government Systems

Outputs

- Spectral emission measurements on numerous Federal Government and non-Government radars.
- Data provided to Federal agencies and spectrum managers and planners for use in electromagnetic compatibility assessments.

Increasing crowding of both Government and non-Government spectrum has highlighted the critical need for accurate measurements of the broadband emission characteristics of Federal systems that occupy the radio spectrum. Such measurements are performed by ITS, and are used by both Government and industry to determine the electromagnetic compatibility (interference) between existing and planned systems, or between groups of existing systems that are experiencing possible interference problems.

ITS maintains the vehicularly mounted radio spectrum measurement system (RSMS) and numerous suitcase-portable systems for performing such measurements. These measurements may be performed when interference problems are known or suspected to exist. Measurements may also be performed to determine electromagnetic compatibility prior to introduction of new systems.

Historically, such measurements were performed on systems as diverse as microwave ovens and HF radio transmitters. But of all the types of radio systems that occupy both Government and non-Government spectrum, radars create some of the largest impacts to overall spectrum use. This is due to the high-power, broad bandwidth, and extensive deployment of numerous types of radars on land, in the air, and at sea.

Currently, many new radar systems are being designed and are proposed for deployment. Even as many proposals have been made to reduce the amount of spectrum available for radars. As a result, ITS acquired emission spectrum data on the following radar types in FY 95 alone: SPS-48, SPS-67, TPS-59, TPS-73, FPS-117, ARSR-1, SPS-64, and others. In conjunction with the spectrum measurements, other radar emission data, such as antenna patterns and pulse characteristics, were also measured. Examples of radar spectra measured by the RSMS in FY 95 are shown in Figures 1 and 2. In contrast to the 50- to 60-dB maximum range offered by most measurement systems, the ITS systems routinely measure radars with a dynamic range of 110-120 dB.

ITS' radar measurement algorithms use computer-controlled systems that can measure radar emissions faster, more accurately, more completely, and with greater dynamic range than permitted by conventional swept-frequency methods.

The control software for these systems was written entirely by ITS engineers. ITS also has developed some radar measurement hardware, such as custom-designed RF front-ends. ITS' software-implemented measurement systems are passive and can be used to acquire emission data from both cooperative and noncooperative radar operations. In addition to emission spectrum measurements, these systems are also used to measure the antenna patterns, pulse width, pulse repetition rate, and other pulse characteristics of radar systems.

ITS' radar data from FY 95, and similar ITS measurement data on many other radars, are kept in an internal database. The data have also been shared with spectrum engineers and planners in NTIA, other Government agencies, and private industry.

Some radar data, as well as the measurement techniques required to acquire the data, also have been provided to the International Telecommunication Union-Radiocommunication Sector Working Groups 1 and 8. Contributions by ITS to these groups have been used to define standard measurement techniques for radar emissions. ITS' radar measurement data have also been used to develop new criteria for radar spurious emission limit masks. These include domestically applied radar spectrum measurement criteria, and also international standards currently under development. ITS' radar measurement data are frequently used to assess the degree of interference between radars and other systems. Such studies are performed by ITS for other Government agencies and for private industry.

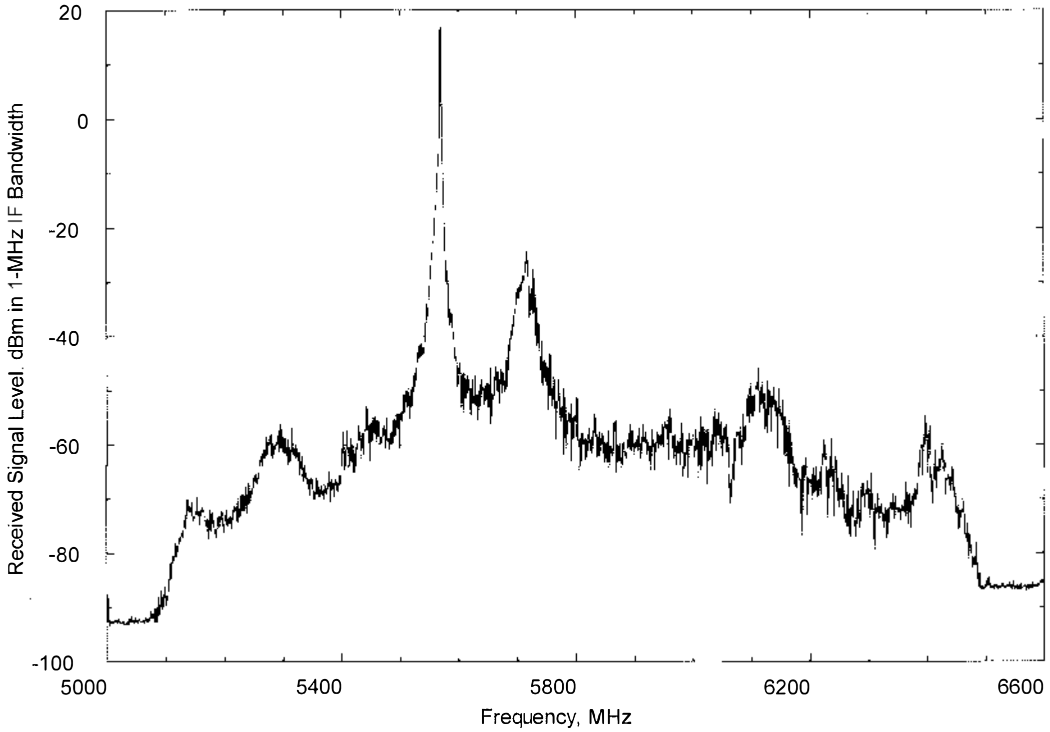

Figure 1. ITS radar emission spectrum measurement of a navigation radar measured with the RSMS.

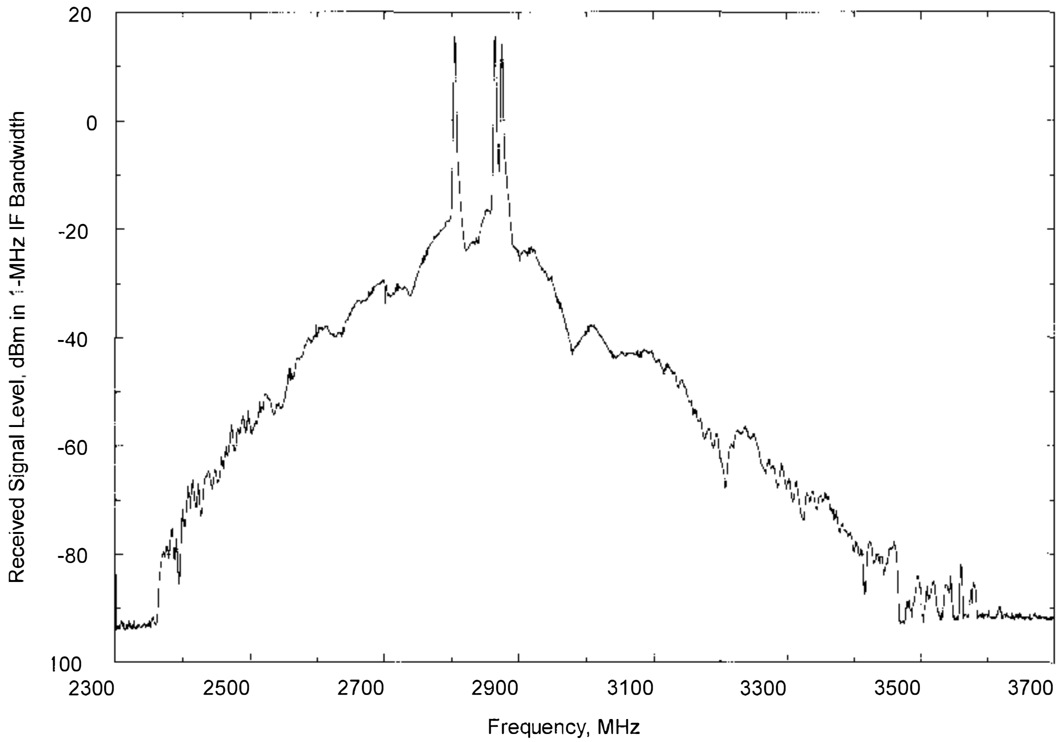

Figure 2. ITS radar emission spectrum measurement of an air search radar measured with the RSMS.

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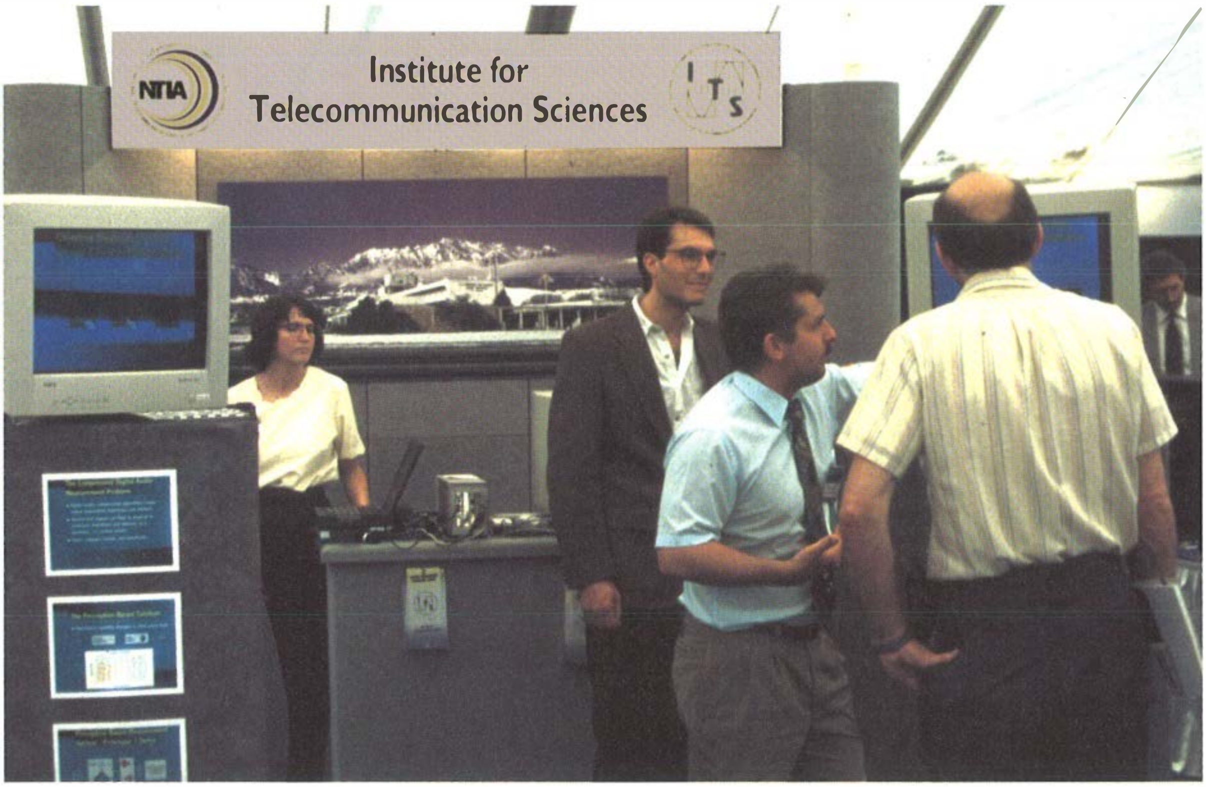


Staff members relate ITS' role in standards development to participants in a trade show sponsored by Bellcore (Photograph by W. Hughes).

Telecommunications 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

ITU-T Standardization Activities

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

Video Quality Standards Development

The Institute conducts research and contributes to standards on user-oriented performance measures for compressed digital video systems. Projects are funded by NTIA and the National Communications System (NCS).

Audio Quality Standards Development

The Institute develops digital signal processing algorithms that provide estimates of perceived audio quality similar to subjective listener judgements. Projects are funded by NTIA and NCS.

Broadband Networks

The Institute contributes to the development and deployment of B-ISDN/ATM technologies through network performance measurement studies and standardization activities. Projects are funded by NTIA and NCS.

Telecommunication Terminology Standards

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

Licensed PCS Standards Support

The Institute leads technical activities and oversees field testing that supports national standardization of licensed PCS technologies. Projects are funded by NTIA and by JTC PCS technology ad hoc groups.

Unlicensed PCS Standards Support

The Institute presents Federal user requirements, defines proposed technology solutions, and leads technical activities supporting standardization of unlicensed PCS. Projects are funded by the Department of Defense.

Wireless LAN Standards Support

The Institute contributes to the development of IEEE standards for wireless LANs through measurement, modeling, and simulation of radio wave propagation and system performance. Projects are funded by NTIA.

Federal Standards for Radiocommunication Systems

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

ITU-T Standardization Activities

Outputs

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

The International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) plays a preeminent role in the cooperative planning of public telecommunications systems and services worldwide. The technical standards (recommendations) developed in the ITU-T have substantial impact on the evolution of the U.S. telecommunications infrastructure and the competitiveness of U.S. telecommunications products and services internationally. The Institute supports ITU-T activities by leading U.S. preparatory committees and international work groups, preparing technical contributions to advance ITU-T standards development, and drafting proposed recommendations on topics important to U.S. Government and industry organizations.

The Institute provides strong support to the U.S. Department of State in leading the U.S. Organization for the ITU-T. During FY 95, Institute personnel served on the U.S. International Telecommunications Advisory Committee, which guides overall U.S. participation in ITU-T activities; personnel also provided leadership for U.S. ITU-T Study Group B, which approves and presents U.S. contributions to the ITU-T on emerging broadband integrated services digital networks (B-ISDNs). These advanced networks will provide integrated audio, video, data, and multimedia communications using ultra high-speed transmission systems and cell-based asynchronous transfer mode (ATM) switching. They are expected to form a principal basis for the emerging U.S. National Information Infrastructure (NII) and the Global Information Infrastructure (GII), a U.S.-motivated international initiative that recently has become a focus of ITU-T activities.

During FY 95, the Institute's responsibilities for ITU-T Study Group B included organization and conduct of U.S. ITU-T preparatory meetings for four ITU-T study groups (9, 10, 11, 13) and leadership of the U.S. Delegations to international meetings of ITU-T Study Group 13, which deals with advanced network planning. The Institute assisted the Department of State in developing innovative approaches to U.S. ITU-T Management; these have been adopted by U.S. study groups and the ITU-T for coordinating ITU-T liaison with U.S.-based industry forums, such as the ATM Forum.

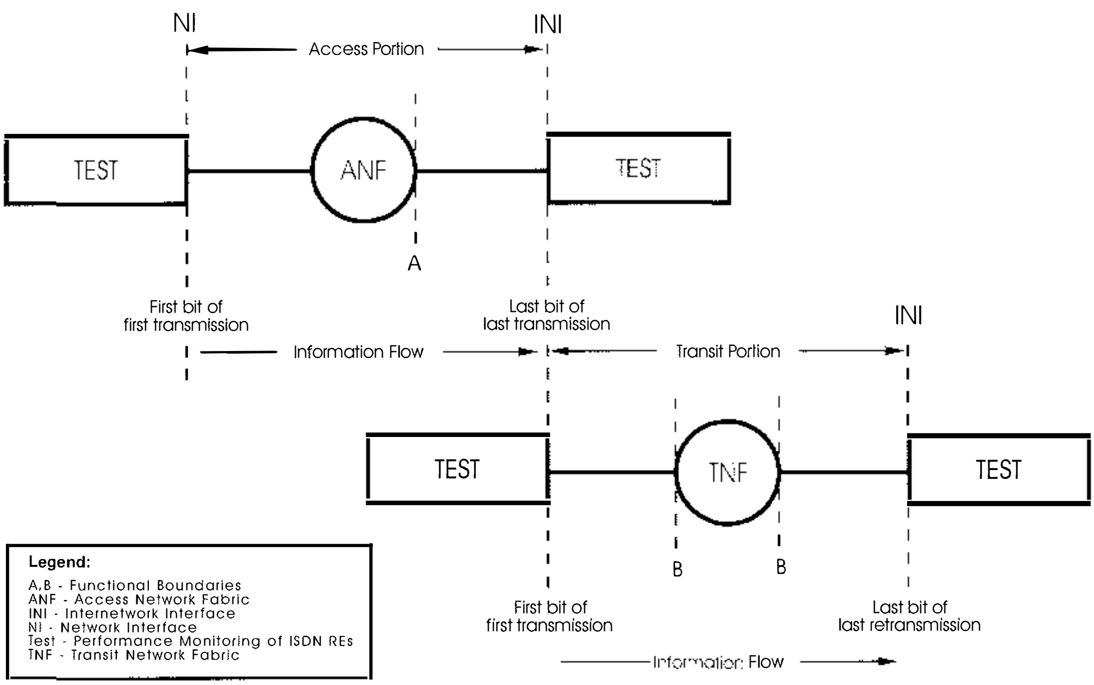
The Institute also provides strong leadership in ITU-T and ANSI-accredited standards committees whose work is relevant to the goals of the Department of Commerce. During FY 95, Institute representatives continued leadership of ITU-T Working Party 4/13; played a prominent management role in ANSI-accredited Committee T1's Technical Subcommittee on Performance (T1A1); assumed expanded technical leadership roles in ITU-T Study Group 12; contributed significantly to the technical standards developed by Working Group T1A1.3; and provided organizational and administrative assistance to Technical Subcommittee T1S1.

During FY 95, the Institute's leadership and contributions in ITU-T Study Group 13 significantly assisted the completion of seven new and revised B-ISDN performance recommendations: I.353, I.35BA, G.827, G.821, G.826, G.81s, and G.810. Revised Recommendation I.353 provides a comprehensive framework for performance specification in related I- and G-series Recommendations. Recommendations I.35BA and G.827 specify availability parameters and objectives for B-ISDN ATM semi-permanent connections and synchronous digital hierarchy (SDH) transmission systems, respectively. Revised Recommendations G.821 and G.826 specify error performance parameters and objectives for narrowband and broadband ISDN connections. Revised Recommendation G.810 and Recommendation G.81s provide performance definitions for synchronization networks and specify timing and synchronization objectives for SDH equipment. These seven recommendations will contribute strongly to the design and worldwide deployment of advanced telecommunications services supporting the GII.

During FY 95, Institute staff members also progressed technical work on two additional B-ISDN performance recommendations scheduled for completion in 1996: Recommendation I.35bcp and revised Recommendation I.356. Recommendation I.35bcp will specify call and connection processing performance for B-ISDNs. Recommendation I.356 will specify numerical objectives for ATM layer cell-transfer performance in B-ISDNs.

A particular focus of the Institute's FY 95 standards work was the specialization of existing ITU-T recommendations on narrowband ISDN performance for application in the U.S. telecommunications environment. Institute staff members spearheaded the development and approval of a new American National Standard, T1.517-1995, which defines speed, accuracy, dependability, and availability performance parameters and worst-case performance objectives for public circuit-mode and packet-mode ISDN bearer services. The circuit-mode performance parameters and objectives apply to individual 64 kbit/s (unrestricted and switched) ISDN connections provided by ISDN B-channels. The packet-mode parameters and objectives apply to individual packet-mode virtual connections provided by ISDN B- or D-channels. The specified parameters and objectives provide a basis for planning, developing, operating, and assessing initial public ISDN service offerings and associated facilities and equipment in accordance with user needs.

The performance parameters and objectives specified in the ANSI T1.517-1995 apply to ISDN connection portions of two general types: access portions and transit portions. The portions are delimited by jurisdictional boundaries between carriers, and corresponding jurisdictional boundaries between carrier facilities and customer premises equipment. The parameters are defined in terms of protocol-specific reference events, each of which corresponds to, and records, the transfer of specified user or overhead information across a portion boundary in accordance with an ANSI-standardized ISDN protocol. The standard provides guidelines for estimating performance values for the jurisdictionally defined connection portions from observations at adjacent, functional boundaries (e.g., switch locations) to facilitate measurement (see the Figure). The standard also provides reference information to assist users in estimating the performance of end-to-end ISDN connections from specified or measured portion performance values.



ANSI T1.517 definition of reference events at the network interface and internetwork interface boundaries.

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Video Quality Standards Development

Outputs

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

Digital video compression, storage, and transmission systems are essential components of the National Information Infrastructure (NII). In FY 95, ITS staff played a key role in the development of three American National Standards that can be used for gauging the quality of these advanced digital video systems. The three standards are:

1. ANSI T1.801.01, "American National Standard for Telecommunications - Digital Transport of Video Teleconferencing/Video Telephony Signals - Video Test Scenes for Subjective and Objective Performance Assessment."
2. ANSI T1.801.02, "American National Standard for Telecommunications - Digital Transport of Video Teleconferencing/Video Telephony Signals - Performance Terms, Definitions, and Examples."
3. ANSI T1.801.03, "American National Standard for Telecommunications - Digital Transport of One-Way Video Signals - Parameters for Objective Performance Assessment."

The first standard, ANSI T1.801.01, provides a set of video test scenes on a digital-format video tape that can be used for subjective and objective testing of digital video systems. Standardized test scenes are important because video images with little detail or motion may retain their quality during digital compression and transmission, while images with extensive detail or rapid motion may be impaired significantly by the same compression and transmission processes. Standardized test scenes allow users to compare directly the performance of two or more systems. The second standard, ANSI T1.801.02, provides a glossary of digital video performance terms. This standard includes a video tape that illustrates common digital video impairments such as tiling, smearing, edge busyness, error blocks, and jerkiness. Thus, this standard gives end-users and service providers a common language for digital video quality. The third standard, ANSI T1.801.03, defines a comprehensive set of objective parameters for measuring the quality of digital video systems. Most of the parameters in this standard originated from the research and development efforts of ITS personnel.

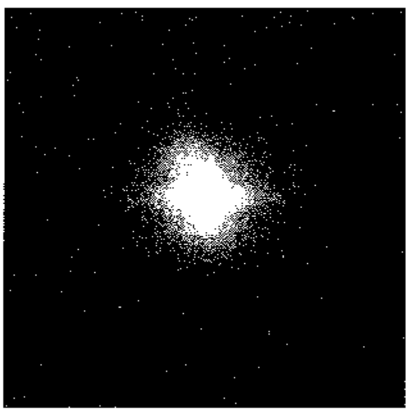
The images in the Figure illustrate one objective parameter developed at ITS that is included in ANSI 801.03. This parameter measures distortions of the edges in an image exhibited by a video system. In the Figure, the output image contains both tiling (i.e., block distortion) and blurring. Tiling is defined in ANSI 801.02 as "distortion of the image characterized by the appearance of an underlying block encoding structure" and blurring is defined as "a global distortion over the entire image characterized by reduced sharpness of edges and spatial detail." As can be seen in the Figure, tiling creates false horizontal and vertical edges while blurring results in missing or less intense edges. By examining the spatial information (SI; a measure of the prevalence of edges in the image) as a function of edge angle, the tiling effects can be separated from the blurring effects. To obtain a pictorial representation, the spatial (edge) information in the horizontal direction (SI_h) and the vertical direction (SI_v) were calculated for each image pixel. The images in the second row display the magnitude of this spatial information. The plots in the third row were generated by counting the number of image pixels at each discrete location, (SI_h, SI_v) and then displaying this count as an intensity. Thus, brighter areas indicate more image pixels with those SI_h and SI_v coordinates. These coordinates (SI_h, SI_v) can also be converted into radius (SI_r) and angle (θ) coordinates. As shown in the third row plots, the tiling adds horizontal and vertical spatial information (i.e., the output plot on the right has more spatial information along the horizontal and vertical axes than the input plot on the left). The blurring results in a loss of diagonal spatial information, (i.e., the output plot on the right has less spatial information along a diagonal direction, such as $\theta = 45$ degrees, than the input plot on the left).

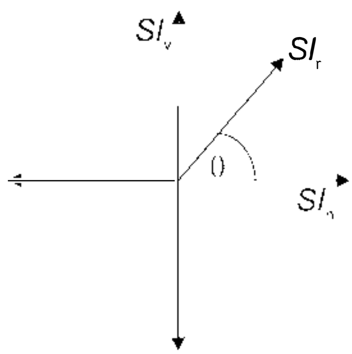
(a) input image.

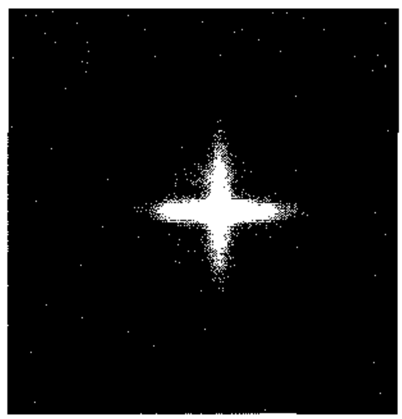
(b) output image.

(c) SI of the input image.

(d) SI of the output image.







(e) SI histogram of the imput.

(f) SI histogram of the output.

Example of objective parameter for the tiling impairment.

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Audio Quality Standards Development

Outputs

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

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

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

The most fundamental and accurate measures of audio quality are the subjective responses of users. These responses can be obtained formally by conducting subjective listening tests. However, these tests are often complex, costly, and time-consuming. In its Audio Quality Standards Development program, the Institute is developing practical alternatives to subjective listening tests: digital signal processing algorithms that objectively estimate perceived audio quality in ways that correlate well with subjective listener judgments.

During FY 95, ITS staff developed an objective audio quality assessment algorithm that would accurately assess the perceived quality of 4-kHz speech coders operating between 1.2 and 64 kbit/s, in both clear-channel and errored-channel conditions. This work extended earlier studies focused on waveform coding systems operating above 16 kbit/s. At bit rates below 16 kbit/s, the highly compressed speech suffers from a wide variety of audible distortions, and these distortions increase when errored channels are encountered. This diversity necessitated the use of a more purely perception-based approach.

The basic premise of the perception-based approach is that by transforming audio signals into an appropriate perceptual domain, only information that is perceptually relevant is retained. By definition, that information is both necessary and sufficient for the accurate assessment of audio quality, independent of the coding, transmission, and decoding applied to the audio signals. In seeking appropriate perceptual transformations, ITS staff members have studied the modeling of human hearing processes as well as higher-level processes of perception and discrimination. Hearing models and test results available in the literature were examined, compared, and incorporated in perception-based measures as appropriate.

Key elements of the human hearing processes are frequency-dependent sensitivity, limited frequency resolution, limited temporal resolution, and amplitude transfer characteristics. In general, these processes are neither linear nor time-invariant.
FY 95 studies resulted in the selection of an effective and robust, yet fairly simple mathematical model for these processes. This particular perceptual transformation has been shown to be appropriate for 4-kHz bandwidth speech signals, although it may require significant modifications and enhancements before it is applied to more general audio signals.

Figures 1 and 2 demonstrate the operation of the ITS-developed perceptual transformation on an audio signal. Figure 1 shows a time-frequency representation of the input audio signal. Increasing signal energy is indicated by a color scale that starts with black and moves through red and yellow to white. The resulting signal after perceptual transformation is shown in Figure 2. Since the signal is now in the perceptual domain, a psychoacoustic frequency scale is used: the frequency axis is calibrated in Bark units rather than kHz. The color scale in Figure 2 represents the perceived loudness of the signal, rather than its energy. Increasing loudness is represented by colors that again start with black and move through red and yellow to white.

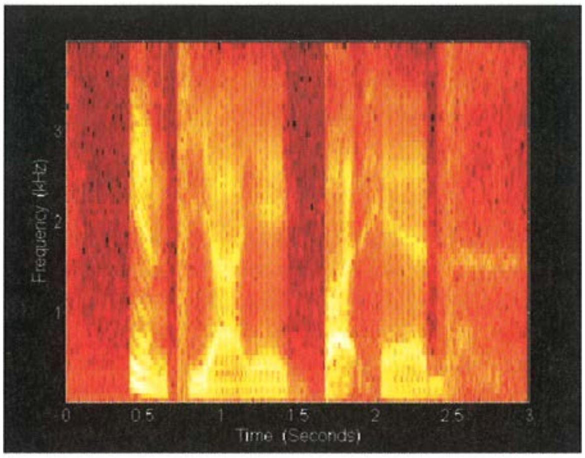

Figure 1. Time/frequency energy representation for an audio signal.

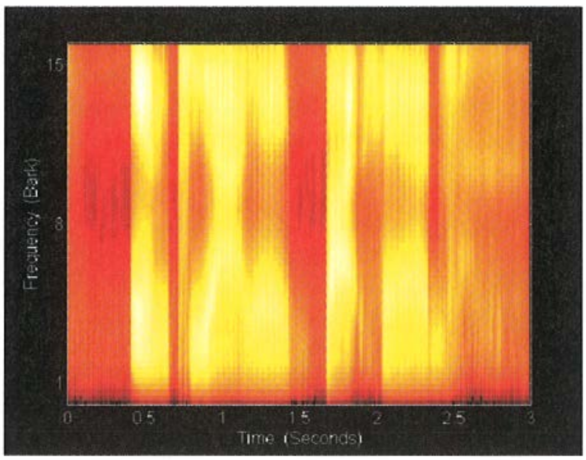

Figure 2. Time/frequency loudness representation for the audio signal in Figure 1 after perceptual transformation.

In measuring audio quality, a perceptual transformation is applied to a reference audio signal and a second version of that signal that has passed through coding, transmission, and decoding equipment. The two audio signals are compared in the perceptual domain, and the measured differences are used to estimate perceived audio quality. Ideally, this step would mimic human judgements exactly when comparing two audible sounds. Since the links between judgement and the underlying physiological processes are not well understood, the details of this comparison process do not correspond to any physiological processes. Much experimental work is still needed to develop a reliable comparison process.

One important objective of the Institute's Audio Quality program is to advance the development of audio performance standards in the ANSI-accredited standards Working Group T1A1.7 (Signal Processing and Network Performance for Voiceband Services). Institute staff members presented technical contributions summarizing recent research findings at several T1A1.7 meetings during FY 95. The Institute also continued its contributions to related performance studies in International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) Study Group 12 (an Institute staff member serves as Associate Rapporteur on Question 13/12, which addresses methods of modeling and measuring nonlinear distortion processes in voice transmission). Relevant results were also presented in the Federal Telecommunications Standards Committee's Multimedia Telecommunication Performance Measurements Subcommittee, led by ITS.

ITS' objective audio quality assessment technologies have been widely disseminated through technical publications and presentations at meetings and workshops involving industry, Government, and academia. During FY 95, staff members demonstrated ITS-developed prototype audio quality test instruments to industry and Government visitors and to attendees at several technical standards meetings. The prototype instruments demonstrated are portable personal computers supplemented with 16-bit analog-to-digital and digital-to-analog converters, customized analog interfaces, and control software. They implement and apply candidate objective measures in assessing the performance of audio channels in real time, enabling researchers to identify more quickly the most practical and useful measures. During FY 95, the prototype test instruments were used to measure speech transmission quality both in the ITS Audio Quality Laboratory and over local and long-distance telephone connections. These instruments have generated significant industry interest and are expected to lead to the development of commercial products that implement the Institute's objective audio quality assessment algorithms.

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Broadband Networks

Outputs

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

Emerging broadband integrated services digital network (B-ISDN) and asynchronous transfer mode (ATM) technologies offer unprecedented transmission capacity and channel assignment flexibility to network designers and are expected to play a key role in realization of the "information superhighways" envisioned by industry and Government planners worldwide. However, these technologies have transmission performance characteristics fundamentally different from those observed in traditional isochronous networks, and require complex traffic control and resource management mechanisms that are not yet fully defined. The Institute's Broadband Networks program contributes to the development and successful deployment of B-ISDN/ATM technologies through network performance measurement studies and associated standardization activities. During FY 95, ITS staff members applied B-ISDN/ATM test equipment in collecting performance data from a prototype ATM network operating in a metropolitan area; added ATM switching capabilities to the Digital Networks Laboratory; and completed the publication of a 6-volume NTIA report that documents standards-compliant data communication performance measurement software developed by ITS staff members.

The ATM network performance measurements were conducted as part of a collaborative project with a public network provider and several other ATM technology developers and users. In these measurements, ITS engineers injected test and background ATM cell streams into the prototype network at carefully controlled rates; looped the test cell stream back to the source test equipment from specified network interface points; and processed corresponding test cell entry and exit events to calculate values for selected ATM cell transfer performance parameters. Collected data were used to 1) enhance the realism of channel impairments generated by the Digital Networks Laboratory's ATM network emulator; 2) validate, demonstrate, and optimize ATM cell transfer performance parameters being defined in national and international standards; and 3) provide practical information about the prototype network's utilization and efficiency.

The physical and logical network configurations tested are illustrated in Figures 1a and 1b, respectively. The physical configuration diagram shows the actual layout of the network and the unidirectional nature of the single-mode fiber. The logical configuration diagram shows the variety of communication channels that were available for testing within those optical fibers, and the path followed by cells on those channels. In some tests, cells were looped back onto the same channel; in other tests, the cells were returned on a separate channel. The ATM layer tests provided a 24-hour utilization profile and some useful preliminary information on cell loss, cell transfer delay, and cell delay variation performance. ITS engineers also injected video and audio information into the network and observed the quality of the resulting video and audio outputs.

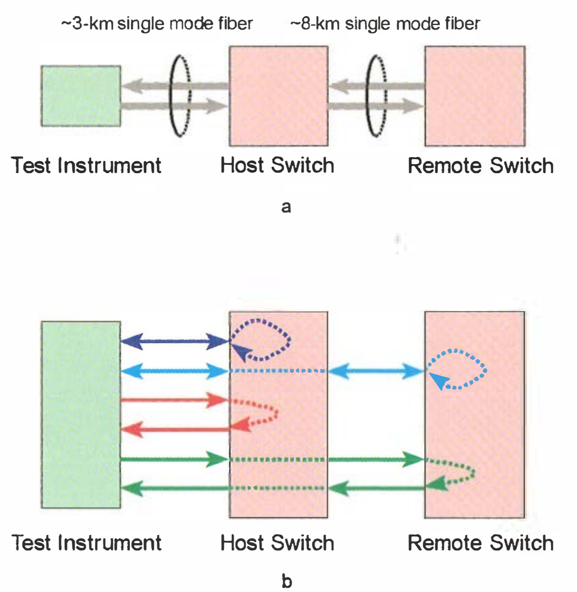

Figure 1. Physical (a) and logical (b) configurations for performance experiments on trial ATM networks.

One observed phenomenon that served to validate and calibrate the test equipment was the correlation between cell loss (a cell discarded or misdirected within the network), cell transit delay (the elapsed time between corresponding cell entry and cell exit events), and cell interarrival time (the time between successive cell exit events). Figure 2 illustrates the effect of individual cell loss on subsequent and related cell transit delay and interarrival time values. The channel used is indicated in red in Figure 1b. Cells were inserted into the network on the test channel at regular 11-microsecond intervals, and the remaining channel capacity was filled with continuous bit rate background traffic. The observed cell loss event caused a 3-microsecond drop in the transit delays for subsequent cells (reflecting a 1-cell reduction in buffer length) and an 8-microsecond increase in the interarrival time between the cells immediately preceding and following the lost cell (the additional 11-microsecond interval minus the 3 microseconds saved by the switch not transmitting the lost cell). The ability of the ITS test system to detect and record such relatively detailed event histories indicates its usefulness in ATM network assessment and optimization.

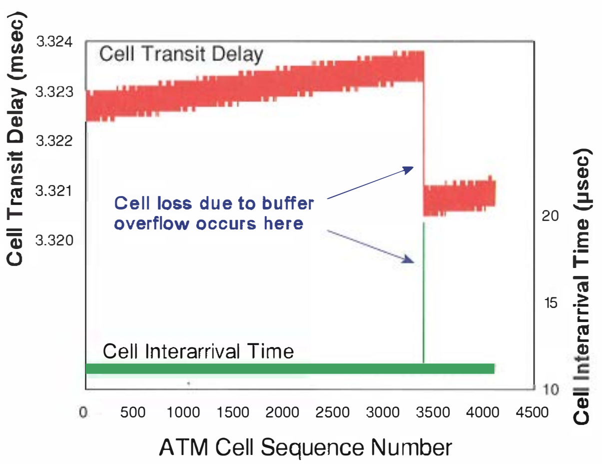

Figure 2. Correlation between cell loss, cell transit delay, and interarrival time.

Recent NTIA Publications

Miles, et al., 1995, "Performance evaluation of data communication services: NTIA implementation of American National Standard X3.141," Volumes 1-6, NTIA Report 95-319.

The Institute's ATM test equipment also functions as a network emulator. The emulator can convert input audio, video, or other data into ATM cell streams; embed those cell streams in synchronous optical network or synchronous digital hierarchy (SONET/SDH) frames; and inject bit-level or cell-level impairments into the resulting encoded data in accordance with ITS-developed error models.

During FY 94, ITS engineers used this capability to assess the ATM layer performance and user-perceived voice and video quality-of-service provided by a digital transmission channel just meeting the error performance requirements of ITU-T Recommendation G.826. In FY 95, ITS supplemented these emulation capabilities by adding two ATM switches to the Digital Networks Laboratory. The switches will be used to provide realistic, yet controlled, traffic loading to study the effects of network congestion on performance. Coordinated error performance and traffic studies will enable ITS to accurately assess the aggregate effects of ATM network impairments on the end-to-end quality of voice, video, and data communication services provided to ATM network users.

Other progress during FY 95 included the publication of a 6-volume NTIA report entitled "Performance evaluation of data communication services: NTIA implementation of American National Standard X3.141," Volumes 1-6. This report describes the implementation and use of NTIA-developed software that automates key aspects of data communication performance measurement. Volume 1 describes the overall X3.141 data communication performance measurement system. Volumes 2 through 6 provide specific information on experiment design, data extraction, data reduction, data analysis, and data display, respectively.

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Telecommunication Terminology Standards

Outputs

- U.S. contributions to ISO/IEC-2382, Information Technology—Vocabulary.
- Camera-ready draft of ANSDIT, American National Standard Dictionary for Information Technology.
- Camera-ready draft of proposed Federal Standard 1037C, Glossary of Telecommunication Terms.

Clear communication of facts and ideas depends upon a common understanding of terminology. Such understanding is particularly important in the rapidly growing field of telecommunications. Both the advancement of telecommunication technology and the successful deployment of telecommunication systems are dependent upon common language. 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 contribute to clarity and precision in all of the aforementioned goals.

Standardized definitions of telecommunication terms are being developed in Federal, national, and international fora. With the sponsorship of the National Communications System (NCS), ITS contributes to vocabulary standards in all three fora. Each glossary involves the development and coordination of a large telecommunications dictionary containing terminology relevant to both general industry needs and to specific NCS and NTIA responsibilities. The latter include advancing National Security Emergency Preparedness (NS/EP) and development of the National Information Infrastructure (NII). Terms relevant to national and global information infrastructures, e-mail, and intelligent network capabilities were of particular interest in FY 95 work.

In Federal fora, ITS chairs the Federal Telecommunications Standards Committee (FTSC) Subcommittee to Revise Federal Standard 1037B, Glossary of Telecommunication Terms. During FY 1995, that group completed the development of almost 5000 proposed revisions to the 1037B glossary. A revised glossary was developed and submitted for a 120-day public review period ending March 10, 1995. Some 3000 comments generated in that review were resolved in a 3-week resolution committee meeting; the final results were compiled into a camera-ready draft of over 400 pages with approximately 5800 entries. Some of the principal disciplines and prospective users associated with this standard are shown in Figure 1. Figure 2 shows several of the resolution committee members in session, with a meeting format allowing participants to see proposed definitions on computer screens. The screens displayed the Subcommittee's revisions, as the text was entered in the database. That database, a draft of proposed Federal Standard 1037C, was also made available to the public via the Internet.

In national fora, ITS serves as Vice Chair of ANSI-accredited Technical Committee X3K5 in developing ANSDIT, American National Standard Dictionary for Information Technology. ITS also serves as project editor for this 220-page glossary, the draft of which was delivered to ANSI for a 4-month public review in August 1995. In the international arena, ITS serves as convener of the International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Working Group 7, Vocabulary for Data Communications. In FY 95, Working Group 7 met twice to develop vocabulary for databases, e-mail, and network management. An ITS representative also serves as project editor for the English text of several parts of ISO/IEC-2382, Information Technology—Vocabulary.

The goal in each committee is to promote a congruence of definitions so that communication is enhanced for users of all of the related terminology standards. By active participation in several glossary fora, ITS promotes congruence between proposed Federal Standard 1037C and other vocabulary standards, including ISO/IEC 2382, the ANSDIT, and specialized terminology standards such as the National Information Systems Security Glossary. The benefits of common vocabulary in all three arenas—Federal, national, and international—reach beyond the vocabulary committees and the laboratories to the purchaser's desks, and into the telecommunications marketplace worldwide.

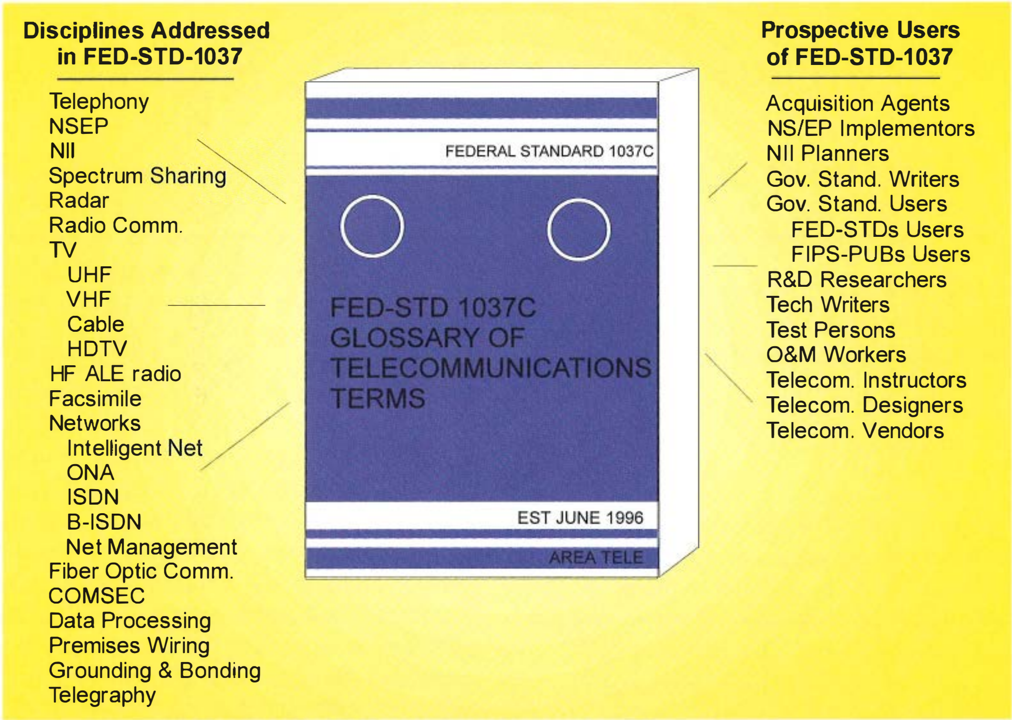

Figure 1. Disciplines addressed in Federal Standard 1037C, and prospective users of the Standard.

Figure 2. Federal Standard 1037C Resolution Committee at work. This committee is comprised of ITS staff members and representatives from several other Federal agencies (photograph by D. Lewis).

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Licensed PCS Standards Support

Outputs

- Technical support and leadership to the JTC.
- Leadership to the JTC and Committee T1 T1P1.4 Subworking Group on Wireless Access to Enhanced 911 Emergency Calling Systems.
- Independent observation of the JTC common air-interface technology field trials.

Personal communications services (PCS) is considered to be the second generation of North American digital mobile telephone service. When available, in 1996 or early 1997, PCS will provide a wide range of integrated voice and data services. These will include digital voice circuits, short messaging services, paging, and other low-rate data services. Although it will be available initially in areas with high population densities, PCS may become the primary data transport link for rural regions of the United States. In March of 1995, the Federal Communications Commission (FCC) completed the first set of broadband spectrum auctions for the first two of six license blocks to be awarded. Completion of this first set of auctions has greatly accelerated activity in the PCS industry and pushed many of the standards toward completion.

In the United States, standards development for PCS is taking place under the Joint Technical Committee on Wireless Access (JTC). The JTC is a joint effort between the Committee T1 and the Telecommunications Industry Association (TIA). The JTC is on an accelerated schedule to ensure completion of standards for the PCS industry. Draft standards for the digital cellular standard-based technology, the IS 95-based technology (code-division multiple access; CDMA), the IS 136-based technology, and personal access communication system (PACS) have been forwarded to the American National Standards Institute (ANSI) for approval as full ANSI standards. Two other technologies, wideband CDMA and composite time-division multiple access (TDMA)/CDMA, have been forwarded to ANSI as trial use standards.

During the past year ITS has played important leadership roles within the JTC. Staff from ITS have chaired numerous ad hoc and subworking groups within the JTC, have overseen the JTC PCS technology field trials, are working on PCS-to-PCS interference coordination, and are leading the effort to provide wireless access to enhanced 911 emergency calling systems.

Under ITS leadership, the JTC Ad Hoc Group on RF Channel Characterization and System Deployment Modeling completed the "Technical report on RF channel characterization and system deployment modeling." This document presents a comprehensive set of radio propagation models on radio channel impulse response, mean transmission loss, building penetration loss, and log-normal shadow fading distributions; it also presents a set of model deployment scenarios. The purpose of the document is to characterize the performance of each proposed PCS air interface in a select set of environments based on a standard deployment scenario. This document is the basis for the evaluation of the recommendation on the international mobile telecommunications 2000 (formerly the future public land mobile telecommunication system) of the International Telecommunication Union.

ITS is providing leadership in the JTC Ad Hoc Group on System Performance and Cross Systems Issues. This group is developing a recommendation to the FCC on out-of-band emission limits and is also developing a technical report on PCS-to-PCS interference coordination and interference mitigation. This technical report will address co-channel interference that occurs at geographic license boundaries and adjacent channel interference that can occur between the six PCS frequency blocks within the same geographic areas. Because there are six digital technologies that may be used for PCS, there are 36 possible interferer-interferee combinations; this creates a complicated cross-system analysis problem. The problem with adjacent channels becomes especially pronounced when the broadcast sites are co-located. Co-location is a likely scenario given that there are limited sites available for radio transmission.

Also under ITS leadership is the T1P1.4 Subworking Group on Wireless Access to Enhanced 911 Emergency Calling Systems. This group, also a JTC ad hoc group, is addressing the air-interface and mobile network aspects of providing wireline service, such as emergency 911 (E911) service, to wireless PCS users. Wireless access to E911 systems will require the PCS system to provide automatic number identification, automatic location identification, priority access for emergency calls, and many other services required for E911 call processing. The location of a mobile subscriber is an especially difficult problem since the user may be inside or outside of a building, may be in or out of a car, and may be in an area where there are tall buildings. This and the nature of multipath propagation make conventional direction-finding and location techniques ineffective for many user locations.

In 1994, the JTC requested that ITS act as an independent observer of the PCS technology field trials. In that capacity ITS has overseen field trials at the US West Boulder Industry Test Bed. Six PCS technologies have been tested in Boulder, Colorado. The ITS-developed PCS test and measurement system is shown in the Figure. These are the PCS 1900 technology, based on the European global system for mobile communications (GSM; also known as DCS 1800); the North American CDMA technology, based on the digital cellular standard IS-95; the North American TDMA technology, based on the digital cellular standard IS-54/IS-136; a wideband CDMA technology; the composite TDMA/CDMA technology, developed by Omnipoint Corporation; and the PACS TDMA microcell system.

PCS test and measurement system as constructed and deployed by ITS (photograph by F. Sanders).

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Unlicensed PCS Standards Support

Outputs

- Federal user requirements for unlicensed PCS.
- Technical contributions to unlicensed PCS standards development.

Unlicensed personal communications services (PCS) technologies are expected to enhance the economy and flexibility of customer premise distribution systems by eliminating wiring costs and constraints on the location of telecommunication terminals within buildings. Under the sponsorship of the Department of Defense, the Institute has participated actively in defining Federal user requirements and proposed technology solutions for unlicensed PCS equipment. This equipment is being standardized by the Telecommunications Industry Association (TIA) TR41.6 committee for operation in the recently allocated 1910-1930 MHz frequency band. In their present form, the unlicensed PCS standards are suited primarily for wireless private branch exchange (PBX) voice services, but all contain provisions for the addition of data services. Four technologies are currently being considered in corresponding working groups under TR41.6:

1. Wireless customer premises equipment (WCPE) a wireless access technology based on digital European cordless telecommunications (DECT), modified for use in the 1920-1930 MHz isochronous (primarily voice) and 1910-1920 MHz asynchronous ("bursty" data) unlicensed PCS frequency bands.

2. Personal communications interface (PCI) a Cordless Telephony 2-based (CT2) wireless mobile system, modified for the 1920-1930 MHz isochronous unlicensed PCS band.

3. Personal access communication system (PACS) a wireless mobile system based on the personal handyphone system (PHS), modified for the 1920-1930 MHz isochronous unlicensed PCS band.

4. Orthogonal code-division multiple access (OCDMA) an emerging technology under development in TR41.6; the physical-layer CDMA waveform will be used with higher layer protocols developed by TIA.

During FY 95, ITS staff members contributed to the TR41.6 technology working groups summarizing requirements developed in the Federal Wireless Users Forum (FWUF), the Federal Wireless Policy Committee (FWPC), and other user forums. The groups identified high-level functional requirements for the air-interface, signaling requirements, and other requirements such as priority access and channel assignment for normal and emergency wireless applications. ITS also proposed technical means for implementing new capabilities such as synchronous data transfer in systems conforming to the TR41.6 proposed standards. Two of the four proposed standards, WCPE and PCI, were submitted for formal TIA balloting during FY 95. ITS will shift its focus to the PACS and OCDMA groups as those standards move closer to completion.

Institute staff members also contributed to proposed technology solutions for wireless user premises equipment during FY 95. A key requirement for certain Federal wireless systems is the provision of synchronous data services; these services serve as transport mechanisms for secure telephone unit (STU)-III voice and data, rate-adapted integrated services digital network (ISDN) service, and end-to-end protocols that require synchronous data streams. Of particular concern in the wireless environment is maintaining data synchronization during handover (the transfer of a mobile terminal from one base station to another). ITS has worked with TIA TR41.6 and each of its four technology groups to include synchronous data services in their specifications, stressing STU-III interoperability. Specifically, ITS has:

1. Presented contributions to the TR41.6 Plenary, including a tutorial on synchronous data services with STU-III applications, and standards documents defining STU-III operation.

2. Developed technical additions to enable the WCPE standard to support synchronous data services. ITS chairs an ad hoc group that is developing synchronous data solutions for WCPE, including STU-III, G3 facsimile, and modem support. The WCPE standard allows

derivation of many interoperability standards from a common standard. ITS also contributed technically to a proposed interoperability standard for wireless PBX voice services (Figure 1).

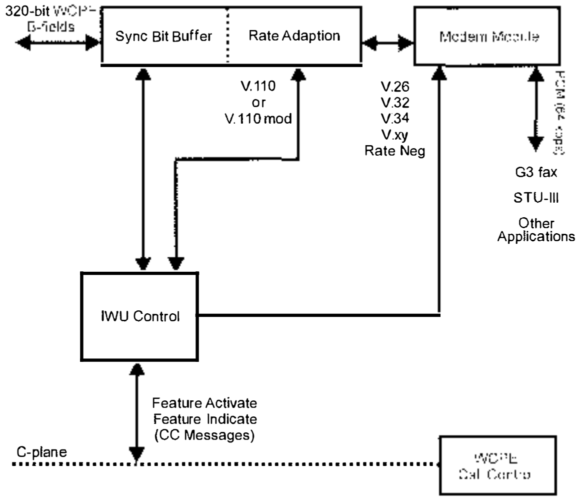

Figure 1. Block diagram of the synchronous data feature implementation in the WCPE standard.

3. Actively participated in verification and validation of the proposed PCI standard. ITS conducted a detailed technical review of the draft standard and made contributions to facilitate the later addition of data services to PCI, which is currently intended for voice-only operation.

4. Identified synchronous data service requirements and alternative technology solutions with both the PACS and OCDMA groups.

Mobility management is a probable focus of future ITS contributions to TIA TR41.6. This feature allows a user to operate the same wireless handset in many different locations based upon proper authorizations and terminal capabilities. ITS participated in FY 95 meetings of the TR41.6 Ad Hoc Group on Mobility Management with considerable interest. Several Federal applications of unlicensed PCS technologies were identified that are likely to involve mobile terminals. At ITS, PCS standards activities are synergistic with PCS network testing, modeling, and evaluation, as shown in Figure 2.

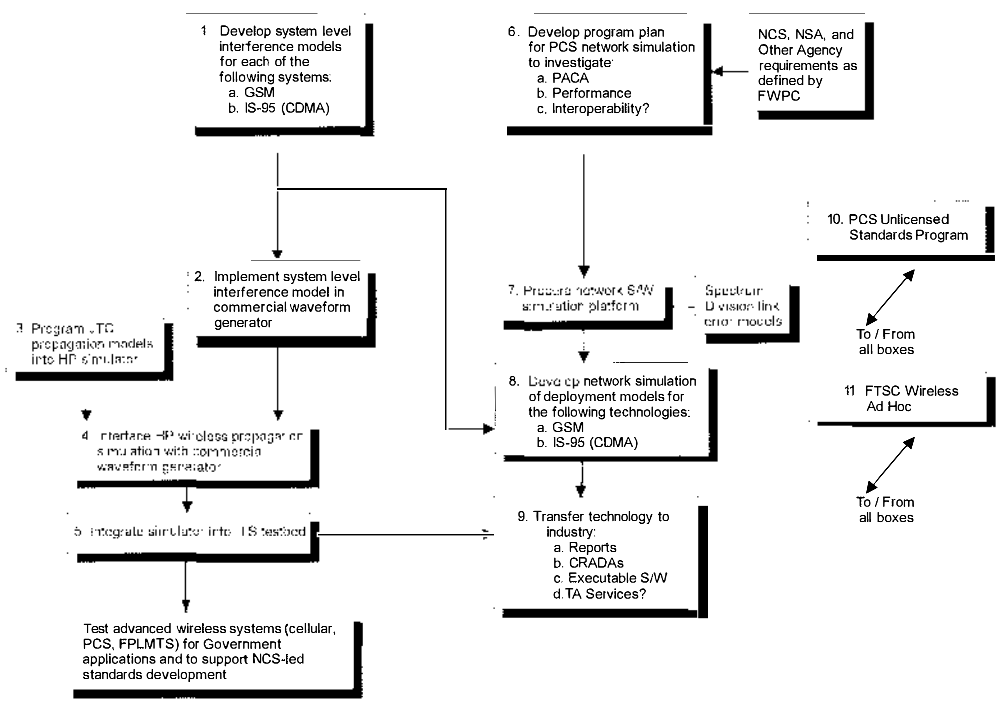

Figure 2. Multiyear, multiagency PCS network testing, modeling, and evaluation program.

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Wireless LAN Standards Support

Outputs

- Indoor channel measurements.
- Indoor channel modeling.
- Performance prediction using software simulation.

Wireless local area network (WLAN) devices are expected to be ubiquitous in the near future. WLAN connectivity was attractive initially to organizations that frequently moved personal computers or point-of-sale terminals. Now, with the advent of laptop computers and personal digital assistants, mobile personal computing is a reality and consumers are demanding high-speed WLAN connectivity.

High-speed WLAN performance is limited by the radio channel. The channel, whether indoors or outdoors, is dominated by the effects of shadowing, multipath, and cochannel interference. Shadowing decreases the radio coverage of a transmitter. Increased effective isotropic radiated power (EIRP) or shorter link distances are necessary to overcome shadowing. Multipath causes power fading in narrowband radios and intersymbol interference in wideband radios. Methods such as spread spectrum modulation, antenna diversity, and channel equalization are used to mitigate the effects of multipath. WLANs currently do not have their own frequency allocation and must work in the presence of cochannel interferers. Spectrum etiquette strategies are needed to allow fair access to the shared spectrum. ITS is committed to solving these problems by participating in the IEEE 802.11 WLAN standards group, conducting radio channel measurements, modeling the radio channel, and performing radio system simulations with realistic radio channels.

At ITS, indoor channel multipath is measured with a wideband channel probe. The channel probe uses a pseudorandom noise, sliding correlator technique that provides excellent dynamic range for the impulse response measurements. The ITS probe is unique in the industry, in that it provides impulse response measurement bandwidths from 200-1000 MHz with excellent time-delay resolution from 10-2 nanoseconds, respectively.

ITS conducted an initial set of indoor radio channel measurements of a hallway, an auditorium, and an open, soft-partitioned office space at 1500 MHz. The office measurements were accepted by the IEEE 802.11 as the standard channel used for simulations submitted to the working group. ITS has made additional measurements in a warehouse environment at 5.8 GHz. This band was chosen to support the movement of WLAN devices to higher frequencies. In the United States, WLANs can use the 5.8-GHz industrial, scientific, and medical (ISM) band while in Europe WLANs can use the 5-GHz HIPERLAN band. Besides relieving spectral congestion in the lower bands, the movement to higher frequencies makes smaller, “smarter” antennas feasible. Smart antennas can mitigate multipath by angle-of-arrival and polarization discrimination. Results from these measurements were used to determine the performance improvements possible with smart antennas. These results will be published as an NTIA report in FY 96.

Figure 1 shows the floor layout of the warehouse where the measurements were conducted. The warehouse has concrete walls and a galvanized roof about 20-ft high. The shelves that delineate the paths are approximately 10-ft high and hold miscellaneous office products. The following WLAN base station configurations were tested: 1) corner mounting with an omnidirectional antenna, 2) corner mounting with a directional antenna, 3) central mounting with an omnidirectional antenna, and 4) central mounting with a directional antenna. Mobile measurements were executed at 20 locations along paths 2 through 6 for each of the base station configurations.

Mobile measurements included one impulse response measurement with an omnidirectional antenna and twelve with a directional antenna. The directional antenna impulse response measurements consisted of six horizontal and six vertical polarization measurements at 0, 60, 120, 180, 240, and 300 degrees bearing. To determine the performance improvement possible with smart antennas as compared to an omnidirectional antenna, the RMS delay spread was computed for each polarization and bearing; the smallest was chosen from all twelve combinations and compared to the RMS delay spread of an omnidirectional antenna. The percent improve-

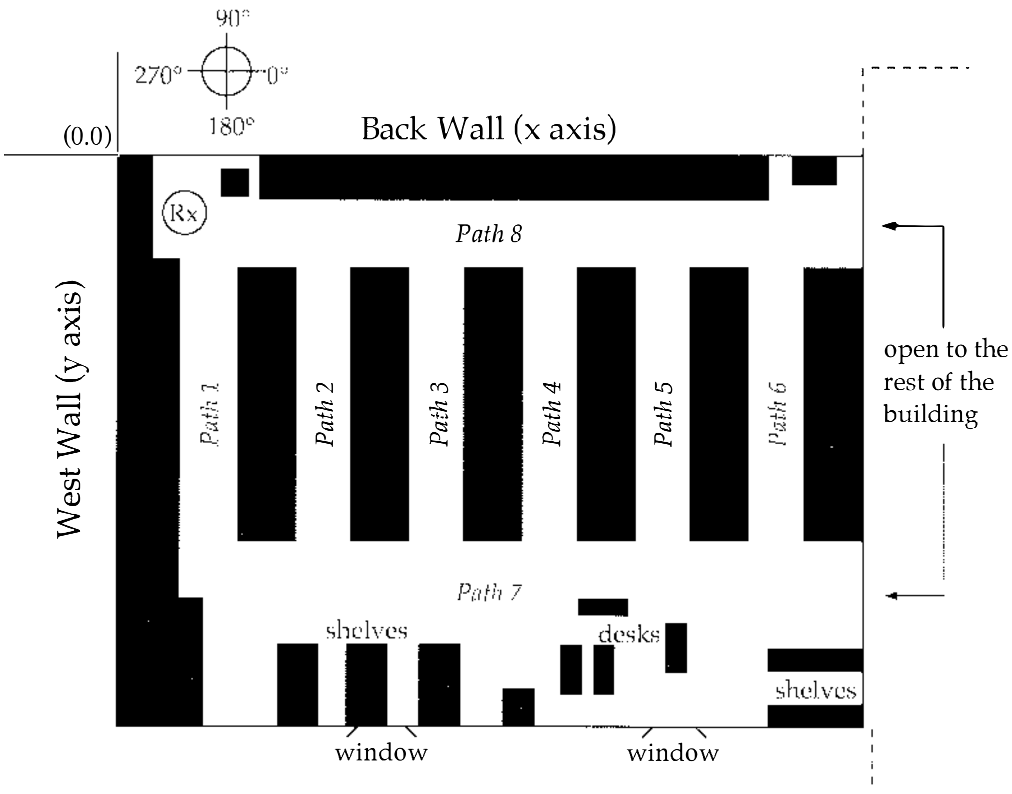

Figure 1. Floor layout of warehouse where the indoor radio channel measurements were conducted.

ment is the difference between the omnidirectional and directional antenna RMS delay spreads divided by the RMS delay spreads of the omnidirectional antenna. Figure 2 summarizes results for a base station with a corner-mounted omnidirectional antenna. The directional antenna was predicted to increase performance of the WLAN link in 19 of the 20 mobile locations. Vertical polarization performance exceeded horizontal polarization performance in 14 of the 19 cases. Improvement ranged from 20-90%.

In FY 95, ITS continued its efforts to predict performance of WLAN devices in realistic channels through software simulation. Realistic channel effects were derived from ITS impulse response measurements and cochannel interference was introduced by other simulated WLANs (Achatz and Quincy, 1995). Error streams from these simulations were collected and used to distort speech and image sources. The quality of the distorted speech and image sources was then objectively measured. It was found that real-time speech and image transmission was feasible with WLANs.

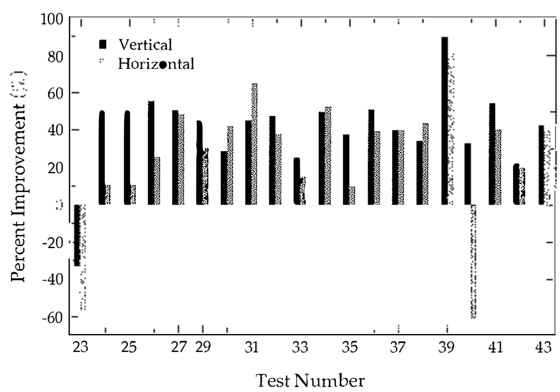

Figure 2. Percent improvement of RMS delay spread for a directional vs. omnidirectional antenna with a corner-mounted omnidirectional antenna base station.

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Federal Standards for Radiocommunication Systems

Outputs

- FTSC subcommittee and working group leadership.
- APCO Project 25 task group leadership.
- Federal Standards for HF and LMR communications.

The Institute provides strong technical support to the National Communications System (NCS) Office of Technology and Standards in managing the Federal Telecommunication Standards Program (FTSP). The FTSP enhances the interoperability, reliability, and security of Government telecommunications by promulgating interface, protocol, and performance standards to be used by Government agencies in equipment and service procurement.

When telecommunication standards needed by Federal agencies cannot be based on existing or evolving voluntary industry, national, or international standards, the NCS-sponsored Federal Telecommunications Standards Committee (FTSC) may commission a technical subcommittee to develop the necessary standards. During FY 95, Institute staff members led two FTSC subcommittees that are important to Federal telecommunication needs: the HF Radio Subcommittee (HFRS) and the Land Mobile Radio Subcommittee (LMRS).

For several years, the HFRS has been developing a family of Federal standards specifying interface, protocol, and performance requirements for automated HF radiocommunication systems. The planned standards are listed in the Table. ITS also supports the HFRS in laboratory and field testing of prototype HF radio equipment. This testing is required before the finalization of draft Federal standards to ensure 1) all specified features and capabilities can be implemented, and 2) interoperability of equipment built to a given standard by different manufacturers.

The Family of Standards for the HF ALE Radio

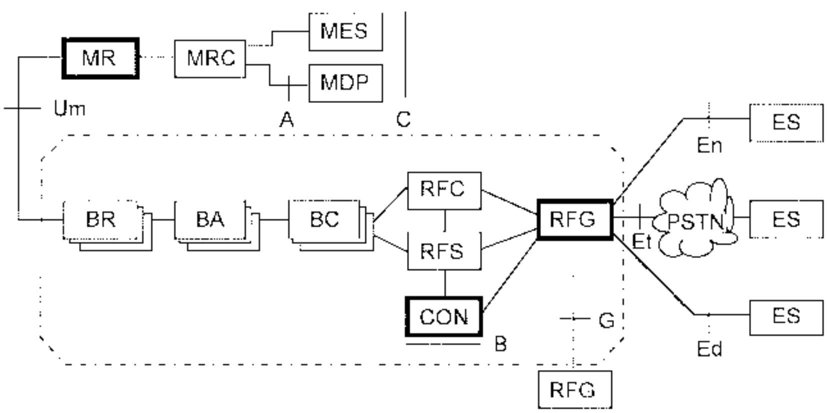
Standard Number	Title
FS-1045A	Telecommunications: High Frequency Radio Automatic Link Establishment (revision of FS-1045).
FS-1046/1/2/3/4	Telecommunications: High Frequency Radio Automatic Networking, Section 1: Basic Networking - ALE Controller. Section 2: Advanced Networking - ALE Controller. Section 3: Advanced Networking - Network-Layer Controller. Section 4: Optional Advanced Networking Features.
pFS-1047/1/2/3	Telecommunications: High Frequency Radio Automatic Message Delivery, Section 1: Automatic Message Exchange. Section 2: Automatic Message Exchange with Store-&-Forward Section 3: Network Coordination and Management.
pFS-1048	Telecommunications: High Frequency Radio Automatic Networking to Multiple-media.
FS-1049/1/2/3/4	Telecommunications: High Frequency Radio Automatic Operation in Stressed Environments, Section 1: Linking Protection. Section 2: Anti-interference. Section 3: Encryption. Section 4: Adaptive Operation.
pFS-1050	Telecommunications: High Frequency Radio Baseline Parameters.
pFS-1051	Telecommunications: High Frequency Radio Systems Controller Interface.
pFS-1052	Telecommunications: High Frequency Radio Modems.
pFS-1053	Telecommunications: High Frequency Radio, Digital Voice.
pFS-1054	Telecommunications: High Frequency Radio, Digital Imagery.

The Institute is also assisting NCS and the FTSC in developing interoperability standards for digital land mobile radio (LMR) equipment used in public safety applications. The LMRS is developing advanced LMR standards in cooperation with the Association of Public-Safety Communications Officials (APCO) and the National Association of State Telecommunications Directors (NASTD) under APCO Project 25.

During FY 95, an Institute representative chaired the APCO Project 25 Encryption Task Group, which develops Project 25 information system security (INFOSEC) standards. Institute staff members also participated in the related Telecommunications Industry Association TR 8.3 Encryption Committee and in other Project 25 task groups to ensure that the LMR standards meet Federal requirements. ITS' leadership of the Encryption Task Group contributed to the successful development of an encryption standard that will protect the confidentiality of voice transmission and other data sent over the Project 25 common air interface.

The Figure identifies the functional groups that may provide confidentiality service in a typical repeater system. The confidentiality service is provided as close as possible to the information origination and destination points to ensure the information is protected across a maximum number of system functions. The reference points are identified by symbols and correspond to physical interfaces between functional groups where an open standard exists. Project 25 defines encryption for confidentiality over the common air interface, but not over other interfaces.

ITS has also contributed strongly to the development of a complex standard and related documentation that define a protocol for over-the-air rekeying of Project 25 radios. INFOSEC documents produced by the Project 25 Encryption Task Group to date include: Security Services Overview, DES Encryption Protocol, Over-The-Air Rekeying Protocol, and Over-The-Air Rekeying Operational Description.



Key

A = radio data preipheral interface
B = man/machine interface
BA = base audio
BC = base control
BR = base radio
C = man/machine interface
CON = console
Ed = host and data network interface
En = system maintenance interface
Et = telephony interface
G = inter-RF-subsystem interface
MDP = mobile data peripheral
MES = mobile end system
MR = mobile radio
MRC = mobile radio control
PSTN = public-switched telephone network
RFC = RF subsystem control
RFG = RF subsystem gateway
RFS = RF subsystem switch
Um = common air interface

▬ = system elements that may provide confidentiality service

Confidentiality in the Project 25 general system model for a repeater configuration.

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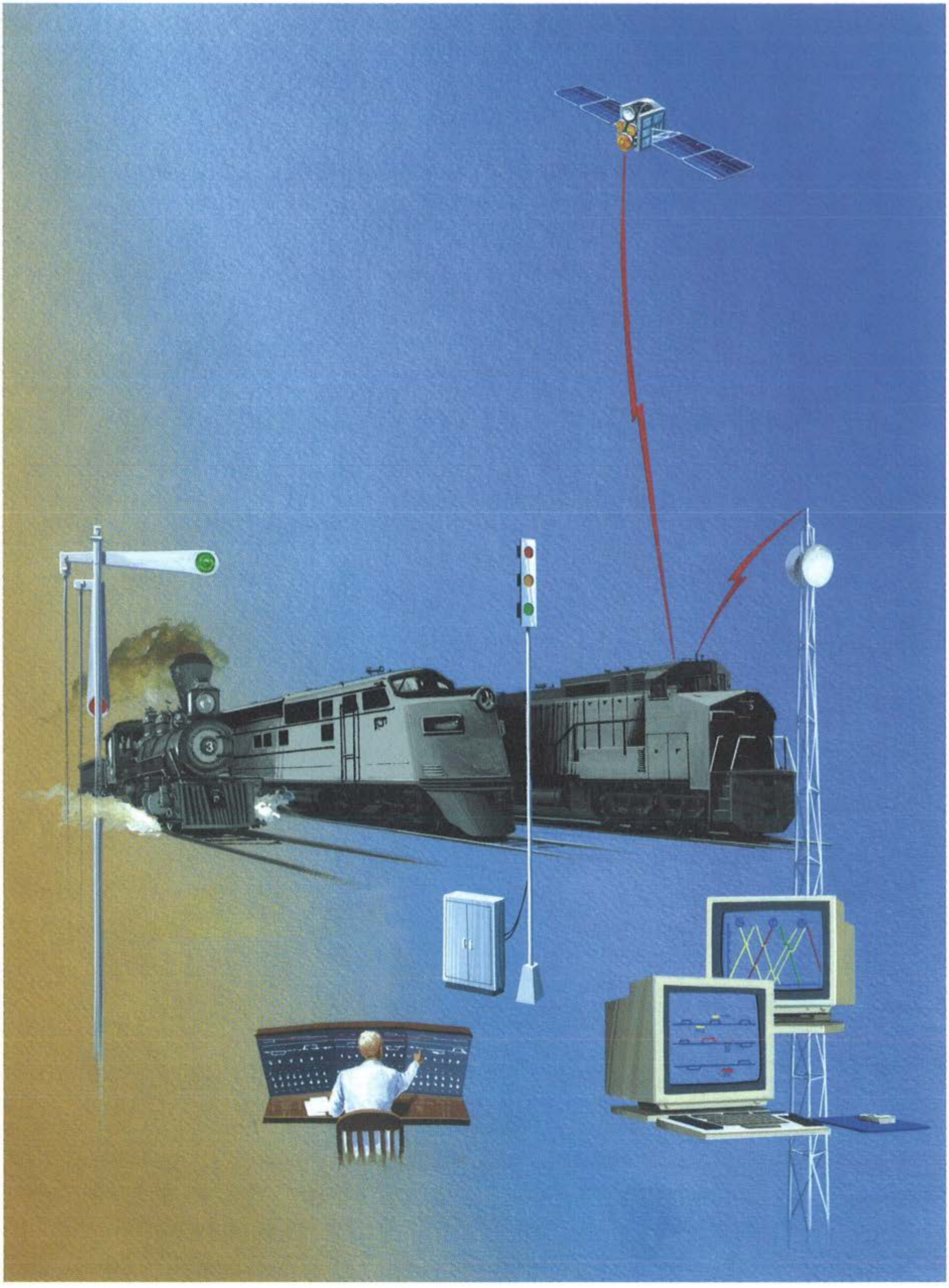


Train control systems are evolving into data communication-based systems that manage traffic and enforce safety restrictions. See Advanced Systems Planning, page 38 (graphic courtesy of Harris Corporation).

Telecommunication Systems Planning

The overall goal of the telecommunication planning process is to ensure that systems or networks satisfy user requirements at an appropriate cost. The process involves identifying current and emerging user requirements, evaluating existing infrastructure, identifying regulatory or policy constraints, investigating relevant standards, assessing technologies, developing network architecture, and designing systems and equipment. Computer models, laboratory simulations, and prototype testing are often used to validate network architectures and system designs. The Institute has the resources to assist with any or all of the aspects of telecommunication systems planning.

Areas of Emphasis

Intelligent Transportation System Planning

The Institute analyzes electromagnetic compatibility for in-vehicle and roadside systems, assesses propagation models for use in intelligent transportation system analysis and design, and evaluates systems for broadcasting digital data via AM and FM subcarriers. Projects are funded by the Federal Highway Administration (FHWA).

Advanced Systems Planning

The Institute provides technical assistance to the Federal Railroad Administration (FRA) in support of the development and deployment of data communication-based positive train separation systems. Projects are funded by the FRA.

National Information Infrastructure Research

The Institute contributes to the advancement of the National Information Infrastructure through standards support, and development and testing of necessary communications infrastructure. Projects are funded by NTIA.

Telecommunications Analysis Services

The Institute provides computerized access to the latest ITS research results, engineering models, and databases, with a current focus on the development of models in the geographic information systems environment for personal communications services. The project is funded by users of the services on a cost-reimbursable basis and by NTIA.

Augmented Global Positioning System

The Institute recommended an augmented GPS to satisfy national positioning and navigation requirements and is assisting in the planning and implementation of a system that will provide nationwide coverage for an intelligent transportation system. Projects are funded by the Department of Transportation and FHWA.

Simulation of PCS Networks

The Institute develops performance metrics, performs interoperability studies for interfaces with existing networks, and assesses system-specific issues on personal communications services in support of other agencies, U.S. industry, and standards bodies. Projects are funded by NTIA.

Intelligent Transportation System Planning

Outputs

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

An intelligent transportation system (ITS) is a group of functions that includes: electronics, computer hardware and software, information-processing, navigation, communications, and control. ITS utilizes computer and telecommunications technology to provide information to travelers about road and transit travel conditions and to monitor, guide, and control the operation of vehicles. ITS can enable travelers to make more informed choices about routes, times, and modes of travel. It can also allow authorities to manage transportation systems and control traffic more efficiently. Examples of this include: rapid response to road accidents to restore traffic flow, redirection of traffic away from the most congested routes, ridesharing, traffic control at intersections and on street networks, ramp metering on freeways, reserved lanes for buses and high-occupancy vehicles, automatic in-transit commercial vehicle weigh-in, and toll collection (see the Figure). In the future, ITS will assist drivers and reduce accidents through automation of vehicle control.

ITS includes a wide range of electrical and electronic devices and equipment. These devices and equipment and the coupling of external signals and interference represent a complex interactive electromagnetic environment with emitters and receptors. The operation of radiocommunication equipment and other electronic devices around ITS-equipped vehicles could cause interference to the resident automotive electronic systems and the electronic equipment in the rest of the environment.

Electromagnetic compatibility (EMC) is a primary factor in the performance, safety, and effective operation of ITS. EMC is the ability of electronic equipment to achieve a specified level of operability in an uncontrolled environment. It involves the orchestration and integration of system components to control interference coupling, and is a primary consideration in ITS system design. The Institute has addressed the EMC of ITS by participating in many activities during the initial conception, design, development and testing phases of ITS. Recent activities and accomplishments on ITS at the Institute include:

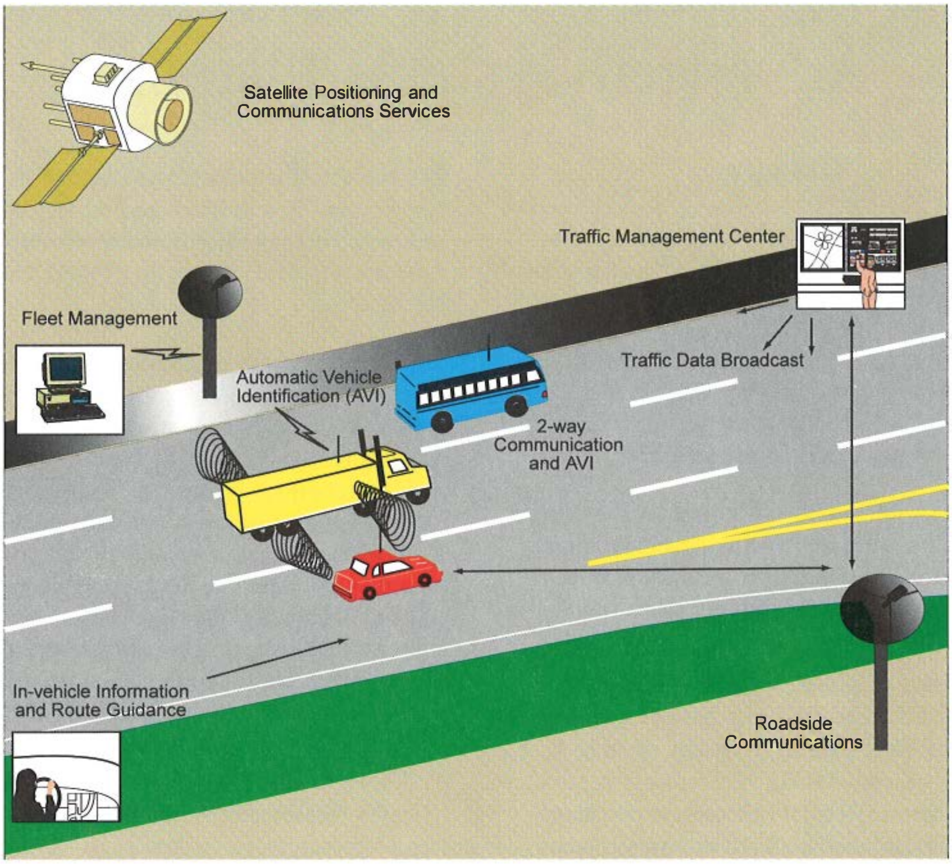
1. A radiation hazard bibliography that contains a comprehensive listing of current literature that identifies existing radiation hazard criteria.

2. A published study of emitters in the radio environment. This study combines the results of an in-depth review of available literature and the Institute's knowledge of the radio environment to identify potential sources of electromagnetic interference (EMI) to which ITS services would be subjected. This study identified the three most significant EMI sources as unintentional radiated noise, radar emissions, and broadcast emissions. There are many sources of natural and man-made interference.

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

4. An assessment of propagation models for use in ITS analysis and design. This assessment was performed to evaluate the capability of existing models. Recommendations for future development of propagation models for ITS in the roadway environment were made.

5. An evaluation of an AM subcarrier operational test currently being performed for a proposed advanced traveler information system (ATIS). The system would be used to disseminate information to travelers in the rural roadway environment. Staff members at the Institute wrote the evaluation plan and will evaluate the field operational test.



A conceptual design of the intelligent transportation system.

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

7. Measurement and verification testing of FM subcarrier system coverage. This testing will support the prediction of area coverage for an FM subcarrier.

8. 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 the FM subcarrier form of ATIS.

9. Development of a medium frequency radio wave propagation model that will be used to analyze ITS at low and medium frequencies.

10. Evaluation of candidate ITS architectures used to select the final consortium for the architecture design. Four architectures were submitted for use as the overall ITS architecture.

11. Ongoing support for ITS communications committees, including the High-speed Data Subcommittee, the ITS-A Telecommunications Committee, and the Transportation Research Board.

Future activities at the Institute include: characterization of the electromagnetic environment, spectrum planning, propagation model development, determination of suitable new and emerging communications technology for ITS, prediction of radio coverage for communication systems, selection and establishment of an EMC requirement standard for ITS, creation of an EMC control plan, selection and development of an EMC testing standard for ITS, and creation of an EMC test plan. The Institute will also be involved in system architecture evaluation in the concept and design phases, and will ensure EMC for demonstration projects during the course of ITS development.

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Advanced Systems Planning

Outputs

- Monitor and provide technical support to the Federal Railroad Administration for data communication-based positive train separation systems.
- Support the Federal Railroad Administration in implementing an augmented global positioning system for positive train separation.
- In cooperation with the Transportation Research Board Committee on Communications, foster planning for communications in intermodal (land, sea, and air) freight operations.

The Association of American Railroads and the Railways Association of Canada have proposed specifications for the North American advanced train control system (ATCS). ATCS is a data communication-based system that transmits command and control information between dispatch centers, locomotives, track maintenance vehicles, and wayside devices. It is intended to provide more economical, efficient, and safer train movement in North America. Figure 1 depicts an existing railroad signaling device.

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

Figure 1. Block-type signal on the Southern Pacific line south of Boulder, Colorado (photograph by F. Sanders).

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

A functional diagram of the PTS system being implemented by BN and UP is shown in Figure 2. The system provides a nonvital safety overlay to existing railroad traffic control and signaling systems by enforcing movement authorities and speed restrictions for PTS-equipped trains. The PTS system accomplishes this through the server, locomotive, and communications segments. The primary function of the server segment is to determine enforceable movement authorities and speed limits. This information is transmitted to the locomotive segment through the communications segment, which incorporates both wireline and wireless networks. The locomotive segment warns the crew of violations, and if the crew does not respond, the train is automatically slowed or stopped.

The Federal Railroad Administration (FRA) strongly supports PTS systems; ITS assists them by monitoring and providing technical support for the BN/UP pilot program. ITS met with program vendors and participated in specification and design reviews. Equipment installation is underway, and testing is scheduled for 1996. ITS will monitor these tests.

Adequate radio frequency spectrum is crucial for the implementation of PTS systems. ITS consulted with the FRA throughout the Federal Communications Commission (FCC) rulemaking on "refarming" the VHF and UHF bands containing railroad allocations. The FCC adopted some new rules, but is still considering others; ITS will continue to clarify railroad radio communication requirements for the FRA.

Location determination systems are also critical to the implementation of PTS systems. ITS provided the FRA with data and recommendations concerning the use of an augmented global positioning system (GPS). FRA used this information to prepare a report to Congress that supports the use of an expanded U.S. Coast Guard differential GPS beacon system for train control. ITS is expected to assist with the installation and testing of differential GPS beacons for the BN/UP pilot program.

In addition to work on train control systems, ITS was a key participant in a workshop sponsored by the Transportation Research Board Committee on Communications. The workshop explored specific communications issues involved in intermodal (land, sea, and air) freight operations. Freight operations have substantial applications toward the development of intelligent transportation systems; the FRA supports efforts to enhance cooperation and information-sharing between railroads and other shippers using different modes of transportation.

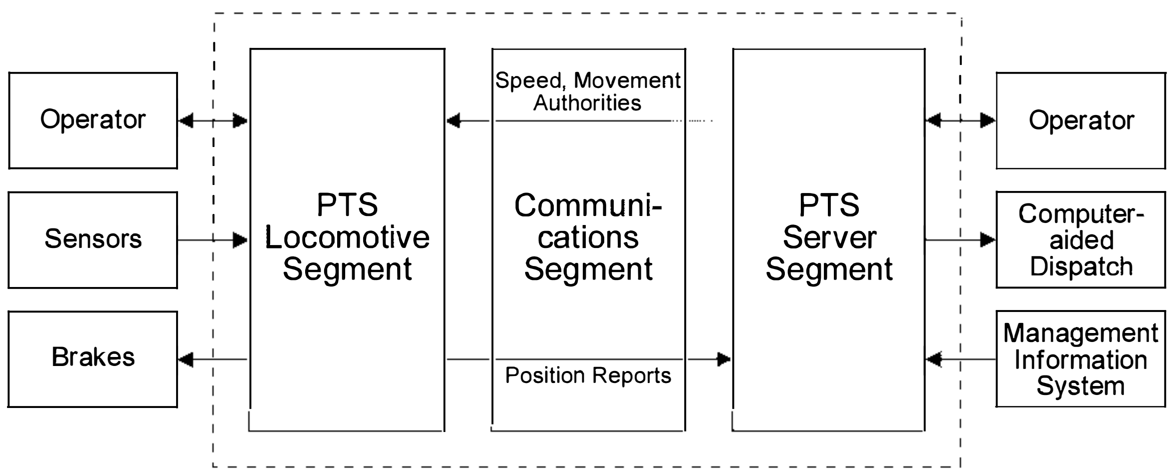

Figure 2. Functional diagram of the Burlington Northern/Union Pacific positive train separation system.

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National Information Infrastructure Research

Outputs

- Technical review assistance for TIIAP grants.
- Rural Multimedia Quality of Service Handbook.
- NTIA report entitled "Survey of Rural Information Infrastructure technologies."

All Americans have a stake in the construction of an advanced National Information Infrastructure (NII), a seamless web of communications networks, computers, databases, and consumer electronics that will put vast amounts of information at users' fingertips. Development of the NII can help unleash an information revolution that will change forever the way people live, work, and interact.

ITS staff have participated in the development of the NII in several important ways. For many years, staff members have been involved in the production of key national and international standards designed to provide the basis for the deployment and efficient operation and testing of the communications infrastructure necessary for the construction of the NII. ITS has also engaged in focused efforts, in cooperation with U.S. industry, to provide access to ITS-developed technology relevant to the NII.

In 1994, NTIA assumed a major responsibility by becoming the administering agency for the Telecommunications Information Infrastructure Assistance Program (TIIAP). This program is designed to promote early use of networking technologies and applications that will be important to the development of the NII. During FY 94 and again in FY 95, ITS staff assisted NTIA's TIIAP program managers by performing technical reviews of grant proposals. These reviews helped NTIA select the best proposals, and also provided valuable information concerning technology alternatives to both those that received grants and those that did not.

In FY 95, Congress stipulated that a small portion of the TIIAP grant funds administered by NTIA could be allocated to ITS to support NII and TIIAP-related applied research. Two major products were delivered as a result of this effort. The first of these, the "Rural Multimedia Quality of Service Handbook," is a multimedia document intended to serve as a reference for rural users of multimedia telecommunication systems and services. The Handbook is an interactive computer program on CD-ROM that provides access to hundreds of megabytes of text, graphics, and audio and video information designed to support a user in understanding and specifying typical multimedia communication systems. Users can access this information randomly, as they would that in a reference book, or they may make use of one of several Applets (small programs that act as interactive assistants) to solve particular problems or to gain knowledge in particular areas. For example, the screen image shown in Figure 1 is part of a tutor Applet that describes how video information is categorized according to its spatial detail and motion content. The various video categories are described through interactive display of example video clips contained on the Handbook's CD-ROM.

The second product of the FY 95 TIIAP research is an NTIA report entitled "Survey of Rural Information Infrastructure technologies." This report contributes to the development of the Rural Information Infrastructure by: 1) defining a set of distinct voice, computer, and video telecommunication services; 2) describing rural information applications that make use of these services; and 3) surveying various wireline and wireless systems and technologies that are being used or might be used to deliver these services to rural areas (Figure 2).

The report is intended to serve as a guide for 1) Federal, state, and local legislators, regulators, economic development officials, and other policy makers; 2) providers of telecommunication services to rural areas; and 3) rural users of telecommunication services, including schools, libraries, health care organizations, businesses, local governments, and individuals.

The report concludes that rural information applications require a wide range of telecommunication services, but no current system or technology is capable of delivering all of these services to all areas. There are many technologies suitable for providing voice telecommunications services in rural areas. It is also technically feasible to provide advanced computer networking and video capabilities to even relatively

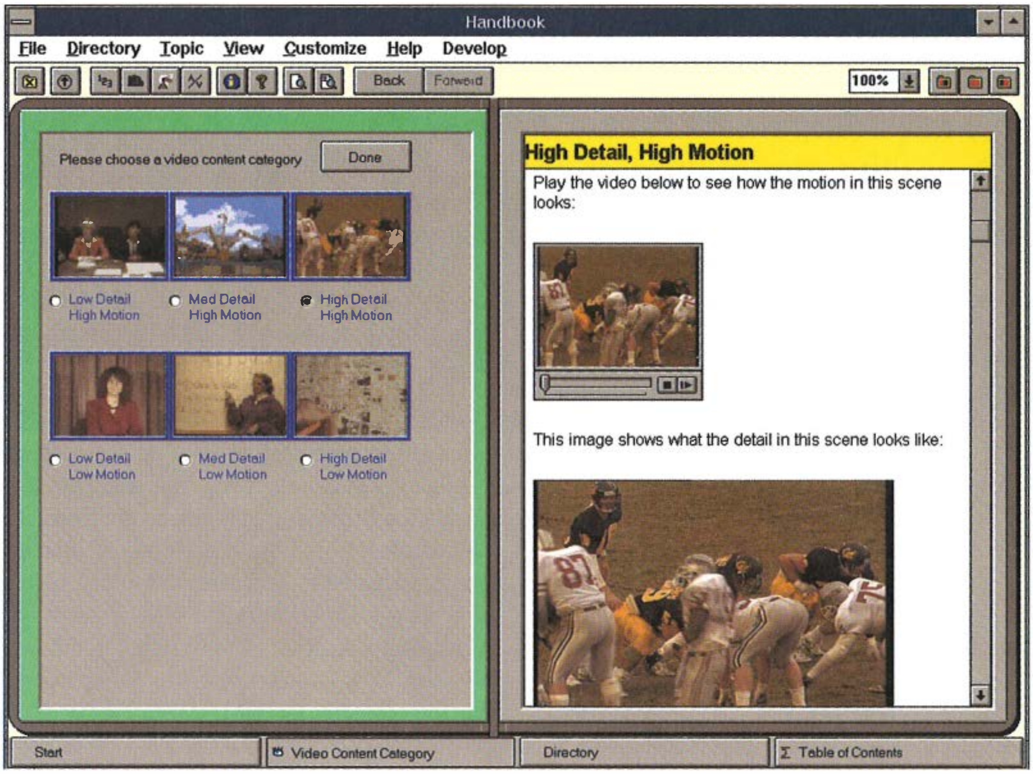

Figure 1. Applet display for video categories from the Rural Quality of Service Handbook.

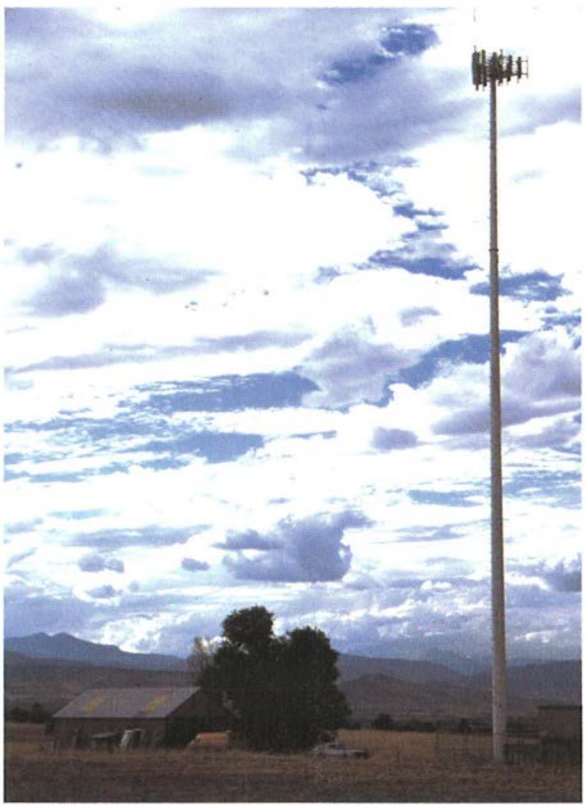

Figure 2. Cellular telephone site located near Longmont, Colorado (photograph by F. Sanders).

small towns in rural areas. No technology was found capable, however, of economically providing these broadband capabilities to the most isolated farms, ranches, and homes. It is expected that new wireless technology will need to be developed to accomplish this. Government regulations and policies will also play an essential role in the development of the Rural Information Infrastructure. Different regulations and policies will likely be required more in rural areas than in urban areas. This report is available electronically through the ITS home page on the World Wide Web at http://www.its.bldrdoc.gov. More information about ITS, NTIA, and TIIAP can also be found at this Web site.

Recent NTIA Publications

Allen, K.C., et al., 1995, "A survey of Rural Information Infrastructure technologies," NTIA Special Publication 95-33.

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Telecommunications Analysis Services

Outputs

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

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

Currently available are: on-line terrain data with 3-arc-seconds (90 meters) resolution for much of the world and 5-minute 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 become available through a bulletin board service to all TA Services users as they are developed. For more information on available programs see the Tools and Facilities section of this report or call the contact listed below.

TA Services currently focuses on the development of models in the GIS environment for personal communications services (PCS). A GIS efficiently captures, stores, updates, manipulates, analyzes, and displays all forms of geographically referenced information. The use of GIS has grown substantially over the past several years 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 databases include terrain, roads, communications infrastructure, building locations and footprints, land type and use, and many others. These databases can be maintained in commonly used and available relational database management systems (RDBMS) that can be connected to the GIS or placed into the GIS RDBMS. This greatly reduces the amount of database development necessary in PCS modeling.

Information on building heights and vegetation is needed for short-path models; however, it is not commonly available. Some city and county governments are beginning to enhance their GIS databases to include this data and this trend is expected to continue. Software is available and under development that allows a user to import digital stereo photographs taken from aircraft at relatively low altitudes or even spacecraft. With sufficient photo quality, this data can be used to create three-dimensional surfaces for the GIS with accuracies on the order of a meter or less. This will greatly reduce the cost of developing databases with the accuracies necessary to ensure reliable analysis results.

The PCS model currently under development at ITS allows a user to select a city or region of interest that has a database developed and imported into the model. Once on board, this environment can be displayed in three or two dimensions as shown in Figure 1 and Figure 2, respectively.

A user can create a database of transmitters and antenna patterns from which analysis scenarios can be created. Transmitters can be described easily and placed either by defining the latitude and longitude or zooming in or out on the map and selecting the location of the transmitter. This GIS will read the location from the map and store it into the transmitter definition table. Antenna patterns can be imported, entered in table form, or drawn on the screen by a user as shown in Figure 3. The user can then give the pattern a name and store it in a personal catalog for future use.

Scenarios created by a user consist of a set of transmitters, antennas, and models chosen to produce propagation results for a region of interest. Models include a road-guided path loss model, an overbuilding model, and a time-domain model. The model also allows the user to see all line-of-sight

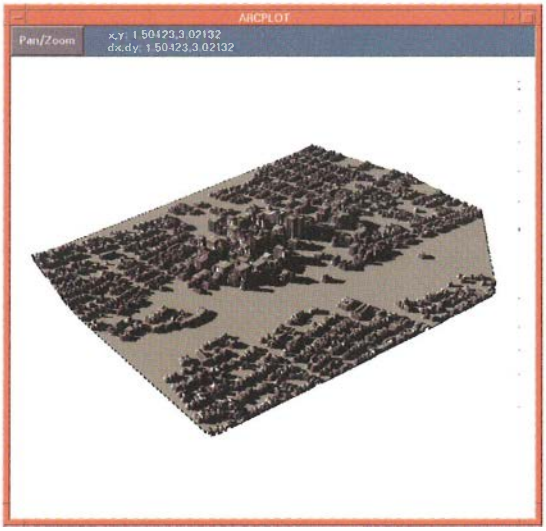

Figure 1. Three-dimensional view of Boulder, Colorado.

Figure 2. Two-dimensional view of Boulder, Colorado.

(LOS) regions. The model has an analysis menu that allows the user to override the selection of appropriate models in the transmitter definition table and force a view of only one model for all transmitters. This menu also controls the results and options for viewing data. The model has a plot menu which allows the user to zoom in, out, left, right, up, or down in the view area and to turn on or off the option to view each cell's data value. From this menu the user can also select contours and the colors of each contour in all subsequent output result displays. The final result of an analysis is shown in Figure 4.

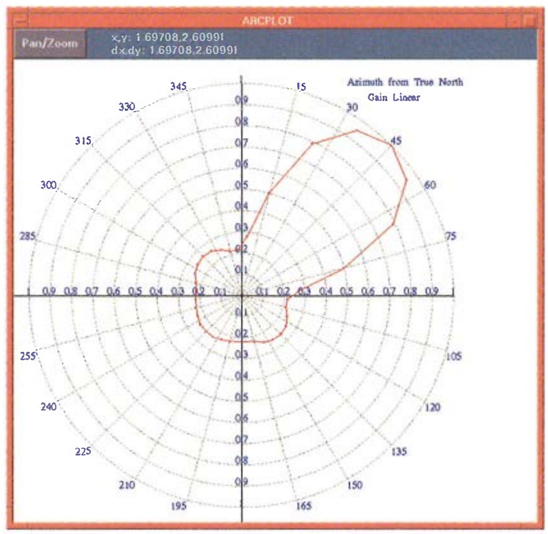

Figure 3. Antenna patterns from TA Services.

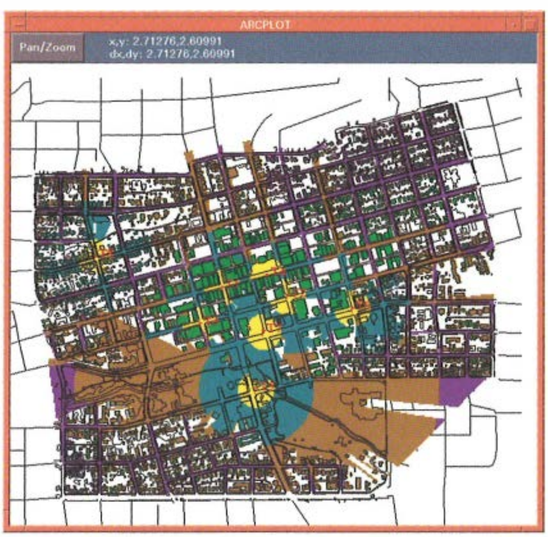

Figure 4. Model output for Boulder, Colorado scenario.

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Augmented Global Positioning System

Outputs

- A recommendation for an augmented GPS to satisfy national positioning and navigation requirements.
- An implementation plan for the successful migration from the present navigation systems to the recommended GPS augmentation.
- An analysis of the differential GPS beacon system that will provide nationwide coverage for the intelligent transportation system.

The NAVSTAR global positioning system (GPS) is a space-based radionavigation system that is operated for the Federal Government by the Department of Defense (DOD) and jointly managed by the DOD and Department of Transportation (DOT). NAVSTAR 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 enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community (see the Figure). In an effort to make GPS service available to the greatest number of users while ensuring that national security interests are protected, two GPS services are used. 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 meters does not meet most civilian 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-meter accuracy for dynamic applications and better than 1-meter accuracy for static users. DGPS places a reference receiver at a precisely surveyed location, compares measured GPS satellite ranges with calculated ranges, and transmits a range-correction signal to the user's receiver.

ITS completed a study, sponsored by the DOT, to investigate and analyze the use of GPS with augmentation. This study was undertaken to 1) prevent an undesirable proliferation of different Federally funded GPS augmentations, 2) keep development and implementation costs as low as practical, and 3) keep user costs at reasonable levels. The current augmented GPS services available, services planned, and those under development were examined for their ability to meet the accuracy, availability, and integrity requirements, and the operational needs of DOT operating administrations.

The results of this study are documented in an NTIA report entitled "A technical report to the Secretary of Transportation on a national approach to augmented GPS services." The report provides conclusions and recommendations that are being used by the DOT to determine which GPS augmentation it should continue to support. The results of this study will also be used to provide guidance and recommendations, where appropriate, to other Federal agencies investigating the use of, or currently operating, GPS augmentations.

The study compiled the navigation accuracy, availability, and integrity requirements of aviation, marine, and land modes of transportation, as well as positioning requirements of the surveying community. In addition, these requirements were evaluated against the technical specifications of the augmented GPS's. The results obtained from this evaluation demonstrated that none of the present or proposed GPS augmentations satisfied the requirements of all operational modes. Several system architectures combining GPS augmentations were then proposed to satisfy requirements of all operational modes. These architectures were then evaluated against performance, cost, and security parameters and the results were used in making the final recommendations of the study.

The report presented the following recommendations for a system architecture that will best meet the needs of all users, nationwide:

- The Federal Aviation Administration (FAA) should continue to implement its wide area augmentation system (WAAS) to satisfy aviation requirements for en route through Category I precision approaches.

GPS provides navigation and positioning service for all modes of transportation (graphic by A. Romero).

- The FAA should develop a local area DGPS to satisfy aviation requirements for Category II and III precision approaches.
- The U.S. Coast Guard beacon system DGPS should be expanded to provide nationwide coverage for land based users.
- All DGPS reference stations should comply with continuously operating reference station (CORS) specifications. CORS provides the capability of postprocessing data to obtain sub-centimeter position accuracy for surveying.

The report also recommended that a study be performed to determine the optimal locations for the additional reference stations required to provide nationwide coverage with the U.S. Coast Guard beacon system DGPS. The Institute is now conducting this study, sponsored by the Federal Highway Administration, to support the navigation and positioning needs of the intelligent transportation system. In addition to determining optimum locations for the reference stations, the study will examine the requirements and needs of users of this system, perform field evaluations of existing beacon system DGPS stations, and develop guidelines for the required reference stations.

The use of DGPS will have an enormous impact on a diverse set of uses, including aviation, ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, and many others that have not yet been identified. The use of DGPS will have an economic impact on tens of billions of dollars and the recommended systems are being implemented as soon as possible in order to realize these benefits.

Recent NTIA Publications

DeBolt, R.O., et al., 1994, "A technical report to the Secretary of Transportation on a national approach to augmented GPS services," NTIA Special Publication 95-31.

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Simulation of PCS Networks

Outputs

- Performance metrics based on PCS deployment, system load, and user services offered.
- Interoperability studies for interfaces with external networks.
- Support of other agencies, U.S. industry, and standards bodies in assessment of system-specific PCS issues.

Widespread implementation of personal communications services (PCS) is expected to revolutionize telephony in the United States, possibly within the next few years. Unfortunately, predeployment field testing of complete PCS systems is not always practical due to cost and time constraints. To aid in the assessment of proposed PCS technologies, ITS has implemented a wireless network modeling, simulation, and testing facility. Key components of the facility are PCS system-specific noise and interference (N/I) models tailored for implementation in a real-time hardware channel simulator, and PCS network-level simulations that use statistical data from the N/I model outputs. These components are hierarchical in that a single PCS system cell is modeled first (Figure 1), and in turn becomes a component in the overall PCS system simulation (Figure 2).

Results from the Institute's PCS network simulation program include quantitative and qualitative performance metrics, interoperability studies, and scenario plans for present and future PCS systems. Beneficiaries include other Government agencies, wireless service providers (especially small service providers), and wireless equipment manufacturers. Acceptable performance in a RF N/I environment is an important consideration when assessing proposed PCS systems. The Institute's program produces accurate N/I modeling and subsequent evaluation of PCS system performance under N/I stress conditions by incorporating system-specific modulation and coding techniques, power control, and standards-mandated requirements into the models.

Interferers are a major hindrance to wireless communication in the 2-GHz PCS band. In a multiple-access environment using microcellular deployment, the most significant unwanted signal sources are interferers rather than natural noise sources. PCS system interference is categorized as either external or internal. External sources of interference are generated by systems outside a given PCS system. These include other PCS systems sharing the same geographical area. Internal interferers are self-generated by the PCS system. These can be either intracell or intercell interferers.

The nature of both types of internal interference is specific to the technology. For example, time-divi-

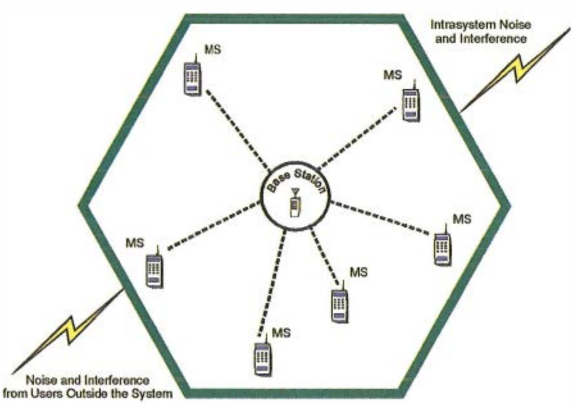

Figure 1. Single PCS system cell (ms=mobile station).

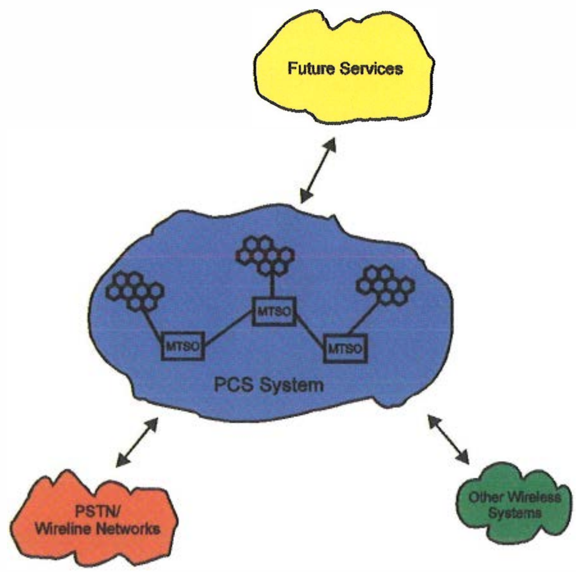

Figure 2. Overall PCS system and interworking networks (MTSO=mobile telephone switching office).

sion multiple access (TDMA) systems do not experience intracell interference if all users in the cell are properly synchronized. Code-division multiple access (CDMA) systems inherently create intracell interference by overlaying user signals within a cell's frequency allocation. Proper modeling of the interferers requires a system-specific analysis of the waveforms involved. ITS' N/I models include both intracell and intercell interferers.

During FY 95, ITS developed N/I models based on cellular geometries for both the global system for mobile communications (GSM) and the CDMA-based IS-95 system. Figure 3 shows sample signal spectra from 100 IS-95 mobile interferers in multiple cells, as seen by an IS-95 base station under test.

In contrast to existing fixed communication services, the PCS network configuration is dynamic by nature. This adds a layer of complexity to the management and control of the PCS system. Because of the obvious difficulties in field testing comprehensive PCS systems, ITS develops network simulations of PCS environments. BONeS Designer discrete event simulation software is used for the network-level models. The simulation adds flexibility in that it is adaptable to any PCS system, and can also be used with other external network models.

In August 1994, the Federal Wireless Policy Committee of the U.S. Government adopted a policy that future Federal wireless system procurements (including PCS) should be digital, ubiquitous, interoperable, transparent, and secure. To aid in evaluating compliance with these Federal requirements, ITS is developing models of proposed PCS systems to investigate performance of voice and data services. These models will evaluate the following performance issues: 1) performance under different load conditions, deployment scenarios, and coverage; 2) system capacity; 3) interoperability with other networks; 4) wireless priority treatment (e.g. priority access and channel assignment; PACA); 5) handoff; 6) signaling; 7) transparency and compatibility with the rest of the public-switched telephone network; 8) security; and 9) cost. Future ITS studies will address system quality-of-service, accessibility, latency, and other service metrics of these issues.

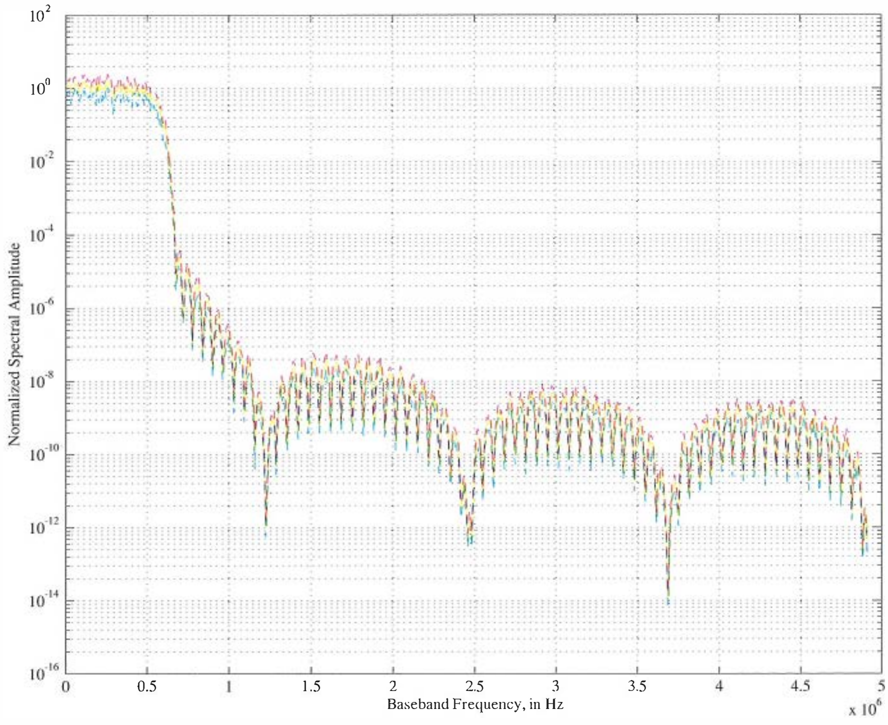

Figure 3. Normalized interference spectra from 100 IS-95 mobile systems incident at a base station under test.

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ITS staff members at work in the Reserve Component Automation System Laboratory (photograph by F. Sanders).

Telecommunication Systems Performance Assessment

ITS assesses the performance of a variety of communications transmission systems and digital communications networks. Assessment tools developed by the Institute include automated analysis techniques used during the system-design process for predicting the performance of a telecommunication system in any specified environment. In addition, hardware and software test and measurement systems are used to evaluate the performance of either prototype or operational transmission systems and networks.

These tools are used to test the performance of a variety of voice, data, and video telecommunication systems that may be entire networks or specific transmission links. The specific assessments undertaken during FY 95 include investigations of transmission system performance in hostile jamming, interference, and fading environments. These assessments address performance for a wide variety of transmission media including HF, VHF, UHF, millimeter-wave, and satellite transmission systems. Models and software were used to develop and verify transmission system design and to test advanced radio systems.

Network performance assessments completed in FY 95 produced unique tools for assessing digital communication network performance and computer responsiveness in environments with heavy traffic.

Areas of Emphasis

Advanced Broadcasting Support

The Institute provides impulse response measurement equipment, measurement support, and data reduction and analysis to the Advanced Television Test Site in Charlotte, Virginia. Support is also provided to the Electronics Industries Association in testing FM high-speed subcarier systems. Projects are funded by NTIA and the Federal Highway Administration.

Reserve Component Automation System Testing

The Institute performs technical testing and evaluation of the U.S. Army Reserve (USAR) Component Automation System (RCAS), an automated information system being developed to accomplish administrative and mobilization functions for the Army National Guard and the USAR. Projects are funded by the USAR RCAS Program Management Office.

Radio System Design and Performance Software

The Institute models the communication systems analysis and the performance of radar systems in a jamming environment. Projects are funded by the U.S. Army National Ground Intelligence Center.

Satellite Studies

The Institute focuses on the roles for advanced communication satellite technology in broadband communications networks and the requirements for performance, interface, and interoperability standards. Projects are funded by NTIA and the National Communications System (NCS).

Advanced HF Testing and Evaluation

The Institute has produced an audio compact disc for testing ALE protocols, a test bed for HF modems/protocols, and plans for over-the-air tests in support of Federal standards for adaptive HF radios. Projects are funded by the NCS.

Advanced Broadcasting Support

Outputs

- Laboratory and field testing results from an FM high-speed subcarrier data delivery system.
- Impulse response measurement data from advanced television field trials.
- Standards support for subcarrier signaling from FM broadcast stations.

In FY 95, ITS completed laboratory and field testing of a 72.2-kHz commercial FM subcarrier-based data transmission and reception system. Designed to achieve reliable communications in multipath and fading environments associated with very high-frequency (VHF) mobile receivers, the system uses high-level signal-processing and error-correcting techniques.

The system was subjected to laboratory and field tests to characterize its data error performance in both a controlled and actual environment. The goals of the laboratory testing were to 1) understand the operation of the system before embarking on the field testing program, 2) verify adjacent subcarrier and entertainment signal compatibility by measuring the occupancy bandwidth of the signal, and 3) determine the system performance under the best possible operating conditions in preparation for field testing. The primary goal of the system laboratory performance testing was to measure error rates versus received signal power. Error performance for the system consisted of three performance metrics: channel error rate (CER), bit error rate (BER) and packet error rate (PER). Each of these were measured and recorded for a range of received signal power levels. The received power level is a metric closely associated with radio area coverage.

Once the laboratory testing of the system was complete, a field test program was initiated. The goals of the field test program were to determine the area over which the system performed adequately, to correlate the system performance with received signal level for a variety of environments, and to compare predicted field strength levels with actual field strength measurements.

The subcarrier system was installed at the transmitter site of KYGO-FM, a FM radio station in Denver, Colorado broadcasting at an effective radiated power (ERP) of 100 kW and at a frequency of 98.5 MHz. The antenna is located roughly 25 miles west of Denver, Colorado (altitude 5,280 ft), at an altitude of 10,597 feet. It has an unobstructed view of much of the Denver metro area. In order to efficiently measure system performance over a wide geographical area, ITS built a special mobile data collection system. This system consists of a van with a receiver system and computer-controlled field strength measurement equipment (Figure 1). GPS receivers were incorporated into both systems so that time and location information could be collected simultaneously with the field strength and system performance data. Data was collected along routes that were classified as urban low-rise, urban high-rise, rural mountains, or rural plains, based on terrain and structure. Figure 2 shows a plot of the performance of the system in a rural plains setting.

ITS also participated on the National Radio Systems Committee's Subcommittee on High-speed Data Delivery. This subcommittee is tasked to evaluate FM-broadcast subcarriers as a means of delivering information. The data could be received by special FM receivers in cars or carried by individuals. ITS also has computed the coverage of the subcarrier signals to major highways from nearby FM stations. These coverage plots help demonstrate the potential of such a service to travelers.

ITS provides measurement equipment to support the Advisory Committee on Advanced Television Systems (ACATS), a joint industry/Government effort to advise and oversee the various aspects of high-definition television (HDTV) planning, development, and testing. This past year, the ACATS performed field tests in Charlotte, North Carolina on the Grand Alliance HDTV design. At each reception location for the tests, measurements of the HDTV system BERs were made. At the same locations, measurements to characterize the multipath environment were made using ITS equipment (Figure 3). With the analysis of the data collected by ITS, the BER results can be correlated with the multipath environment.

Figure 1. Mobile data collection van with generator (photograph by B. Ramsey).

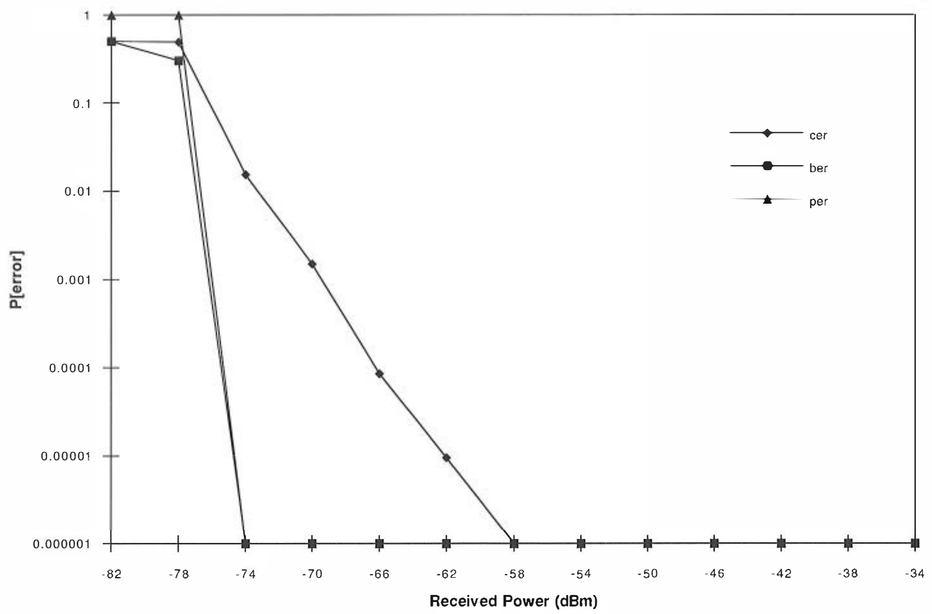

Figure 2. Median error rates vs. received signal power for a rural plains environment.

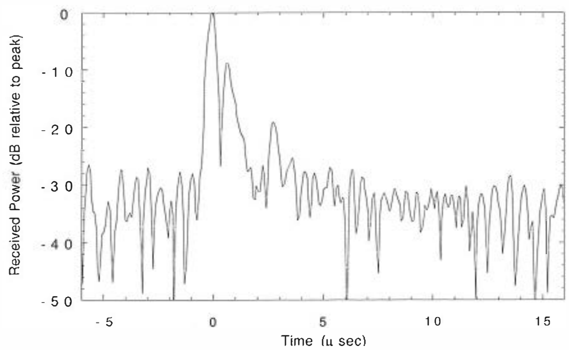

Figure 3. Measured impulse response used to characterize the advanced television broadcast channel.

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Reserve Component Automation System Testing

Outputs

- Test design plans.
- Independent evaluation reports.
- Engineering study reports.

The U.S. Army is developing the Reserve Component Automation System (RCAS) to improve the operational readiness of the Reserve Component of the total Army force. The Reserve Component consists of the Army National Guard (ARNG) and the U.S. Army Reserve (USAR). The RCAS is a state-of-the-art, distributed information processing system that automates many administrative Reserve Component functions and provides timely and accurate information to assist Reserve Component forces in mobilization.

The RCAS hardware consists of commercial database servers, desktop computers, and peripherals; local area networks (LANs); and interconnecting wide area network (WAN) facilities. Computer equipment and LANs are being installed at approximately 9,800 ARNG and USAR units throughout the United States and at selected overseas locations. Units will be interconnected via dial-up or dedicated data communication circuits. The RCAS software includes commercial office automation programs for word processing, electronic mail, spreadsheets, graphics, and desktop publishing as well as mission-specific RCAS application software. The RCAS relies on a fully integrated relational database design to provide electronic document exchange.

ITS is responsible for performing technical testing and independent evaluation of RCAS. Institute staff members support the RCAS Program Management Office (PMO) by developing technical test plans, operating a technical test bed, and conducting technical tests to verify the compliance of delivered products with the baseline system requirements. ITS' testing and evaluation activities assess and enhance telecommunications connectivity and performance, computing and storage system responsiveness and capacity, and information security mechanisms. In FY 95, ITS developed and conducted a series of regression tests to verify system performance improvements and functional corrections that were expected in a major RCAS software delivery.

The Institute's RCAS team uses ITS-developed test tools to perform many of the required network and computer performance evaluations. One of these tools is capable of imposing a calibrated load of electronic messages on the WAN mail transfer servers that switch messages among RCAS units. During FY 95, ITS staff members programmed this load generator tool with representative RCAS user message traffic models and used the tool to assess the message throughput and transit delays of RCAS mail transfer servers under conditions representative of a full RCAS deployment.

In March 1995, the RCAS PMO transitioned to a new software application development methodology in which user requirements and software products are defined in a concurrent working environment. The PMO also began to redesign the underlying RCAS technical architecture. The new architecture is a client-server configuration with centralized data servers located at approximately 100 headquarters. ITS contributed to these program transition activities in several ways during the course of the fiscal year.

In one task, ITS designed an interim interface between the existing RCAS network and the Internet to give RCAS users external electronic mail communications capabilities. This study produced the modified RCAS network architecture shown in Figure 1. The study also identified design options for firewall technologies to protect the RCAS network from intrusion; evaluated alternative Internet access services; and assessed external message integrity and privacy improvement mechanisms. Results were documented in alternative least-cost and best technical design solutions.

ITS also assisted the RCAS PMO in evaluating a proposed design change that would have replaced a large number of "reduced instruction" computers with lower-cost Pentium machines. ITS conducted experiments to collect quantitative information on the relative performance of the two computer technologies under workload conditions representative of the RCAS processing environment. The experiments were conducted using remote terminal emula-

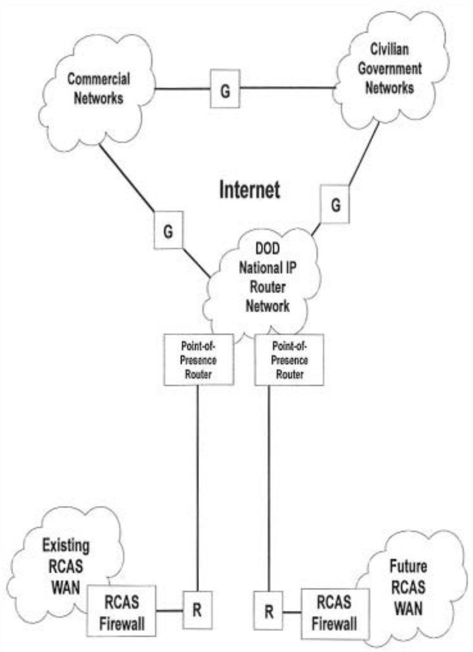

Figure 1. Internet connectivity architecture (R=router and G=gateway).

tion (RTE) test tools developed at ITS. In a typical configuration, users establish sessions, via X-terminals, to exchange graphical information with their database/application server. Each server is designed to support several X-terminals on a common LAN. Figure 2 illustrates the RTE-based computer performance evaluation technique.

Use of the RTE has enabled ITS to capture representative user workload scripts and to replicate and play back a mix of these scripts to emulate a large number (e.g., dozens) of users simultaneously performing work. The RTE system measures transaction response times and other system metrics, such as CPU and memory use, and disk access activity.

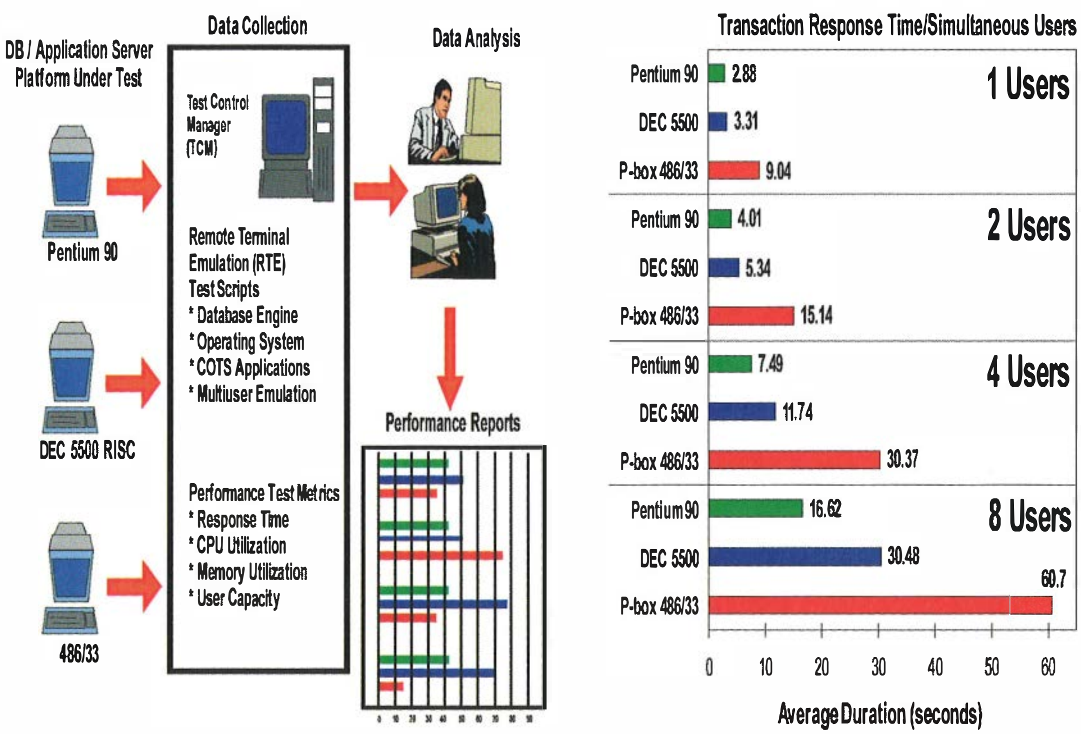

Figure 2. Computer performance evaluation.

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Radio System Design and Performance Software

Outputs

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

The Jammer Effectiveness Model (JEM) was expanded in FY 95 to include not only communication systems analysis in a jamming environment, but also radar systems performance in a jamming environment. The latest version of JEM runs as a Windows application and is user-friendly and menu driven. This model is highly structured and modular in design, which allows for greater flexibility and expandability. Addition of the radar analysis capability is obtained by adding another scenario to the extensive inventory of JEM and the modification of the propagation models for radar calculations. The analysis and design capability of this program was previously available only on mainframe computers. The Figure is a flowchart of JEM, demonstrating how a user can modify databases, create scenarios, and perform analyses.

The development of JEM as a communications analysis model was completed in FY 94. The program 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 scenarios 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 airborne or ground-based transmitters or receivers.

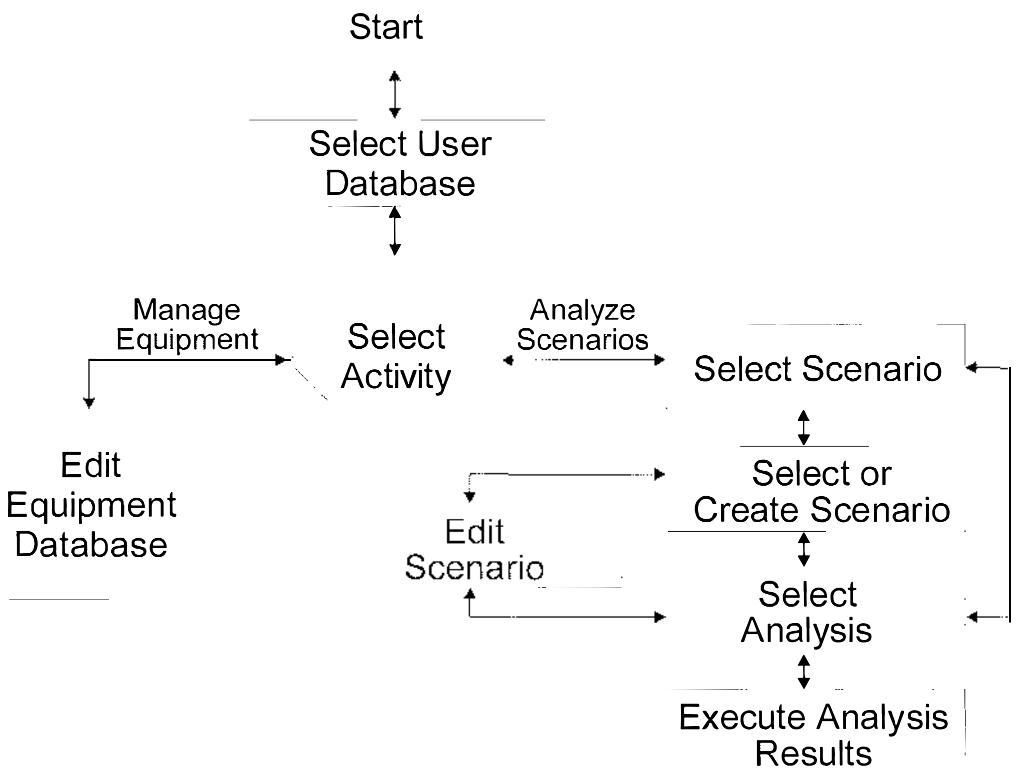
The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. The valid frequency range of JEM currently is from 2 MHz to 300 GHz and includes complete analysis capability for both the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

The 2- to 30- MHz range contains propagation models for both the ground wave and the sky wave. The scenarios available in this frequency range include jamming from an airborne or ground jammer, and jammer versus network from an airborne or ground jammer.

An irregular terrain model for the 20-MHz to 20-GHz frequency range has also been integrated into JEM. The model includes not only the average level of received power, but a statistical description of the received signal variability. The received signal will actually vary in time due to changing atmospheric conditions that cause refraction effects. The signal will also change in space due to a change in terrain along the propagation path. The low-frequency limit for the 20-MHz to 20-GHz model was set at 30 MHz, since ionospheric propagation is likely to occur below this frequency. JEM runs this model only above 30 MHz and uses a combination of ground-wave and sky-wave propagation models for 2- to 30-MHz performance predictions. The scenarios available in the 20-MHz to 20-GHz frequency range are jamming from an airborne or ground jammer, and the jammer versus network scenario from an airborne or ground jammer.

Data entry for 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 analyzes the case represented by the scenario description data.

The JEM is organized into six scenarios. A scenario represents either a communication path geometry description or a jamming geometry description. The four scenarios in the communication geometry description are: ground-to-ground, ground-to-satellite, ground-to-aircraft, and aircraft-to-satellite. The two scenarios in the jamming geometry description



JEM flowchart demonstrating how a user can modify databases, create scenarios, and perform analyses.

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 a jammer on up to five communication nodes. For the jamming geometry description, the receiver, transmitter, and jammer platforms can be on the ground or airborne. The jamming and jammer versus network scenarios are the major features of JEM for electronic warfare and interference analysis. The other four scenarios are used as an aid in evaluating and designing microwave communication systems. They allow the user to simulate a wide variety of propagation effects on the system that occur in the higher frequency ranges by including clear-air absorption losses and losses due to rain attenuation. The user can perform several different types of analyses on the data without having to re-enter it.

The radar scenario of JEM currently under development will allow radar analysis for different combinations of radars and jammers that are on the ground or carried by airborne stations.

Recent NTIA Publications

DeMinco, N., 1995, “Engineering manual for the Jammer Effectiveness Model,” NTIA Report 95-322.

Geikas, J. and N. DeMinco, 1995, “Jammer Effectiveness Model,” NTIA Report 95-317.

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Satellite Studies

Outputs

- ACTS performance measurement results.
- Experiment plan for testing ACTS National Security Emergency Preparedness applications.
- PEACESAT system engineering assistance.

Geostationary satellites have two major advantages over terrestrial communication technologies: their ability to "broadcast" signals over large coverage areas and their ability to connect any specified points within a coverage area independent of intervening terrain. These advantages should enable advanced satellites to extend the benefits of emerging telecommunication technologies (e.g., asynchronous transfer mode; ATM) and services to geographical areas that would otherwise be underserved.

However, effective integration of advanced synchronous satellites with terrestrial broadband facilities will require careful design, both to overcome potential inefficiencies caused by satellite propagation delay and to permit rapid reallocation of satellite transmission capacity in response to changing terrestrial traffic conditions. The Institute's Satellite Studies program contributes to these objectives through focused performance measurements, application demonstrations, and system engineering activities.

During FY 95, ITS staff members 1) conducted experiments on the performance of the Advanced Communications Technology Satellite (ACTS); 2) planned additional experiments to evaluate the effectiveness of ACTS and related technologies in supporting National Security Emergency Preparedness (NS/EP) communications; and 3) provided system engineering support to the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT) program. ITS staff members completed user-oriented measurements of ACTS performance in supporting four services: 1) circuit-switched data over a 64-bit/s integrated services digital network (ISDN) B channel, 2) X.25 packet data over an ISDN B channel, 3) X.25 packet data over a 16-bit/s ISDN D channel, and 4) 9.6-bit/s voiceband data over a satellite-derived analog telephone line. Experiment design, execution, and data analysis were accomplished in accordance with American National Standards X3.102 and X3.141, both of which were developed under ITS leadership. Test results in the Table show that ACTS had nearly error-free transmission performance—only one lost byte was recorded during all of the FY 95 tests. The D channel packet service did not perform as well as expected—throughput was limited to 10 bit/s. The observed performance values did not vary substantially over time or destination location.

The ACTS collaboration is a joint effort among ITS, the National Institute of Standards and Technology (NIST), COMSAT Laboratories, and MITRE Corporation (funded by the National Communications System; NCS). Three Earth Stations and several other telecommunication capabilities will be used to assess the operational effectiveness of digital transmission methods and advanced satellite technology to support NS/EP communication needs.

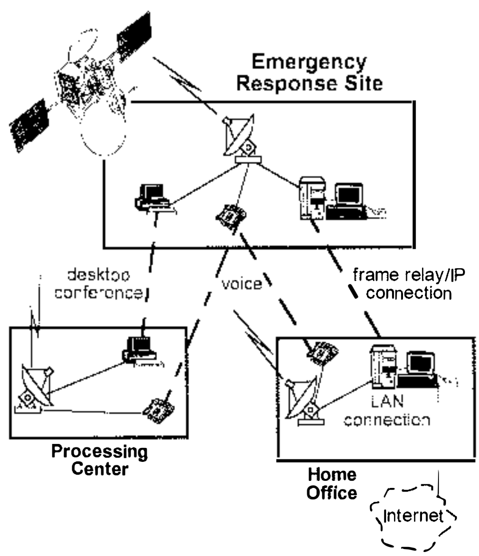
In a national emergency, there are typically urgent and highly variable needs for communications supporting law enforcement, medical aid, relocation assistance, and other public services. The collaboration experiments will identify advanced telecommunication and information technologies that can provide reliable, flexible, and cost-effective communications for a wide variety of emergencies. The new technologies include advanced digital communication satellites; ISDN, frame relay, and ATM communication systems; and emerging applications such as desktop teleconferencing. A draft plan for the collaboration experiments was completed in FY 95. The plan will be finalized and used to guide actual experiments during FY 96. An emergency scenario, shown in the Figure, provides a framework for the communications functions to be tested. Voice and data communication including a LAN interface, slow-speed video conferencing, high-resolution imaging, and other functions will be tested. The voice quality measurements will be accomplished using procedures and equipment developed at ITS. NIST is developing performance measures for various advanced computer applications. COMSAT will determine performance of the communications protocols—ISDN, frame relay, and ATM—over the satellite. Final results will guide NCS in developing requirements and guidelines for using advanced satellites in NS/EP situations.

Summary of Performance Parameter Estimates for X.25 over a Circuit-switched Channel

Performance Parameters	95% Confidence Lower Limit	Sample Mean	95% Confidence Upper Limit	Total Number of Trials
Access Time (s)	0.83	0.85	0.86	1100
User Fraction of Access Time (%)	46.67	47.29	47.91	1100
Incorrect Access Probability	0	0	$1.3 \times 10^{-2*}$	1100
Access Denial Probability	0	0	$1.3 \times 10^{-2*}$	1100
Access Outage Probability	0	0	$1.3 \times 10^{-2*}$	1100
Block Transfer Time (s)	9.64	9.66	9.68	650
User Fraction of Block Transfer Time	7.11	7.28	7.45	650
User Fraction of Input/Output Time	6.75	6.80	6.86	13
User Information Bit Transfer Rate (bps)	62950	63000	63040	13
Bit Error Probability	0	0	$6.0 \times 10^{-7*}$	20800000
Bit Loss Probability	0	0	$6.0 \times 10^{-7*}$	20800000
Extra Bit Probability	0	0	$6.0 \times 10^{-7*}$	20800000
Block Error Probability	0	0	$2.2 \times 10^{-2*}$	650
Block Loss Probability	0	0	$2.2 \times 10^{-2*}$	650
Extra Block Probability	0	0	$2.2 \times 10^{-2*}$	650
Transfer Denial Probability	0	0	$5.0 \times 10^{-2*}$	277
Source Disengagement Time (s)	0.85	0.86	0.87	1100
User Fraction of Source Disengagement Time (%)	3.50	3.63	3.77	1100
Source Disengagement Denial Probability	0	0	$1.3 \times 10^{-2*}$	1100
Destination Disengagement Time	1.17	1.18	1.18	1100
User Fraction of Destination Disengagement Time	8.00	8.01	8.02	1100
Destination Disengagement Denial Probability	0	0	$1.3 \times 10^{-2*}$	1100

* Assumed that the conditional probability (an error occurs given that an error just occurred) is 0.8.

The PEACESAT program supports distance education, community service, health care, and emergency communication needs of U.S. and native populations in over 20 widely dispersed Pacific islands, all of which are underserved by conventional terrestrial communication systems. During FY 95, satellite support for the PEACESAT network was shifted from GOES-3 to GOES-2 due to the depletion of station-keeping fuel for GOES-3. The PEACESAT program managers also began implementing an enhancement of PEACESAT network services, including Internet connections and other database access and the addition of video technology to support distance education. The Institute provided essential engineering services to the PEACESAT Program Manager in determining the service improvements that can be supported by GOES-2 using a digital-services overlay to the existing single-channel-per-carrier (SCPC) analog system. Under the enhancement plan, analog service will be reduced from 15 to 9 carriers. Some of the 28 digital carriers will provide multiple data and digital voice channels and video teleconferencing capabilities. Some users' Earth stations will be upgraded from 3-m to 6-m systems, and a 10-m system will be installed at the University of Hawaii as the network hub. ITS' role in the PEACESAT enhancement included defining technology options, reviewing contractor proposals, and providing technical support in testing the upgraded system.



Emergency scenario to evaluate advanced telecommunication technologies for NS/EP communications.

Recent NTIA Publications

Weibel, M.L., 1995, "Data communication performance testing of ACTS," NTIA Report 95-320.

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Advanced HF Testing and Evaluation

Outputs

- Facility for evaluating and comparing HF digital modems and protocols.
- Support for HF radio standards development.
- Audio compact disk for ALE interoperability testing.
- Anonymous FTP access to software for generating clean and degraded ALE tones.

HF radio is currently experiencing a revival in popularity, due, in part, to technological advances such as automatic link establishment (ALE) computer-controlled radios. The Institute has been in the vanguard of HF technology advances in several areas, including modeling, testing, and evaluation.

The Federal Emergency Management Agency depends on the large number of established HF radio operators to supplement its own resources during national emergencies. In an emergency situation, interoperability and transmission efficiency are vital. To help evaluate and compare the wide range of HF packet radio modems and their associated protocols, ITS has developed the HF modem/protocol test bed illustrated in Figure 1. Using two HF channel simulators, the test bed is capable of subjecting modems and protocols to a wide range of controlled and repeatable channel conditions. The test bed was designed to be flexible, allowing standard and nonstandard modems to be tested with little or no reconfiguration. The automatic features of its controller permit extended, unattended testing.

ITS is supplementing its HF simulation and laboratory test capabilities with field measurements. In the World-wide HF Network project, ITS engineers are cooperating with counterparts in other countries to develop an international test bed for advancing the state-of-the-art in adaptive HF communications, networking, high-speed data transmission, and reliable communications in stressed environments. Results are expected to be documented in national and international standards. This work is being conducted under the sponsorship of the National Communications System (NCS), which has overall responsibility for the development of Federal standards for adaptive HF radio. To achieve these goals, advanced HF radio technology contributions have been solicited from Government and industry through the Federal Register and the Commerce Business Daily. To date, several contributions have been received in response to these solicitations, and interest in this technology has led to the planning of multiyear over-the-air tests on a worldwide basis. An initial test network is nearing completion, with network nodes located at ITS, the Australian Defence Science and Technology

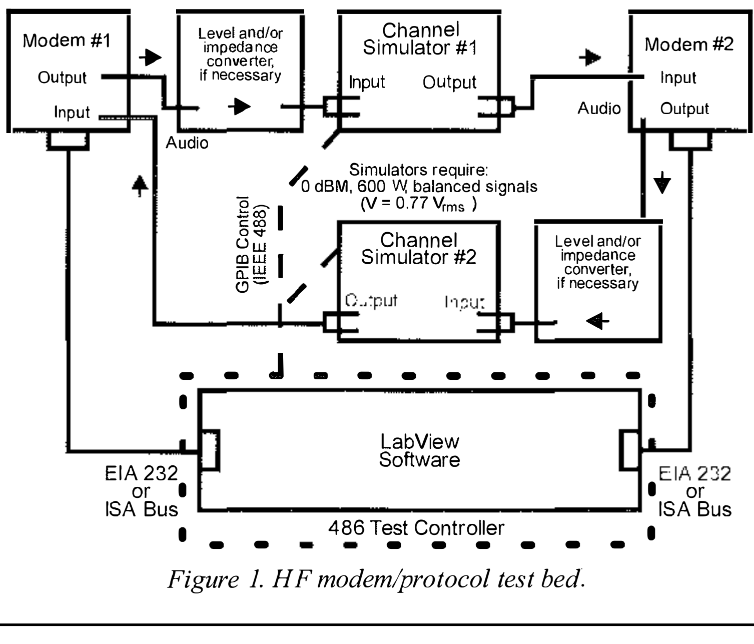

Figure 1. HF modem/protocol test bed.

Organization, Rome Labs, US Navy NRaD, and Rockwell International. Experiments will be used to determine the feasibility and performance of advanced HF communication protocols.

ITS personnel are currently developing an HF radio ALE network simulation capability based on proposed Federal Standard 1046, "Telecommunications: HF Radio Automatic Networking." The simulation programs will be used to study network performance, as an aid in preliminary evaluation of proposed standards features and changes, and in support of over-the-air network tests. These network simulation products will aid users, designers, and system administrators in determining efficient network resource configuration and utilization. HF radio channel efficiency, throughput, and delay can be substantially improved through proper selection and use of newly developed advanced network features and functions such as frequency scanning, sounding, polling, alternate or indirect routing, connectivity information exchange, automatic message exchange, and store and forward message exchange. However, these advanced capabilities have overhead implications and must be used carefully. The results of simulation studies will allow network users and administrators to balance network use and channel condition monitoring for optimum network utilization.

ITS is developing both network and single radio HF protocol models under the sponsorship of NCS. An ALE protocol model, based on the ITS-developed Federal Standard 1045A, "Telecommunications: HF Radio Automatic Link Establishment," was used to create an innovative, effective, and economical ALE radio test product, the ALE Clean Tones audio compact disk (CD). The ALE CD is now available to the public through NIST Special Databases. It is listed in the NIST Standard Reference Data Products Catalog 1995-96 (NIST Special Publication 782, 1995-96 Edition). For information on how to order, phone (301) 975-2208, FAX (301) 926-0416, or e-mail SRDATA@enh.nist.gov..The ALE CD has been used successfully in laboratory testing and has been distributed widely in the HF radio industry. The ALE CD directly supports the continuing ITS function of HF radio performance and interoperability testing. It has proven to be useful as an aid to HF radio vendors and users in interpreting and analyzing radio implementation of the Federal Standard. ITS is providing continued support to the High Frequency Industry Association and other Government agencies in extending the ALE CD capabilities to meet the needs of both radio users and vendors.

The alecall program was used to create the sounds recorded on the CD; it can also create sound files on a personal computer, which may then be played through a sound card. This ability to create ALE calls "on the fly" is useful for real-time laboratory testing and analysis. During FY 95, ITS engineers produced a version of the alecall program that imposes ionospheric propagation impairments on ALE waveforms. Digital signal processing techniques were used to simulate ionospheric conditions based on the Watterson HF channel propagation model (developed at ITS). A user may specify Gaussian noise, fading, or multipath conditions to the output signal. Using this new capability, ITS has created a set of degraded tones to assess radio system compliance with probability-of-linking statistics specified in Federal Standard 1045A. Using the program nfmgen (Noise, Fading and Multipath protocol GENerator), degraded conditions were applied continuously over a series of tone test sets, as shown in Figure 2. Corresponding degraded tones CDs, also targeted for performance and interoperability testing, were created and will be available in the near future.

The alecall program is available to the public by anonymous FTP through the Internet. FTP to ntia.its.bldrdoc.gov, entering ftp as your user name and your full e-mail address as the password. Retrieve the readme.txt file from the /dist/ale-cd directory for detailed file instructions.

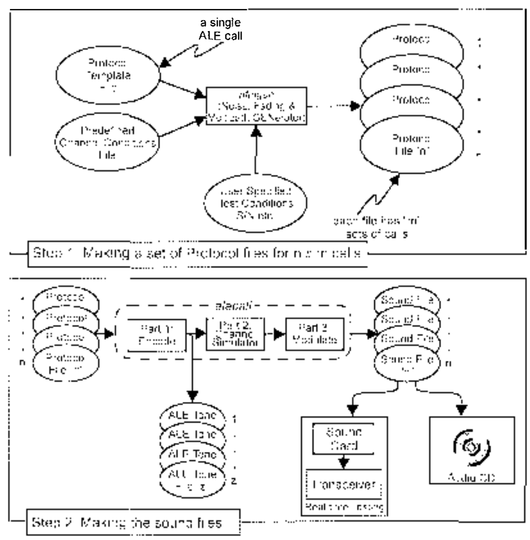

Figure 2. Generation of degraded ALE tones for testing Federal Standard 1045 radios.

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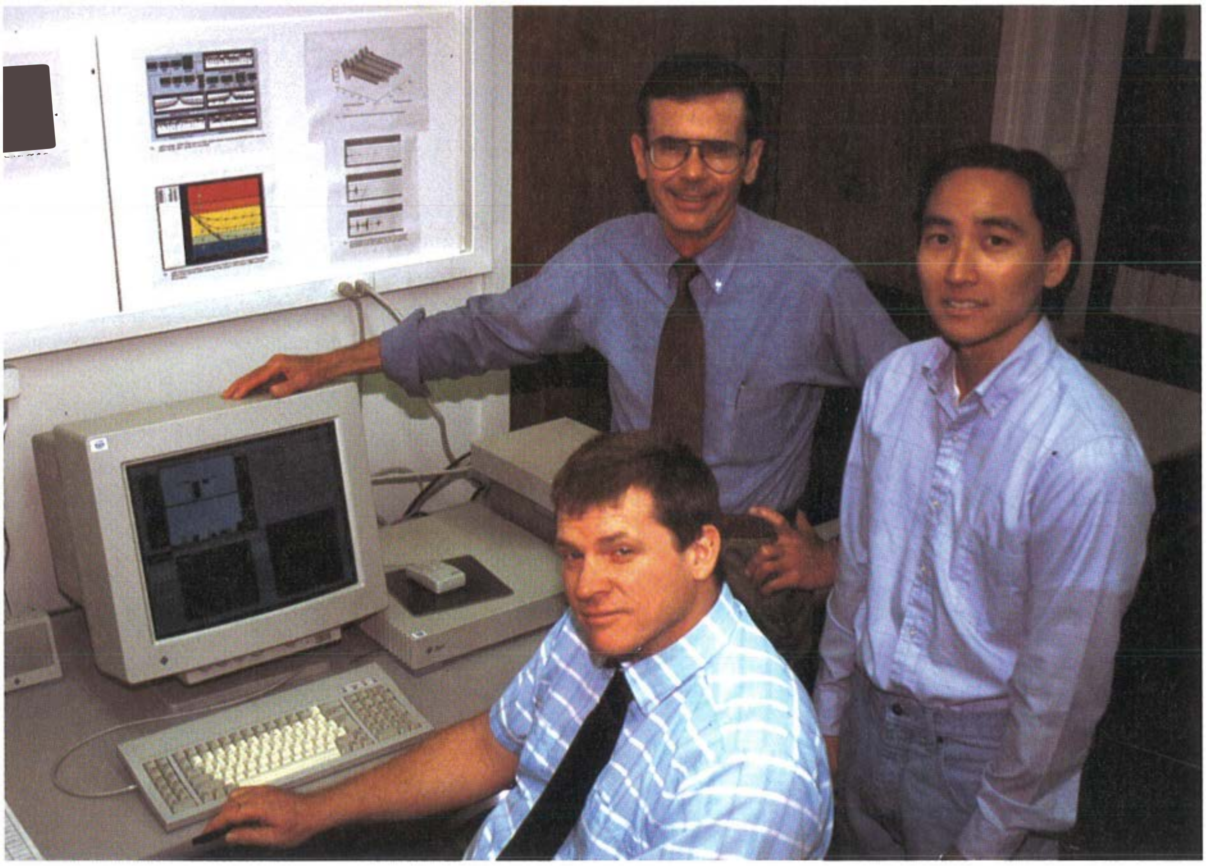

ITS staff members in the Wireless Simulation Laboratory at ITS (photograph by F. Sanders).

Applied Research

The rapid growth of telecommunications over the last 40 years continues to cause crowding in the radio spectrum, even though increasing amounts of telecommunication services are now carried by fiber optic systems. New applications of technology have required a new understanding of the behavior of radio waves in all parts of the radio spectrum. Research at ITS includes projects from the lowest frequencies (LF noise measurements) to the highest frequencies in use (millimeter-wave modeling).

This work extends ITS' expert understanding of the ways that propagation of radio signals is affected by the propagation medium comprised of the Earth's surface, the atmosphere, and the ionosphere. It is resulting in new propagation models for the broadband signals used in some of the new radio systems. Other efforts at ITS aid in increasing our understanding of the propagation of millimeter-wave frequencies, and providing a large band for future expansion of new radiocommunication services.

The Institute has a long history of radio-wave research and propagation prediction development that provides a substantial knowledge base for the development of state-of-the-art telecommunication systems. A major goal of ITS is to transfer this technology to the user community, both public and private, where knowledge is transformed into new products and new opportunities.

Areas of Emphasis

Cooperative Research with Industry

The Institute is actively engaged in technology transfer and commercialization efforts by fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities. Projects are funded by US WEST Advanced Technologies, Inc. (US WEST), Telesis Technologies Laboratory (TTL), General Electric Co., Motorola, Inc., and Hewlett-Packard Co.

PCS Measurements

The Institute leads and contributes to the understanding of the PCS radio propagation channel necessary for the design and development of PCS systems. Projects are funded by NTIA, US WEST, and Motorola, Inc.

Millimeter-wave Research

The Institute conducts research and adds to the knowledge of factors affecting the millimeter-wave radio propagation channel. The results of the research enable industry to develop and deploy local multipoint distribution service systems. Projects are funded by NTIA, Hewlett-Packard Co., and TTL.

Wireless Channel Modeling and Simulation

The Institute conducts software simulation of the radio channel to predict performance for new radio systems without the cost and delay of building hardware systems. Projects are funded by NTIA and the National Security Agency.

Wireless Link Modeling and Simulation

The Institute conducts wireless link software simulation of the radio system and channel for a variety of channels, modems, processing techniques, and sources. Projects are funded by NTIA.

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.

Cooperative Research with Industry

Outputs

- A study of broadband millimeter wave propagation to assist in the evaluation, planning, and deployment of local multipoint distribution services.
- Measurements of channel impulse response from 800 MHz to 2 GHz for characterization of broadband propagation in urban and suburban microcells and macrocells.

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

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

ITS has been a premier laboratory in millimeter-wave research for over two decades. Now ITS is applying this unique expertise while conducting research into radio propagation considerations for local multipoint distribution services (LMDS). It has been proposed to put LMDS systems in the frequency band from 28-38 GHz where equipment is not well-established and propagation effects are not entirely known. ITS has entered into CRADAs with TTL and HP for LMDS research. Under current agreements, ITS is developing propagation models for the LMDS channel, making field measurements to characterize radio frequency propagation of an LMDS system, and reviewing the performance of LMDS equipment.

As part of an earlier agreement with TTL, ITS developed 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. The probe has a dual, independent channel design and has the capability of absolute time measurement and Doppler spread measurement. The digital sampling channel probe has been used to obtain channel impulse response measurements to characterize wideband radio propagation in a wide variety of environments and applications. ITS has made measurements in urban high-rise, suburban, rural hilly-terrain, and rural flat-terrain environments, and investigated features such as antenna diversity, Doppler shift, and angle-of-arrival.

ITS also has a CRADA with Superconducting Core Technologies (SCT), for research on superconducting microwave devices. Under this agreement with SCT, ITS will assist in testing the performance of devices for use in wireless communication networks, and will consult on circuit designs and fabrication techniques to meet the defined performance specifications. Once filter and oscillator prototypes of appropriate performance have been developed, ITS and SCT will cooperatively test the prototypes in the field. ITS will also assist SCT in investigating the application of voltage-tunable superconducting microwave filters and oscillators to improve the performance and reduce the cost of Government wireless communication systems.

Much of the Institute's work in personal communications services (PCS) has been accomplished through CRADAs. Under CRADAs with Motorola and US WEST, ITS has conducted field measurements to characterize the PCS radio channel in a variety of urban and suburban environments. These measurements are described in more detail in PCS Measurements on page 64. As part of the CRADA with US WEST, ITS also provided a site for an experimental PCS base station that is part of the Boulder Industry Test Bed (see the Figure). ITS is serving as an independent observer as the Joint Technical Committee on Wireless Access conducts field trials of proposed PCS air-interface standards in this test bed. This work will further ITS' support of PCS standards and the rapid deployment of PCS wireless communication systems.

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

ITS is interested in assisting private industry in all areas of telecommunications as appropriate. The pages of this technical progress report reveal many technological capabilities that may be of value to various private 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 emerging telecommunication technologies, including PCS, wireless local area networks, digital broadcasting, LMDS, the National Information Infrastructure, and intelligent transportation systems, ITS plans to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. In addition, ITS plans to commit substantial resources of its own to the development of these new technologies and standards.

Antenna of a PCS base station in the Boulder Industry Test Bed (photograph by F. Sanders).

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PCS Measurements

Outputs

- Data analyses and NTIA report on building penetration measurements from low-height base stations at 912, 1920, and 5990 MHz.
- Impulse response measurements in various macrocells in Phoenix, Arizona and Los Angeles, California.
- Report on impulse response measurements in the 1850- to 1990-MHz band for channel modeling applications.

Personal communications services (PCS) comprise the second generation technologies of digital mobile telephone service. These include voice and data services coupled with the benefits of advanced network capabilities. While PCS was originally envisioned as an advanced mobile telephone system based on a microcell architecture, due to market forces it has become a system more similar to digital cellular service (although operating at higher frequencies). PCS, however, does offer such services as paging and short messaging, not provided by digital cellular service.

Over the past year, several major developments have paved the way for development and deployment of PCS. Spectrum was allocated for PCS, rules were established by the Federal Communications Commission (FCC), spectrum auctions for licenses in some of the allocated bands were completed, and the establishment of air-interface standards for PCS neared completion.

Despite these recent developments, the noise and interfering environments and the characteristics of the radio propagation channel in which PCS systems will operate are still not well-known. Knowledge of these environments and the channel characteristics is needed before PCS systems can be designed, implemented, and deployed. Therefore, radio propagation measurements continue to play an important role in these aspects of PCS development.

In FY 95, ITS staff members conducted building penetration and impulse response measurements for PCS. Building penetration measurements are of interest in the deployment of PCS systems because an outdoor cell has the potential to provide service to indoor subscribers. This would greatly reduce the need for indoor base stations and the associated problems of handoff between indoor and outdoor base stations; this would thus produce tremendous cost-savings.

Received signal power data from a set of narrowband building penetration measurements taken near Boulder and Denver, Colorado were analyzed. Data analyses included path loss distributions, penetration losses, building shadowing loss, loss into basements, slow fading, fast fading, and variations in loss due to frequency, building height, and building construction. The results of the analyses provided a comparison of propagation effects between 912, 1920, and 5990 MHz; between residential and high-rise office buildings; and between line-of-sight (LOS) and non-line-of-sight (NLOS) paths. Figure 1 shows the cumulative distribution of building penetration loss along NLOS paths in residential buildings. Note how the penetration loss increases with increasing frequency. This result was observed consistently for the residential buildings, but in some of the high-rise office buildings penetration losses were lower at 1920 MHz than at 912 MHz. Building penetration losses were significantly greater into basements than into other levels of the buildings. The high-rise buildings showed greater building penetration losses than the residential buildings. The results of these measurements and analyses are discussed in more detail in NTIA Report 95-325, written in FY 95.

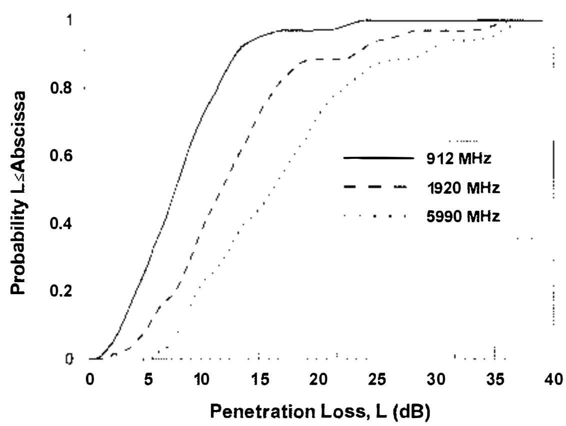

Figure 1. Cumulative distribution of building penetration loss for NLOS paths in residential buildings.

Impulse response measurements of the radio propagation channel are important in the design, development, and planning of radio systems since they provide a more complete description of the channel than narrowband measurements. With the knowledge of the noise and interfering environment, impulse response measurements can be used to predict radio system performance.

The Institute has two different types of impulse response measurement systems suitable for PCS measurements. Both systems can be configured for different bandwidths (and therefore resolutions), maximum measurable delays, and carrier frequencies. One of these systems, the digital sampling channel probe, has been used to identify reflections differing in path length by as little as 40 feet, making it ideal for outdoor measurements. It also can measure impulse responses rapidly. The time required to generate an impulse response is dependent upon the specific configuration used. One commonly used configuration produces an impulse response within approximately 51 μs. The digital sampling channel probe is a dual-channel design permitting simultaneous measurements of any combination of two carrier frequencies, antenna polarizations, or antenna spacings. When a resolution finer than 40 feet is desired, an analog sliding correlator channel probe is available that provides a maximum resolution of 2 feet. This channel probe is ideal for making indoor measurements.

Mobile impulse response measurements at 915 MHz were conducted in both Phoenix, Arizona and Los Angeles, California as part of a cooperative research agreement with Motorola, Inc. The primary purpose of these measurements was to aid in the deployment of a new code-division multiple access (CDMA) system in these areas. Impulse responses were measured within existing macrocells (cell radii typically around 1-3 miles) where service is currently provided by Advanced Mobile Phone Service (AMPS) systems. An example base station and antenna tower at a cell site in Los Angeles, California, is shown in Figure 2. The measurements were taken using the digital sampling channel probe and represent the most advanced impulse response measurements performed at the Institute to date. Besides providing a large number of independent complex impulse responses within each cell, the measurements include Doppler, absolute time, and position information.

Results of the measurements are being used to model the performance of the new CDMA system. Additionally, the data were analyzed to determine optimal RAKE receiver parameters for each environment to maximize receiver performance.

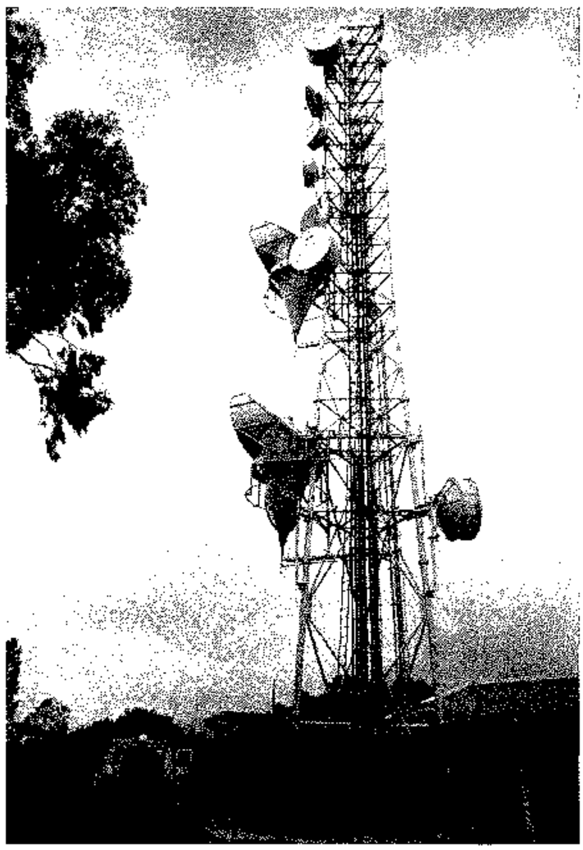

Figure 2. Cellular base station and antenna tower at a cell site in Los Angeles, California (photograph by F. Sanders).

Recent NTIA Publications

Loew, L.H., Y. Lo, M.G. Laflin, and E.E. Pol, 1995, “Building penetration measurements from low-height base stations at 912, 1920, and 5990 MHz,” NTIA Report 95-325.

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Millimeter-wave Research

Outputs

- LMDS propagation channel measurements.
- Millimeter-wave propagation channel models.
- Simulation of LMDS performance including effects of nonlinear radio equipment, propagation channel, and noise.

Over the past few years, consideration has been given to the reallocation of frequencies in the extremely high-frequency (EHF) band so that wireless video, voice, and data services could be made commercially available to consumers. The potential availability of spectrum for these “wireless” services, 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 predicting atmospheric effects (e.g., attenuation and dispersion by absorption lines). Through cooperative research and development agreements, ITS is applying its technical expertise in millimeter waves to problems of commercial interest in the planning and development of LMDS.

Current research activities include the development and implementation of measurement strategies that will enable the characterization of an LMDS system operating in a microcellular environment (< 0.7 km). The objectives of the measurements are to determine area coverage for microcells, cell-to-cell interference, delay spread, and fast-fading statistics for proposed radio channels. The resulting data will be used to develop statistical environmental models that can be used to simulate the performance of both currently available and proposed radio frequency systems.

In addition, ITS is in the process of developing simulation models tailored to specific problems associated with LMDS. The models are designed to combine the effects of radio frequency equipment, and the propagation channel (e.g., multipath fading, interference from adjacent transmitters, and noise) with a variety of modulation methods to determine the optimum design in terms of coverage area and spectrum utilization. Digital methods under study include both the serial transmission of symbols and more recently developed parallel methods such as orthogonal frequency division multiplexing (OFDM). A variety of digital modulation techniques such as m-ary phase shift-keying and quadrature amplitude modulation are utilized. LMDS simulation capabilities include the effects of nonlinear amplifiers (e.g., traveling wave tube; TWT) which are commonly used for wideband broadcasts in the EHF band. The simulation models are used to predict system performance in the presence of deleterious effects such as intermodulation; multiplicative noise, including co-channel interference; and additive noise.

The Figures on the following page show typical simulation results. Figures 1 and 2 show the effects of a TWT amplifier (operating at saturation) on the received constellation in the case of quadrature phase shift-keying (QPSK). Figure 1 is the received signal for a serial transmission of symbols. Note the rotation (AM/PM conversion) and scatter due to intermodulation products. Figure 2 shows the received signal for OFDM. Here, much of the scatter and rotation have been removed by equalization. Figure 3 is a characterization of a typical diffuse propagation channel composed of uncorrelated scatterers. Figures 4 and 5 show the effects of this propagation channel on the received constellation for QPSK (serial transmission of symbols). Figure 5 shows the improvement when a 91-tap least mean squares equalizer is applied.

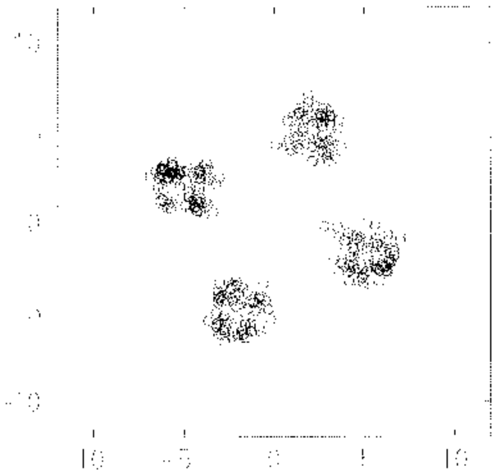

Figure 1. A received QPSK constellation showing the effects of a nonlinear transmitter amplifier (serial transmission of symbols).

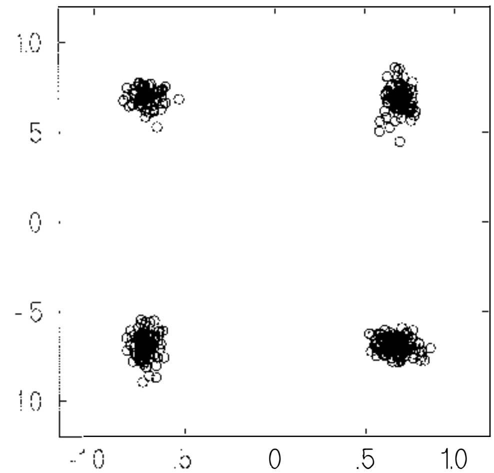

Figure 2. A received QPSK constellation showing the effects of a nonlinear transmitter amplifier (OFDM, equalized).

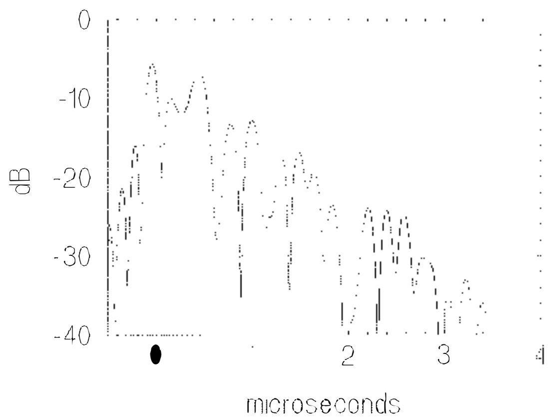

Figure 3. Channel response for a diffuse channel consisting of uncorrelated scatterers.

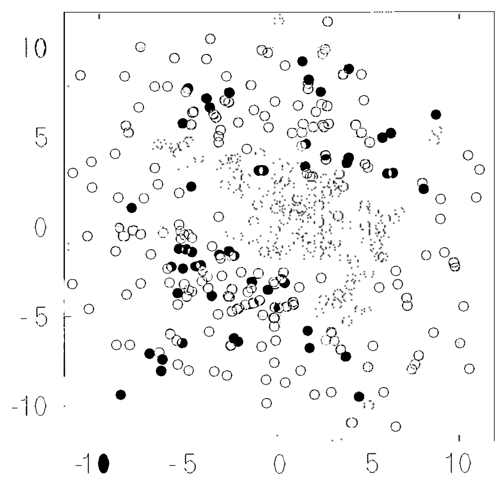

Figure 4. Received QPSK constellation showing the effects of the propagation channel without equalization (serial transmission of symbols).

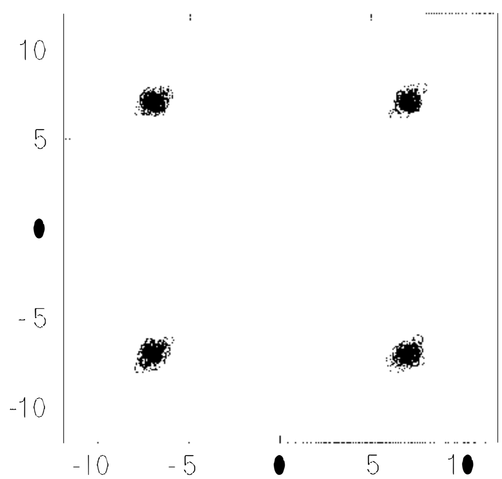

Figure 5. A received QPSK constellation using a 91-tap equalizer (serial transmission of symbols).

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Wireless Channel Modeling and Simulation

Outputs

- Validation of channel models and simulation software modules.
- Simulation of impulse responses employed in performance prediction of wireless links.
- Simulation of channel time-varying impulse responses and transfer functions.
- Calculation of power delay profile, delay spread, and Doppler spectra of simulated impulse responses.

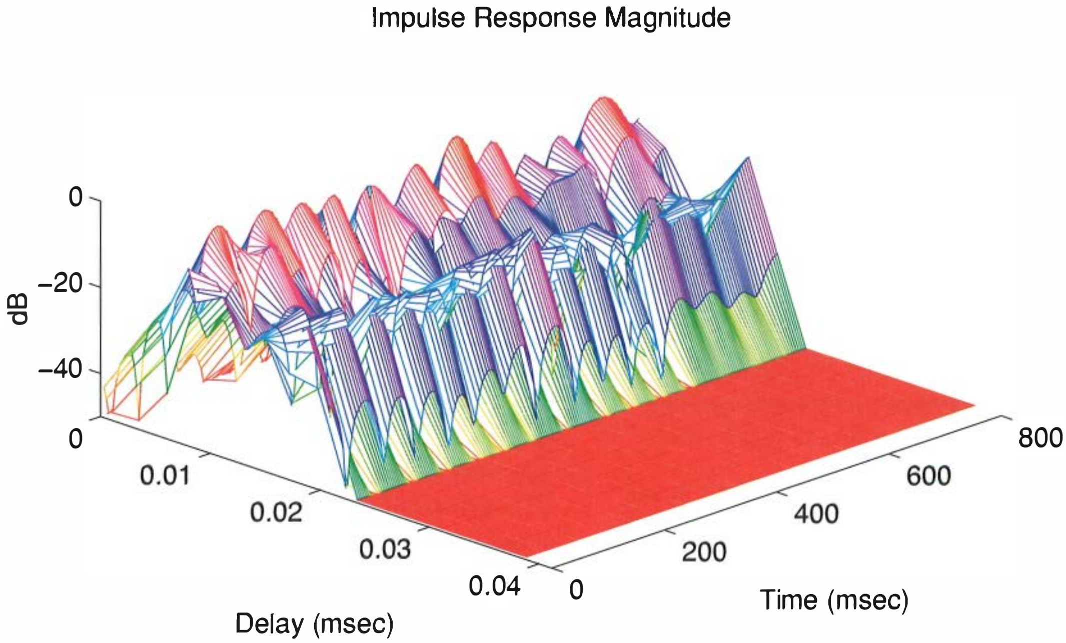
Rapid development of wireless technology has stimulated the need for performance prediction of these systems before they are built, standardized or deployed. Channel models representative of the deployment environment are essential to providing realistic performance predictions. ITS has been conducting research on radio channel propagation, impulse response measurement and modeling, and software simulation of the channel for many years. Channels include ionospheric, outdoor macrocell and microcell, and indoor microcell environments. In recent years, ITS has incorporated these software channel models in complete simulation of radio links to predict system performance.

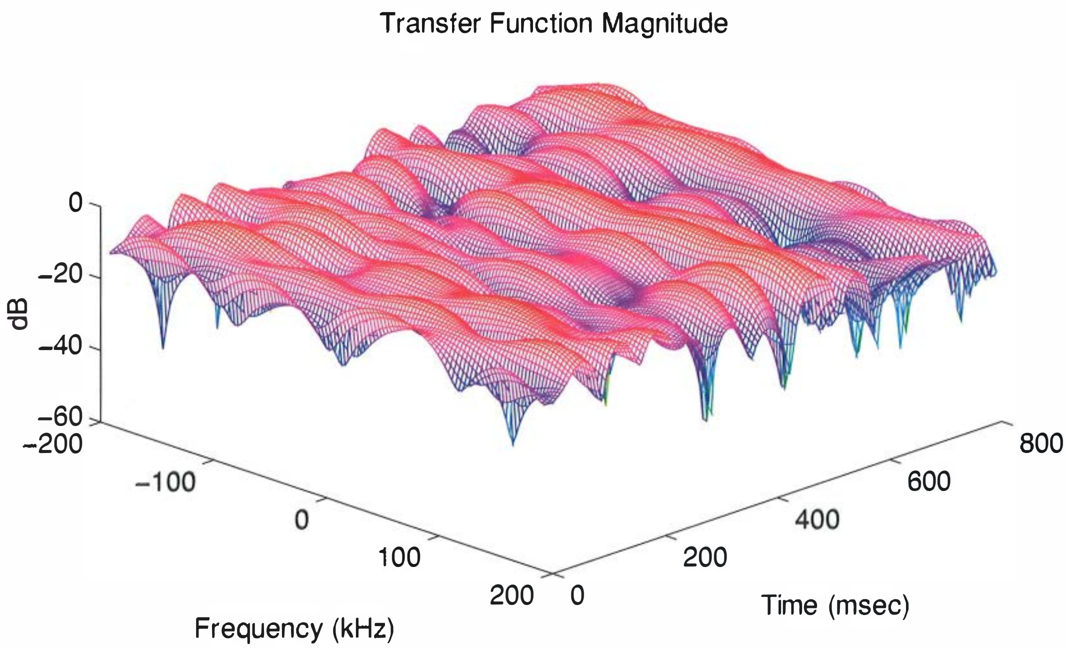
Recently, a tapped-delay line generic channel simulator (GCS) software package was developed by the MITRE Corporation under the sponsorship of the National Security Agency (NSA). The Joint Technical Committee (JTC) has adopted a set of standard channel models with parameter specifications for a variety of wireless deployment environments. This GCS software was made available to the JTC to provide a common basis of link evaluation. ITS has received this GCS software from NSA and is validating the software using the JTC model parameters. In addition, ITS is employing impulse responses from the channel simulator in a wireless link simulation package to predict performance of the proposed JTC modem standards.

Currently, ITS is simulating and predicting performance of the IS-54 proposed standard that incorporates a $\pi/4$ quadrature phase shift-keyed (QPSK) modem and time-division multiple access.

The GCS software can generate impulse response for a suite of models for personal communications services, HF, and mobile channels. The JTC has published model parameters for one set of PCS environments. ITS is working cooperatively with MITRE Corporation to extract new model parameters from ITS' field measurements of impulse responses and to validate the GCS software for these parameters. This new development will provide the radio and wireless development and testing community with standard simulator software and models based on ITS field measurements.

The Figure illustrates the magnitude of the time-varying impulse responses and corresponding transfer function produced by the GCS software with parameters set in accordance with a JTC-specified channel and environment. The PCS case selected for this validation corresponds to an urban/suburban low-rise, low antenna, pedestrian environment. The six tapped-delay line parameters were specified for their worst channel conditions and a pedestrian velocity of 3.36 mph in the JTC (AIR)/94.08.01-065R4 Draft Final Technical Report on RF Channel Characterization and Deployment Modeling. Simulations are conducted at baseband employing a complex in-phase and quadrature component form. Peaking of the impulse response can be observed around 0.01 msec, corresponding to the longest tap delay. Bandlimiting effects cause smearing of the individual tap responses over a significantly longer delay than 0.01 msec. Doppler shift effects corresponding to pedestrian motion can be observed by the fading of both the impulse response and transfer function as time varies.





Validation of a simulated JTC urban/suburban low-rise, low antenna channel model for worst channel conditions in a pedestrian application.

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Wireless Link Modeling and Simulation

Outputs

- Channel simulation (impulse response, noise, and interference) software modules.
- Validated system and channel simulation software modules.
- Predicted bit error rate performance as a function of signal-to-noise ratio and interference.
- Predicted speech and image quality as a function of bit error ratio, signal-to-noise ratio, and interference.

ITS has been conducting research of wireless systems for many years. Past efforts include radio channel propagation and impulse response measurement and modeling; software simulation of the channel for system performance prediction; hardware simulation of the channel for system hardware testing; and network performance prediction. Recent efforts have predicted link 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 (LMR), wireless private branch exchange (WPBX), global system for mobile communications (GSM), wireless local area networks (WLAN), 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, images, and automatic link establishment signals. Performance is described by bit error ratio (BER), frame error ratio, eye diagrams, in-phase/quadrature (I/Q) diagrams, character error ratio, speech quality, and image quality.

Figures 1 through 4 illustrate the predicted performance of a GSM digital cellular system traveling through an urban low-rise environment (near downtown Boulder, Colorado) while operating in the 900-MHz frequency band with a data rate of 271 kbps. GSM provides European countries with a standard digital cellular architecture for communications and is a proposed standard for U.S. digital cellular service. A voice-encoded speech source was transmitted by a GMSK modem through a channel model derived from ITS impulse response measurements. The system employed a convolutional channel encoder, Viterbi decoder, and a minimum-mean-square-error equalizer. Similar, but uncorrelated GSM cochannel interference was introduce in the channel and is represented in the performance specifications by the carrier-to-interference ratio (CIR).

Figures 1 and 2 show how voice-encoded speech and image quality performance can be predicted for wireless systems through software simulation by relating regions of speech quality to the system and channel operational parameters: BER, signal-to-noise ratio (SNR), and CIR. Figures 3 and 4 provide examples of Class 5 and Class 2 received speech and image quality. Class 5 represents the best quality and Class 2 represents marginal quality. Errors in the received bits were introduced by additive white Gaussian noise, a 5-path channel with an approximate delay spread of one-half of a symbol period, and cochannel interference. Predicted performance of wireless systems is used to compare proposed wireless standards, determine design specifications, and select deployment parameters of military and commercial communication systems.

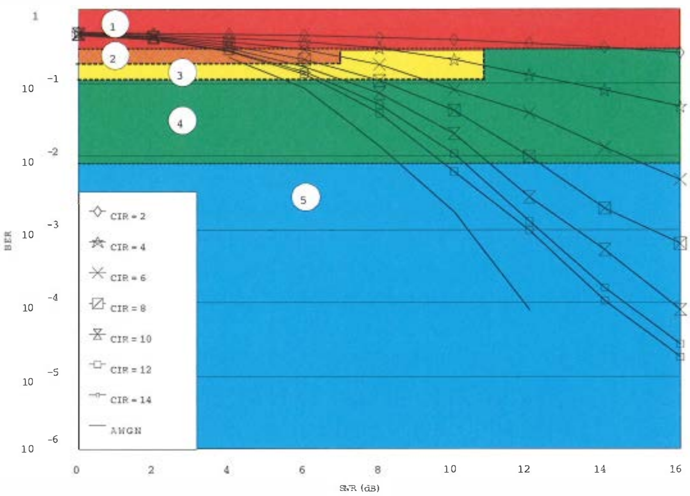


Figure 1. GSM performance relating speech quality to system and channel parameters (circled numbers associated with colored bands indicate quality classes).

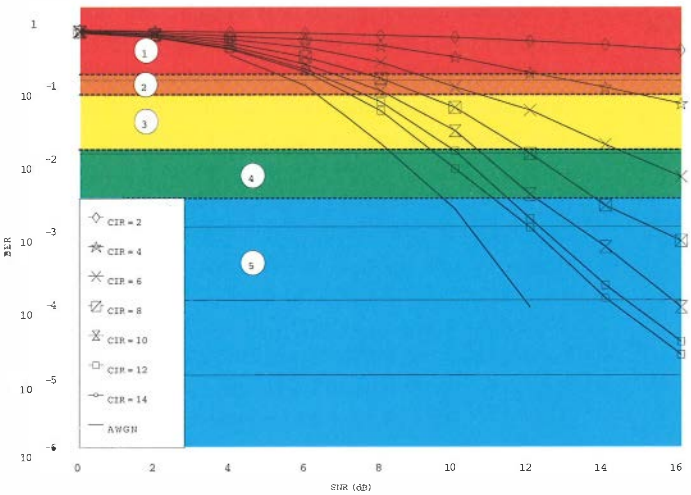
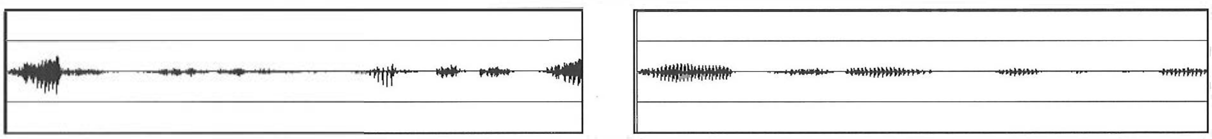
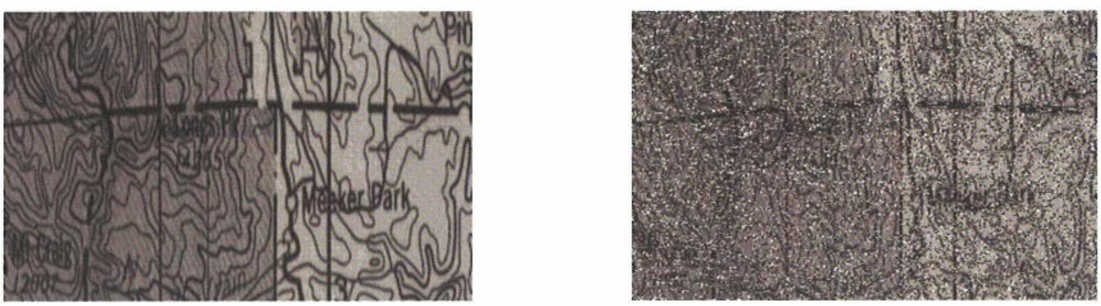


Figure 2. GSM performance relating image quality to system and channel parameters (circled numbers associated with colored bands indicate quality classes).



(a) (b)

Figure 3. GSM speech waveforms received under two operating conditions: (a) Class 5 (SNR = 16 dB, CIR = 12 dB, BER = 0.0000270) and (b) Class 2 (SNR = 8 dB, CIR = 8 dB, BER = 0.107).



(a) (b)

Figure 4. GSM images received under two operating conditions: (a) Class 5 (SNR = 16 dB, CIR = 12 dB, BER = 0.0000270) and (b) Class 2 (SNR = 6 dB, CIR = 8 dB, BER = 0.208).

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HF Channel Modeling and Simulation

Outputs

- Wideband/narrowband HF channel model valid for many propagation conditions.
- Real-time HF channel propagation, noise, and interference simulator that implements the wideband/narrowband model.

HF propagation models have existed for many years, but have been restricted to narrowband channels (e.g., 3 kHz) and to a limited set of observed propagation conditions. The traditional models also do not address noise and interference, which can dramatically affect the end-to-end performance of HF radio systems. Recent technology advances and increasing user interest in digital HF communication systems have created a need for accurate modeling and real-time simulation of propagation, noise, and interference effects in HF channels with bandwidths up to 1 MHz. During FY 95, ITS continued to develop an advanced computer-controlled hardware simulator to meet that need. The simulator is expected to be used to develop and evaluate advanced HF systems and equipment including wideband (1 MHz) direct sequence spread-spectrum HF radios.

The channel model ITS developed consists of a deterministic part and a stochastic part. The former represents the theoretical median of the channel, while the latter simulates the time-varying distortion of a transmitted signal due to dispersion and scattering caused by irregularities in the ionosphere. Three ionospheric parameters are used by the deterministic model for each propagation mode: layer height of maximum ionization, layer thickness, and penetration frequency. The output can be thought of as a median ionogram (the variation of propagation delay as a function of the operating frequency). The three ionospheric parameters are obtained from an ionospheric prediction program capable of providing the parameters for any specified path, month, time of day, and sunspot number.

The stochastic model was formulated by developing an expression for the scattering function, which is the Fourier transform over time of the complex received signal autocorrelation function C1(r; t) and consists of three parts: Doppler spread, delay spread, and a phase function that provides both a basic Doppler shift and a variation of Doppler shift with the delay r. Once the two models were developed, the channel transfer function was derived for use in the hardware channel simulator.

Previously, ITS staff members developed a prototype hardware channel simulator that implements the wideband HF propagation, noise, and interference models in real time. In FY 95, ITS began constructing an improved version of the simulator (Figure 1). The simulator is capable of testing all HF systems (conventional narrowband, frequency hopping, or direct sequence-spread spectrum) in a realistic fading, noise, interference, and jamming environment. The processing occurs digitally at baseband. The digital filter that implements the propagation channel is implemented in the frequency domain and is downloaded from the master computer to update the channel characteristics at periodic intervals.

The noise models consist of a narrowband interference model and a man-made noise model implemented in the frequency domain, as well as an impulsive noise model and a Gaussian noise model implemented in the time domain. The jamming signal model is implemented in the frequency domain.

The system has significant flexibility in its design. An entirely different channel model can be downloaded into the simulator, the filter length can be changed, and different jamming signals can be added as desired. The RF and IF conversion sections were designed and built at ITS. The FFT and IFFT sections are implemented using commercially available, high-speed, FFT-specific digital signal processing boards. The frequency-domain and time-domain effects are implemented using commercially available, digital signal-processing boards. A standard, 80486-based desktop computer, running software written at ITS, is used to control the entire system over a VME bus. The computer also calculates the transfer function and noise model values and downloads these over the bus at specific intervals. A photograph of the system is shown in Figure 2, while the controller's display is shown in Figure 3. Many of the channel modeling and simulator design techniques developed in implementing the HF wideband/narrowband channel simulator could be adapted for use in simulating other channel types.

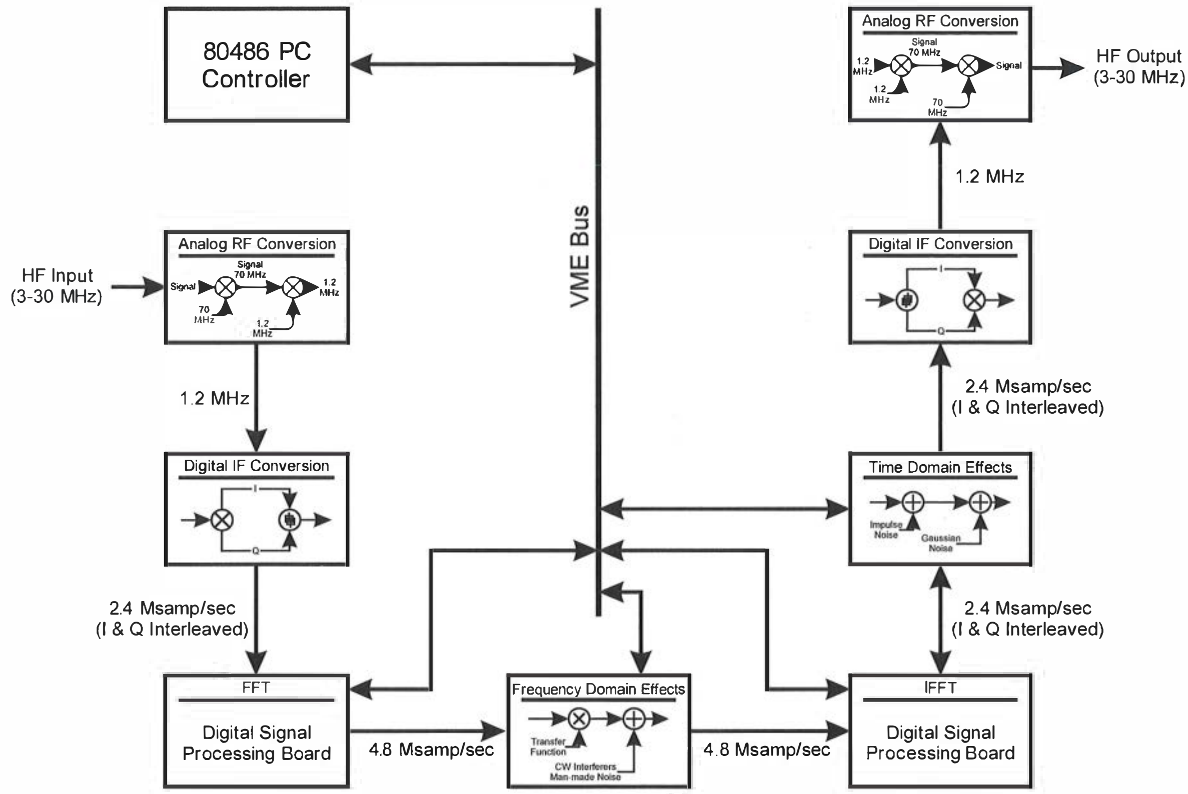

Figure 1. Block diagram of a wideband HF simulator.

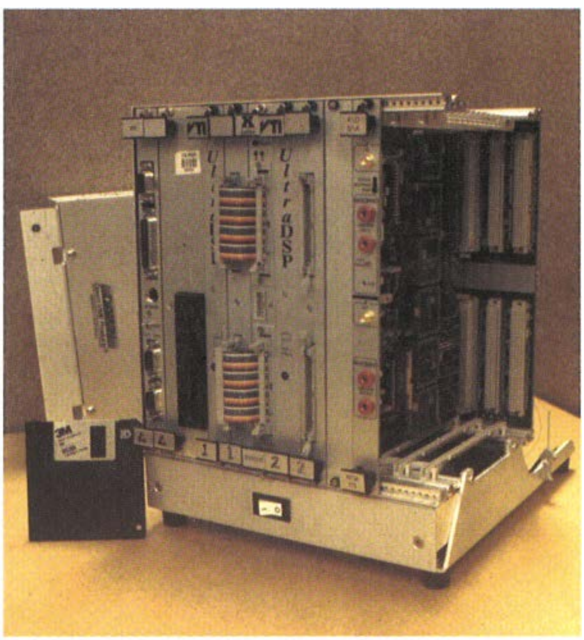

Figure 2. Wideband HF simulator (photograph by F. Sanders).

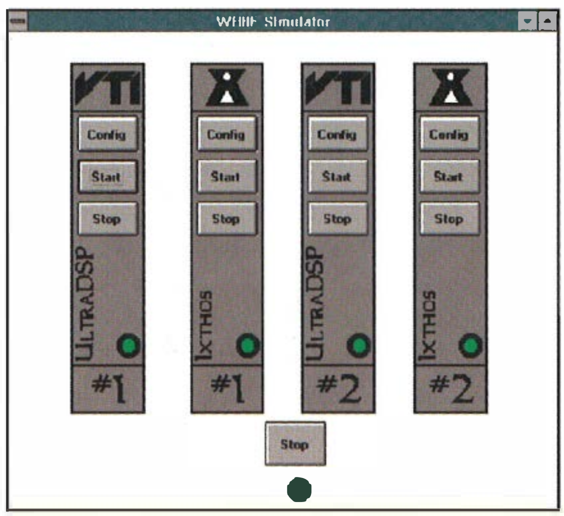

Figure 3. Wideband HF simulator control panel.

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Radio research measurement van configured for a 30-GHz local multipoint distribution services propagation study. This vehicle, equipped with a GPS dead-reckoning system, is used for mobile cellular radio, PCS, and millimeter-wave measurement studies (photograph by F. Sanders).

ITS Tools and Facilities

Advanced Communications 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 NASA, and associated performance measurement equipment. The experimental Ka-band ES is capable of a 1.8-Mbps data rate, integrated services digital network (ISDN) communications, and full-mesh connectivity with other ACTS ES's. The performance measurement equipment includes two data communication test sets and three voice quality assessment systems. The data communication test sets consist of UNIX workstations, an ISDN miniswitch, ISDN terminal adapters, satellite clocks, and modems. 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 measurements. The performance measurement equipment is being used to characterize the communication service provided by ACTS from the user's perspective. The ACTS test facility is available for Government, industry, and university use given approval by the NASA ACTS Experiment Office.

Audio Quality Laboratory

The Audio Quality Laboratory supports ITS' audio quality research and standards development. The laboratory equipment allows high-quality recording, analysis, and reproduction of digital audio signals. It includes workstations with 16-bit analog-to-digital and digital-to-analog converters, a computer-controlled digital audio tape recorder, a compact disk player, a spectrum analyzer, signal generators, level meters, mixers, amplifiers, microphones, speakers, and headphones. This equipment and customized software and databases of subjectively rated digital audio signals allow ITS staff to determine the impact of various coding and transmission systems on the perceived quality of audio signals. They also allow staff to develop and test objective measurements of the perceived quality of audio signals.

The laboratory also supports the design and construction of prototype portable audio quality test instruments. These instruments are constructed by adding sound cards and customized software to portable personal computers. 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.

Digital Sampling Channel Probe

ITS, in a joint effort with Telesis Technologies Laboratory, has developed and patented an innovative digital sampling channel probe (DSCP) for personal communications services measurements. The probe consists of a separate transmitter and receiver section. Ideal for making outdoor impulse response measurements, the DSCP can be used to characterize wideband propagation in the radio channel. The system currently can transmit two different pseudorandom noise codes on different carrier frequencies, with different antenna polarizations, or with different antenna spacings. In the typical configuration, the null-to-null bandwidth of the probe is 20 MHz providing a delay resolution of 100 ns and a maximum measurable delay of 51 s. The probe can be configured easily for wider bandwidths (finer time resolution) and different maximum delays.

The dual-channel design allows the implementation of different carrier frequencies, antenna spacings, or antenna polarizations at the receiver and at the transmitter. With a personal computer used to control the receiver, the signal is converted to an intermediate frequency and then digitized. The in-phase and quadrature phase components of the impulse responses are then computed by software. The system has a processing gain of 27 dB with a receiver noise figure of approximately 8 dB. In addition, it can measure absolute time-of-flight and Doppler spread. Recently, the system received two improvements: 1) the addition of automatic gain control at the receiver, providing greater dynamic range; and 2) global positioning system monitoring capabilities, which provide speed and location information. Currently, the DSCP is being configured for rapid acquisition (3 ms or more between impulses) for extended periods of time and real-time processing of impulses. Future plans include expanding the probe to more channels for use in measurements helpful in analyzing the potential benefits of adaptive antenna arrays.

HF Communications System Test and Evaluation Facility

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

The 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 FED-STD-1045A is available to all Government agencies, industry, and other ALE users. With a standard audio CD player, anyone can use the ALE CD to test a radio against FED-STD-1045A. The test is performed by connecting the headphone jack output of the player to the voice-activated input of a 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.

The HF channel and modem software simulator consists of software modules for testing ALE protocols, 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 are also useful to HF ALE radio users, standards developers, network designers, and radio manufacturers and vendors.

The real-time hardware channel simulation capability at ITS 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 capability 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 to support the Federal Emergency Management Agency (FEMA); 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. Proof-of-concept testing has also been conducted for more robust, high-speed systems such as the proposed Federal Standard 1052, “Data Link Protocol.”

Integrated Networks Simulation Environment

Computer-based modeling and simulation is a research tool that is rapidly growing in the field of telecommunications engineering for network-level performance prediction and design optimization. ITS maintains a comprehensive environment for model development and communications network simulation. The modeling and simulation tools available in this environment include the object-oriented Optimized Network Engineering Tools (OPNET) program and the Block Oriented Network Simulation (BONeS) program for developing, executing, debugging, and analyzing simulation models. These programs are hosted on Silicon Graphics and SUN workstations in a networked environment to allow sharing of resources between researchers. The OPNET and BONeS tools have flexible capabilities for modeling complex telecommunications networks including ethernet and FDDI LANs, packet- and circuit-switched networks, asynchronous transfer mode networks, satellites links, and other systems.

Integrated Networks Test Bed

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

ITS' Local Area Network

ITS maintains a state-of-the-art local area network (LAN) that provides public information to the Internet and also supports important computing applications and internal information services. The LAN's structured design and open systems approach allows ITS to respond rapidly to changing information technologies and new telecommunication research, engineering, and standards programs. A structured cabling system featuring both optical fiber and Category 5 twisted-pair cables to each desktop provides flexibility in delivering high-bandwidth services wherever they are needed. Since 1992 this system has interconnected every laboratory and office at ITS, allowing reconfiguration of logical networks and test beds to suit different research programs. The Transmission Control Protocol/Internet Protocol (TCP/IP) suite and the Network File System (NFS) are the network's main protocols. This applications software on over 180 PCs, Macintosh computers, printers, and UNIX workstations provide internal file and printer sharing, e-mail, network news, and other services for over 100 staff members. Public services include the ITS World Wide Web (WWW) site and documents available through anonymous FTP (ftp.its.bldrdoc.gov). ITS' WWW Home Page is located at URL address http://www.its.bldrdoc.gov. Any ITS employee may be contacted via Internet e-mail using the following format: <first initial><last name>@its.bldrdoc.gov. General and publications information is available from info@its.bldrdoc.gov. For more details on ITS' networks and information services, please contact Darren L. Smith at (303) 497-3960 (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 frequency range of 10-220 GHz. 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 Kelvins. 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 conducting experiments that are representative of satellite heights for most applications. This tool is available for use by private parties on a reimbursable basis.

Microwave LOS and Troposcatter Channel Probes

ITS uses these channel probes to measure the amount of multipath on either line-of-sight (LOS) or troposcatter communication links. Multipath is the result of reflections, scattering, or atmospheric refraction of the signal as it propagates from the transmitter to the receiver. It causes a deterioration of radio performance. Channel probes are used to measure the amount of multipath, which is a dynamically changing quantity, when radio performance is measured. This permits a correlation of the amount of multipath with the performance level of a radio.

Mobile Millimeter-wave Measurement Facility

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

Radio Spectrum Measurement System

The radio spectrum measurement system (RSMS) is a self-contained, vehicularly mounted system owned by ITS. It is used by agencies within the U.S. Department of Commerce and is also available for use by other Government agencies and by private industry on a cost-reimbursable basis. The RSMS can be used to perform spectrum measurements between 1 MHz and 19.7 GHz. To accomplish this, the RSMS incorporates two separate internal systems: one system that measures from 1-2 GHz, and another system that measures from 900 MHz to 19.7 GHz. The vehicle is RF-shielded, contains two 30-ft masts, an on-board 10-kW generator, air conditioners, four equipment racks, and storage space. The RSMS utilizes extensive computer control with software written by ITS. RSMS measurements can be performed in fully automatic, semiautomatic, and fully manual modes. Types of emitters that the RSMS can measure include mobile radios, fixed communication links, radars, ISM devices, broadcast signals, and special-purpose transmitter systems. For a more complete description of the RSMS, see Appendix A of Sanders and Lawrence (1995).

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 ever-present interference found in most areas of the nation. As the use of electronic systems (garage door openers, computers, citizen band radios, cellular telephones, arc welders, and appliances such as microwave ovens), the number of radio and TVstations, and new uses for the radio frequency spectrum increases, the average level of electromagnetic energy across the spectrum will increase. This is important to companies involved in developing sensitive radio receivers and signal processing equipment, since the equipment is often saturated by the background signal level. The Table Mountain facility is available for use by private parties on a reimbursable basis.

Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provide the latest engineering models and research data developed by ITS to industry and other Government agencies. TA Services is interactive and computer-based, and is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunication systems. Currently available are: on-line terrain data with 3-arc-seconds (90 meters) resolution for much of the world and 5-minute resolution data for the entire world; the 1990 census data; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (arcinfo). Other Government databases and reports are available through a bulletin board service available to all users of TA Services as they are developed. TA Services is currently developing models in the GIS environment for personal communications services (PCS; see Telecommunications Analysis Services, page 42). The following is a brief description of some programs available through TA Services.

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

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

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

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

PROFILE - Extracts path profiles according to user-specified input parameters, such as location and bearing. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also 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 page 80. 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, can also 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.

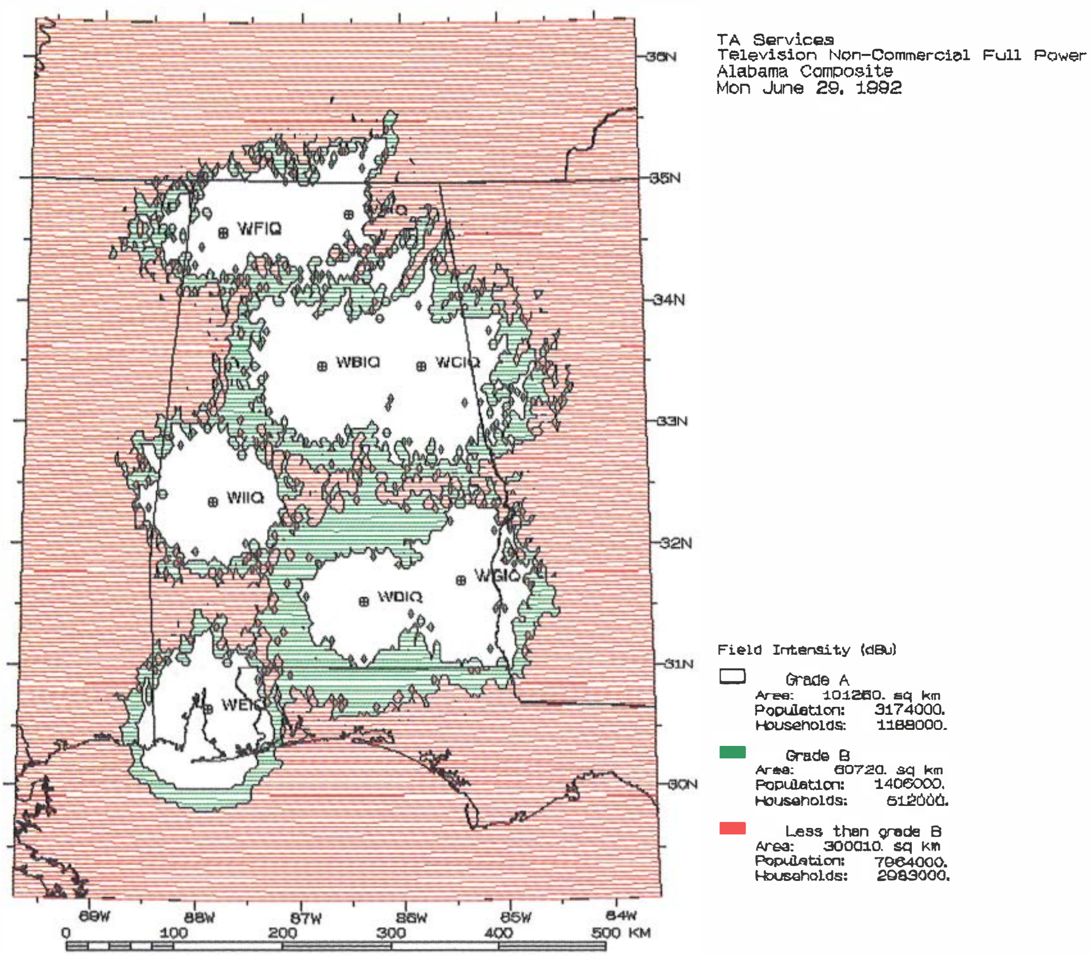
Video Quality Laboratory

The Video Quality Laboratory at ITS is used to develop and test automated techniques for assessing the quality of video and image data. The objective measurement laboratory consists of several high-performance workstations that are used for prototyping and testing 1) video and image parameters; 2) real-time PC-based systems that can perform video quality measurements in the field; and 3) an ensemble of video-switcher-connected broadcast quality cameras, video recorders, video monitors, image capture and display equipment, video signal generators, and video coders/decoders. A viewing room, built to conform to ITU-R Recommendation 500, provides a means for validating objective video and image parameters that have been implemented on the laboratory's computer-based systems. Since new video systems used in the telecommunications industry are digital, the video quality laboratory hardware and software have been specifically designed to address the particular measurement problems encountered in assessing digital systems. For example, video coders and decoders are used in conjunction with network error simulators to generate impaired digital video for objective and subjective quality testing. New additions to the objective measurement laboratory in FY 95 included a 40-GB read/write optical jukebox for storing digitized images.

Wireless Link Simulation Laboratory

This laboratory at ITS simulates wireless systems and channels to predict performance for data, compressed or uncompressed speech and images, and fax sources. ITS specializes in end-to-end results by performing channel characterization measurements, modeling the measurements, imbedding the models in simulation software, and predicting the system performance via simulation. Typically, predicted speech and image quality are determined as a function of signal-to-noise ratio, carrier-to-interference ratio, and bit error ratio for a selected radio system and channel. Real-time link bit error generator models are available for each simulation used to study the effects of the link conditions on various sources and 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 and UNIX-based link software simulation packages and a generic channel simulator software package are available to perform wireless simulations, predict performance, and perform signal processing. Laboratory hardware consists of RISC and Pentium workstations to run simulation and signal processing software. An audio cassette, S-VHS recorder and players, and S-VHS TV monitor are available for storing and demonstrating speech, images, and video. Programmable digital signal-processing boards and card cage are available to download wireless link simulations for real-time testing of transmitters, receivers, and channel models. A programmable 6-MHz bandwidth hardware channel simulator is also available for testing transmitters and receivers.



Example transmitter coverage calculated using CSPM (see Telecommunications Analysis Services, page 78).

ITS Projects in FY 1995

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

Analysis of the Global Positioning System (GPS) - Examine current augmented GPS requirements and needs of aviation, marine, and land users and evaluate the options for meeting these needs. Recommend the GPS augmentations that would satisfy civil and commercial requirements without compromising national security (see page 44).
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Electromagnetic Compatibility of the Intelligent Transportation System (ITS) - Provide support to the ITS program as it applies advanced technology for safety and throughput. Develop communication systems that will provide information to travelers, their vehicles, and the infrastructure. Support development of standards and identify spectrum issues as they relate to electromagnetic compatibility of the ITS (see page 36).
Project Leaders: Robert J. Matheson (303) 497-3293, Nicholas DeMinco (303) 497-3660, John J. Lemmon (303) 497-3414, and Frank H. Sanders (303) 497-5727
e-mail rmatheson@its.bldrdoc.gov, ndeminco @its.bldrdoc.gov, jlemmon@its.bldrdoc.gov, fsanders@its.bldrdoc.gov

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

Federal Railroad Administration

Railroad Telecommunications Study - Review and comment on the ability of a new railroad telecommunications system to provide safety features desired by the Federal Railroad Administration (see page 38).
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

General Electric

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

Hewlett-Packard Co.

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

McLean Research

HF Support - Provide consultation and advisory services regarding radio propagation.
Project Leader: Gregory R. Hand (303) 497-3375
e-mail ghand@its.bldrdoc.gov

National Aeronautics and Space Administration

Multipath Measurements in the Land Mobile Satellite Radio Channel - Support the development of a global positioning measurement system for measuring multipath propagation in the land mobile satellite radio channel.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

National Center for Atmospheric Research

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

National Communications System

Compact Disc for Interoperability Testing of HF Automatic Link Establishment (ALE) Radios - Develop an audio CD that will provide a precise duplication of the HF radio ALE tones that represent standardized calls used for communications between ALE-equipped HF radios (see page 58).
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

Development of Federal Standard 1037C, Glossary of Telecommunication Terms - Provide expert technical support in developing this revised standard. This document provides Federal departments and agencies a comprehensive source of definitions of terms used in telecommunications and related fields used by international, and U.S. Government telecommunications specialists (see page 24).
Project Leader: A. Glenn Hanson (303) 497-5449
e-mail ghanson@its.bldrdoc.gov

Development of the Multimedia Handbook - Develop a multimedia handbook in conjunction with the Multimedia Performance Measurements Subcommittee of the FTSC. Present technical contributions to standards fora (see article on page 40).
Project Leader: William R. Hughes (303) 497-3728
e-mail whughes@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 datkinson@its.bldrdoc.gov

Interoperability and Performance Assessment of Multimedia Information Systems - Provide NCS with expert technical support in developing an interoperability and performance reference model for multimedia information systems (MMIS) and in tracking 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 NCS in developing 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 for public safety applications.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@its.bldrdoc.gov

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

Performance Assessment of Personal Communications Services Networks - Develop network modeling and simulation capabilities and apply these tools to the performance assessment of design alternatives for personal communications services.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

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

Research and Development Engineering Services - Test the performance of HF radio modem products that embody packet HF protocols.
Project Leader: James A. Hoffmeyer (303) 497-3140
e-mail jhoffmeyer@its.bldrdoc.gov

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

Test of Concepts and Prototypes for Proposed Federal Standard 1049, HF Radio Automatic Operations in Stressed Environments - Evaluate concepts and prototypes and perform appropriate testing to determine performance and functional

interoperability capability.
Project Leader: Chris Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Voice Quality Interoperability Standards - Provide expert technical support for voice communications performance measurement and standardization.
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

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

National Institute for Standards and Technology

Collaborative Planning for the Advanced Communications Technology Satellite (ACTS) - Develop a collaborative proposal with COMSAT, MITRE, and NIST to assemble a three-terminal satellite network using ACTS Earth Stations. This network will be used to determine the performance of several applications using ACTS (see page 56).
Project Leader: William A. Kissick (303) 497-7410
e-mail wkissick@its.bldrdoc.gov

National Security Agency

Evaluation of Wireless Security Performance - Assist NSA in assessing the security performance of personal communications services technologies. Represent the security interest of Government users in associated standards bodies.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

NSA Consulting - Provide consultation and advisory services in areas such as optimum system design and performance determination, detection algorithms, and interference modeling.
Project Leader: Ronald L. Ketchum (303) 497-7600
e-mail rketchum@its.bldrdoc.gov

Standards Development for Asynchronous Transfer Mode - Assist NSA 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 technical objectives to wireless standards working groups and contribute technical information relevant to the objectives in wireless standards.
Project Leader: James G. Ferranto (303) 497-7153
e-mail jferranto@its.bldrdoc.gov

NTIA

Advanced Satellite Communications Technology Studies - Conduct experiments, using the Advanced Communications Technology Satellite, to characterize system performance for the next generation of communications satellites that will use scanning, spot-beam antennas, and onboard signal processing. Investigate appropriate roles for advanced communications satellites in providing broadband integrated services digital networks, asynchronous transfer mode and desktop conferencing (see page 56).
Project Leader: Marjorie L. Weibel (303) 497-3967
e-mail mweibel@its.bldrdoc.gov

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 (see page 20).
Project Leader: Stephen D. Voran (303) 497-3839
e-mail svoran@its.bldrdoc.gov

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

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

Broadband Wireless Standards - Provide leadership and technical contributions to national and international wireless standards development that enhances domestic competitiveness, improves foreign trade opportunities, and facilitates more efficient use of the radio spectrum. Active support is provided in the International Telecommunications Union-Radiocommunication Sector, the Joint Technical Committee for PCS air-interface standards, and the IEEE 802.11 Wireless Local Area Networks Standards Committee.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Broadcasting Studies - Provide support to NTIA's Office of Policy Analysis and Development in the development of advanced television (ATV) and high-definition television (HDTV). Analyze measurements to determine ATV channel characteristics and develop models to analyze the potential for interference between HDTV systems and present-day television systems (see page 50).
Project Leaders: Bradley J. Ramsey (303) 497-3165 and Eldon J. Haakinson (303) 497-5304
e-mail bramsey@its.bldrdoc.gov or ehaakinson@its.bldrdoc.gov

Digital Networks Performance - Promulgate and demonstrate compatible Federal and American National Standards and international standards for measuring data communication performance. Develop and validate the ATM network emulator and evaluate performance issues relevant to the National Information Infrastructure (see page 20).
Project Leader: David J. Atkinson (303) 497-5281
e-mail datkinson@its.bldrdoc.gov

International Standards - Provide leadership to T1 and U.S. International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) preparatory 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 (see page 16).
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Personal Communications Services (PCS) Networks - Implement a wireless network modeling, simulation, and testing facility for PCS system-specific noise and interference (N/I) models tailored for implementation in a real-time hardware channel simulator, and PCS network-level simulations that use statistical data from the N/I model outputs.
Project Leader: James G. Ferranto (303) 497-7153
e-mail jferranto@its.bldrdoc.gov

Personal Communications Services (PCS) Radio Systems - Provide support for the development of PCS 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 (see pages 26 and 28).
Project Leader: Ronald L. Ketchum (303) 497-7600
e-mail rketchum@its.bldrdoc.gov

Radio Spectrum Measurement System (RSMS) Engineering Enhancements - Enhance the measurement capabilities of the RSMS (both the vehicle and suitcase-deployable system) as needed to provide improved measurement data.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Radio Spectrum Measurement System Operations - Measure spectrum use, and other technical parameters of radio systems, needed for frequency management planning activities (see page 10).
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

Rural Information Infrastructure (RII) Technology - Contribute to the development of the RII by identifying and responding to relevant telecommunication technology issues. In FY 95, ITS conducted a study of telecommunication technologies available or emerging that could contribute to the RII.
Project Leader: Kenneth C. Allen (303) 497-5474
e-mail kallen@its.bldrdoc.gov

Rural Quality-of-Service Development - Develop an interactive Rural Multimedia Handbook to assist telecommunications users and planners in specifying quality-of-service requirements and assessing alternative technologies. These technologies would support distance education, telemedicine, audiovisual library, and community service applications in rural areas (see page 40).
Project Leader: William R. Hughes (303) 497-3728
e-mail whughes@its.bldrdoc.gov

Satellites and Integrated Services Digital Networks (ISDNs) - Identify needs and recommend solutions for interoperation of advanced satellite and

broadband terrestrial networks that use asynchronous transfer mode (ATM) to provide broadband ISDNs. Evaluate the application of perception-based metrics for multimedia systems and services applied to advanced satellite networks. Participate in standards organizations concerned with the use of ATM on satellite networks and the performance and interoperability of advanced satellite and terrestrial broadband ISDNs (see page 56).
Project Leader: Raymond D. Jennings (303) 497-3233
e-mail rjennings@its.bldrdoc.gov

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

Spectrum Engineering Models - Develop and implement spectrum engineering models necessary to effectively manage the Government's use of the radio spectrum (see page 12).
Project Leader: Robert J. Matheson (303) 497-3293
e-mail rmatheson@its.bldrdoc.gov

Spectrum Resource Assessments - Assess spectrum utilization, identify existing or potential compatibility problems among Federal telecommunications systems, provide recommendations for resolving any compatibility conflicts in the use of the frequency spectrum, and recommend changes to improve spectrum management procedures.
Project Leader: Kenneth C. Allen (303) 497-5920
e-mail kallen@its.bldrdoc.gov

Technical Assistance for the Pan-Pacific Education and Communications Experiment by Satellite (PEACESAT) - Provide technical assistance to the PEACESAT program in the application of satellite communications and network technology. PEACESAT is administered by the University of Hawaii to provide international distance education, research, telemedicine, emergency management, and economic development communications to 40 locations in 21 countries throughout the Pacific Basin using a retired Geostationary Operational Environmental Satellite (GOES; see page 56).
Project Leader: Raymond D. Jennings (303) 497-3233
e-mail rjennings@its.bldrdoc.gov

Telecommunications Analysis Services - Make available to the public, through user-friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools (see page 42).
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@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 Sector. Focus on applications in video teleconferencing, high-definition television, and video communications (see page 18).
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

Telesis Technologies Laboratory

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

Propagation Study for Local Multipoint Distribution Services (LMDS) - Identify propagation factors that require further study before the performance of LMDS systems can be predicted. Provide a practical plan for obtaining the necessary measurements identified.
Project Leader: Roger A. Dalke (303) 497-3109
e-mail rdalke@its.bldrdoc.gov

U.S. Air Force

HF Propagation Prediction - Modify the PC-ICEPAC HF propagation prediction program to allow area coverage calculations to be mathematically combined.
Project Leader: Gregory R. Hand (303) 497-3375
e-mail ghand@its.bldrdoc.gov

Spectrum Survey at Whiteman Air Force Base, Missouri - Perform a broadband spectrum survey at Whiteman Air Force Base; analyze spectrum measurement data to summarize spectral activity.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

U.S. Army

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

Independent Evaluation of the Reserve Component Automated System (RCAS) - Establish a comprehensive evaluation program for RCAS technical testing. Independently evaluate testing methodology and results, and report on the findings (see page 52).
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail vpietrasiewicz@its.bldrdoc.gov

Jammer Effectiveness Model Development - Develop a Jammer Effectiveness Model using a windows interface shell and ITM, GWAPA, and IONCAP propagation models (see page 54).
Project Leader: Nicholas DeMinco (303) 497-3660
e-mail ndeminco@its.bldrdoc.gov

Technical Test of the Reserve Component Automated System (RCAS) - Provide technical testing and evaluation during the development and fielding phases of the RCAS. The RCAS is an automated information system including computers, software, and networks connecting over 5000 sites to improve operational readiness of the Army National Guard and Army Reserves (see page 52).
Project Leader: Richard E. Skerjanec (303) 497-3157
e-mail rskerjanec@its.bldrdoc.gov

Test Support for the Army High-frequency Electronic Warfare System (AHFEWS) - Perform spectrum measurements simultaneously with specified AHFEWS tests.
Project Leader: Patricia J. Longstaff (303) 497-3568
e-mail plongstaff@its.bldrdoc.gov

U.S. Information Agency

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

US WEST

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

Impulse Response Measurements - Measure outdoor impulse responses for a new generation of digital cellular telephone system. Characterize wideband propagation in the 902- to 928-MHz ISM band. This information will enable evaluation of proposed code-division multiple access system performance.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Response Measurements with Spatial Diversity - Study impulse response measurements taken in urban and suburban environments to provide delay statistics, spatial diversity statistics, multipath power statistics, Doppler shifts, arrival angles, and the effects of directional antennas.
Project Leader: Lynette H. Loew (303) 497-3874
e-mail lloew@its.bldrdoc.gov

ITS Publications in FY 1995

NTIA Publications

Allen, K.C., et al., 1995, "Survey of Rural Information Infrastructure technologies," NTIA Special Publication 95-33.

Communication and information technologies can reduce the barriers of distance and space that disadvantage rural areas. This report defines a set of distinct voice, computer, and video telecommunication services; describes several rural information applications that make use of these services; and surveys various wireline and wireless systems and technologies that are being used or might be used to deliver these services to rural areas. Rural information applications require a wide range of telecommunication services, but no current system or technology is capable of delivering all of these services to all areas. This report concludes that there are many technologies suitable for providing voice telecommunication services in rural areas. It is also technically feasible to provide advanced computer networking and video capabilities to even relatively small towns in rural areas. No technology was found capable, however, of economically providing these broadband capabilities to the most isolated farms, ranches, and homes. It is expected that new wireless technology will need to be developed to accomplish this. Government regulations and policies will also play an essential role in the development of the Rural Information Infrastructure. Different regulations and policies will likely be required in rural areas that in urban areas.

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

This report documents the development of recommendations for a national approach to augmented Global Positioning System (GPS) services. The Institute for Telecommunication Sciences led a study team that included the U.S. Army Topographic Engineering Center, the Volpe National Transportation Systems Center, and Overlook Systems Technologies, Inc. The study team identified Federal navigation, positioning, and timing requirements for land, marine, air, and space modes of operation. The study team then evaluated numerous operating and proposed systems that augment the GPS Standard Positioning Service. The most promising systems were combined in six different architectures intended to meet the widest possible range of user requirements. One of these architectures was eliminated from consideration due to technical concerns. The study team evaluated each of the remaining architectures against a set of performance, cost, and security factors. Based on the architecture evaluations, the study team developed a set of recommendations for a coordinated, national approach to augmented GPS services that meets Federal requirements while avoiding unnecessary duplication of facilities.

DeMinco, N., 1995, "Engineering manual for the Jammer Effectiveness Model," NTIA Report 95-322.

The engineering manual describes a user-friendly and menu-driven computer program called the Jammer Effectiveness Model (JEM). The models used in JEM to analyze the effectiveness of a jammer in jamming a receiver/transmitter pair or network of receivers and transmitters are described. The JEM runs on a personal computer in a Windows environment. The extensive design and analysis capabilities of this program have been previously limited to mainframe computers. This computer model is highly structured and modular in design, which allows for flexibility and expandability for future modifications.

Geikas, J. and N. DeMinco, 1994, "Jammer Effectiveness Model," NTIA Report 95-317.

The Jammer Effectiveness Model (JEM) is a Windows-based computer program which provides an integrated procedure for modeling propagation effects on telecommunication links and the effect of a jammer on communication links and networks. JEM provides the user with the ability to define equipment such at transmitters, receivers, and antennas and then use these definitions in a variety of analyses. JEM can be used easily after only a short learning period.

Holloway, C.L., P.L. Perini, R.R. Delyser, and K.C. Allen, 1995, "A study of the electromagnetic properties of concrete block walls for short path propagation modeling," NTIA Report 95-326.

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 are applicable to microcellular personal communications services deployments in urban canyons as well as indoor wireless private branch exchanges and local area networks.

Johnson, E.E., C. Redding, D.F. Peach, and R.T. Adair, 1995, "Implementation guide for Federal Standard 1049 Section 1, Linking Protection," NTIA Technical Memorandum 95-166.

Automatic Link Establishment (ALE) technology automates the selection of channels and establishment of links among high-frequency radios, but creates a vulnerability in such automated networks to hostile manipulation of network operations. The Linking Protection (LP) technique described in this report was developed to protect against such manipulation, while causing minimal degradation to network performance. This report provides a summary of ALE operation, followed by a discussion of the LP technique and suggestions for producing high-performance implementations of LP, based upon simulation studies of protected-mode performance.

Lemmon, J.J. and P.B. Papazian, 1995, "Impulse response measurements over space-earth paths using the GPS coarse/acquisition codes," NTIA Report 95-324.

The impulse responses of radio transmission channels over space-earth paths were measured using the coarse/acquisition code signals from the Global Positioning System of satellites. The data acquisition system and signal processing techniques used to develop the impulse responses are described. Examples of impulse response measurements are presented. The results indicate that this measurement approach enables detection of multipath signals that are 20 dB or more below the power of the direct arrival. Channel characteristics that could be investigated with additional measurements and analyses are discussed.

Loew, L.H., Y. Lo, M.G. Laflin, and E.E. Pol, 1995, "Building penetration measurements from low-height base stations at 912, 1920, and 5990 MHz," NTIA Report 95-325.

Building penetration measurements were taken simultaneously at three potential Personal Communications Services (PCS) frequencies: 912, 1920, and 5990 MHz. The continuous wave (CW) measurement system employed a fixed outdoor transmitter and a mobile indoor receiver. The goal was to quantify building penetration losses at these frequencies to determine the viability of indoor coverage using street microcells and base antenna heights below the roof level of surrounding buildings. Eleven different buildings representing typical residential and high-rise office building environments were used for the measurements. Vertically polarized transmit and receive antennas were used for all measurements. Statistical analyses of the data include mean building attenuation losses, standard deviations, cumulative probability distribution functions, and correlation coefficients. The analyses were used to characterize propagation effects and provide a comparison between three frequencies, two cell environments, and two transmission paths.

Miles, M.J., et al., 1995, "Performance evaluation of data communication services: NTIA implementation of American National Standard X3.141," Volumes 1-6, NTIA Report 95-319.

This report describes the implementation and use of NTIA-developed software that automates key aspects of data communication performance measurement. Volume 1 describes the overall X3.141 data communication performance measurement system. Volumes 2 through 6 provide specific information on experiment design, data extraction, data reduction, data analysis, and data display, respectively.

Parlow, R.D., et al., 1995, "Land mobile spectrum planning options," NTIA Special Publication 95-34.

No abstract available.

Parlow, R.D., et al., 1995, "Spectrum reallocation final report," NTIA Special Publication 95-32.

No abstract available.

Parlow, R.D., et al., 1995, "U.S. national spectrum requirements: projections and trends," NTIA Special Publication 94-31.

No abstract available.

Peach, D.F., 1995, "Dependence of foreign sources as it impacts the U.S. telecommunications infrastructure," NTIA Report 95-318.

The ability to rapidly mobilize the telecommunications industry is of concern in national security/emergency preparedness planning scenarios. This report assesses the extent to which the U.S. telecommunications industry is dependent on foreign sources for key components. It concludes that there is a severe dependence on foreign sources for certain types of semiconductor devices, as well as many factory materials and other raw materials used in manufacture of these devices. This dependence is of particular concern because of the length of time it takes to build a semiconductor factory to replace a lost supply. The long-term impacts of a disruption in supply for semiconductor devices are somewhat mitigated by the fact that most semiconductor factory equipment can be obtained from domestic sources. There is little foreign source dependence for fiber optic and related optoelectronic devices. The report also discusses some of the factors that affect the relative competitiveness of U.S. manufacturers and makes recommendations for improving U.S. firms' competitive position, thereby reducing foreign source dependence.

Sanders, F.H., and V.S. Lawrence, 1995, "Broadband spectrum survey at Denver, Colorado," NTIA Report 95-321.

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 Denver, Colorado during September and October of 1993.

Weibel, M.L., 1995, "Data communication performance testing of ACTS," NTIA Report 95-320.

The results of a series of data communication tests, which define the digital end-to-end performance of the Advanced Communication Technology Satellite (ACTS), are presented. The experiment consisted of a test set characterization, to determine the effect of the test set of the results, a preliminary characterization, to define the failure/nonperformance outcome thresholds, and a full characterization. The experiments' design, execution, and analysis comply with American National Standards X3.102 and X3.141. The tests found that ACTS has a very clean data channel (only recorded one lost byte during all the tests), that the X.25 packet mode did not perform as well as expected, and that the parameter estimates did not vary substantially over time or destination location.

Other Publications

Achatz, R.J. and E.A. Quincy, 1995, "Performance prediction of WLAN speech and image transmission," in *Proc. IEEE Vehicular Technology Conf.*, pp. 559-563.

The effects of multipath, noise, and cochannel interference on performance are shown for two wireless local area networks (WLANs). Measured impulse responses from an office environment provided the multipath distortion. The first WLAN system uses frequency hopped (FH) Gaussian frequency shift keying (GFSK) and the second uses direct sequence (DS) differential binary phase shift keying (DBPSK). Both modulations are part of the proposed WLAN IEEE 802.11 standard. Vocoded speech and image quality were predicted for wireless systems through software simulation by relating quality classes to the following system and channel operational parameters: bit error rate (BER), signal-to-noise ratio (SNR), and carrier-to-interference ratio (CIR). Experimental results are summarized by overlaying image and vocoded speech quality classes on a BER, SNR, and CIR graph.

Aguirre, S., L.H. Loew, and Y. Lo, 1994, "Radio propagation into buildings at 912, 1920, and 5990 MHz using microcells," in *Record of 3rd Intl. Conf. Universal Personal Commun.*, San Diego, CA.

Continuous wave (CW) propagation experiments were conducted at 912, 1920, and 5990 MHz simultaneously using a narrowband system consisting of a fixed transmitter and a mobile receiver. The goal of the experiments was to quantify building penetration losses at various frequencies to determine the viability of indoor coverage using street microcells with base antenna heights below the roof level of nearby buildings. Statistical analysis included the computation of mean building penetration losses, standard deviations, cumulative probability distribution functions, and correlation coefficients.

Gray, E., 1995, "Preserving due process in standards work," *StandardView*, December.

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

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

No abstract available.

Holloway, C.L. and E.F. Kuester, 1995, "Closed-form expressions for the current density on the ground plane of a microstrip line, with application to ground plane loss," *IEEE Trans. Microwave Theory and Techniques*, vol. 43, no. 5, pp. 1204-1207.

In this paper closed-form expressions for the current density on the ground plane of a microstrip line are derived. The derivation is based on a quasistatic Green's function approach. These expressions are compared to both experimental and numerical values, and excellent agreement is demonstrated. The loss on a ground plane for a microstrip structure is calculated using these expressions, and comparisons with results from Wheeler's incremental inductance rule are made.

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

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

Holloway, C.L. and E.F. Kuester, 1995, "A low-frequency model for wedge or pyramid absorber arrays - II: computed and measured results," *IEEE Trans. Electromagnetic Compatibility*, vol.36, no.4, pp. 307-313.

Based on the theoretical model developed in Part I of this two-part paper, we present numerical results for the plane-wave reflection coefficient from arrays of pyramid-cone absorbers when the period of the array is smaller than half a wavelength. Comparison is made with results of a moment-method calculation, as well as with experimental measurements. The model is then used to modify the design of some existing types of commercially available absorbers for reduced reflection in the frequency range of 30-300 MHz. These improved absorbers have been installed in an anechoic chamber used for electromagnetic compatibility and electromagnetic interference (EMC/EMI) measurements. Site attenuation measurements from this chamber are presented which show closer correspondence to an ideal open-field test site.

Holloway, C.L., P. McKenna, and R.R. DeLyser, 1995, "A numerical investigation on the accuracy of the use of homogenization for analyzing periodic absorbing arrays," in *Proc. Intl. Symp. Electromagnetic Theory*, St. Petersburg, Russia, pp. 296-298.

Homogenization has been recently used to analyze periodic electromagnetic absorbing materials. The accuracy of homogenization is dependent upon the period of the absorbing material being small, as well as the material properties of the absorber and free space being of the same order of magnitude. Therefore, to analyze electromagnetic absorbing materials with homogenization it is important to determine first, how large of a period can the structure have (or how high in frequency can we expect homogenization to hold), and secondly how large of values of material properties the absorber material can have. In this paper we have set out to answer these two questions.

Kuester, E.F., and C.L. Holloway, 1994, "A low-frequency model for wedge or pyramid absorber arrays - I: Theory," *IEEE Trans. Electromagnetic Compatibility*, vol. 36, no. 4, pp. 300-306.

The interaction of electromagnetic waves with an array of absorbing wedges or pyramid cones is studied in the low-frequency limit, i.e., when the period of the array is small compared with wavelength. A theoretical model is obtained using the method of homogenization, which replaces the transversely periodic structure with a transversely uniform medium possessing a certain (generally anisotropic) effective permittivity and permeability. Plane-wave reflection from such structures can then be modeled using well-known techniques for one-dimensionally inhomogeneous media; a Ricati equation for the reflection coefficient is used in this work. This model is appropriate for use with absorbers found in anechoic chambers used for electromagnetic compatibility and electromagnetic interference (EMC/EMI) measurements over the frequency range of 30-1000 MHz. Numerical results and application to the design of such absorbers are given in Part II of this two-part paper.

Lataitis, R.J., S.F. Clifford, and C.L. Holloway, 1995, "An alternative method for inferring winds from spaced antenna radar measurements," *Radio Science*, vol 30, no. 2, pp. 463-474.

One variation of the spaced-antenna technique for measuring atmospheric winds using a pulse Doppler radar is based on a calculation of the complex temporal cross-correlation function for the backscattered fields detected by a pair of spaced receiving antennas. The delay to the peak of the cross-correlation amplitude, adjusted for the temporal evolution of the backscattered field pattern through an extended analysis, is related to the so-called trace velocity along the antenna pair baseline, with two non-parallel baselines yielding the full horizontal wind vector. We suggest an alternative method

for inferring the horizontal wind from the temporal cross correlation. We demonstrate that the slope of the cross-correlation amplitude at zero lag, normalized by the level of the cross-correlation amplitude at zero lag, is directly proportional to the component of the wind velocity along the antenna pair baseline. We illustrate that this measure of the horizontal wind is insensitive to the temporal evolution of the backscattered field pattern. Therefore no extended analysis is needed to estimate the horizontal wind vector The advantage of this approach is that it is a very simple and direct method of retrieving the horizontal wind.

Quincy, E.A. and R.J. Achatz, 1995, "Performance prediction of GSM digital cellular speech and image transmission," in *Proc. 1995 IEEE Pacific Rim Conf. Communications, Computers, and Signal Processing*, pp. 26-31.

The Group Special Mobile (GSM) digital cellular system provides the European countries with a standard land mobile radio (LMR) architecture. This paper illustrates how voice coded (vocoded) speech and uncompressed image transmission can be expected to degrade as a function of signal-to-noise ratio (SNR) and carrier-to-interference ratio (CIR) for a cochannel GSM interferer. Performance is predicted by Monte Carlo simulation of the system. This simulated GSM system employed (1) a Gaussian minimum shift keying (GMSK) modem with convolutional coding and Viterbi decoding, (2) a five-path urban channel impulse response with additive white Gaussian noise (AWGN), (3) a minimum mean square error (MMSE) equalizer, and (4) limiter-discriminator detection. These results demonstrate GSM systems in an urban environment can transport useable speech and images without packet retransmission provided the SNR ≥ 8 dB and CIR ≥ 8 dB.

Redding, C. and D. Weddle, 1994, "Adaptive HF radio tests results using real-time evaluation systems," in *Proc. IEEE Military Commun. Conf.*, Ft. Monmouth, NJ, pp. 31.6-1-31.6-5.

To facilitate the development of anti-interference features for proposed Federal Standard 1049 (adaptive high-frequency (HF) radio standard), adaptive radio systems and concepts have been solicited from Government and industry. One such contribution is an adaptive HF radio system, termed the SMARTNET (Skywave Management for Automatic Robust Transmission Network), that is capable of adapting power, data rate, and frequency under the direction of a network control computer. A recent over-the-air test was conducted to characterize system behavior on an 1100 kM test link between Boulder, CO, and Richardson, TX. A second adaptive system, capable of adapting frequency and based upon the Federal Standard 1045 Automatic Link Establishment (ALE) protocols, operated in parallel with the SMARTNET system during the test period. Data was collected automatically from both systems and analyzed off-line so that the results were compared with predicted data generated by the Ionospheric Communication Enhanced Profile Analysis Circuit Prediction Program (ICEPAC). ICEPAC is an improvement on the older Ionospheric Communications Analysis and Prediction Program (IONCAP). Comparison of the two systems consisted of: (1) power required to maintain the link, (2) selection of the best frequency, and (3) link availability percentage. This paper presents these results, and where appropriate, attempts to draw conclusions as to the significance of future adaptive HF data networks, and to the emerging Federal Standard 1049 interoperability standard.

Voran, S.D., 1994, "Techniques for comparing objective and subjective speech quality tests," in *Proc. Speech Quality Assessment Workshop*, Ruhr-Universitat Bochum, Germany.

Objective (or instrumental) tests of speech quality have been proposed as ways to reduce the need for expensive and time-consuming subjective (or auditory) tests. Both types of tests attempt to quantify the range of opinions that listeners express in response to a group of speech transmission or storage devices, but objective test results often show measurable deviation from subjective test results. This deviation may be judged to be acceptable if the objective test offers significant savings of time and expense. This cost-performance judgement cannot be made without a meaningful statistical measure of the deviation that is likely to be associated with the objective test. This paper offers a number of techniques that compare both the central tendencies and the uncertainties of two tests. The resulting statistics have direct, intuitive interpretations.

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

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

Voran, S.D. and C.D. Sholl, 1995, "Perception-based objective estimators of speech quality," in *Proc. 1995 IEEE Workshop on Speech Coding for Telecommunications*, Annapolis, MD, pp. 13-14.

Four proposed perception-based techniques for objectively estimating speech quality and three traditional estimators are applied to coded speech samples. Agreement between objective estimates and corresponding subjective test scores is reported. Several observations on key elements of perception-based estimators are offered.

Wepman, J.A., 1995, "Digital sampling channel probe," *Federal Lab Tech Briefs*, May, p. 6a.

An innovative probe provides impulse response characterization of radio propagation channels and enables performance prediction of radio communications systems.

Wepman, J.A., 1995, "Analog-to-digital converters and their applications in radio receivers," *IEEE Communications Magazine*, May, pp. 39-45.

Rapid advances in hardware development of analog-to-digital converters (ADC) have paved the way for development of radio receivers using digitization at the IF, and in some cases, at the RF. The constraints placed on these receivers due to hardware limitations of these devices are discussed and some examples of high-speed, state-of-the-art ADCs are given.

Wepman, J.A., J.R. Hoffman, and L.H. Loew, 1994, "Characterization of macrocellular PCS propagation channels in the 1850-1990 MHz band, in *Proc. 1994 3rd Annual International Conf. Universal Personal Communications*, San Diego, CA, pp. 165-170.

Wideband propagation measurements for personal communications services (PCS) were taken in the 1850-1990 MHz band in three different outdoor macrocellular (cell radii of 5 km) environments: flat rural, hilly rural, and urban high-rise. The data were analyzed to provide a description of the statistical behavior of the impulse responses in each cell. This analysis included RMS delay spread statistics, multipath power statistics, number of paths and path arrival time statistics, and effects of spatial diversity. The number of paths and path arrival time statistics provide particularly useful information in the design of tapped delay line models of the radio channel for PCS applications.

Wepman, J.A., J.R. Hoffman, and L.H. Loew, 1995, "Analysis of impulse response measurements for PCS channel modeling applications," *IEEE Trans. Vehicular Technology*, vol. 44, no. 3, pp. 613-620.

Impulse response measurements for personal communications services (PCS) were taken in the 1850-1990 MHz band in three different outdoor macrocellular (cell radii of 5 km) environments: flat rural, hilly rural, and urban high-rise. The data were analyzed to provide information to assist in the development of radio propagation channel (especially tapped delay line) models for PCS applications. Analyses included number of paths, path arrival time, and path power statistics. Results of the analyses were found to be highly dependent on the threshold level used in processing. The urban high-rise cell showed a far greater number of paths than the rural cells for threshold levels 20 and 10 dB below the normalized peak of the power delay profiles.

Wurman, J., M. Randan, C.L. Frush, E. Loew, and C.L. Holloway, 1994, “Design of a bistatic dual-Doppler radar for retrieving vector winds using one transmitter and a remote low-gain passive receiver,” in *Proc. IEEE*, vol. 82, no. 5, pp. 1861-1872.

A bistatic dual-Doppler network consisting of an existing single transmitting pencil-beam weather radar and a remotely located, nontransmitting, passive bistatic receiver with a low-gain antenna was constructed and tested during 1993. High-quality dual-Doppler vector winds were retrieved from this system The windfields were compared to those collected with a traditional two-transmitter dual-Doppler system.

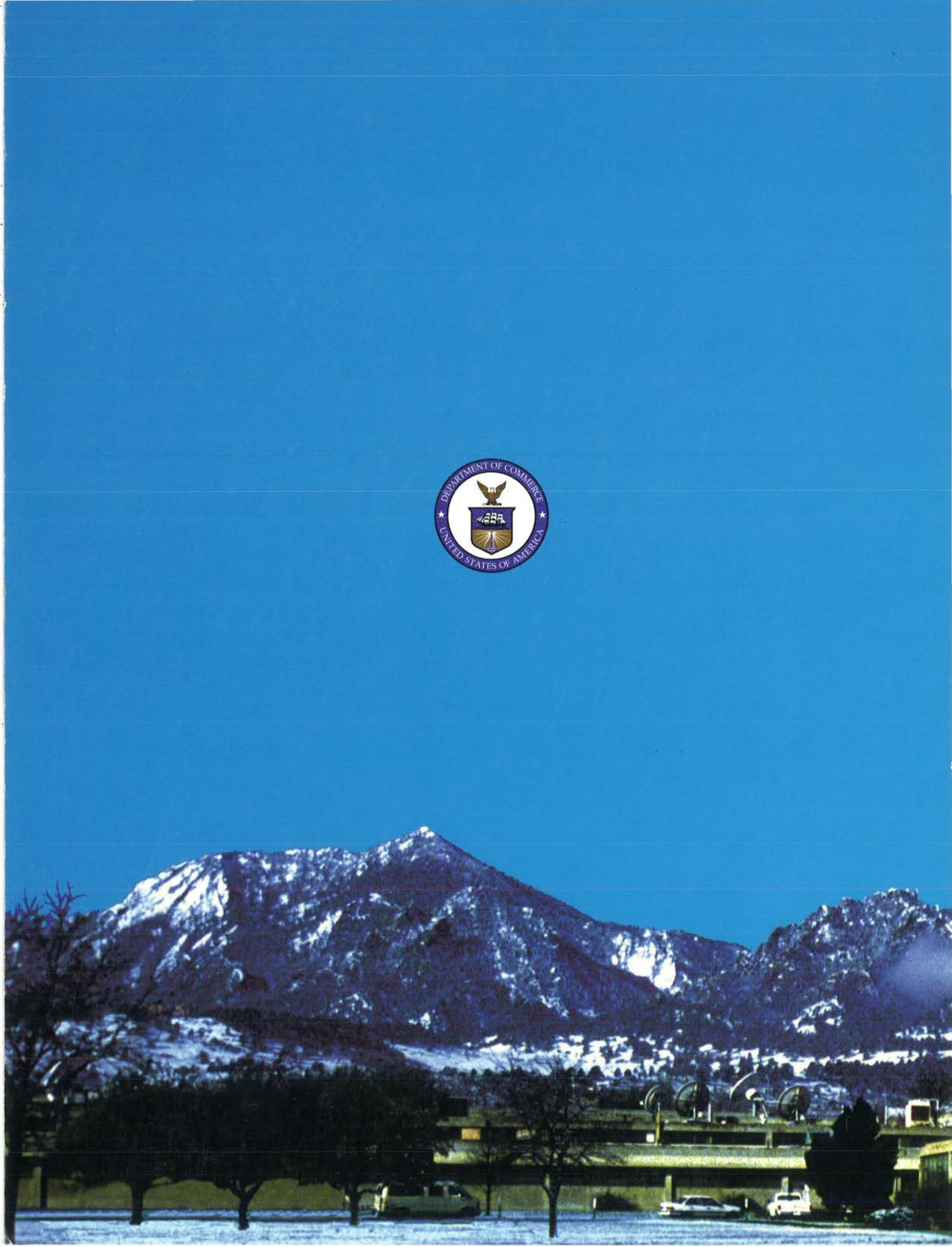
Several interesting engineering challenges relating to frequency and timing synchronization were resolved in order to retrieve successfully Doppler velocities at a remote bistatic site. Frequency synchronization was achieved by using extremely stable local oscillators, linked by both Global Positioning Satellite (GPS) signals and transmitter sidelobe coupling. Both methods provided the necessary one part in 109 coherence necessary for calculating accurate Doppler velocities. Timing/gating synchronization with submicrosecond accuracy was achieved by using local oscillators at each site linked with GPS and sidelobe coupling.

The successful test of this system demonstrates that inexpensive and practical bistatic multiple-Doppler networks can be deployed. These systems can provide three-dimensional vector winds for a number of purposes in research, aviation, media, weather prediction, education, meteorological modeling, and severe weather detection.

Abbreviations

ACATS	Advisory Committee on Advanced Television Systems
ACTS	Advanced Communications Technology Satellite
ALE	automatic link establishment
AMPS	Advanced Mobile Phone Service
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials
ARNG	Army National Guard
ATCS	advanced train control system
ATIS	advanced traveler information system
ATM	asynchronous transfer mode
B-ISDN	broadband integrated services digital network
BER	bit error ratio
CDMA	code-division multiple access
CER	channel error rate
CIR	carrier-to-interference ratio
CRADA	cooperative research and development agreement
DECT	digital European cordless telecommunications
DGPS	differential global positioning system
DOD	Department of Defense
DOT	Department of Transportation
DSCP	digital sampling channel probe
EHF	extremely high frequency
EIRP	effective isotropic radiated power
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ERP	effective radiated power
ETTM	electronic toll and traffic management
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTSC	Federal Telecommunications Standards Committee
FTTA	Federal Technology Transfer Act
GCS	generic channel simulator
GII	Global Information Infrastructure
GIS	geographic information systems
GMSK	Gaussian minimum shift-keying
GPS	global positioning system
GSM	global system for mobile communications
HDTV	high-definition television
HF	high frequency
HFIA	High-Frequency Industries Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMT-2000	international mobile telecommunications-2000
INFOSEC	information system security
ISDN	integrated services digital network

ISM	industrial, scientific, and medical
ISO	International Organization for Standardization
ITS	Institute for Telecommunication Sciences intelligent transportation system
ITU-R	International Telecommunication Union-Radiocommunication Sector
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
JTC	Joint Technical Committee on Wireless Access
LAN	local area network
LMDS	local multipoint distribution service
LMR	land mobile radio
LOS	line-of-sight
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 Emergency Preparedness
NSA	National Security Agency
NTIA	National Telecommunications and Information Administration
OFDM	orthogonal frequency division multiplexing
OSM	Office of Spectrum Management
PACS	personal access communication system
PBX	private branch exchange
PCI	personal communications interface
PCM	pulse-code modulation
PCS	personal communications services
PEACESAT	Pan-Pacific Education and Communications Experiment by Satellite
PER	packet error rate
PHS	personal handyphone system
PPS	precise positioning service
PTS	positive train separation
QPSK	quadrature phase shift-keying
RCAS	Reserve Component Automation System
RII	Rural Information Infrastructure
RSMS	radio spectrum measurement system
SCPC	single-channel-per-carrier
SDH	synchronous digital hierarchy
SNR	signal-to-noise ratio
SONET	synchronous optical network
SPS	standard positioning service
TDMA	time-division multiple access
TIA	Telecommunications Industry Association
TIIAP	Telecommunications Information Infrastructure Assistance Program
USAR	U.S. Army Reserve
WAAS	wide area augmentation system
WAN	wide area network
WCPE	wireless customer premises equipment
WLAN	wireless local area network
WPBX	wireless private branch exchange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