Institute for Telecommunication Sciences
1999 Technical Progress Report

U.S. Department of Commerce
William M. Daley, Secretary
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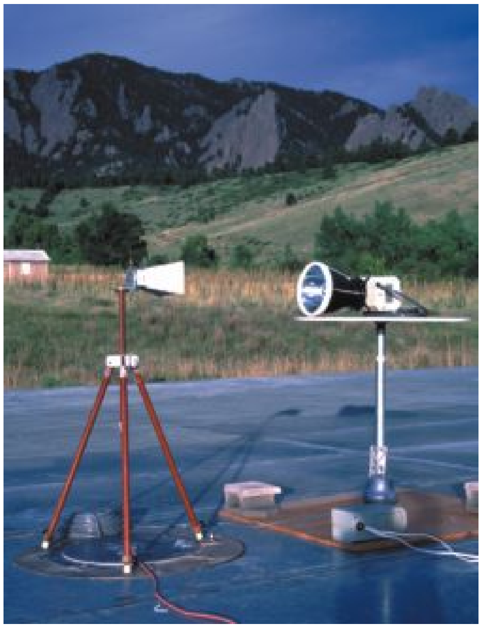
Publications Cited | Abbreviations/Acronyms

ITS Home

Disclaimer

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

The ITS Mission



ITS measurement antenna (left) and new-technology light source (right) on an outdoor antenna range at the Department of Commerce Boulder Laboratories. The light source, which is driven by the same radio tube as that found in microwave ovens, produces radio noise that ITS measurements quantified for interference analysis studies (photograph by F.H. Sanders).

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

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

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

The ITS Radio Spectrum Measurement System (RSMS) transmitting simulated satellite-radar signals into a nearby air traffic control (ATC) radar at Linthicum, MD. These tests determined levels at which such satellite signals would interfere with ATC radar operations (photograph by F.H. Sanders).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the chief research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. ITS employs individuals with substantial engineering and scientific skills and experience to support our technical programs. The majority of our employees are electronics engineers, with a complement of mathematicians, physicists, computer scientists, and computer programmers. ITS' support during the 1999 fiscal year consisted of $3.8 million of direct funding from the Department of Commerce and approximately $5.6 million for work sponsored by other Federal Government agencies and U.S. industry.

History

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

Activities

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

- *Spectrum and Propagation Measurements:* The Institute designs, develops and operates state-of-the-art, automated spectrum measurement and propagation measurement systems. ITS measures spectrum occupancy trends and patterns; measures emission characteristics of new and existing Federal transmitter systems; identifies and resolves radio frequency interference involving Federal systems; and performs radio propagation measurements for model development.

- *Telecommunications and Information Technology Planning:* The Institute plans and analyzes existing, new and proposed large-scale telecommunication resources, to improve efficiency and enhance technical performance and reliability.

- *Telecommunication Engineering, Analysis and Modeling:* The Institute evaluates and enhances the technical performance characteristics of existing, new and proposed individual telecommunication systems, to improve efficiency and enhancing technical performance.

- *Telecommunications Theory:* The Institute develops and contributes to innovative telecommunication technologies and engineering tools through the use of electromagnetic theory, digital signal processing techniques, models of human perception, propagation modeling, and noise analysis.

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 Government to support national and international competitiveness, bring new technology to users, and expand the capabilities of national and global telecommunications infrastructures.

Outputs

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

- Engineering Tools and Analyses: Predictions of transmission media conditions and equipment performance; test design and data analysis of computer programs; and laboratory and field tests of experimental and operational equipment, systems, and networks.
- Standards, Guidelines, and Procedures: Contributions to and development of national and international standards in such areas as network interconnection and interoperation, performance evaluation, and information protection.
- Research Results: Mathematical models for electromagnetic wave propagation, noise, and

interference characterization.

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

Organization

ITS is organized into four program divisions: Spectrum and Propagation Measurements, Telecommunications and Information Technology Planning, Telecommunications Engineering, Analysis, and Modeling, and Telecommunications Theory.

The Institute's research and engineering work is supported by the ITS Director's Office, which promotes the Laboratory's mission nationally and internationally. The Director's Office also provides general guidance and support to the program, budget, and administrative functions of the Institute.

The Institute has recently created a Program Development Office (PDO) to lead, coordinate, and integrate program development efforts for the Institute. The PDO works to identify new program areas that the Laboratory should explore, consistent with its telecommunications and information research and engineering mission.

The Institute has also established an NTIA Laboratory Liaison function to provide advice and assistance to NTIA on preparation for and participation in national and international conferences and negotiations. In addition, the liaison coordinates technical research of the laboratory with other Federal agencies, e.g., the National Communications System.

Sponsors

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

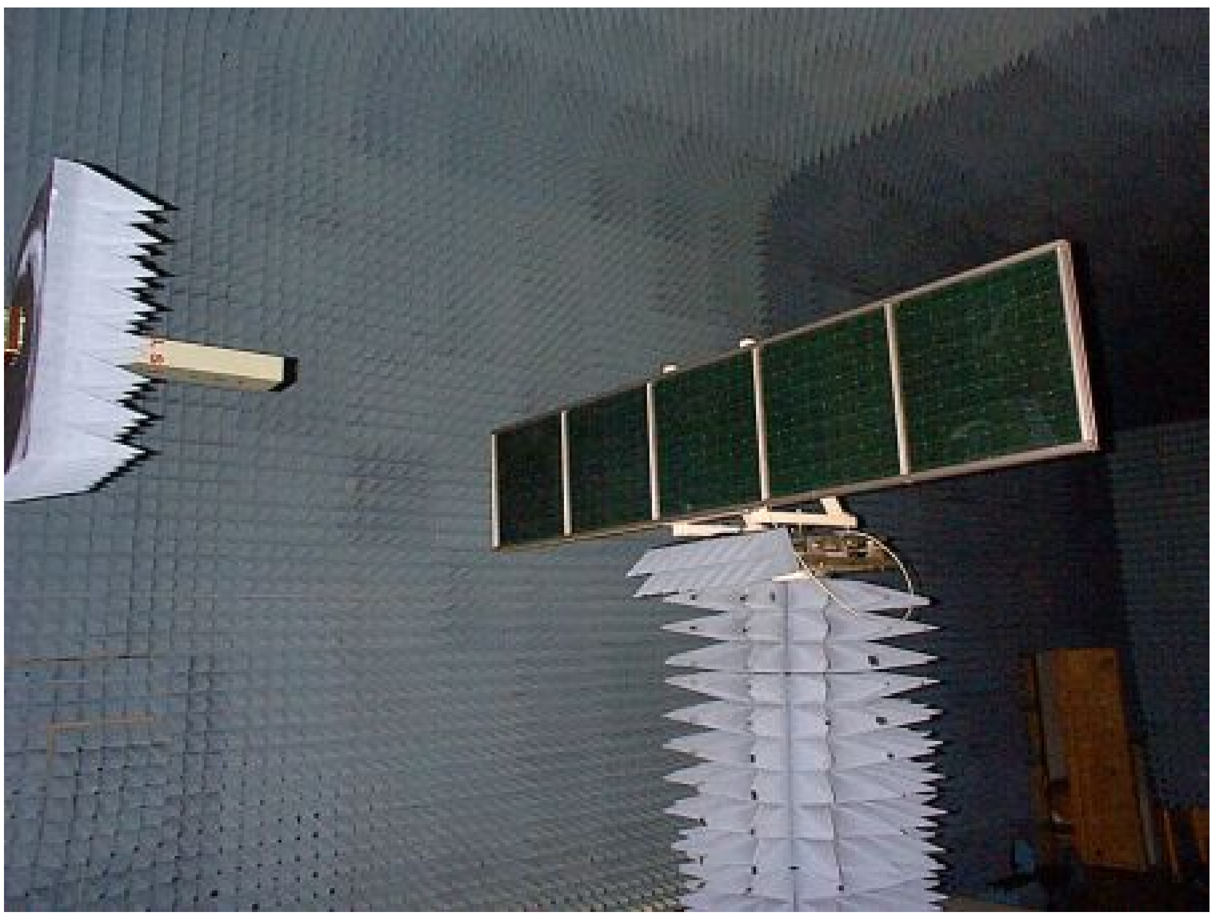
Cooperative research agreements with telecommunication-operating companies and manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the Department of Commerce. ITS has cooperative research agreements with large established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

Because of its centralized Federal position, ITS is able to provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides scientific research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 1999 to both the public and private sectors.

Cooperative Research with Industry

Outputs

- Development of a three-dimensional time-domain finite-difference model that characterizes the notional design of an anechoic chamber.
- PC-based tools that provide real-time, quality information on speech that has been transmitted through a telecommunications system.
- Measurements defining the electromagnetic environment near military and air-traffic control radar facilities.
- Characterization of the antenna pattern of a narrow beam antenna.


Array antenna mounted in the test chamber (photograph by Nino Canales).

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

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

- Lehman Chambers and ITS have entered into a CRADA to conduct cooperative research and development in the area of electromagnetic compatibility (EMC) analysis for development of anechoic chambers. The long-term goal of this cooperative research is the development of a software tool for the analysis of anechoic chambers, that can be accessed through ITS' Telecommunications Analysis Services (TA Services) by chamber designers.

- ITS and Netrix Corporation continue to collaborate under the terms of a CRADA. The collaborative work now focuses on the application of ITS objective speech quality assessment tools to Internet-telephony systems that are being developed by Netrix. The ITS tools are PC-based, and provide real-time speech quality information to Netrix engineers. This enables system optimization and debugging, and provides ITS with valuable data on this emerging telecommunications technology.

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

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

- Lucent Technologies, Bell Laboratories and ITS have entered into a CRADA to characterize the antenna pattern of a narrow beam antenna supplied by Bell Laboratories (see Figure). Future work will verify the operation of this antenna in a variety of environments. The data obtained will be used in planning further measurements to determine channel characteristics of fixed wireless loop 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. The pages of this technical progress report reveal many technological capabilities that may be of value to various private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology that would be useful to them. Because of the great commercial importance of many new emerging telecommunication technologies, including PCS, wireless local area networks, digital broadcasting, LMDS, and intelligent transportation systems, ITS plans to vigorously pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies. In addition, ITS plans to commit substantial resources of its own to the development of these new technologies and standards.

Recent Publications

C. L. Holloway, M. G. Cotton, and P. McKenna, "A model for predicting the power delay profile characteristics inside a room," *IEEE Trans. on Vehicular Technology*, vol. 48, no. 4, pp. 1110-1120, 1999.

C.L. Holloway, P. McKenna, and R.T. Johnk, "The effects of gaps in ferrite tiles on both absorber and chamber performance," in *Proc. IEEE 1999 International Symposium on EMC*, Seattle, WA, Aug. 1999, pp. 239-244.

S. Voran,"Objective estimation of perceived speech quality, Part I: Development of the measuring normalizing block technique; Part II: Evaluation of the measuring normalizing block technique," *IEEE Transactions on Speech and Audio Processing*, vol. 7, no. 4, pp. 371-382 and pp. 383-390, Jul. 1999.

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ITU Standards Activities

Outputs

- Leadership of ITU and related U.S. telecommunications standards committees.
- Technical contributions presenting U.S. standards proposals and ITS research results.
- Proposed ITU Recommendations and associated U.S. industry standards.

The Institute's Randy Bloomfield participates in the Opening Plenary of an ITU-T Study Group 13 meeting in Geneva (photograph courtesy of the International Telecommunication Union).

The Institute has a long and distinguished history of leadership, technical contributions, and advocacy of U.S. government and industry proposals in international and related national telecommunication standards committees. These activities have been focused in the International Telecommunication Union (ITU) -- the United Nations-affiliated standards organization responsible for the cooperative planning and interoperation of public telecommunication systems and services worldwide. The ITU's technical work is centered in two permanent organs: the Telecommunication Standardization Sector (ITU-T), and the Radiocommunication Sector (ITU-R). The ITU-T develops international standards (Recommendations) addressing technical, operating, and tariff questions relating to all aspects of wireline telecommunications. The ITU-R develops Recommendations and contributes to Regulations addressing radio spectrum use, interference, propagation, and radio services. The ITU-T and ITU-R work programs are conducted in Study Groups whose responsibilities are distinguished on the basis of particular technical specialties and standards development needs. The Recommendations developed in these international organizations strongly impact both the evolution of U.S. telecommunications infrastructures and the competitiveness of U.S. telecommunications equipment and services in international trade.

ITU-R Recommendations provide the technical basis for spectrum allocation decisions and spectrum use both globally and regionally. They help to ensure compatibility between radio systems operated by

U.S. government and industry organizations and those operated in other countries. The agreements reached at ITU-R sponsored World Administrative Radio Conferences ultimately become international treaties for the United States. These impacts make it vital that U.S. interests and positions be effectively represented in ITU-R Recommendations and conference negotiations. Institute staff members have played a central role in the development of ITU-R (previously CCIR) Recommendations for over three decades, and a substantial proportion of existing ITU-R/CCIR Recommendations are based on ITS research. The historical importance of ITS leadership in international radio communication standards development is evident in the fact that the previous two Directors of the CCIR were former Directors of ITS. Experimental results and mathematical models developed at ITS are used throughout the world in the prediction of radio wave propagation, noise and interference, and area coverage. They provide technical information used by the FCC and other regulatory agencies in controlling the locations, frequencies, and power levels of radio and television broadcast transmitters, and in regulating terrestrial mobile communications. In recent years, Institute staff members have led and contributed to the technical activities of three ITU-R Study Groups: SG 1 on Spectrum Management, SG 3 on Radio Wave Propagation, and SG 8 on Mobile Services.

In its current ITU-R work, ITS is supporting international efforts to advance existing radio wave propagation, noise/interference, and coverage prediction techniques to substantially better levels of accuracy and resolution. During FY 99, Institute staff members obtained the National Geophysical Data Center (NGDC) 1-km world-wide terrain database from the National Oceanic and Atmospheric Administration (NOAA) and successfully introduced the database for international use in ITU-R Study Group 3. ITS is working to develop and standardize algorithms for extracting path profiles from such terrain databases. ITS has also contributed to the enhancement and use of the Okumura-Hata model, which provides coarse estimates of excess path loss due to land use/land cover (e.g., vegetation, buildings). ITS is developing and demonstrating still more precise land use/land cover models derived from multiple photographic images of target areas (e.g., cities). These models are expected to be widely used in the design of radio systems where line-of-sight paths are required (e.g., local multipoint distribution systems). Finally, ITS is spearheading the development of a new ITU-R Handbook that will guide users in the application and interpretation of propagation calculations used in the Land Mobile Radio Service.

ITS has also played a strong role in international negotiations of the ITU-T. The Institute's long-term technical goal there -- and in related national standards work -- has been to motivate the development and standardization of user-oriented, technology-independent measures of telecommunication service quality. Such measures promote competition and technology innovation among equipment and service providers; facilitate interworking among independently-operated networks and dissimilar technologies in the provision of end-to-end services; and give users a quantitative, practical means of defining their specific telecommunication requirements and selecting the products that most effectively meet those needs.

The Institute's long-term work towards that goal has progressed in three broad phases. In the first phase, ITS participants led ITU-T and related U.S. standards committees in defining the basic principles and framework that underpin a user-oriented approach to telecommunications quality assessment. In the second phase, participants developed a set of generic, user-oriented quality measures for call processing and data transfer functions, and applied those generic measures in deriving technology-specific performance parameters and measurement methods for X.25-based packet switching, frame relay, narrowband and broadband integrated services digital network (ISDN), and asynchronous transfer mode (ATM) technologies. This work has produced over a dozen ITU-T Recommendations and related U.S. industry standards, and has strongly influenced both the theory and practice of digital network performance description. In the third phase, still in progress, ITS participants are applying the performance description principles and framework to IP-based networks, and are developing user-oriented, perception-based quality metrics for voice, video, and multimedia services.

The Institute's ITU-T activities are currently focused in two ITU-T standards groups: Study Group 13 Working Party 4, which develops performance Recommendations for high-speed synchronous digital hierarchy (SDH), broadband integrated services digital network (B-ISDN), asynchronous transfer mode (ATM), and Internet protocol (IP)-based technologies, and Study Group 12 Working Party 2, which defines end-to-end transmission performance parameters and objectives for voiceband networks and terminals. ITS also provides leadership and technical contributions in the American National Standards Institute (ANSI) accredited T1 (Telecommunications) Committee's T1A1 (Performance) Subcommittee, and in T1A1 Working Groups whose activities support ITU-T goals. During FY 99, ITS leadership in Study Group 13 contributed to the completion and approval of two new ITU-T Recommendations (IP packet transfer and availability performance, ISDN call processing performance) and two revised Recommendations (error performance, timing and synchronization performance in broadband transmission networks). ITS spearheaded development of an American National Standard that adopts the new ITU-T Recommendation on IP performance. In ongoing work, ITS participants are contributing to the standardization of QoS objectives for voice over Internet protocol (VoIP) and other real-time IP services, and are leading the ITU-T Voice Quality Experts Group in a comprehensive, multi-laboratory evaluation of proposed video quality assessment technologies proposed for international standardization. Future work in the latter area will be focused on IP-based networks as well.

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Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers benefit to all by supporting a variety of uses, including communications and remote sensing. Unlike many other natural resources, the spectrum is non-depleting so it can be used indefinitely. But its shared use requires planning and coordination to ensure its effectiveness and to avoid interference. Efficient and effective use of the spectrum is a key element in both the NTIA and the ITS mission. NTIA manages the Federal Government's use of the spectrum to ensure maximum benefit to all users while accommodating additional users and new services.

ITS engineers perform measurements on a radio communication link at a remote desert location in southern California. These measurements were intended to isolate reported interference to the link from cellular telephone transmitters (photograph by F.H. Sanders).

The Spectrum and Propagation Measurements Division performs research and engineering to support the goals of more efficient and effective use of the spectrum, and to open up more spectrum at ever-higher frequencies. The following areas of emphasis are indicative of the work done recently in this Division to support NTIA, industry, and other federal agencies.

Areas of Emphasis

Domestic Spectrum Analysis

The Institute assists NTIA and other agencies with the development of national policies regarding the spectrum by assessing current and expected frequency band usage and predicting the effects of sharing among existing and/or emerging technologies. The project is funded by NTIA.

Spectrum Compatibility Testing

The Institute participates in measurements of the emission characteristics of new or proposed systems to help determine their compatibility with each other and with existing systems. The project is funded by NTIA.

Spectrum Occupancy Measurements

The Institute performs spectrum usage and occupancy measurements in any band in any environment to provide information to determine the degree of crowding or to identify the opportunities for new services.

Projects are funded by NTIA, the U.S. Coast Guard, and the U.S. Army.

Spectral Assessment of Government Systems

The Institute performs measurements on old and new systems to determine their emissions characteristics, to confirm proper operation, or to identify and mitigate interference or other incompatibilities. Projects are funded by NTIA.

Radio Frequency Interference Monitoring System

The Institute designs and develops spectrum and radio measurement systems for other agencies. For example, a set of measurement vans were constructed for the FAA. Each national FAA region will have one van to assist with the identification of unwanted, interfering signals. The project is funded by the FAA.

Millimeter-Wave Research

The Institute conducts research on the characteristics of millimeter-wave channels. Measurements and theory are used to develop models useful for the deployment of LMDS, wireless LAN, PCS, and other advanced systems that will use ever-higher frequency bands. Projects are funded by NTIA.

Domestic Spectrum Analysis

Outputs

- Draft report on fixed services spectrum usage.
- Short paper on fixed wireless access (FWA) alternatives.
- Short paper on rural wideband services.

Domestic spectrum analysis efforts are directed towards helping frequency managers and spectrum policy makers develop better ways to make use of the radio spectrum. Major activities in FY 1999 included the preparation of a report on the fixed services (e.g., point-to-point microwave) and continued work on flexible spectrum use rights. Other work included internal short papers prepared for NTIA policy makers on fixed wireless access (FWA) technologies and deployment of rural wideband data technologies.

A report on the fixed services was completed this year and will be published in FY 2000. This report, "Spectrum usage for the fixed services," is an update to an ITS staff study published six years earlier. The report provides detailed information on the spectrum usage in more than 30 bands that are used primarily for the fixed services, e.g., point-to-point microwave. Typical information for each band includes geographical distribution of licenses (Figure 1), system bandwidths (Figure 2 above) and applications, new markets and technologies, growth predictions, and more.

The fixed services have been particularly interesting to spectrum managers for several reasons. Chief among these reasons is the belief that the actual usage by microwave systems is decreasing as point-to-point microwave systems are rapidly being replaced by optical fiber. Because large amounts of spectrum were originally allocated to the fixed services, some of this spectrum may well be "ripe" for reallocation to newer services like PCS and satellite systems. The current PCS spectrum at 1.8 GHz, for example, uses frequencies that were recently reallocated from the fixed services.

This research shows several trends, some of them unexpected. Some microwave bands show a greatly decreased number of licenses. The number of licenses in the 4 GHz common carrier band, which was once the most intensely used fixed band, has decreased to less than a third of its former peak. Many bands seem to have plateaued, with licensed usage remaining approximately constant over the past several years. Some bands continue healthy growth: the 18 GHz band shows 12% annual growth over the last 5 years. When all of this is summarized in a single graph (Figure 3), the total number of licenses for all fixed services (Federal, private, broadcast auxiliary service, and common carriers) has remained constant at about 165,000 licenses. This graph omits about 200,000 licenses used for cable relay service (CARS) and private cable.

Although Figure 3 shows that fixed service growth has stopped, what is not shown is even more interesting. In the last few years, many non-licensed point-to-point microwave systems have been installed using the 2.4 GHz and 5.8 GHz ISM bands. One major manufacturer of these systems claims to have produced 20,000 of these radios in the last several years. In addition, many of the fixed service bands that are actively being developed for high density microwave systems—including the 24 GHz band, the 28 GHz LMDS band, and the 38 GHz band—are licensed by geographical area only. Individual microwave links are not licensed, so all of this growth is invisible to the license databases used in this report. Moreover, growth in these bands has just begun on an experimental/developmental basis. Huge business/consumer markets are expected in the next few years.

The recent change in the direction of microwave growth can be understood by looking at optical fiber, the chief microwave competitor. When fiber was first used, a single fiber could carry 100 Mb/s—about as much traffic as a wideband microwave link. Five years ago, a fiber could carry 2.5 Gb/s—as much traffic as a whole microwave band. Now, a single fiber can carry 1,000 Gb/s—as much as the whole radio spectrum. As a consequence, microwave is often no longer a replacement for wideband fiber carrying the aggregated traffic of many customers; microwave simply does not have enough capacity. However, microwave is falling into a niche where it can provide medium bandwidth links to individual customers at locations where fiber is too expensive to install. In this new role, tens of thousands of additional microwave links may be needed and many of the higher frequency microwave bands may soon be filled with new systems.

This represents a considerable change for an industry that was once among the most stable and elite of uses, doing the "heavy lifting" for a select group of large telecommunications corporations. The near future may bring complex microwave systems into the homes and businesses of many consumers, with all of the excitement and paradigm-changing significance of a new mass market driving a new wave of consumer expectations.

Figure 1. Density of fixed licenses per square degree in the 5925-6425 MHz band.

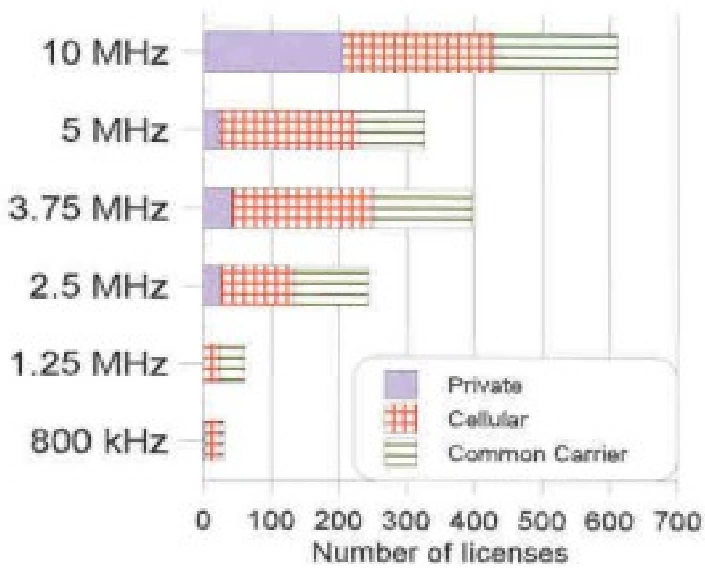

Figure 2. User bandwidths for the 5925-6425 MHz band.

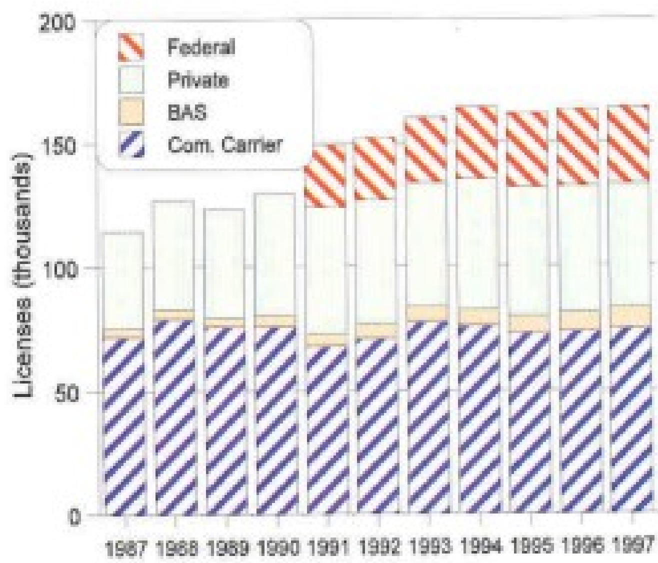

Figure 3. Summary of fixed service licenses, not counting CARS/private cable.

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Spectrum Compatibility Testing

Outputs

- Measurements of harmonic and non-harmonic spurious emission levels from 800 MHz analog and digital cellular telephone transmitters, 1.9 GHz digital personal communication services (PCS) telephone transmitters, and 800 MHz public safety solid-state hand-held transmitters.
- Spectrum emission measurements on new-technology ultrawideband (UWB) radar and communications transmitters.

The introduction of new-technology systems can cause electromagnetic compatibility (EMC) problems when such systems are deployed in proximity to existing ones. NTIA proactively tracks the development of such new technologies and routinely performs EMC analyses and measurements to minimize the extent of such problems involving Government systems.

A recent concern of spectrum managers has been the level of spurious emissions (both harmonic and non-harmonic) from new-technology mobile radio transmitters. These include 800 MHz hand-held radios, and in particular the spurious emission levels produced by solid-state 800 MHz radios being procured by public safety agencies. Criteria are being developed to regulate spurious emission levels from solid-state 800 MHz transmitters, but NTIA needed to know what levels are already achieved by existing 800 MHz and 1.9 GHz hand-held transmitters.

To determine these levels, an extensive set of measurements were performed at the ITS Boulder laboratory on emissions from 800 MHz analog cellular telephones, 800 MHz digital telephones, 1.9 GHz personal communication system (PCS) telephones, and a new, solid-state 800 MHz public safety hand-held radio. Measurements were performed up to the third harmonic, and emphasis was placed on determination of emission levels in Global Positioning Satellite (GPS) bands. An example of the measurement arrangement is shown in Figure 1. The mobile radio measurement results were forwarded to NTIA's Office of Spectrum Management (OSM). The data thus obtained have been used to develop realistic criteria for spurious emission limits on solid-state hand held 800 MHz transmitters.

Another class of new-technology transmitters that has attracted considerable attention from both the public sector and the Government are ultrawideband (UWB) radar and communication transmitters. These systems may provide substantial benefits in such diverse fields such as law enforcement (e.g., covert communications), industrial process control (e.g., the level of liquid in a vessel), and military and peace-keeping operations (e. g., land-mine clearance). However, spectrum managers have expressed considerable concern about the potential for EMC problems that may occur if UWB

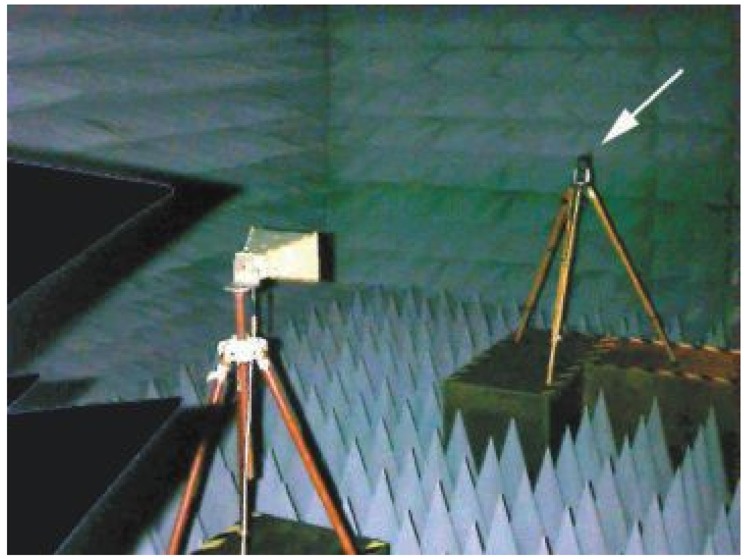

Figure 1. A calibrated measurement antenna and 800 MHz radio transmitter (indicated by an arrow) inside a National Institute of Standards and Technology (NIST) anechoic chamber at the Department of Commerce Boulder Laboratories (photograph by F.H. Sanders).

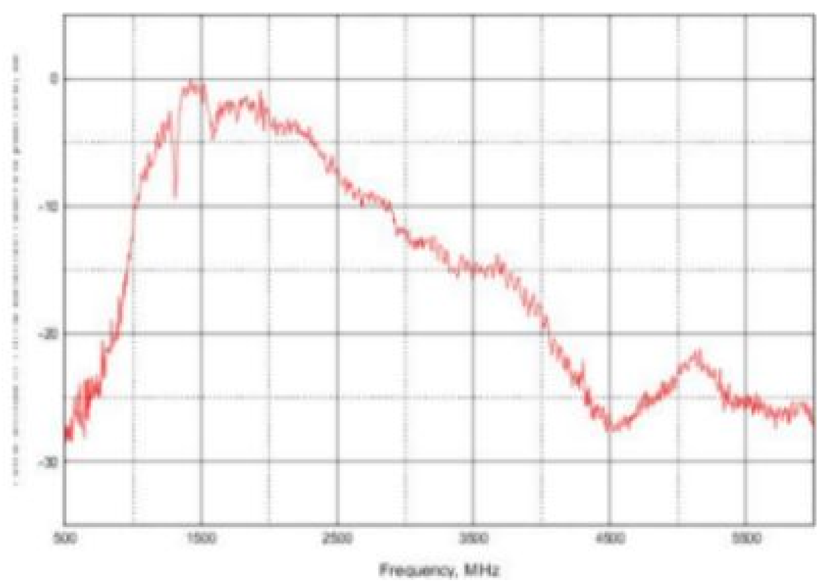

Figure 2a. Generic broadband transmitter spectrum measured with an ITS suitcase measurement system.

systems are widely deployed.

To quantify the level of EMC threat that UWB transmitters may pose, NTIA and the Federal Communications Commission (FCC) in 1999 continued a project to obtain detailed emission measurements in laboratory environments. Using portable measurement systems from the ITS Boulder laboratory, and also FCC equipment and facilities in Columbia, MD, these measurements have detailed the extent of emissions from a variety of UWB transmitters across wide portions of the spectrum (Figure 2). The measurements have also quantified radiation patterns and time-domain behavior of various UWB transmitters.

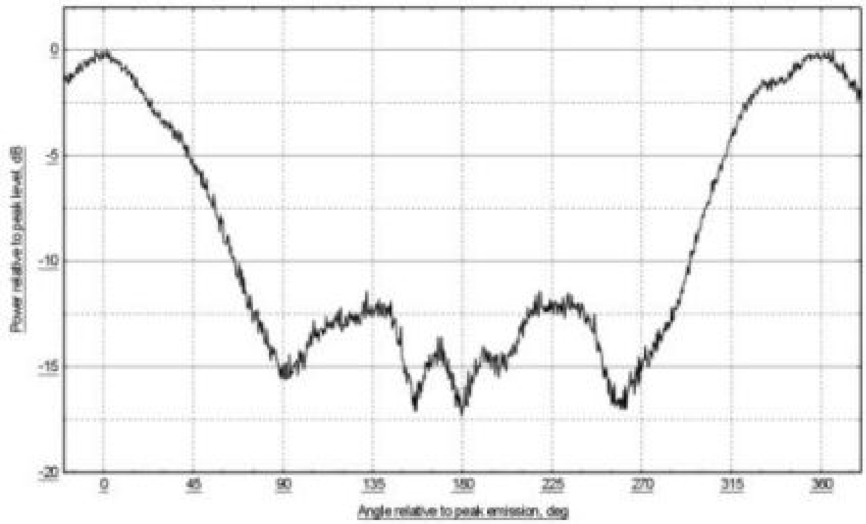

Figure 2b. Generic broadband transmitter radiation pattern.

These measurement results have been forwarded to OSM, and have in turn been provided by NTIA to spectrum managers on the Interdepartmental Radio Advisory Committee (IRAC) in Washington. The data have provided spectrum managers with vital information concerning the potential for EMC problems (if any) between UWB and other systems. The data have also been used to design additional tests and measurements that need to be performed on UWB transmitters in fiscal year 2000.

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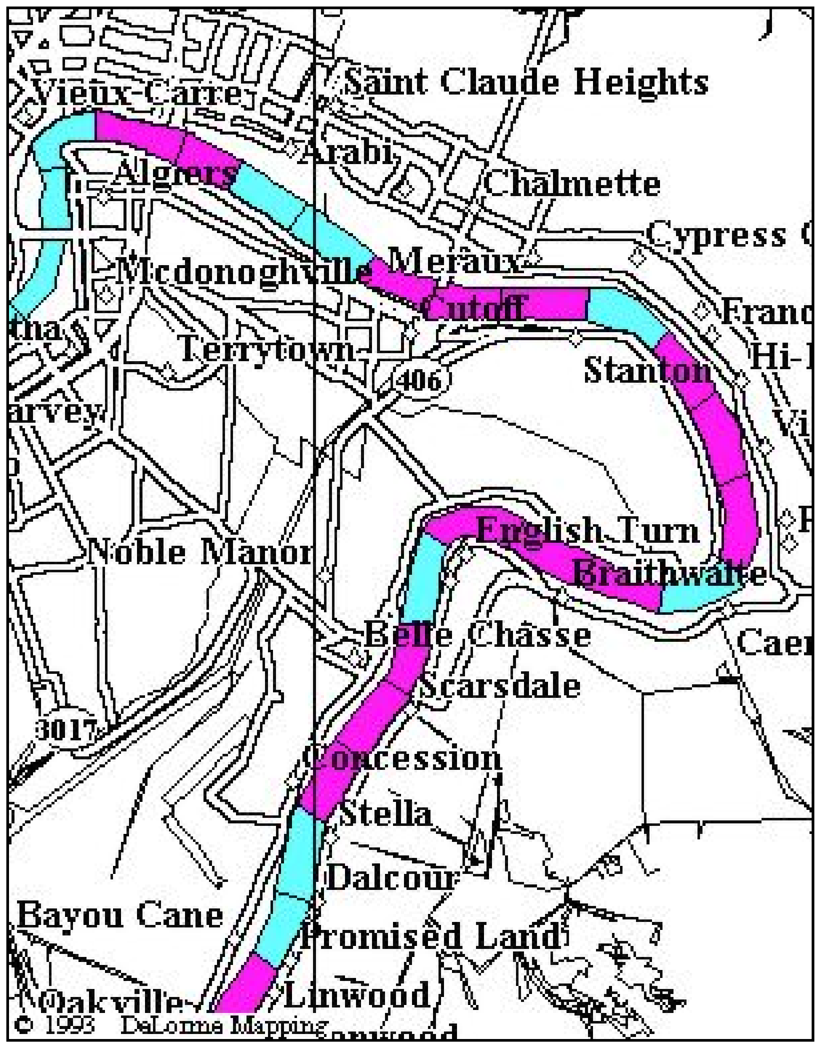
Spectrum Occupancy Measurements

Outputs

- Detailed measurements of spectrum availability and verification of system performance on new Coast Guard precision navigation systems in the New Orleans, LA area.
- Interference-assessment measurements and broadband spectrum surveys for the U.S. Army at Ft. Irwin, CA to determine electromagnetic environment during field maneuvers.

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



In Fiscal Year 1999, ITS, OSM, and the U.S. Coast Guard (USCG) participated in a joint technical effort to determine spectrum availability and system performance for a new class of maritime navigation system being deployed near New Orleans, LA. The transmitters are digital transponders carried by marine traffic on the Mississippi River. These devices transmit vessel identification and location (as determined by on-board Global Positioning System (GPS) receivers) to other vessels and USCG shore stations.

This transponder technology represents a considerable improvement in tracking capabilities for the Vessel Traffic Service (VTS), part of the Ports and Waterways Safety System (PAWSS).

Figure 1. Result of VTS frequency survey measurements along a section of the Mississippi River near New Orleans, LA. Interference levels for a particular channel are indicated by colors (violet for SINAD ≥ 16 dB, and blue for 12 dB ≥ SINAD < 16 dB).

The new VTS digital transponders currently occupy marine VHF channels on a temporary basis. Part of the NTIA and USCG effort was devoted to identifying a set of permanent channels for the transponder signals. Another part of the effort was to determine the extent to which those channels experience a variety of interference effects, including intermodulation and adjacent-channel problems.

ITS, OSM, and USCG personnel made four trips to New Orleans to perform the necessary measurements (Figure 1) using suitcase measurement systems from ITS. Additional data were collected at ITS in Boulder. The total data set has been used to determine available channels and system performance for the new VTS transponders.

Figure 2. ITS engineer loading measurement gear onto a military helicopter at a remote desert location at Ft. Irwin, CA (photograph by F.H. Sanders).

In response to reported radio interference problems at the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) National Training Center (NTC) at Ft. Irwin, CA, ITS measurement systems were deployed at the NTC. This directly reimbursable project had three parts: measurements were performed to determine whether commercial cellular telephone signals were interfering on specific frequencies; measurements were performed to determine the overall occupancy of the spectrum between 30 MHz and 22 GHz during Army maneuvers; and performance tests were conducted at remote locations (Figure 2).

Measurements were performed at several locations, including some that required extended camping on the range (Figure 3). Background spectrum occupancy data were collected during a period when no maneuvers were occurring at the NTC, and signals originating on the range were turned off, so as to identify background signals on the same frequencies. Finally, three measurement systems were operated in the midst of armored field maneuvers. ITS wrote a Sponsor Report that detailed the extent and nature of electromagnetic interference and spectrum occupancy at the NTC.

Figure 3. Convoy of ITS RSMS van, U.S. Army high mobility multipurpose wheeled vehicle (HMMWV), and towed power-supply generator prepares to leave base area at Ft. Irwin, CA for a measurement location in the desert. The RSMS crew camped on the range with the van and performed broadband spectrum occupancy measurements during a week-long military exercise at that facility (photograph by F.H. Sanders).

Recent Publication

R.L. Sole and B. Bedford, "Lower Mississippi River VTS frequency survey," NTIA Report 99-364, June 1999.

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Spectral Assessment of Government Systems

Outputs

- Spectrum emission measurements on new type of Department of Defense high-power transmitter.
- Spectrum emission measurements on TPS-59 high-power air search radar.

Radio spectrum in the United States is being placed under increasing demands due to increasing numbers of users and the development and deployment of new types of radio transmitters. Such spectrum demands often result in electromagnetic compatibility (EMC) problems that threaten Government radio operations, and new Government systems cannot be fielded until tests and measurements have been performed to verify that they will not generate EMC problems for other systems. Further, in the event that new or existing Government systems do create or receive EMC problems, it is necessary to resolve these problems promptly and efficiently. ITS provides extensive EMC measurement and analysis capabilities for preventing potential EMC problems and solving existing ones.

Figure 1. ITS Radio Spectrum Measurement System (RSMS) van at Twentynine Palms, CA, performing emission spectrum measurements on Marine Corps TPS-59 radar transmitter. Radar is approximately one-quarter mile away; measurement antenna is raised on telescoping mast to avoid nearby terrain and structural obstacles (photograph by F.H. Sanders).

In 1999, ITS performed measurements on Department of Defense (DoD) transmitters at two locations in the desert Southwest devoted to prevention of EMC problems. One set of measurements was devoted to preventing interference domestically, while measurements were performed on another system to demonstrate EMC measurement methodology for foreign participants at a meeting of the International Telecommunication Union (ITU).

The first transmitter to be measured was a high-power system being operated experimentally at an indoor test facility, and which DOD needed to operate outdoors in a later test series. Before NTIA could authorize outdoor operations, verification was needed that spurious emission levels in air traffic control bands, Global Positioning System (GPS) bands, and other parts of the spectrum were sufficiently low to ensure safety of air traffic in the event that outside operations were to commence. In response, the ITS Radio Spectrum Measurement System (RSMS) van (Figure 1) was deployed to the transmitter location. RSMS equipment and measurement software were used at the indoor facility to measure the device's emissions, and spurious emission levels in all relevant bands were determined. The measurement results were forwarded by NTIA to other Government agencies on the Interdepartment Radio Advisory Committee (IRAC) in Washington, DC, where spectrum planners used the RSMS data to devise outdoor operation protocols for this transmitter.

Spurious emission levels produced by Government high-power radars are also a major concern for spectrum planners, and a controversy has developed at the ITU between the United States and other Administrations concerning the proper methodology for measurement of such radar emissions. Some Administrations have maintained that solid-state transmitters in radars cannot meet exacting emission criteria. The United States has countered that some measurements that appeared to show unacceptably high spurious levels have not been performed properly. To demonstrate the proper methodology for such measurements, the RSMS was deployed to Twentynine Palms, CA, to measure emissions of a TPS-59 solid-state air search and anti-tactical ballistic missile radar (Figure 2).

The measurements were performed by allowing the radar to radiate and scan the sky in normal operational modes while the RSMS received its signals at a distance. The effects of selecting a range of measurement parameters were demonstrated. In addition, measurements of pulse shapes were performed to determine the time waveforms to which receivers near such radars will be subjected at selected frequencies, including GPS bands.

The results of these measurements have been forwarded to NTIA in Washington, where they will be used by the United States at the ITU, as well as by domestic spectrum planners who are concerned with spectrum compatibility issues associated with radar systems.

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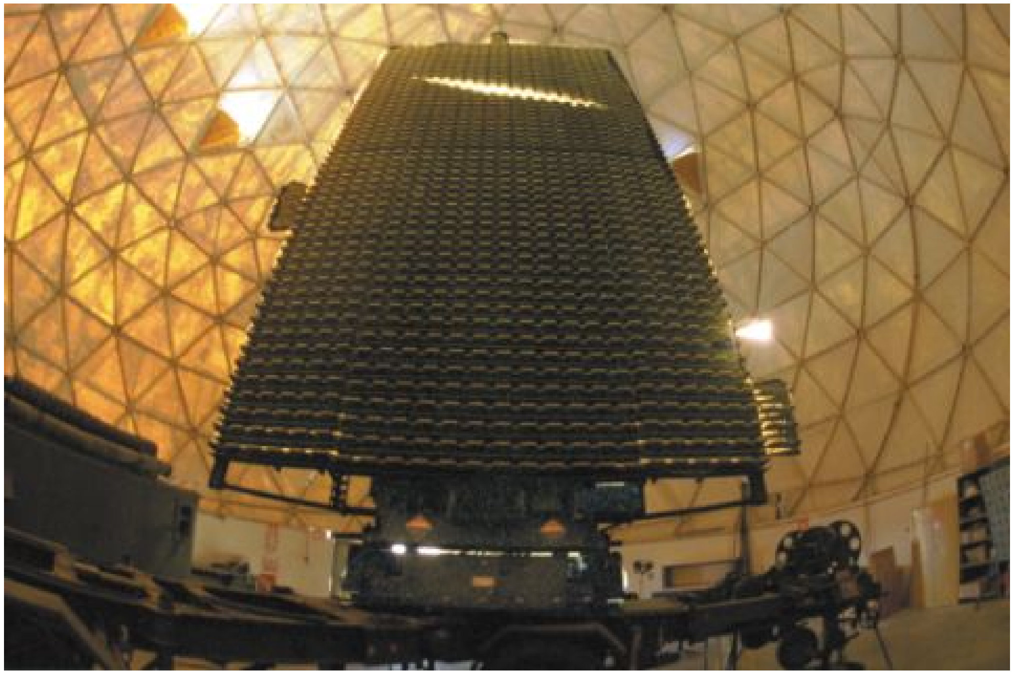

Figure 2. TPS-59 radar antenna. ITS systems perform measurements on this and other radar transmitters while the radar antennas are rotating and radiating in normal operational modes (photograph by F.H. Sanders).

Radio Frequency Interference Monitoring System

Outputs

- Six production Radio Frequency Interference Monitoring System (RFIMS) vehicles assembled, tested and delivered to the Federal Aviation Administration (FAA).
- Familiarization and Orientation training classes given to FAA region and Technical Center personnel.

Figure 1. A production RFIMS vehicle (photograph by B. Bedford).

ITS offers expertise in custom measurement system design to other Federal agencies and industry. One such design effort is the Federal Aviation Administration (FAA) Radio Frequency Interference Monitoring System (RFIMS), with units being provided nationwide to every FAA region. Under the RFIMS program, ITS personnel analyzed FAA requirements and developed an automated, custom-designed radio frequency measurement system; integrated and tested a prototype mobile system; and have now integrated and tested nine (of eleven total) systems. ITS also plans and implements associated support requirements including documentation of the system, training of the operating personnel, and operation of the RFIMS Development Lab located at ITS. In fiscal year 1999, ITS provided technical support to the regions that had received systems in 1998. The support included answering questions about operating the system and assistance in troubleshooting problems.

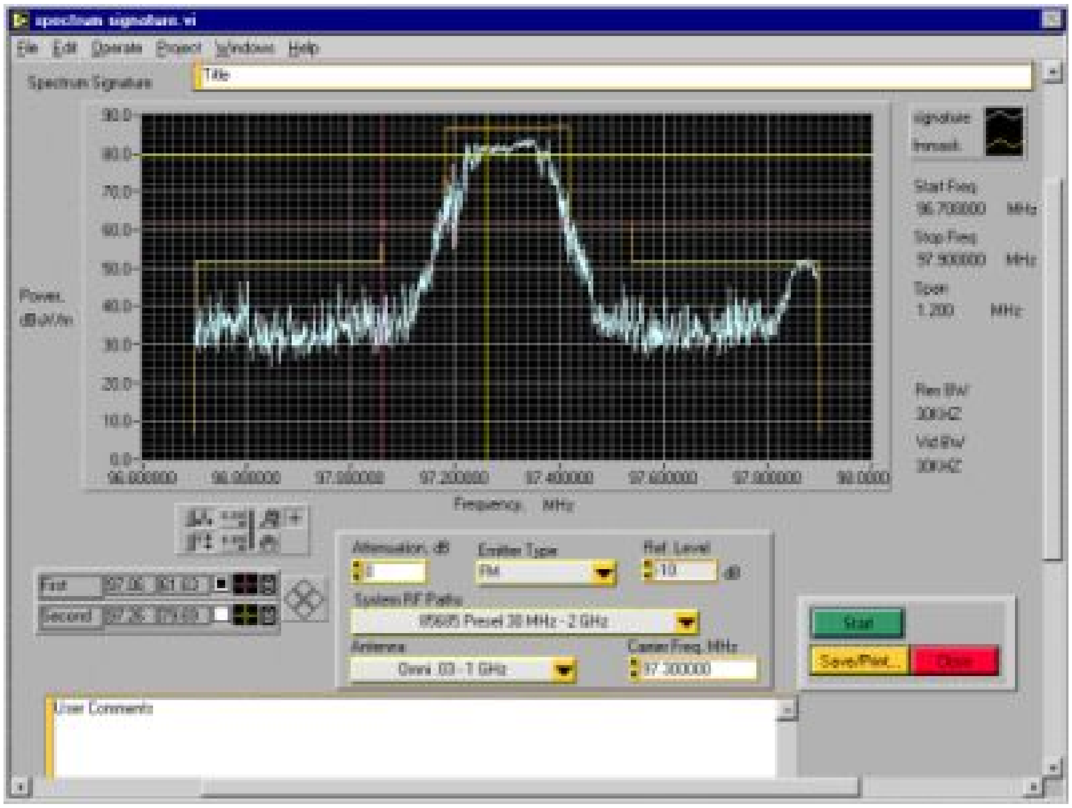

Figure 2. The spectrum signature measurement panel.

The RFIMS program effort was divided into three tasks. Task 1 included an assessment of requirements, option evaluations, and development of a measurement system specification. Task 2 included system acquisition and testing of a prototype RFIMS, delivered in February 1998 to the FAA. In task 3, which is still ongoing, ITS assembles, tests and delivers the remaining ten systems. In fiscal year 1999, ITS delivered seven RFIMS vehicles to the FAA. The following FAA regions received these systems: Southern, Technical Center, Northwest Mountain, Central, Great Lakes, Eastern, and New England. Each system was assembled and tested by ITS personnel to assure peak performance upon delivery.

The RFIMS development process was divided into three major subsystems: the vehicle, the Integrated Electronic Package (IEP) hardware, and the Measurement Control System (MCS) software. The vehicular platform is a Ford Econoline© outfitted with three six-foot equipment racks (Figure 1). The IEP is designed to use commercial off-the-shelf measurement equipment, but includes three devices that were designed, developed and assembled by ITS. These devices are a mast-top signal preamplifier and preselector system, an automated measurement path selector and an automatic/ manual controller device for the mast-top system. These three devices are not available in the commercial market and represent innovative and unique solutions developed at ITS. The MCS (written in LabView©) controls the measurement system and records and documents the automated measurements. Information automatically recorded in every scan includes data, antenna factors for antennas, measurement system gains and losses, and equipment parameter settings.

The IEP integrates various test and measurement devices to produce a system that is capable of more sophisticated measurements than would be possible with the individual devices. The IEP is subdivided into three areas. The first area is the antenna package. Four antennas are provided to encompass the range of frequencies and measurement scenarios that are envisioned by the FAA. An antenna mounting assembly, designed and constructed by ITS, is provided to aim the antennas (when necessary) and adjust their polarization.

The second area of the IEP is the mast-top signal preamplifier and preselector system. This system provides filtering to reject unwanted signals. It also provides amplification to create a highly sensitive measurement system. The third area is the rack mounted equipment, which includes a commercial spectrum analyzer, a communications test set, and an oscilloscope. Signals to be measured are routed to the commercial test and measurement equipment by an ITS-designed automated measurement path selecting device. This device channels the incoming signal to the appropriate measurement device under manual or computer control. Another rack mounted, ITS-designed device provides manual or computer control of the mast-top signal preamplifier and preselector system.

The MCS incorporates a suite of custom measurement routines specified by the FAA. These automated capabilities allow the FAA to perform standardized computer-controlled measurements that would be impractical to perform manually. This includes those measurements that require highly repetitive tasks and extensive post processing. An example of this type of measurement is the Air Traffic Control Radar Beacon System (ATCRBS) antenna pattern assessment. This measurement utilizes a unique algorithm that resulted in a patent for novel use of software and hardware to determine directional and omni-directional antenna patterns without interrupting beacon operations. Other computer-controlled measurements include a spectrum signature (Figure 2), radar pulse repetition frequency and spectragraph. The spectragraph graphically shows the time variation of the spectrum. This unique ITS-developed tool is useful for determining the causes of interference and intermodulation products.

The RFIMS Program is an excellent example of how ITS can assist other Federal agencies with their spectrum measurement needs. ITS engineers have both the hardware and software engineering expertise, and the knowledge of spectrum monitoring and measurement techniques necessary for automated spectrum measurement design and development.

Recent Publication

P. Raush, J. Kub and E. Gray, "Automatic radio frequency monitoring measurements," in *Proc. IEEE Symposium on EMC*, vol. 2, Seattle, WA, Aug. 1999, pp. 716-721.

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Millimeter Wave Research

Outputs

- Measurement of 30 GHz signal attenuation characteristics due to changing vegetation.

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

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

In recent years, ITS has completed a number of propagation experiments and studies relating to propagation in urban and suburban environments for several private sector organizations interested in LMDS. These studies resulted in a detailed analysis of area coverage for 30 GHz LMDS, including depolarization caused by vegetation (e.g., Papazian et al. 1992, Papazian et al. 1997, Papazian & Hufford 1997; see **Publications Cited**).

In Fiscal Year 1999, ITS completed a study of seasonal variations in signal attenuation by vegetation (trees). A narrowband link at 28.8 GHz was set up on a 1-km path between wing 4 of the Radio Building of the Department of Commerce Boulder Laboratories, and Enchanted Mesa, 1 km west on the campus. The transmitter, located at the Enchanted Mesa site, used a dish antenna with 1.2-degree beamwidth and 43-dB gain. The receiver used a horn antenna with 5.5-degree beamwidth and 30-dB gain. There was a single tree about 15 m from the receiver.

Propagation measurements were made with the tree on path and near path for several weeks with leaves both on the tree and off. Figure 1 shows the path profile, including wing 4 and wing 6 of the Radio Building, the transmit and receive antenna locations and the terrain. The radio path cleared the high roof of wing 6 by more than two Fresnel clearance zones, which limited the loss due to diffraction to less than 1 dB. Consequently, receiver positions not obscured by the tree canopy had a clear radio line-of-sight to the transmitter.

Before looking at the seasonal changes, ITS measured the average signal attenuation by the tree canopy with no leaves present at six receiver locations. For each measurement the transmit antenna was pointed to obtain maximum signal power. Received power was measured for 2-3 minutes at 1 Hz intervals and then averaged. In Figure 2, the signal attenuation is plotted versus location. The obscured positions at—10 m and 10 m had the greatest attenuation ranging between 16 and 18 dB, consistent with previous measurements for deciduous trees with no leaves at 28.8 GHz (Papazian et al. 1992; see **Publications Cited**).

To track seasonal change, the daily average received power was computed. Data from the fall measurements had diurnal changes as large as 5 dB but show a 10-dB decrease in attenuation between days 15 and 20 when the leaves dropped. Received power during the spring for two paths, the first obscured by the trees and the second, the new line-of-sight (LOS) path, are shown in Figure 3. The second receiver was positioned at—10 m, which had a 3 m LOS clearance from the tree canopy but was still in the antenna main beam. We see that seasonal change took 10 days. During this time the signal level dropped as much as 14 dB but stabilized between 10 dB and 12 dB.

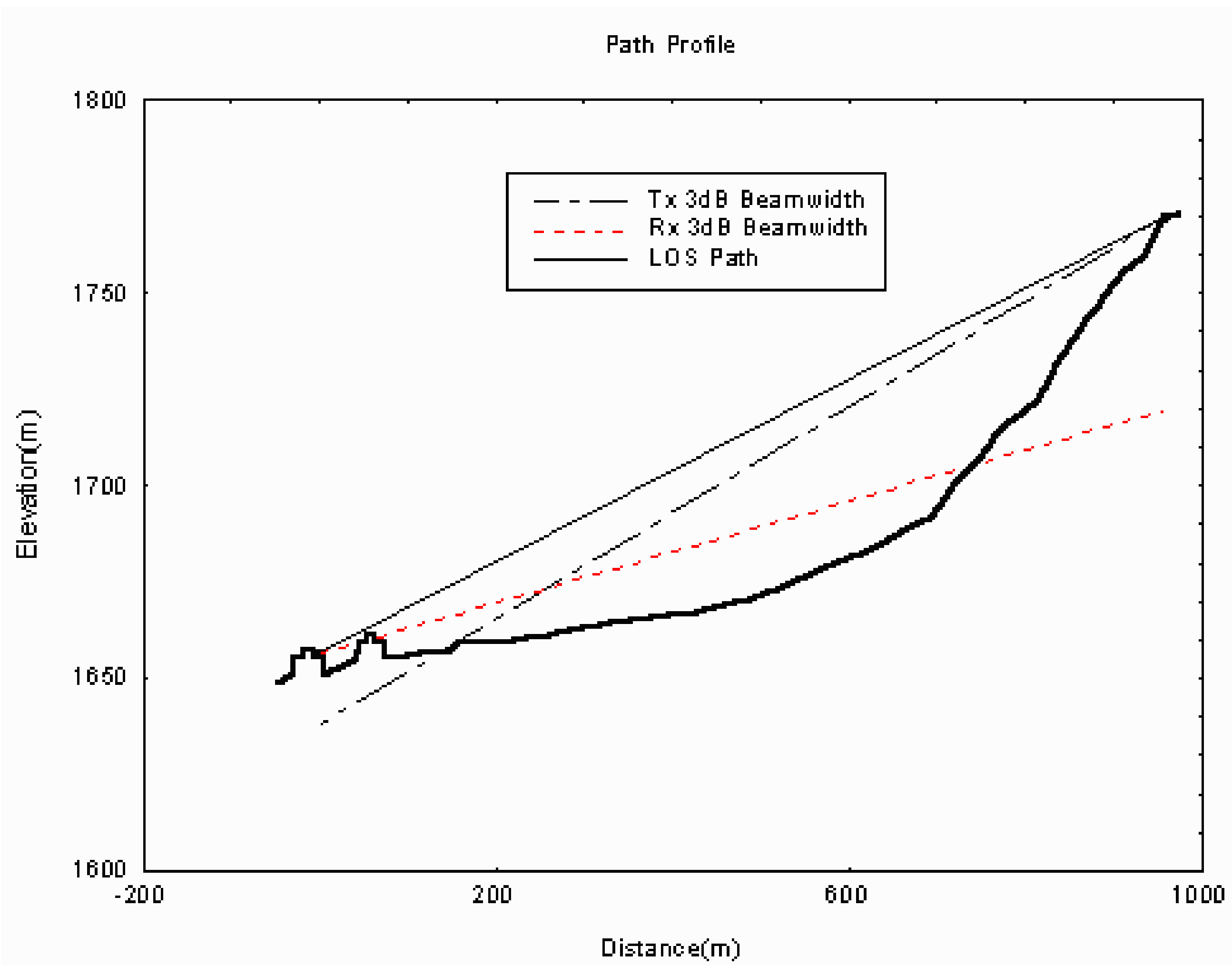

Figure 1. Path profile for vegetation experiment. Wing 4 of the Radio Building is the structure on the far left, wing 6 is next to it, and the heavy line outlines the terrain leading up to the transmitter.

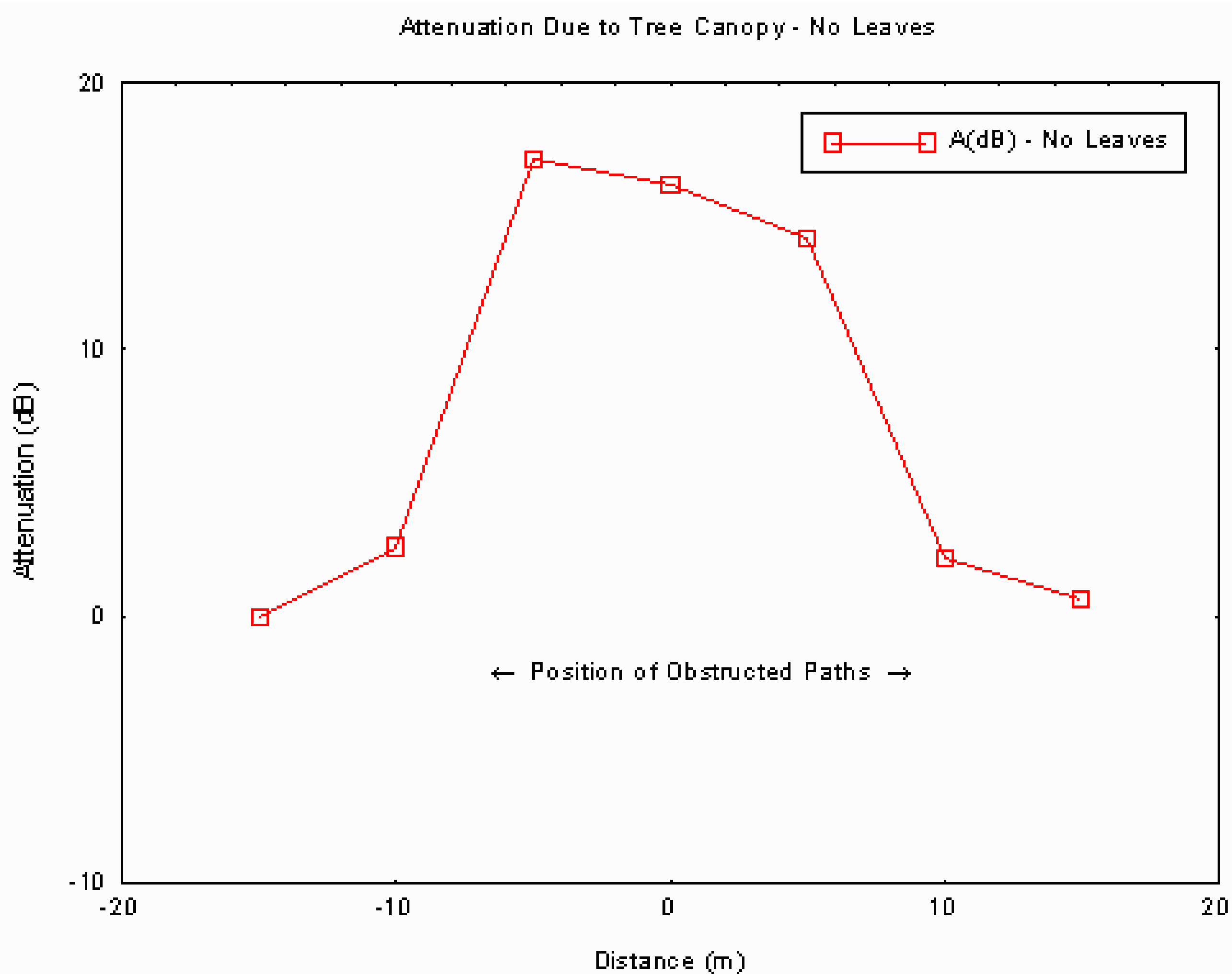

Figure 2. Attenuation due to trees on path with no leaves.

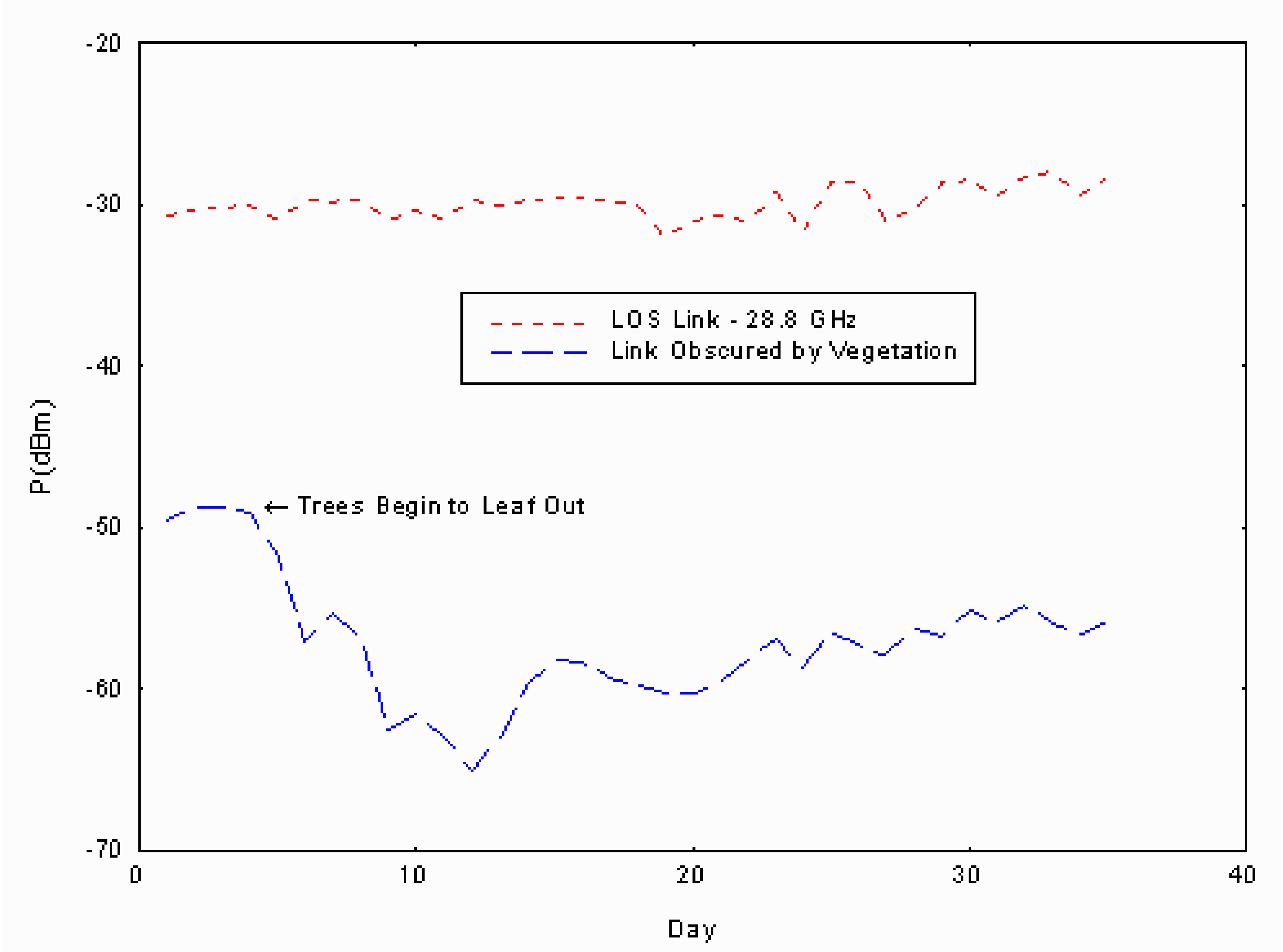

Figure 3. Average daily signal power, May 9—June 12, 1999.

Recent Publication

P. Papazian and Y. Lo, "Time variability of a local multi-point distribution service radio channel," in *Proc. 1999 IEEE Radio and Wireless Conference (RAWCON)*, Denver, CO, Aug. 1999, pp. 211-214.

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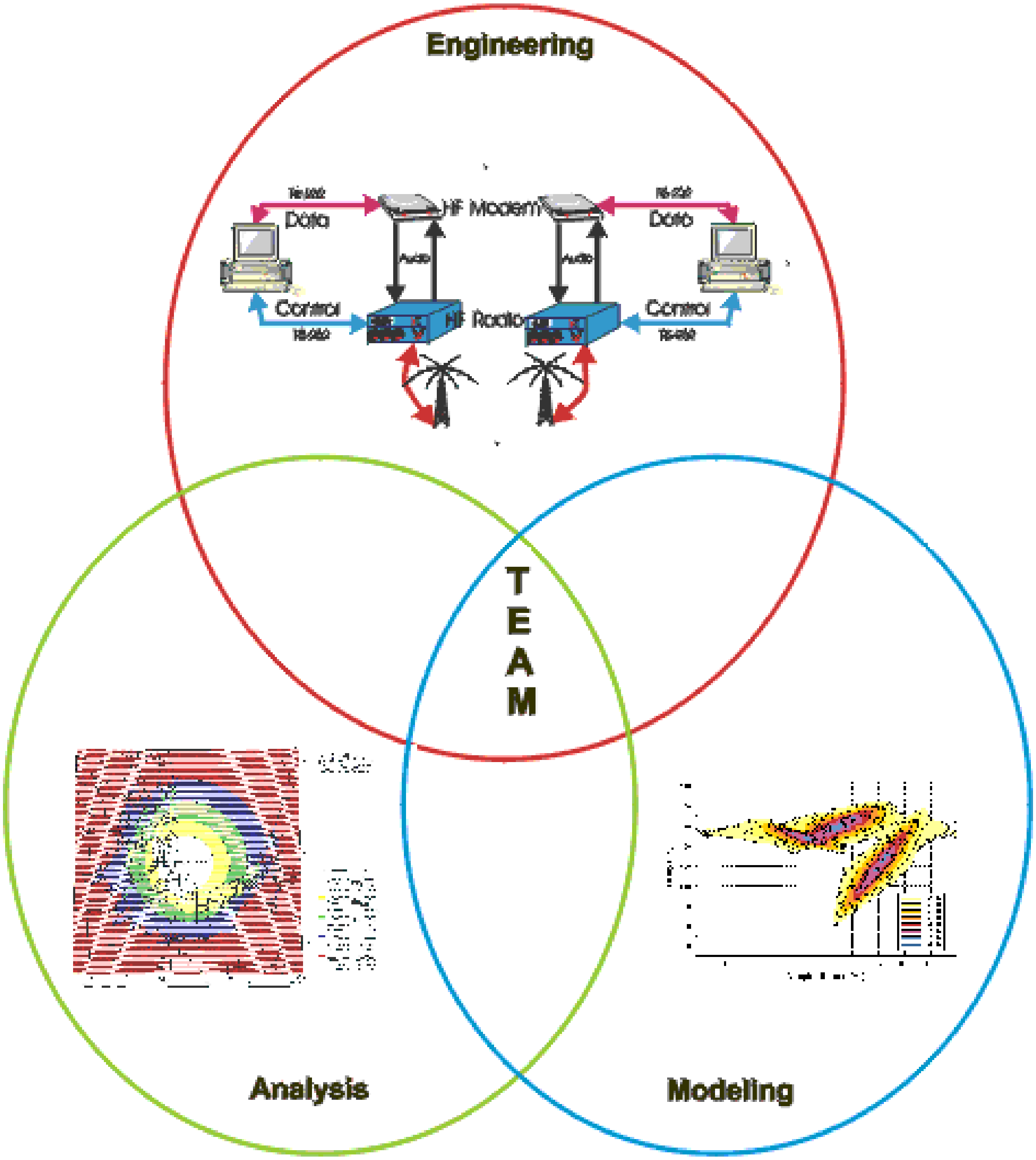
Telecommunications Engineering, Analysis and Modeling

The Telecommunications Engineering, Analysis and Modeling Division conducts studies in these three areas for wireline and wireless applications. Results are reported to the scientific community, standards bodies, and industry and user group forums.



The three areas of the Telecommunications Engineering, Analysis, and Modeling (TEAM) Division illustrate a synergistic approach to examing and designing telecommunication systems.

Engineering work includes assessment of the components of telecommunications systems, such as RF delivery methods, vocoding techniques, and network topologies; and evaluation of protocol and transport mechanism effects on network survivability and performance. The impact of interoperability, timing, and synchronization is accessed to determine a system's effectiveness in a National Security and Emergency Preparedness (NS/EP) environment.

Analysis work is often performed in association with the program area of Telecommunications Analysis (TA) Services, which offers many analysis tools on line via the Internet. In addition, ITS can provide custom tools and analysis for larger projects, or specific government agencies.

Modeling has been one of ITS's greatest strengths for many years. Models include various terrain databases and other data. Adaptions of historic propagation models such as IONCAP and ICEPAC have been developed and enhanced, as well as models for more specialized situations such as the Jammer Effectiveness Model (JEM).

Areas of Emphasis

ENGINEERING

HF Program The Institute promotes technology advancement in the radio communication industry and improvements to the interoperability and effectiveness of HF radio systems supporting NS/EP needs. Sponsors include the National Communications System (NCS) and NTIA.

Network Survivability The Institute develops practical and effective ways of specifying and assessing the survivability performance and reliability of wireless communications networks. The project is funded by NCS.

PCS Applications The Institute helps the Telecommunications Industry Association (TIA) committee TR46.2.1 develop an inter-PCS interference model and handbook. The project is funded by NTIA and NCS.

Wireless Network Access The Institute examines the application of Internet Protocol (IP) to wireless terrestrial and satellite links, focusing on priority wireless network access, voice over IP (VoIP), and secure data transfer; and evaluates the applicability of cellular phone and satellite technologies to mobile computing for NS/EP environments. The project is funded by NCS.

ANALYSIS

Telecommunications Analysis (TA) Services The Institute provides network-based public access to the latest ITS research results, engineering models, and databases supporting broad applications in wireless telecommunications system design and the evaluation of broadcast, mobile, and radar systems. These services are funded by fee-for-use charges paid by users and by fee-for-development charges for new software/model tools.

MODELING

Jammer Effectiveness Model The Institute assesses the impacts of jamming and interference on communications and radar system performance in electronic warfare scenarios. The project is funded by the U.S. Army.

Modulation Bandwidth Requirements In coordination with NTIA's Office of Spectrum Management (OSM), the Institute develops improved mathematical models to examine digital modulation techniques from the perspectives of spectrum efficiency and adjacent channel interference. Projects are funded by NTIA.

Propagation Model Development In coordination with OSM, the Institute develops enhancements to existing propagation models and works to harmonize related models. The project is funded by NTIA.

HF Program

Outputs

- Development and standardization of the third generation HF messaging protocol, MIL-STD-188-141B.
- DRAFT update of the HF modem standard, MIL-STD-188-110A, to revision B.
- Assessment of performance of an optimized HF e-mail protocol stack.

The National Communications System (NCS) has overall responsibility for managing the Federal Telecommunications Standards Program (FTSP). The FTSP is implemented through an interagency committee structure that comprises the Federal Telecommunications Standards Committee (FTSC) and the High Frequency Radio Subcommittee (HFRS). ITS chairs the HFRS, co-chairs the Technical Advisory Committee (TAC) and provides technical contributions to related working groups. These activities promote technology advancement in the radiocommunication industry and improve the interoperability and effectiveness of HF radio systems supporting National Security and Emergency Preparedness (NS/EP) needs.

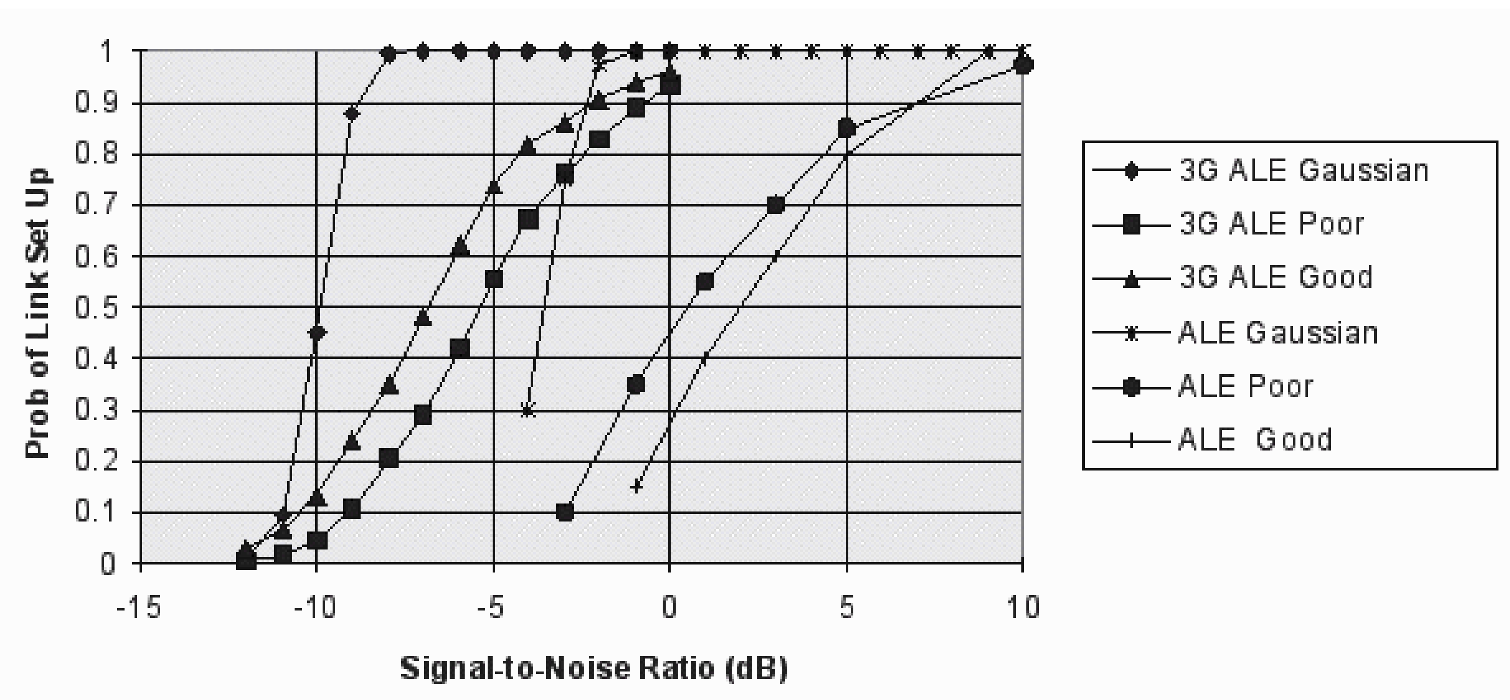
Prior ITS and HFRS efforts have produced a series of Federal standards that specify interface, protocol, and performance requirements for HF automatic link establishment (ALE) radio systems. Commercial radio equipment that implement these standards are being widely used in the Federal Government.

During FY99, ITS participated in three efforts concerning HF radio systems. The first of these was the development and standardization of the third generation (3G) HF messaging protocol, MIL-STD-188-141B. The need for the 3G HF messaging protocol suite stems from the growing need for HF voice and data messaging systems offering high reliability and high capacity. HF continues to play a crucial role in NS/EP communications; however, this role is changing as more HF users extend the Internet into the battlefield. The use of standard Internet applications (such as e-mail) over the HF channel creates heightened technical challenges which are not met adequately by existing HF communications protocols. The existing protocols do not provide effective channel access mechanisms, and, as a result, tend to break down due to collisions and congestion under heavy network loads. The current ALE and data link standards (i.e., FED-STD-1045A and FED-STD-1052) use very different modulation formats (8-ary FSK versus serial tone PSK), resulting in a performance mismatch between the linking subsystem and the message delivery subsystem. Current HF automatic repeat request (ARQ) protocols require complicated methods for matching the waveform and/or data rate to the channel conditions.

The 3G system attempts to meet all of these challenges with simple but effective designs for prioritized channel access and collision avoidance, a unified and scaleable burst waveform, and an enhanced ARQ protocol that significantly increases throughput in all channel conditions. Proof-of-concept testing (POC) of the 3G system is being planned under the guidance of the HFRS and will be conducted when prototypes become available. The Figure shows a performance comparison between the second and third generation ALE systems.

ITS's second effort in FY99 consisted of updating the HF modem standard, MIL-STD-188-110A, to revision B. The revision has been completed in draft form and final coordination will be conducted among Government and industry organizations in FY 2000. The revision to MIL-STD-188-110A primarily focuses on converging the FED-STD-1052 and Standards Agreement (STANAG) 5066 data link protocols for the purpose of US interoperability with NATO forces. The end result will be a single data link protocol for the military community, Federal agencies, and NATO. Collaboration in the TAC is being conducted with representatives from all three communities to meet the requirements of each user group. Also included in MIL-STD-188-110B is a modem waveform and coding specification for data rates of 3200, 4800, 6400, 8000, 9600 and 12,800 b/s.

In a third effort in FY 1999, ITS assessed the performance of an optimized HF e-mail protocol stack. The objective of this project was to quantify the performance of an HF-optimized protocol stack for sending e-mail messages over degraded HF channels. This work builds upon previous ITS work that quantified the performance of a first-generation HF e-mail system. This protocol stack is the result of work done by the HFRS which incorporates an off-the-shelf SMTP mailer, FED-STD-1052 data link protocol, and HF modem. Throughput was measured in the lab using the Watterson model HF channel simulator. (See the **ITS Tools and Facilities** section for a description of the ITS HF communications system test and evaluation facility.)



- 2G ALE (FED-STD-1045) cannot link on low-SNR links that are usable for data transfer (via MIL-STD-188-110A serial tone and FED-STD-1052 data link protocol)
- 3G ALE provides a 6dB improvement

Performance comparison between second and third generation ALE systems. Channel conditions shown (Gaussian, poor, good) are from ITU-R Recommendation F520-2: Use of High Frequency Ionospheric Channel Simulators (March 1992).

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Network Survivability and Restoration

Outputs

- Technical Contributions to ANSI Working Group T1A1.2.
- Draft NTIA Report and technical report to NCS defining techniques to specify and assess network survivability performance.

As the world becomes more and more interconnected, concern is mounting about the effect of possible network failures caused by physical damage (such as severe weather, fire, or terrorism), failures in software or control systems, or terrorist hacker attacks on the network infrastructure. Simultaneously, the need for voice and data messaging systems offering high reliability and high capacity is growing dramatically. Existing standards do not provide effective survivability performance measures and, as a result, congested networks tend to break down due to collisions under heavy traffic loads. Multi-vendor environments create the potential for a performance mismatch. The ANSI Standards Committee T1 (Telecommunications) Working Group T1A1.2 (Network Survivability Performance) attempts to meet these challenges with simple but effective performance metrics for use in the design of survivable networks.

The National Communications System (NCS) asked ITS to participate in and develop technical contributions to T1A1.2, in order to provide more practical and effective ways of specifying and assessing the survivability performance and reliability of wireless communications networks, and to help motivate, strengthen, and extend the work of T1A1.2. The results will advance national security and emergency preparedness (NS/EP) goals by making network survivability—and the potential benefits of survivability enhancement techniques—more quantifiable. This work supports NCS in its mission to protect the national security telecommunications infrastructure, and to ensure the responsiveness and survivability of essential telecommunications during a crisis.

ITS's formal contributions to T1A1.2 Working Group in the past year included two general assessments of network survivability performance assessment methods and two further documents detailing a proposed method for quantitatively determining a network's expected survivability performance.

In the first of the general assessment documents, T1A1.2/99-007, "Suggestions for Areas of Work in Network Survivability Performance," ITS personnel conducted a review of T1 Technical Reports 24 ("A Technical Report on Network Survivability Performance," Nov. 1993), 24A ("Supplement to Technical Report No. 24," Aug. 1997), and 42 ("A Technical Report on Enhanced Analysis of FCC-Reportable Service Outage Data," Aug. 1995). In their review, ITS personnel identified areas for work that would further the interests and activities of T1A1.2 and its constituents. They targeted areas in statistical analysis and discrete mathematics that are applicable to telecommunications networks and network survivability performance.

In the second of the general assessment documents, T1A1.2/99-023, "Survivability Analysis and Assessment Methods, " ITS presented preliminary ideas and example methods that can be used in survivability analysis and assessment of both digital and analog communications networks. ITS examined methods for simplifying the complex calculations involved, and also considered extensions to survivability measurements involving performance. This document proposed that Appendix B of T1 Technical Report 24 be enhanced and augmented with specific methods similar to the methods discussed.

In contribution T1A1.2/99-027, "Network Redundancy as a Measure of Survivability," ITS proposed a new network survivability measure designated as *Redundancy*. It was proposed and accepted that this performance measure will be included in the revised T1 Technical Report 24. The Redundancy of a network is defined as the average number of spanning trees in a network under random failure of the links. A polynomial time method for calculating Redundancy was also presented. This method is robust and simple enough that it is not necessary to assume that the probability that a link is functioning correctly is uniform throughout the network.

At the request of T1A1.2, the Redundancy measure was developed further and a tutorial example was presented in document T1A1.2/99-054, "Example Application of Network Redundancy as a Measure of Survivability." This document presented more of the mathematical basis for the Redundancy measure and presented an example application of network redundancy as a measure of network survivability. It illustrated Redundancy of the signaling network for a single connection in the Public Switched Telephone Network (PSTN). This contribution was also proposed and accepted as an addition to the Appendix of T1 Technical Report 24.

Working Party T1A1.2 requested that the two documents relating to the Redundancy measure be combined into a section of Appendix B of the revised T1 Technical Report 24. This document will be finalized in FY 2000. The presentation of the Redundancy measure will form the basis of a technical report to NCS as well as an NTIA Technical Report.

As an example of the Redundancy measure, a ring network on five nodes is illustrated in blue in Figure 1. One of its corresponding spanning trees is shown in red in Figure 2. The nodes themselves are in green in both figures. These figures illustrate one spanning tree for only one of the network nodes. Since the Redundancy of a network is defined as the average number of spanning trees in a network, the Redundancy of this network will be found by averaging the number of spanning trees over all of the nodes.

In Fiscal Year 2000 ITS continues to address network survivability and the measurement of its performance. In addition many issues associated with the multiple vendor community are arising in this new networking and Internet environment. The work on survivability performance must of necessity be conducted with the help of representatives from network providers as well as NCS. The work in FY 2000 is expected to involve survivability of IP and other packet-based networks.

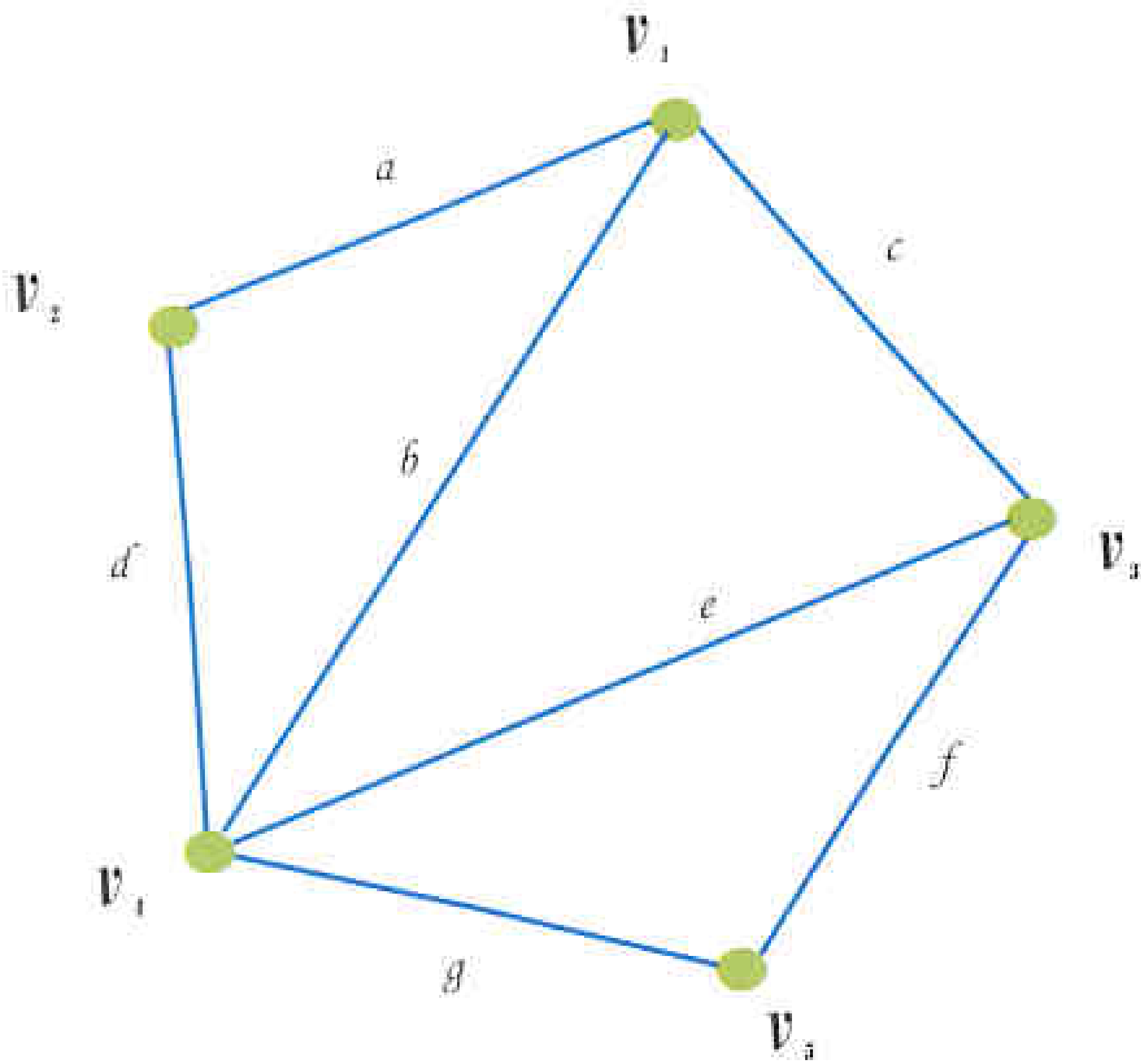

Figure 1. Five-node, seven-link network.

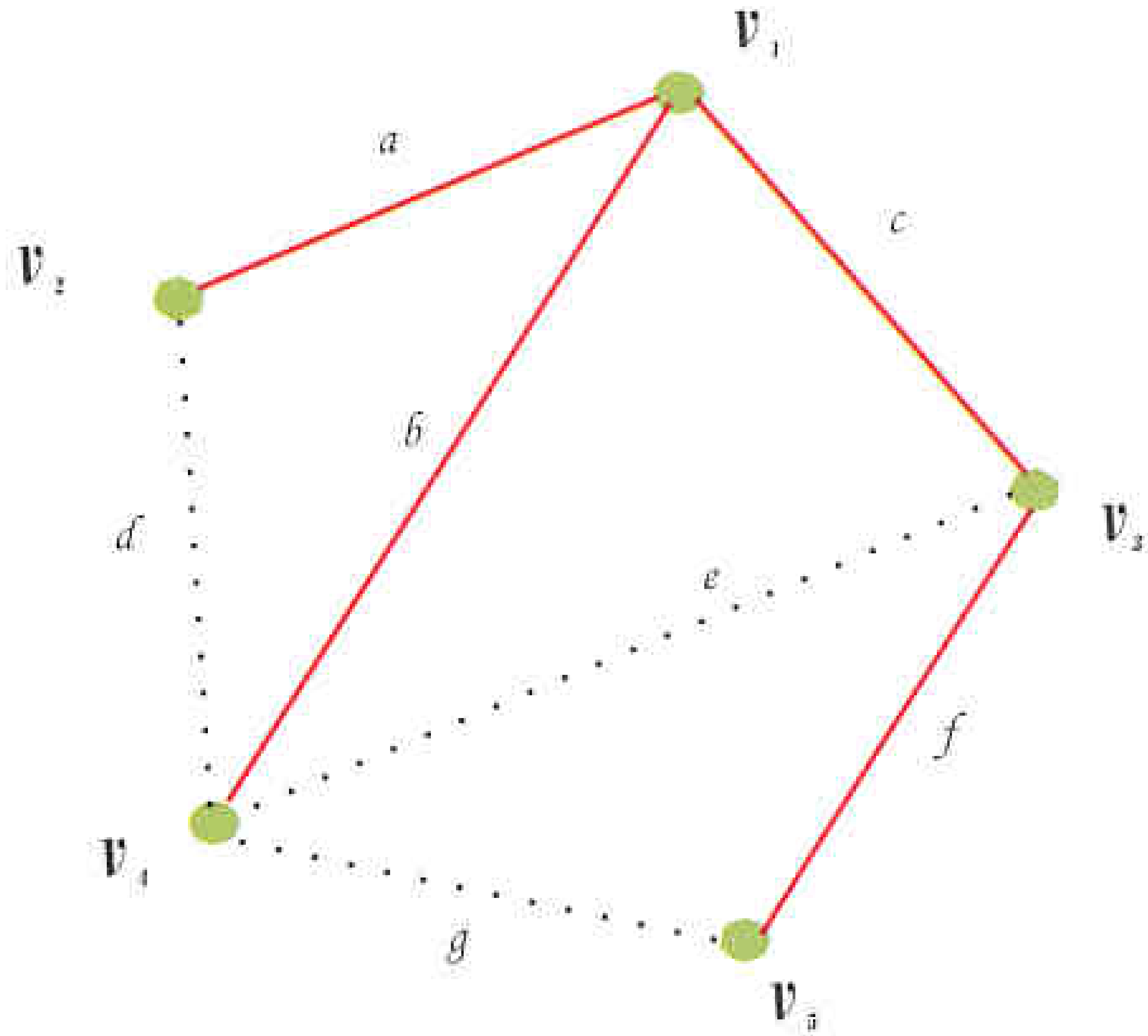

Figure 2. Spanning tree for five-node, seven-link network.

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PCS Applications

Outputs

- Interference model for the various PCS technologies currently in use, as well as proposed technologies for third generation systems.
- Contributions to industry developed inter-PCS interference handbook for predicting, identifying, and solving interference related problems.

Personal Communication Services (PCS) and other advanced terrestrial wireless technologies are emerging as popular and convenient choices for mobile communication. These wireless networks have the potential to be significant resources in the support of emergency recovery of the overall telecommunication infrastructure following a natural disaster. Cell networks cover significant geographic areas, but unfortunately, the cellular environment consists of a number of technologies that are not interoperable. Diverse systems function separately while using the same radio frequency bands and infrastructure (base station sites and towers). When a calamity occurs that damages the terrestrial telecommunication infrastructure, users naturally migrate to cellular resources. This sudden influx of traffic by private, commercial, civil, and Federal users results in wireless system overloads in the affected area(s). The high density of radio users operating in the same geographical areas may cause interference and disruption of service among the wireless networks. It is critical that NS/EP planners and network operators understand these traffic-related interference effects in quantitative terms. To operate effectively in an overloaded environment, it is necessary to characterize the interfering environment caused by large numbers of active users.

Currently, PCS service implementation is a "first-out captures the market" proposition. Equipment manufacturers and service providers do not always consider the effects their equipment may have on the equipment of other providers. A typical response by a service provider who experiences interference from adjacent or co-located services is to increase power. This is not effective in many cases, and leads to an escalation of interference as other service providers increase power to offset the increased interference they experience.

ITS' contributions in the inter-PCS interference arena currently are focused on offering our telecommunication expertise to the development of an inter-PCS interference handbook being developed by the Telecommunications Industry Association (TIA) committee TR46.2.1 (Telecommunications Systems Bulletin TSB-84A, Licensed PCS to PCS Interference). During the development of the handbook, it was revealed that no equipment manufacturer has measured something as simple as the C/(N+I) (carrier to noise and interference) signature for their equipment. Also, there is no standardized method to test and evaluate equipment or present the results. Manufacturers and providers are more inclined to put the best possible face on their results, emphasizing those areas in which their products excel. Standardized test equipment, procedures and reporting is needed to compare different systems and to determine system parameters for optimum performance in any given installation environment.

Currently, several standard propagation models are accepted by industry members (Okumura and COST-231/Walfish/Ikegami) but no interference models have been developed or accepted. In 1997, ITS produced a multi-user, multi-network PCS interference model (Ferranto 1997; see **Publications Cited**) covering two PCS systems – GSM/PCS1900 and IS-95/CDMA. These basic modeling concepts are being applied to the other PCS technologies, as well as third generation technologies. The model covers the interference generated by adjacent or co-located PCS systems on one another. It takes into account system considerations and management functions (such as power control in CDMA) that are affected by the dynamic nature of the interference.

The generic model involves a hexagonal cellular geometry, with each cell having six adjacent cells (see Figure). A single base station is located in the center of each cell and any number of mobile stations are randomly located within a cell's radius. The interference model consists of two parts:

Uplink:

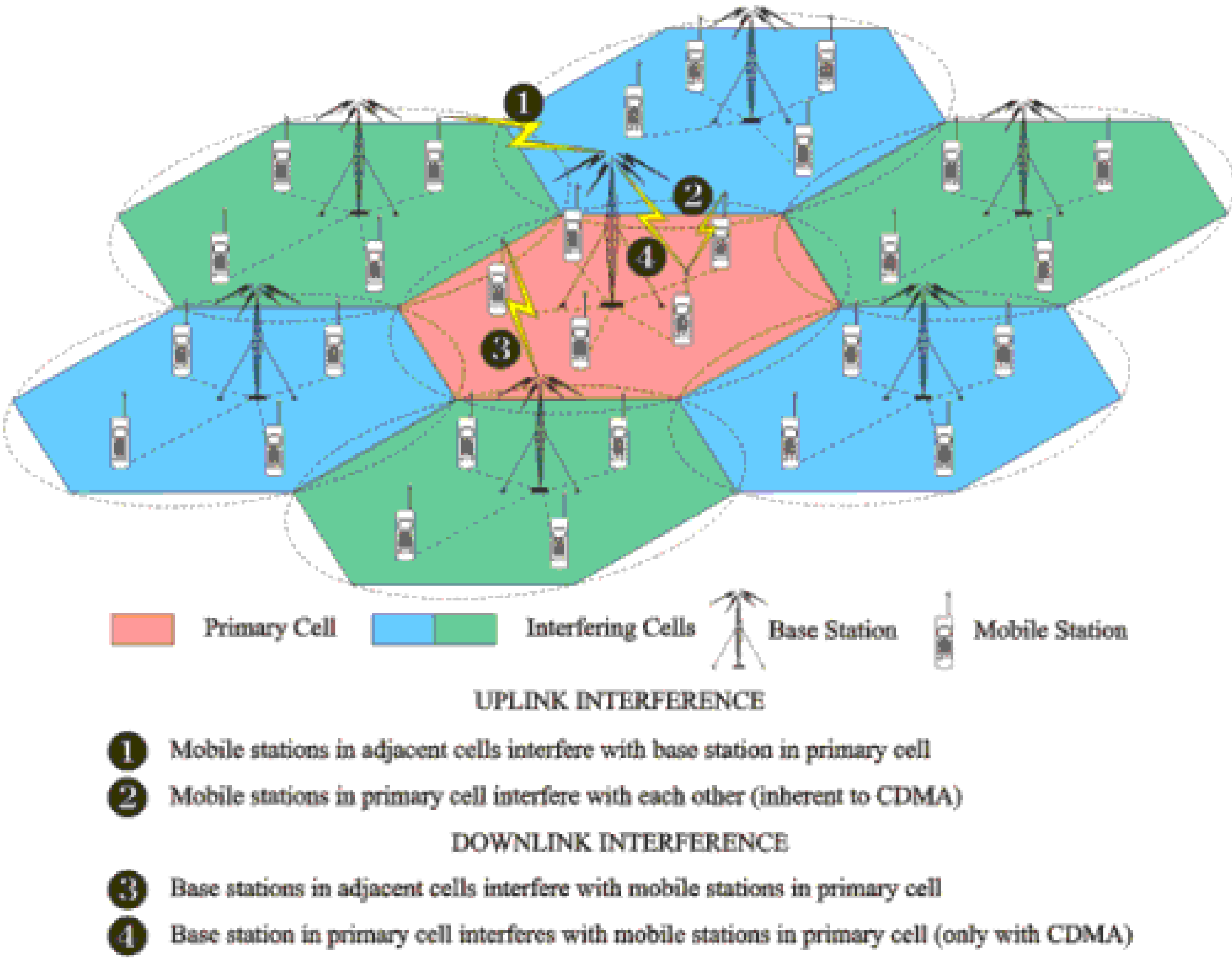
- the victim base station is interfered with by mobile stations in adjacent cells.
- victim mobile stations are interfered with by other mobile stations in the same cell.

Downlink:

- victim mobile stations are interfered with by base stations in adjacent cells.
- victim mobile stations are interfered with by the base station in the same cell (for CDMA systems only).

The output of the model consists of voltage envelope, power envelope, and phase distribution histograms of the aggregate interference waveform. This information can be used as input to a hardware simulator or a software modeling program, to evaluate system designs or actual hardware implementations. It also can be used to characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions can be proposed; these solutions can be used by field personnel to solve existing problems, or to anticipate and avoid potential problems.

As a result of ITS' involvement with TR46.2.1, TIA has recognized the value of ITS' noise and interference model. In a letter to ITS, the Chair of TR46 stated that he believed proper management of the interference issues of PCS systems, as they are built out and as they mature, will help determine the economic viability and the resultant costs for these PCS operators. He noted that ITS is a valuable and objective resource in helping TIA achieve these goals and encouraging participation in this process.



PCS cellular geometry for intra-system co-channel interference.

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Wireless Network Access

Outputs

- Planning and development of wireless network performance measurements.
- Assessment of wireless Internet access technologies, and draft report on same.
- Contributions to wireless standards and protocol development.

Data over wireless is still very much an emerging technology. Future networks will arise from a convergence of present wireless voice and data networks and computer networks. On the computer network side, most private networks have been superceded by the now ubiquitous Internet. In the wireless world, second and now third generation terrestrial wireless systems, together with a new generation of communications satellites operating in the low earth orbit (LEO), will soon provide voice and data services anywhere in the world. These future wireless systems and the Internet will form a true global data access network.

LEO satellites are now being deployed in large numbers: several competing satellite systems are expected to blanket the globe with a combined constellation of over 500 LEOs by 2004. LEO satellite systems combine attributes of cellular telephone systems with those of traditional satellite communication networks to provide seamless global communications. These networks are divided into two elements, the satellite constellation and the terrestrial segment. The interconnection between the two segments is provided via terrestrially-based gateway stations that are strategically positioned within each particular network. Voice communications are provided via hand-held telephones where users will be able to place or receive calls by way of the local terrestrial service provider or, in the absence of such service, directly to the satellite. Data services will also be accessible via hand-held devices, personal data assistants (PDA) or computers.

There are predominately five terrestrially-based non-propriatary wireless data services. Presently none of these services can achieve theoretical data rates greater then 20 kb/s. Several studies have shown that the fastest current cellular and personal communications systems (PCS) data technology, cellular digital packet data (CDPD), has difficulty delivering even a modest data rate of 10 kb/s, far below the theoretical rate of 19.2 kb/s. Cellular and PCS networks offering data service include , CDPD, TDMA (time division multiple access), CDMA (code division multiple access) and GSM (Global System for Mobile communications). All of these systems exist in the U.S. to greater or lesser degrees. GSM and CDMA presently offer circuit switched data service at 9.6 and 14.4 kb/s, respectively. Higher bandwidth services have been slated for both, as the industry moves toward the 2 Mb/s data rate goal promised for 3G (third generation wireless).

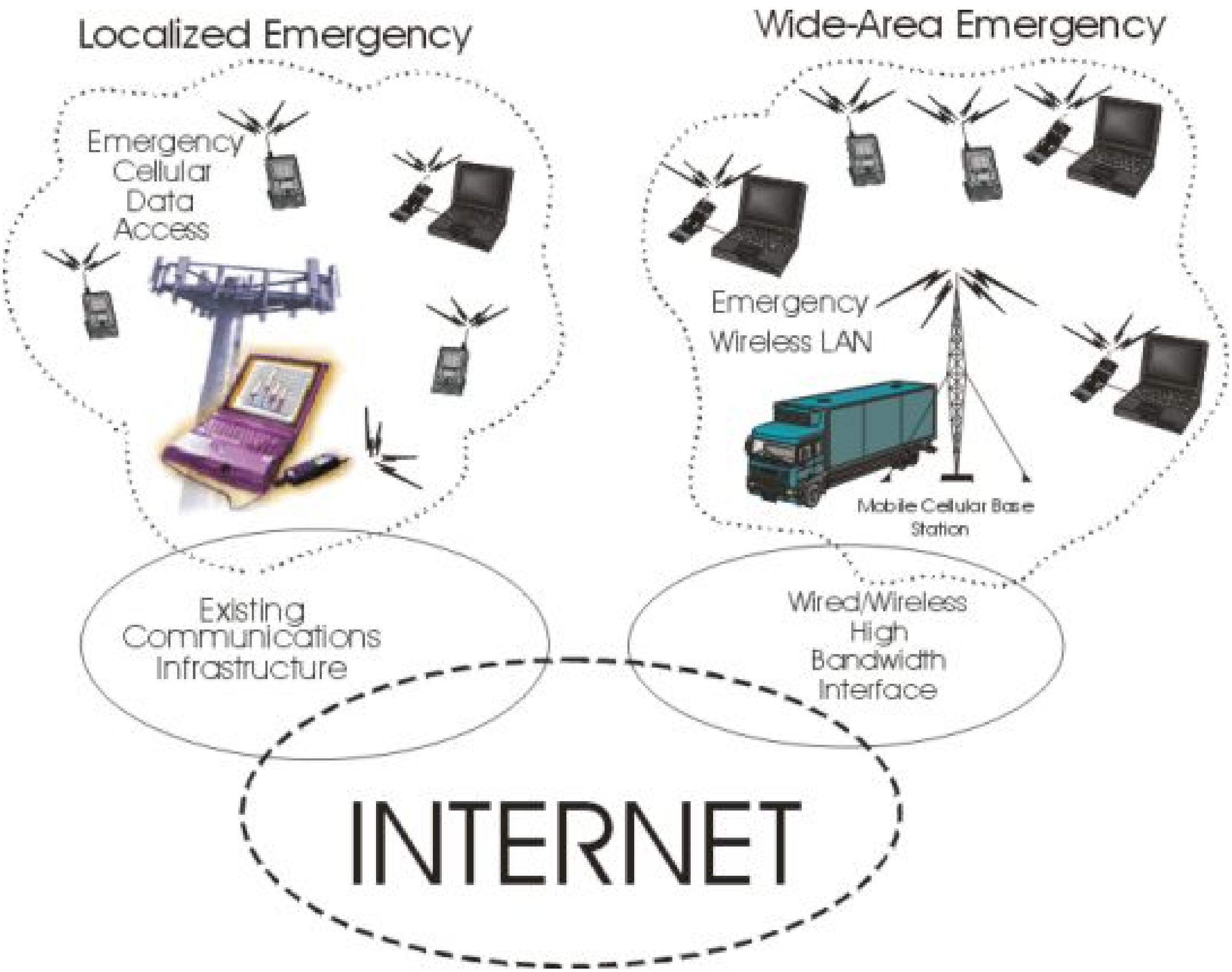
In FY99 ITS examined the application of the Internet protocol (IP) to wireless terrestrial and satellite links. This work resulted in assessments in two areas: encrypted voice over IP, and Internet connectivity for mobile computing in National Security and Emergency Preparedness (NS/EP) environments. This project is continuing in FY 2000, with measurements of wireless network performance.

The Figure illustrates the use of Internet connectivity in various types of emergency situations. For example, in a localized emergency the existing cellular/PCS infrastructure should be usable for communication purposes. But in a more widespread disaster, it may be necessary to bring in a mobile infrastructure, in the form of an ad hoc wireless network with mobile cellular base stations, rather than trying to utilize the network at the scene.

Industry has been pushing to bring online Internet content to wireless users, but most wired users are unaware of the difficulty in matching a wire-based protocol to the unreliable RF communications environment. By design, IP is unsuitable for wireless links since it relies on end-to-end data verification. Yet users are clamoring for Internet connectivity when they are mobile. New implementations of transmission control protocol (TCP) must be designed to make wireless connectivity more error tolerant and keep TCP/IP's end-to-end data verification paradigm intact.

Through performance measures of systems such as broadband PCS data services, which provides high speed data applications, the limitations of TCP/IP can be determined. ITS can then help to influence the direction taken by new implementations of the IP so as to make it more RF friendly. It is highly desirable that an independent organization devise methods and perform wireless network measurements that are made freely available.

ITS is uniquely qualified to devise standard performance measures for wireless networks because of its historical background as a telecommunications laboratory specializing in radio propagation and its traditional role as an independent evaluator of federal networking systems.



Mobile IP scenarios.

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Telecommunications Analysis Services

Outputs

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

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

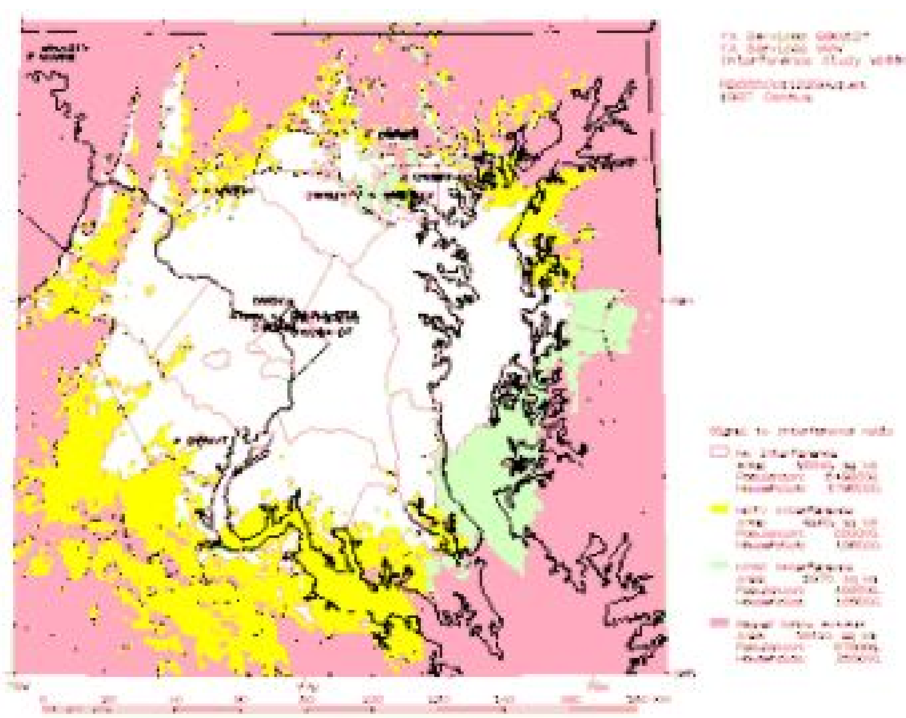

Figure 1. Interference analysis for a proposed digital station in Washington, D.C.

Currently available are: on-line terrain data with some 1-arc-second (30 m) and 3-arc-seconds (90 m) resolution for much of the world and 30 second resolution data for the entire world; the 1990 census data with the 1997 population updates; Federal

Communications Commission (FCC) databases; and geographic information systems (GIS) databases such as the land use/land cover (LULC) database. For more information on available programs see the Tools and Facilities section of this report or call the contact listed below.

TA Services is currently assisting broadcast television providers with their transition to digital television (DTV) by providing a model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations updated weekly from the FCC from which these scenarios are made. Results of analyses show those areas of new interference and the population and households within those areas. Figure 1 shows the result of a study done for a proposed digital station in Washington, D.C. In addition to determining the contribution to interference from other stations to a selected station, the model can tell

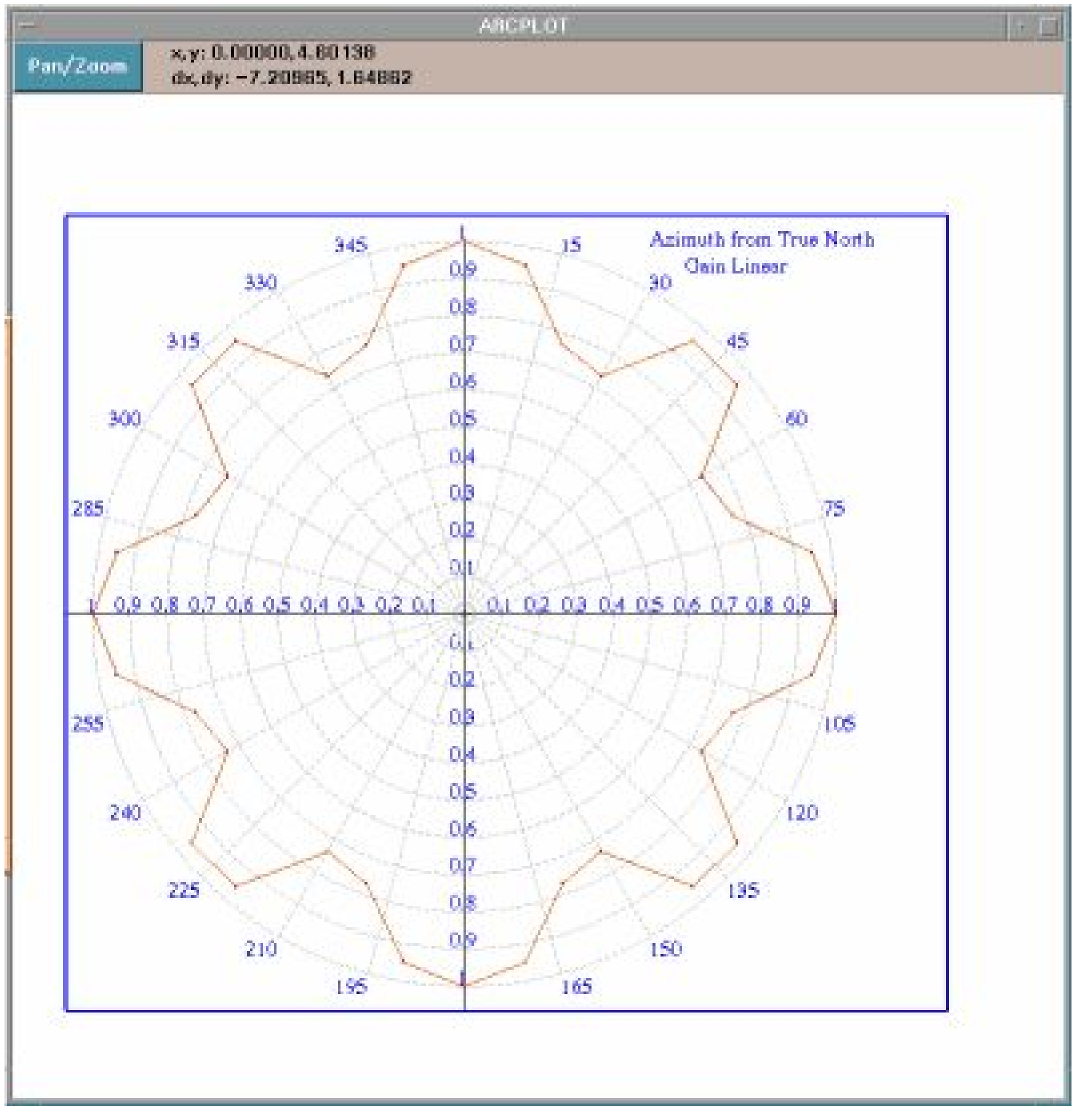

Figure 2. Antenna pattern from the user catalog in the TA Services PCS/LMDS model.

the user the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to his station and determine the effect these modifications have on the interference his station gives other surrounding stations. In addition to creating a plot similar to that shown in Figure 1, the program creates a table which shows the distance and bearing from the selected station to each potential interferer as well as a breakdown of the amount of interference each station generates. This model can be accessed via a network browser.

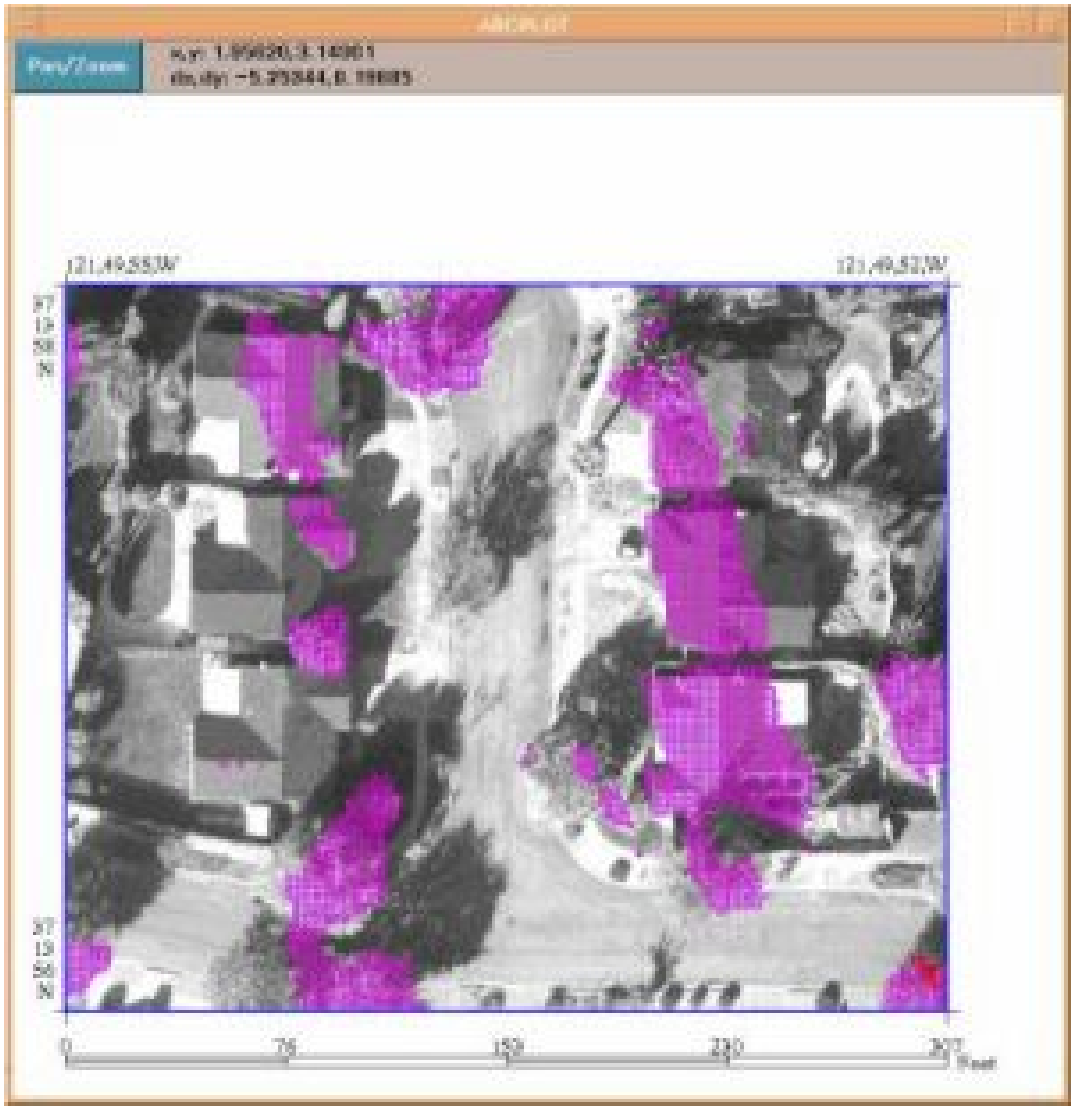

Figure 3. Line-of-sight region near a residential PCS/LMDS transmitter.

TA Services continues to develop models in the GIS environment for personal communications services (PCS) and local multipoint distribution systems (LMDS). A GIS efficiently captures, stores, updates, manipulates, analyzes, and displays all forms of geographically referenced information. The use of GIS has grown substantially over the past several years. As a result, databases necessary for telecommunication system analysis are 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, can be maintained in commonly used and available relational database management systems (RDBMS) that can be connected to the GIS or placed into the GIS RDBMS. This greatly reduces the amount of database development necessary in PCS/LMDS modeling.

As the frequency of an application increases, the level of detail required to adequately describe the path also increases. At PCS and LMDS frequencies, we need to know the location of trees and buildings, the kind of vegetation a signal is penetrating, and the shape and materials used in buildings. Software available at ITS allows us to import digital stereo photographs or other remote sensing data taken from aircraft at relatively low altitudes or spacecraft and convert these images to 3 dimensional models of the region. This highly accurate surface is then imported into the GIS PCS/LMDS model.

The PCS/LMDS model under development at ITS lets a user select a region of interest with a database generated or imported into the model. These environment and analysis results can be displayed in 2 or 3 dimensions. A user can create a database of transmitters and antenna patterns from which to create analysis scenarios. The GIS software reads the location of the transmitter from the map and stores it in the transmitter definition table. Antenna patterns can be imported, entered in table form, or drawn on the screen by a user as shown in Figure 2.

Analysis scenarios consist of a set of transmitters, antennas, and models chosen to produce propagation results for a region of interest. Models include a line of sight (LOS) model, a diffraction model, and a ray tracing model transmitter located on a street corner. The shaded areas are line-of-sight to the transmitter.

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Jammer Effectiveness Model for Communication and Radar Analysis

Outputs

- Development of Windows® 95, 98, and NT compatibility for Jammer Effectiveness Model (JEM).
- Development of ability to perform received signal power versus range computation independent of a scenario.

In FY 99, ITS continued to make improvements to the Jammer Effectiveness Model (JEM). JEM, developed by ITS for the U.S. Army to evaluate electronic warfare scenarios, runs as a Windows® application on a personal computer. This model is a very flexible analysis tool and can be used to perform many different types of analysis, because it is highly structured and modular in design. ITS has developed two versions of JEM: one for communications analysis and the other for radar analysis.

Each version of JEM includes a user-created catalog of equipment, ground stations, aircraft and satellite platforms; the software for creating and maintaining this catalog; a climatological database for much of the world; a library of propagation subroutines; and the analysis software. The JEM propagation library includes subroutines for use in calculating clear-air attenuation, rain attenuation, multipath attenuation, diffraction losses, and troposcatter losses. In FY99, work focused on developing Windows® 95, 98, and NT compatibility. The valid frequency range of the communication version of JEM is currently 2 MHz to 300 GHz, while that of the radar version is currently 30 MHz to 20 GHz.

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

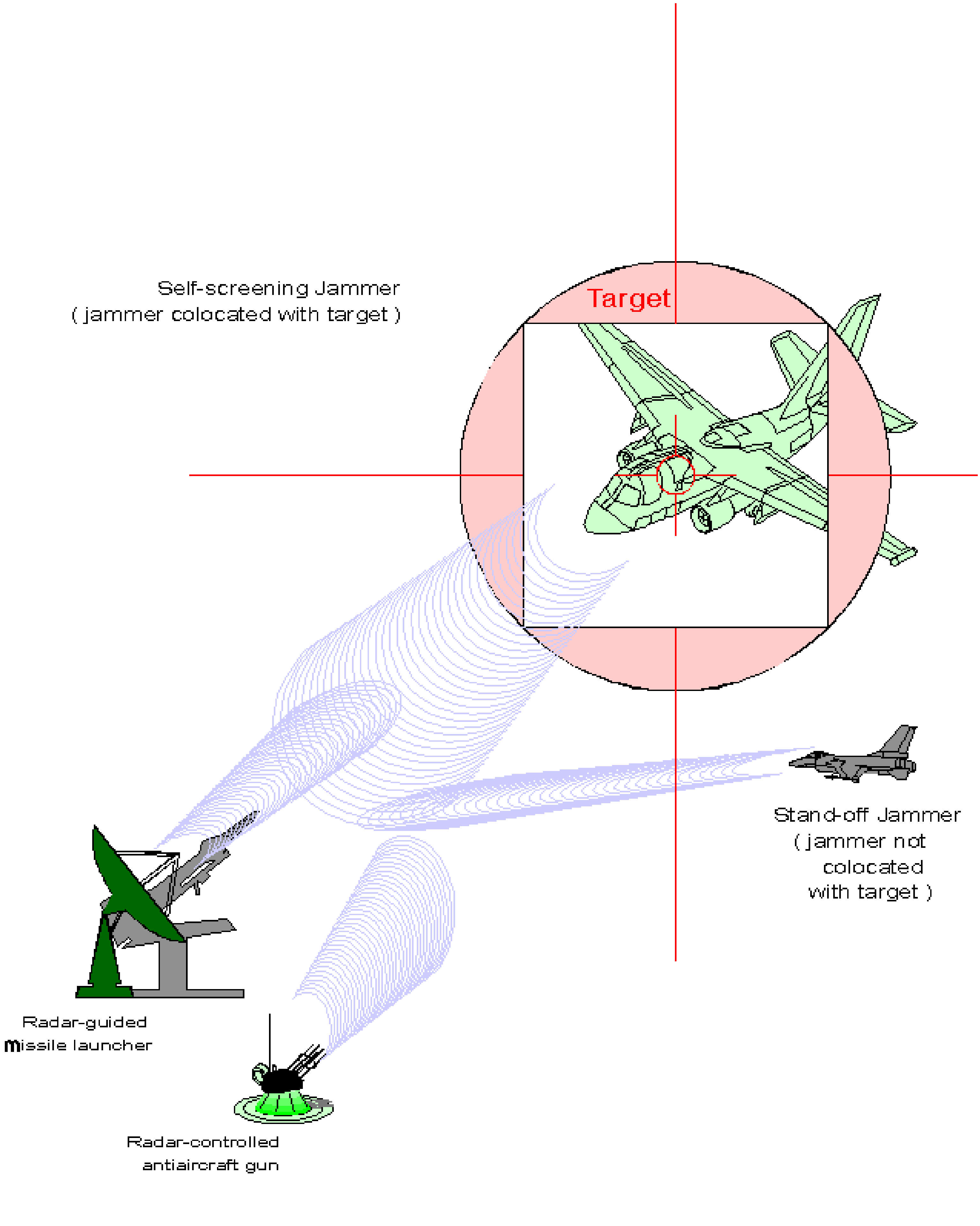
The communications analysis version of JEM is primarily used to model communication systems in electronic warfare scenarios where these systems are being jammed or interfered with. This version of JEM is organized into six scenarios, each of which represents either a communication path geometry description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

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

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

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

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


Self-screening Jammer
(jammer colocated with target)
Target
Stand-off Jammer
(jammer not
colocated
with target)
Radar-guided
missile launcher
Radar-controlled
antiaircraft gun

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

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Modulation Bandwidth Requirements

Outputs

- Power spectral density for signal parameters and percent power within a bandwidth.
- Spectral peak locations with spline interpolation between peaks for envelope if required.
- Equation describing Occupied Bandwidth in terms of signal and modulation parameters.
- Equation describing Necessary Bandwidth in terms of signal and modulation parameters.

The Office of Spectrum Management (OSM) in NTIA is responsible for managing the radio spectrum used by the Federal Government. ITS supports OSM by establishing a methodology for specifying spectrum requirements of various modulations employed by the Government. With the continuing development of new digital modulations, it is essential to analyze the spectra of the modulations to determine their bandwidth requirements. Allocating spectrum for a modulation without knowing the width and shape of its spectrum could cause one system's spectrum to overlap onto an adjacent channel spectrum occupied by another system, resulting in potentially serious interference problems.

The flowchart in Figure 1 shows the steps used in analyzing the spectrum and establishing the Occupied Bandwidth (OBW) and Necessary Bandwidth (NBW) formulas. After a modulation is selected, its spectra is calculated from an analytic equation. Alternatively, the transmitter can be simulated and the spectra can be calculated from the waveform. Then the total power contained in a bandwidth (BW) is calculated, and the 99% power BW is specified parametrically. The next step is to spline interpolate between spectral peaks to establish the spectral envelope. Following that, the OBW is specified in terms of the 99% power BW, and the NBW is specified in terms of the spectral envelope 20 dB down frequency. With these new results, the OBW and NBW can be specified in terms of system and modulation parameters and can be explicitly calculated from the power spectral density (power spectrum), thus providing a methodology for efficient management of the changing spectrum environment.

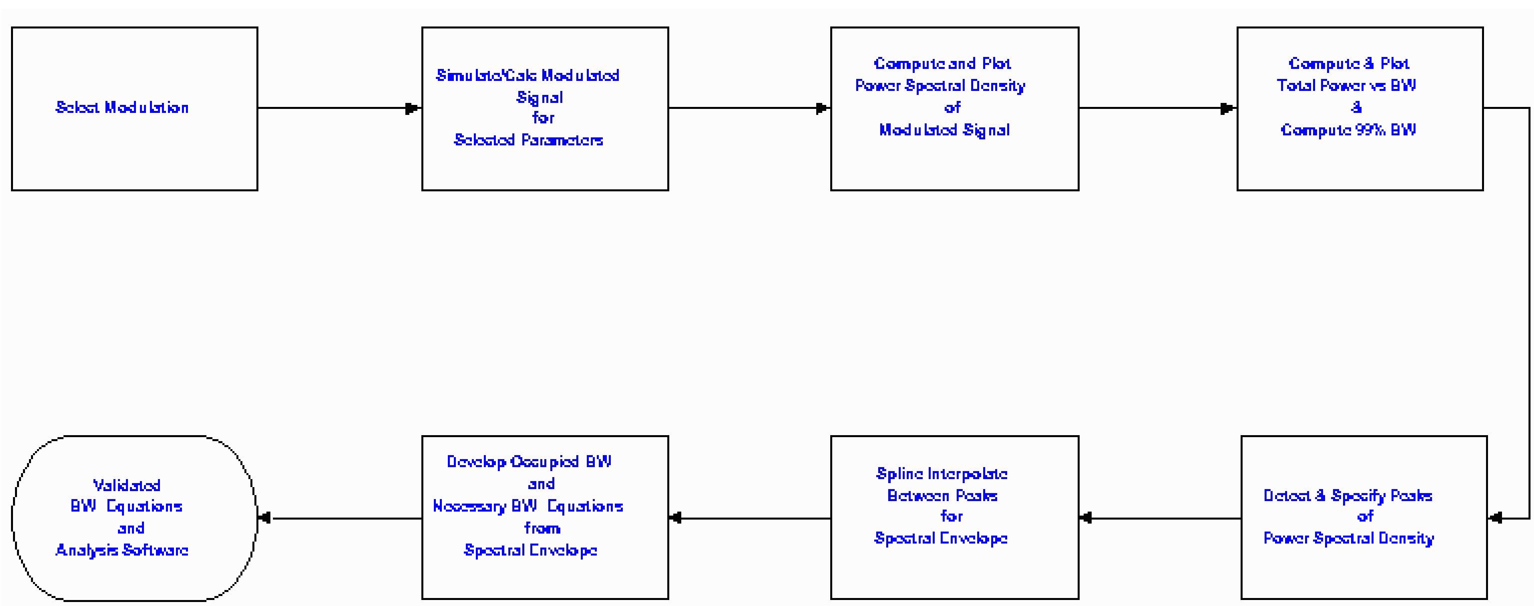

Figure 1. Spectral analysis of modulations flowchart.

In FY 99, this analysis was applied to minimum-shift keying (MSK) that provides an analytically tractable baseline for comparison with other modulations, orthogonal frequency division multiplex (OFDM) also referred to as multicarrier modulation (MCM) and Gaussian minimum-shift keying (GMSK).

A transmitter block diagram and analysis results for GMSK are shown in Figures 2-5. Figure 2 describes the major blocks of the transmitter where a non-return to zero (NRZ) data stream is employed, and T is the symbol duration which is used in normalizing the analysis results. All results are shown for a Gaussian filter with a 3dB bandwidth B and a normalized bandwidth of BT=0.25. Sidelobe ripple increases with increasing BT.

The one-sided linear power spectrum of the transmitter output is shown in Figure 3, demonstrating the effect of the Gaussian filtering on the input data stream. The log of the power spectrum is given in Figure 4, along with the calculated 3 dB and 20 dB down bandwidths of 0.207 and 0.504. The BW where the spectral envelope has rolled off by 20 dB is proposed as the NBW. All bandwidths are one-sided and normalized to the symbol duration.

The spectrum in Figure 3 was integrated to obtain the total power in the BW specified by the abscissa and given as a percentage of total power contained in a BW. This is shown in Figure 5. The BW containing 99% of the total power (also OBW) was calculated to be 0.430.

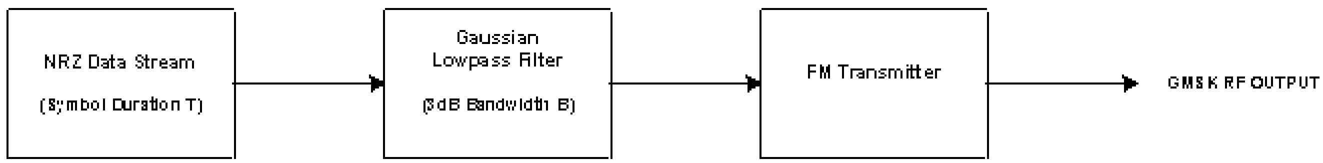

Figure 2. GMSK transmitter.

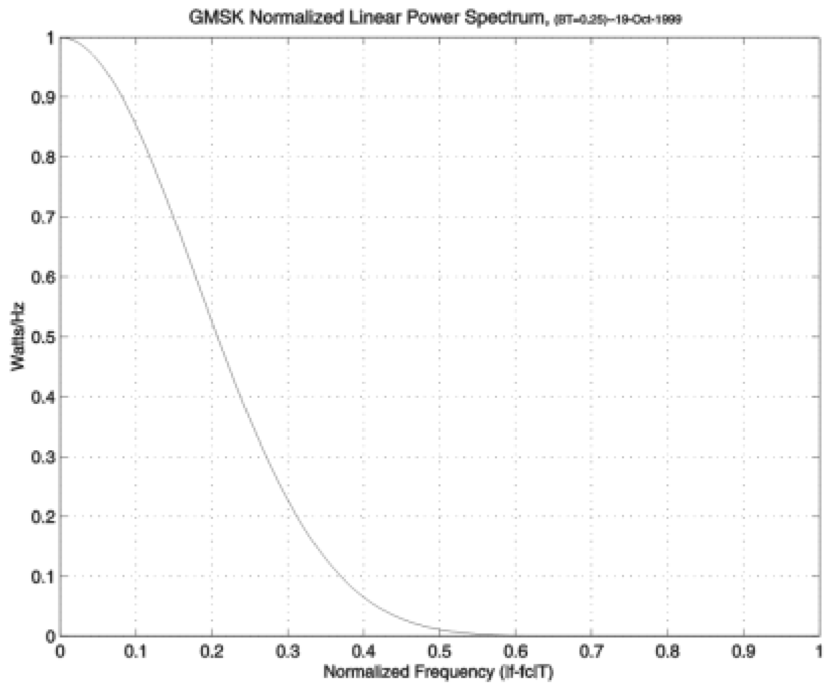

Figure 3. GMSK linear power spectrum.

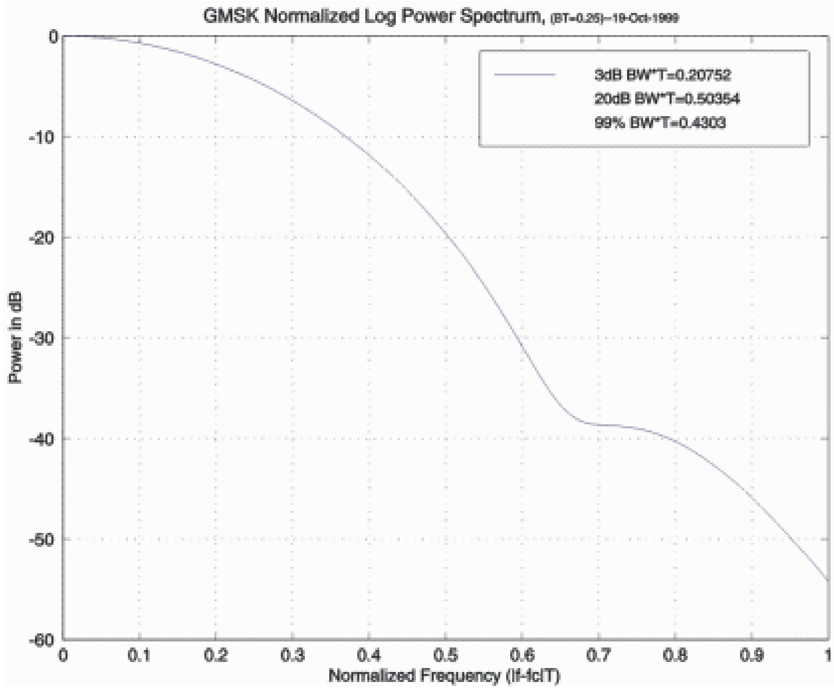

Figure 4. GMSK log power spectrum.

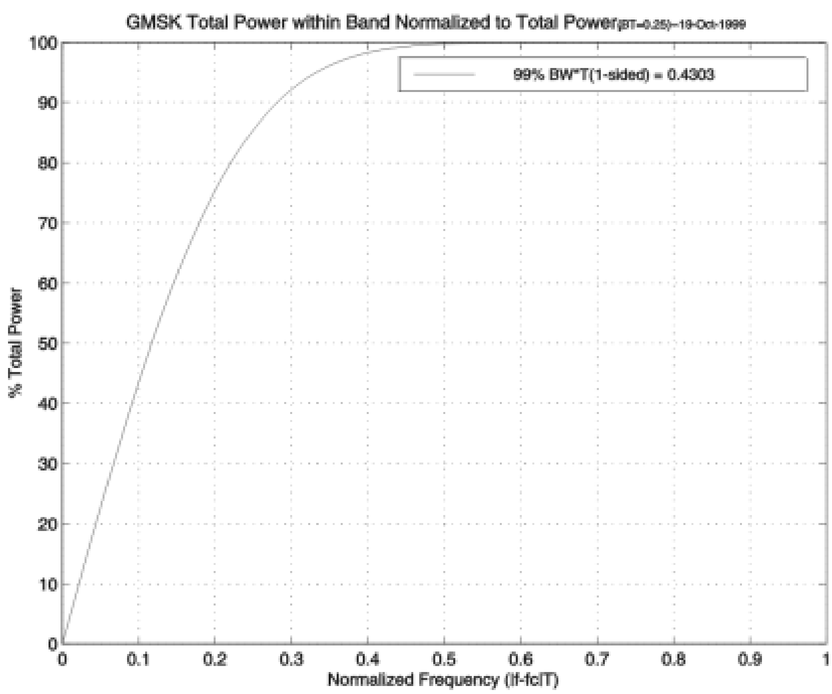

Figure 5. GMSK total power within a bandwidth.

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Propagation Model Development

Outputs

- Enhancements to Okumura-Hata model.
- Analysis performed to support the FCC regarding the Satellite Home Viewer Act.
- Contributions to ITU-R.

Since its early days as part of the Central Radio Propagation Laboratory (CRPL), ITS has been deeply involved in research on how radio waves travel from one point to another, i.e., radio wave propagation. Past work has included the development of the radio wave propagation models for all frequency ranges. These include the famous Longley-Rice model, developed in the 1960's, for frequencies between 20 MHz and 20 GHz. Another widely-used model is the Ionospheric Communications Analysis and Prediction Program (IONCAP), which was first released in 1983. IONCAP's descendants include VOACAP, which was modified by the Voice of America to meet the needs of the HF broadcaster community, and the Ionospheric Communications Enhanced Profile Analysis and Circuit prediction program (ICEPAC). All these models have been modified for use on personal computers.

Current ITS work on propagation modeling includes developing enhancements to existing models. NTIA's Office of Spectrum Management (OSM) and ITS have adopted for their own use two radio propagation models that are generally applicable for mobile communications applications: (1) Okumura-Hata modified to extend range, antenna heights and frequency (Okumura-Hata-Davidson); and (2) Longley-Rice (area mode). These models are widely accepted for urban/suburban and rough terrain applications, respectively. However, there currently does not exist, in the public domain, a working model that can handle the mix of land cover (Okumura-Hata) and terrain (Longley-Rice). During FY 1999, ITS personnel performed a review of the relevant open literature, as the basis for a comprehensive mobile propagation model applicable to the full range of urban, suburban and rural locations for both smooth and rough terrain. Propagation subroutines were written based on the Fresnel-Kirchhoff methodology. This work will provide improvement over empirical Okumura-Hata type models. Follow-on work will include testing and documentation of the above model and various upgrades.

Propagation models made the national news this year, in the midst of controversy over the Satellite Home Viewer Act. In 1988, Congress passed the Satellite Home Viewer Act, which permitted satellite providers to retransmit network-affiliated stations to viewers outside the Grade B service area of local terrestrial broadcasters. However, satellite providers were accused of providing service to ineligible viewers, and in the process, the method used by the Federal Communications Commission (FCC) to determine Grade B coverage came under fire. In the fall of 1998, the Longley-Rice propagation model was chosen as the new method for determining Grade B coverage. The FCC issued a Notice of Proposed Rule Making (NPRM) to determine the best method for such a prediction and determination of signal coverage.

NTIA provided plots for the largest TV designated market areas (DMAs) to show coverage by the FCC Broadcast Curves method, the Longley-Rice method, and the Longley-Rice method as clipped by the FCC Broadcast Curves for Grade B. Comments to the NPRM indicated that satellite service providers believed another propagation model, the Terrain Integrated Rough Earth Model (TIREM) was a better predictor, but no evidence for this claim was provided. TIREM is maintained by the DoD's Joint Spectrum Center (JSC) and distributed by NTIA to Federal Agencies. The FCC asked NTIA to evaluate TIREM. NTIA/ITS was able to complete the evaluation by running its analysis program for 16 broadcast stations using both TIREM and Longley-Rice under identical conditions. The results were provided to the FCC in time for their evaluation. Figure 1 shows a broadcast television coverage map for the TriCities region of Virginia, computed using the Longley-Rice model.

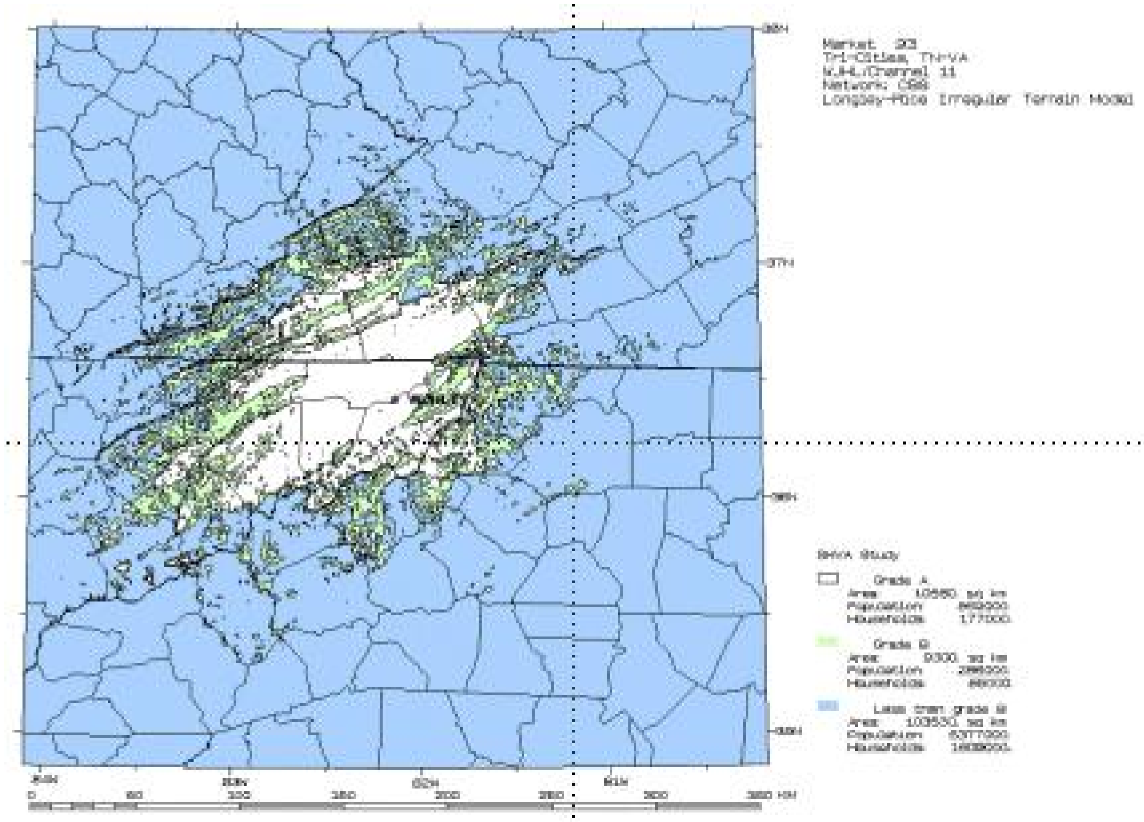

Figure 1. Broadcast television coverage map for the TriCities region of Virginia, computed using ITS's Irregular Terrain Model, also referred to as Longley-Rice.

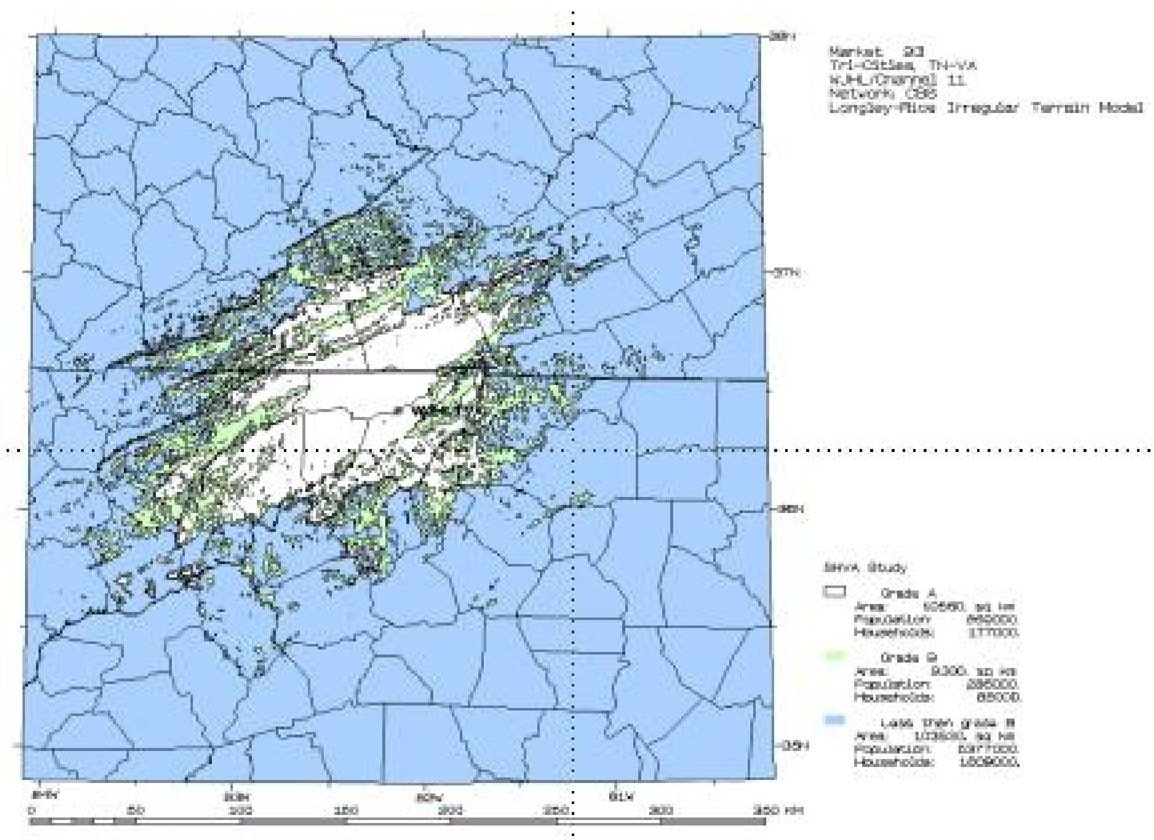

Figure 2 shows a broadcast television coverage map for the same area, computed using TIREM.

Figure 2. Broadcast television coverage map for the TriCities region of Virginia, computed using TIREM (Terrain Integrated Rough Earth Model).

Congress has now ordered the FCC to develop a point-to-point prediction method that accounts for ground clutter (manmade objects and vegetation) near a specific TV home viewer's antenna location. In conjunction with NTIA, ITS plans to modify the Longley-Rice model to account for land use and land cover features. The modifications will become part of the public domain Longley-Rice software code. In addition, ITS will work in coordination with OSM to harmonize the Longley-Rice model and TIREM, to ensure that they provide the same (or nearly the same) predictions.

In FY 1999, ITS also participated in and made contributions to the International Telecommunication Union - Radiocommunication Sector (ITU-R). ITU-R is the ITU body responsible for developing international standards (ITU-R Recommendations) for radio systems. ITS 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. ITU-R has divided its work program into study groups that develop Recommendations. In FY 1999, ITS staff members participated in U.S. Study Group 3 (Radiowave Propagation). An ITS staff member acted as the national chair of the U.S. contingent of Study Group 3, and as the international chair of Working Party 3K (Point-to-Area Terrestrial Propagation Issues) of Study Group 3.

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Telecommunications and Information Technology Planning

The telecommunications and information technology planning function represents the highest-level system or network perspective of the Institute. That is, this portion of the ITS technical program encompasses work that is frequently known in industry as "systems engineering". This work can be characterized generally as planning and analyzing existing, new, and proposed telecommunications and information technology systems, especially networks, for the purpose of improving efficiency and enhancing the technical performance and reliability of those systems. In many cases, ITS performs these work activities in the context of multi-technology environments, both for wireline and wireless applications.

As the name implies, all phases of strategic and tactical planning are conducted under this work area, but problem solving and actual implementation engineering also are done. ITS engineers identify or derive users' functional requirements, and translate them into technical specifications. Telecommunications designs, network services, and access technologies are analyzed, as well as information technologies (including Internet and Intranet-related schemes). Associated issues, such as network management and control and network protection and privacy, are also addressed. Integration of individual services and technologies is a common task in many projects, along with the application of new and emerging technologies to existing applications.

Areas of Emphasis

Broadband Wireless Standards

The Institute develops new radio propagation algorithms and methods that improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in broadband wireless systems. The project is funded by NTIA.

Low-Cost HF Automatic Link Establishment (ALE)

The Institute develops a real-time software modulator-demodulator for ALE tones, and an entire HF ALE software program which will allow ham radio operators to participate in ALE networks supporting emergency communication needs. The project is funded by the National Communications System (NCS).

Public Safety Telecommunications Interoperability Standards

The Institute conducts a technical program aimed at providing effective interoperability and information-sharing among dissimilar telecommunications and information technology systems of the public safety community. The main thrust is the development of interoperability standards. Projects are funded by NTIA, NCS, and a Center of the National Institute of Justice—the Office of Law Enforcement Standards.

Railroad Telecommunications Planning

The Institute performs radio infrastructure system planning in support of a high-speed rail pilot program, and evaluates a proposed railroad VHF band channel plan. The Federal Railroad Administration funds this project.

Satellite Studies

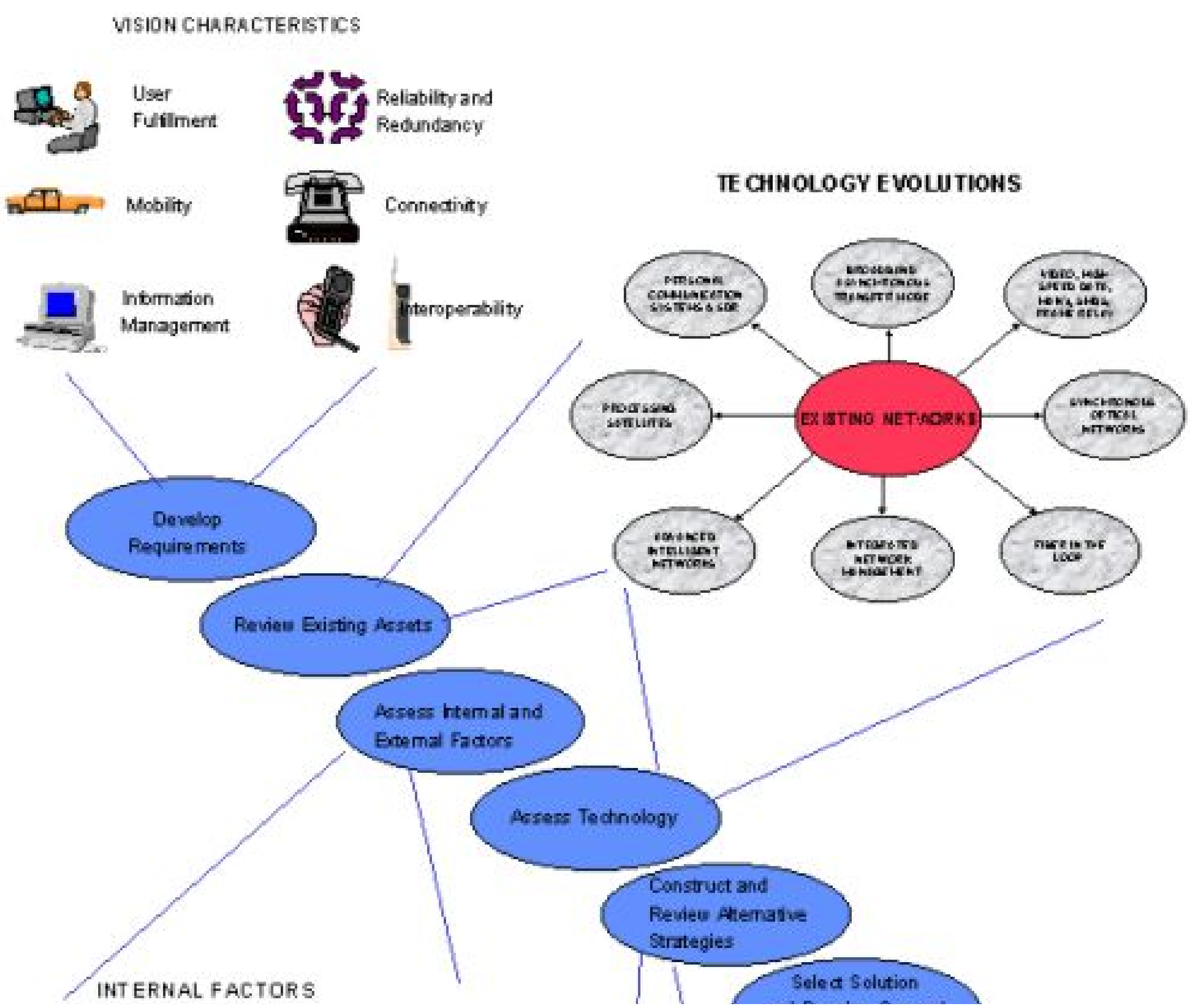
The Institute develops measurement systems and conducts performance measurements of MPEG-2 video over satellite ATM circuits using the ITS Transportable Video Quality Measurement System. The project is funded by NTIA.

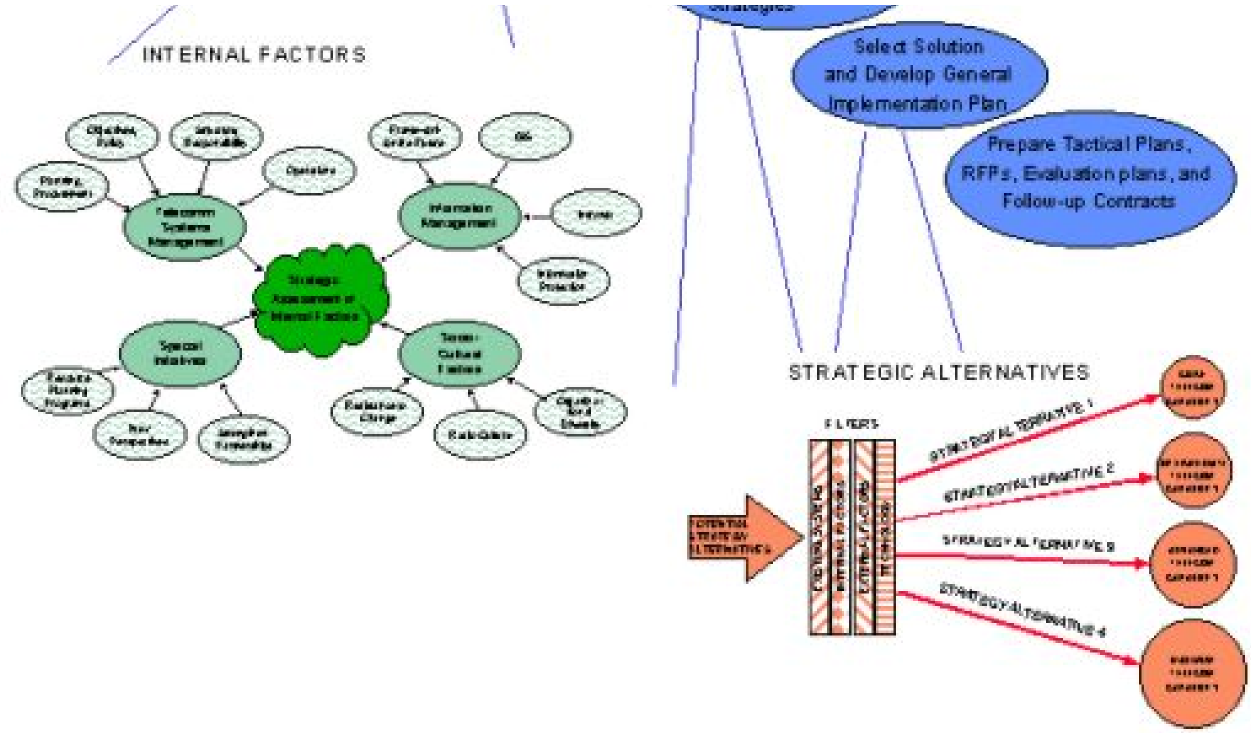
Telecommunication Terminology Standards

The Institute develops a search engine to facilitate the use of FED-STD-1037C, and develops on-line mechanisms through which experts can submit new Web terminology and computer-security terminology for a revision to the standard. The project is funded by NCS.

Use of IP-Based Networks in Real-time NS/EP Applications

The Institute conducts research to describe issues surrounding the potential performance of real-time communication applications (e.g., voice over Internet Protocol (IP)) that will use IP-based networks as their communication infrastructure. Recommendations are formulated concerning IP-related standards development efforts that should be initiated or monitored. The project is funded by NCS.





Telecommunications Information Technology planning process overview.

Broadband Wireless Standards

Outputs

- Preparation of technical standards and documents that support the U.S. interest in broadband wireless systems.
- Development of new radio propagation algorithms or methods that improve spectrum usage of wireless systems.

The wireless industry projects an explosive growth in wireless system use within the U.S. as new users begin using wireless services. Table 1 below shows how industry expects the U.S. population to accept wireless services by subscriber penetration.

Table 1. Growth in Subscriber Penetration for Wireless Services

	1998	2000	2002
Wireless service subscriber penetration in the U.S.	24%	35%	42%

As users expect better quality voice service and more features such as caller ID and call forwarding, etc. the wireless services providers have moved from analog modulation on single channels to digital modulation using a variety of channel access methods. All of these changes are made to improve the quality of the service, add features, and serve more users on the system.

The wireless industry has made projections on how they expect the rollout of technology to progress in the next few years, as shown in Table 2.

Table 2 shows that the number of wireless service users is expected to nearly double. In addition to the increase in the number of users, the types of services (beyond just voice communications) will also increase, with more emphasis on internet-type uses. The new uses require greater bandwidths (and more radio spectrum).

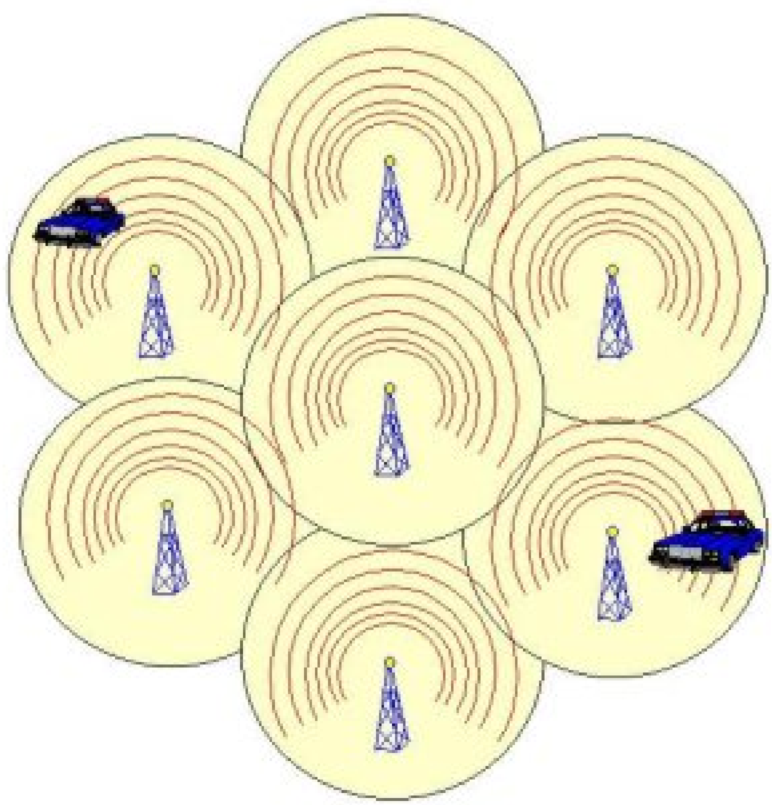
Table 2. Growth in Subscribers (North America) by Wireless Service Technology

Technology	1998	2000	2002
Advanced mobile phone service (AMPS), analog	53 million	42 million	24 million

Time Division Multiple Access (TDMA), digital	10 million	27 million	44 million
Code Division Multiple Access (CDMA), digital	8 million	27 million	52 million
GSM, a TDMA standard developed in Europe with worldwide use	4 million	10 million	20 million

The infrastructure must support the increased usage by making better use of the spectrum that the system has available for the service.

The Figure below shows a normal cellular area coverage scheme. Base stations provide multiple channels that users gain access to, through their mobile phones. The cells have overlapping coverage to provide redundancy and allow for handoffs as the user moves from one cell to the next. The Figure depicts perfect circular-signal coverage from the cell center. In fact, topography and man-made obstacles prevent circular coverage; irregular-shaped coverage would be more realistic.



Normal cellular area coverage scheme, showing base stations.

In order to predict the more realistic coverage, ITS and other research organizations are developing and evaluating propagation models that are more responsive to the needs of the cellular and private land mobile radio service providers for signal coverage predictions. A common model used by system planners is the ITS Irregular Terrain Model (ITM) which is also known as the Longley-Rice model. While a good predictor in irregular terrain, it does not have the capability to utilize land-use, land-cover data bases to predict losses due to man-made objects.

Another common model is the Okumura-Hata model. This model is a good predictor in urban and suburban environments but it does not handle irregular terrain nor does it handle changing environments, for example from urban to suburban to rural.

By using land-use, land-cover data bases in radio propagation predictions, it should be possible to determine a better estimate of signal loss due to the objects that are represented in the databases. The improved predictions will allow service providers to better evaluate locations for base stations and to predict where additional base stations might be needed to fill in holes of inadequate signal coverage. ITS is evaluating the incorporation of land-use, land-cover databases into the ITM propagation prediction model to provide better estimations of signal loss. Although better databases are now available for land-use, land-cover descriptions, the signal loss associated with the various land-use, land-cover categories is not well known nor is the loss versus frequency well known. ITS is also evaluating the means of incorporating land-use, land-cover information into the Okumura-Hata model, to make it more responsive to the changing environment.

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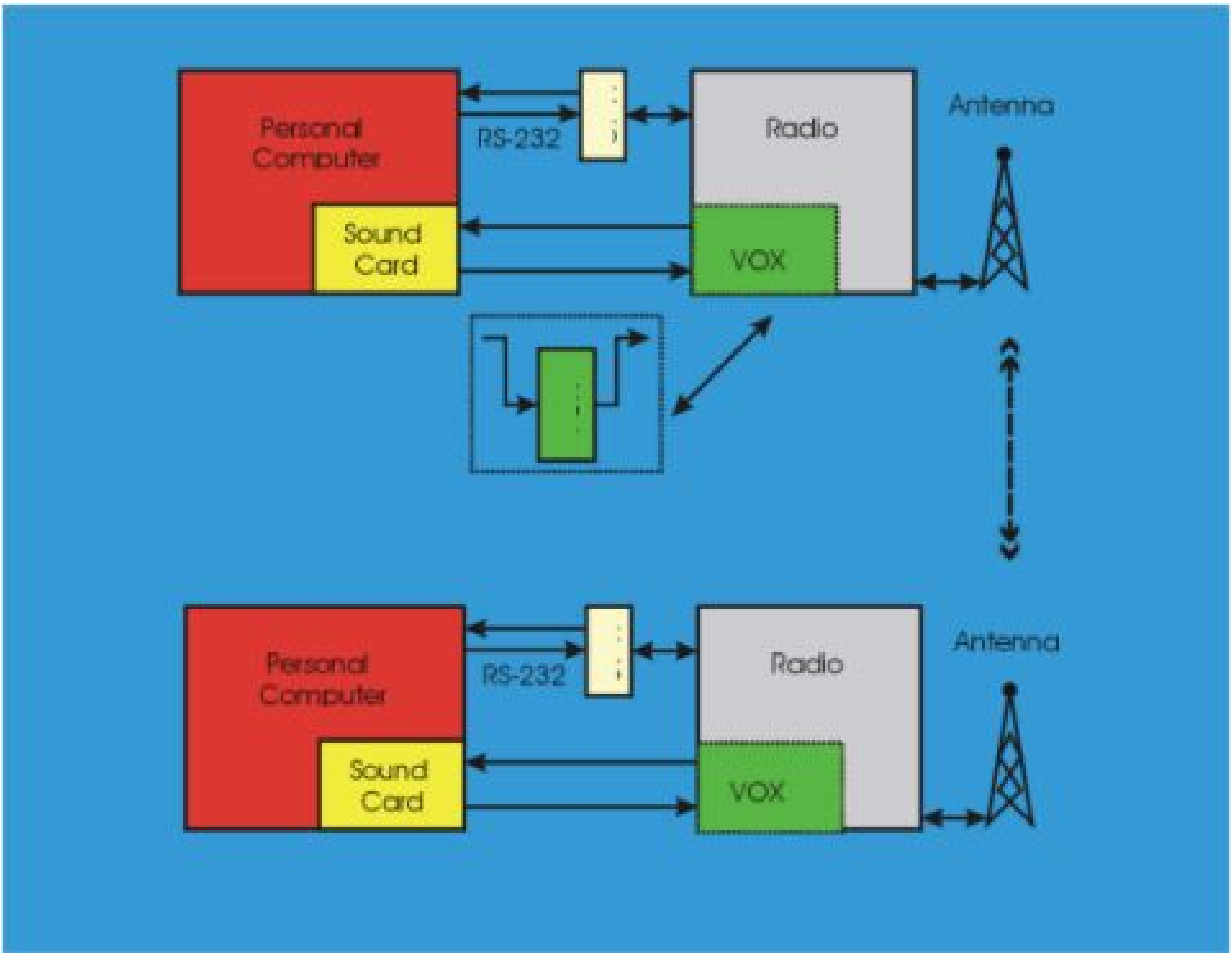
Low-Cost HF Automatic Link Establishment

Outputs

- Real-time software modulator-demodulator for ALE tones.
- Software ALE controller for personal computers.



HF link using two low-cost ALE systems.

The high frequency (HF) band, 3-30 MHz., has always been heavily used, with broadcast, mobile, fixed, maritime, aeronautical, and amateur allocations. Because of the worldwide propagation characteristics of HF, this band has proved to be very reliable and in some past emergency situations has been the only communications system available for contact with isolated groups of people. During times of national emergency, HF systems have proven to be critical elements of wireless communications. However reliable transmission in the HF band is complex: conditions change diurnally, seasonally, with solar conditions and with other ionospheric conditions. This complexity has necessitated an infrastructure of frequency planners, prediction programs, and simple trial-and-error methods to achieve the best results.

FED-STD-1045A, HF Radio Automatic Link Establishment (ALE), was developed to make HF radio operation simpler by automatically selecting the best frequency available for establishing a radio link. In an ALE system, the cooperating radios periodically send sounding signals over a range of operating frequencies. Each receiver scores each sound (or any other received ALE signal) and keeps track of the best frequencies at any given time. When a link to another radio is desired, the ALE system automatically selects the best frequency and establishes a connection through an automatic protocol. If a chosen frequency proves to be unusable, the ALE system will automatically and iteratively connect on the next best frequency. Once the connection has been made, any normal type of traffic (voice or data) can be passed. ALE radios allow faster connection times, more reliable connections, and simpler operation — and therefore a reduced requirement for skilled operators. ALE systems are currently being used successfully by many government and military organizations.

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

In order to make ALE techniques widely available, ITS has written an ALE controller program which runs on a standard PC in the Windows® environment. The PC connects to a standard (non-ALE) HF radio (at present only ICOM radios are supported) through a serial port for radio control and an audio cable for sending and receiving ALE tones. If the radio does not provide a voice-actuated switch function, this must be provided externally. The only special PC requirement is an audio card that is DirectX® compatible. The ALE controller program is multi-threaded. One thread provides an ALE tones modem and ALE word encoding and decoding. The other thread provides all other controller functions, such as user interface, configuration data manager, signal quality history, radio control, sounding, reception, scanning, connection, channel selection and Automatic Message Display interchange.

In the ALE signal, information is encoded by sending out tones which last eight milliseconds each. There are eight tones, so that each tone represents three bits ($2^3 = 8$) of information. The low-cost ALE modem uses a computer soundcard to sample these tones on input, and to reproduce them on output. In receive mode, the tones are sampled in overlapping four-millisecond windows, so that each tone is checked four times. A special digital filter, which is very robust against noise, is used to identify the tone in each window and a sophisticated pattern matching scheme is used to determine the identity of the sampled tone. This information is converted into a tone number between 0 and 7 (three bits) and is passed to the decoding routine for further processing. The encoding routines send the transmit portion of the modem numbers from 0 to 7 and it produces an eight-millisecond long tone for each number that it receives. Both of these processes must occur in a real-time fashion, with no interruption from other programs, and so they depend very heavily upon threaded code techniques.

The low cost ALE controller program is available for download from the Institute's Web page at **http://www.its.bldrdoc.gov/**

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Public Safety Telecommunications Interoperability Standards

Outputs

- Voice and data encryption standards.
- User requirements documents for wireless communications and information technology (IT) interoperability.
- Specifications for Interoperability Process and Procedures testing of public safety radios.

With the explosion of telecommunications and information technologies has come a disturbing trend – a lack of interoperability among systems. This is demonstrated most dramatically in the public safety community, as police and other agencies (such as fire departments, emergency medical services, etc.) fail to communicate with each other during multi-jurisdictional events (such as the Columbine High School tragedy). Even when local or regional calamities do not occur, however, daily interoperability problems continue to plague public safety agencies nationwide.

ITS is conducting a technical program that is aimed at providing effective interoperability and information sharing among dissimilar public safety communications and information technology systems. The key to the program is the identification and/or development of interoperability standards that will allow local, state, and Federal agencies to exchange information between organizations, without requiring substantial changes to internal systems or procedures. The ITS program is sponsored by three Federal agencies: the National Communications System (NCS), NTIA (through its Public Safety Program), and the National Institute of Justice (NIJ) (through its Advanced Generation of Interoperability for Law Enforcement (AGILE) Program). Although each sponsoring agency has a slightly different objective for the ITS work, their projects are highly complementary, and provide benefit to each other and to the entire public safety community. Each of the three projects is summarized below.

National Communications System Support
The Institute is assisting NCS's Technology and Programs Division (NCS-N2) in developing a comprehensive series of interoperability standards for digital land mobile radio (LMR) for public safety applications. Next generation LMR standards are being developed by the Federal Government, in conjunction with industry and local and state governments, within a group called Association of Public-Safety Communications Officials /National Association of State Telecommunications Directors/Federal (APCO/NASTD/FED) Project 25. This project consists of three phases. Phase 1 of Project 25 has been completed. It included the development of a comprehensive set of standards for 12.5 kHz digital LMRs. Phase 2 is in progress and has the goal of developing a set of interoperability standards for narrowband (6.25 kHz) digital LMRs. Phase 3, which has also begun, is focused on the development of standards for wideband mobile data applications. (Phase 3 is sometimes referred to as "Project

34"). Current ITS efforts have mainly supported Phase 2.

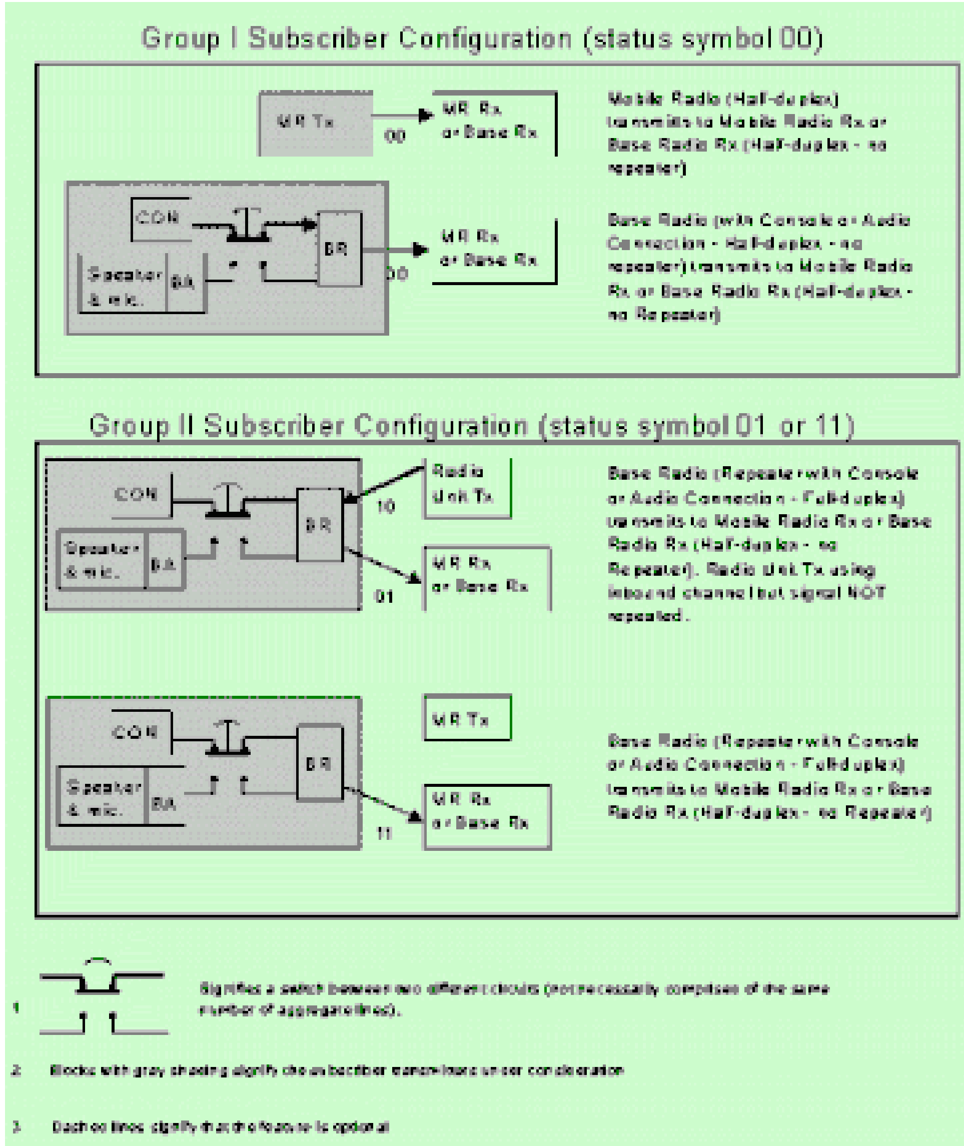
Phase 2 standards will cover 6.25 kHz FDMA radios and, in addition, a set of standards defining TDMA radios with an equivalent 6.25 kHz/channel efficiency may be developed. The NCS, Federal law enforcement agencies, and the National Security Agency (NSA) with assistance from ITS are participating in the development of these standards, and are taking the lead in the development of related Information System Security (INFOSEC) standards.

An Institute representative chairs the Project 25 Encryption Task Group and works closely with its members in developing Project 25 INFOSEC standards. ITS also participates on the related Telecommunications Industry Association (TIA) TR 8 Encryption Committee to insure that TIA standards meet Government requirements. ITS also participates in other TIA TR 8 Committees and Project 25 working groups as necessary to insure that the total suite of Project 25 LMR interoperability standards meets Federal requirements, and to continually assess Project 25's impact on Federal agencies. An ITS representative also serves as alternate for NCS on the Project 25 Steering Committee.

To date ITS has contributed to the development of standards for the protection (encryption) of voice and data sent over the Project 25 Common Air Interface and for the over-the-air-rekeying (OTAR) of Project 25 radios.

NTIA's Public Safety Program Support

As a result of the findings from the NTIA and FCC Public Safety Wireless Advisory Committee's (PSWAC) Final Report, NTIA established the Public Safety Program (PSP) to follow-up on the PSWAC recommendations. ITS has provided some of the technical engineering support to develop standards and specifications for the Project 25 system. In particular, ITS has been involved with the development of the Interoperability Process and Procedures specifications. This year, ITS wrote and presented for committee approval the Test Procedures for Conventional Voice Common Air Interface. The Figure shows some of the radio system configurations that are tested for interoperability. ITS is presently developing the test specifications for OTAR, Data Services, and Trunking. ITS has also provided technical support to the development of the Inter-RF SubSystem Interface (ISSI) specification. This document defines the message and control flow across the ISSI to allow mobile units to roam from one jurisdiction's radio system to another. In addition, ITS has conducted various engineering studies for the PSP. For example, a proposed system for measuring spectrum occupancy by public safety agencies was evaluated.



Example of a radio equipment test configuration to evaluate equipment interoperability.

NIJ's AGILE Program Support

As the U.S. Department of Justice's science and technology arm for assisting state and local agencies, NIJ has been addressing interoperability technology issues for some time. However, the AGILE program has applied a concentrated thrust to facilitate the efforts of the criminal justice and public safety organizations to effectively coordinate and share information with other criminal justice (CJ) and public safety (PS) organizations. This will be accomplished primarily through standardization. The AGILE program will identify relevant standards developed by other standard development organizations (like the TIA, the Institute of Electrical and Electronics Engineers (IEEE), etc.) and adopt them as NIJ interoperability standards. (In rare cases, new standards will need to be developed by AGILE.) ITS leads the AGILE standardization activities under the auspices of the National Institute of Standards and Technology's Office of Law Enforcement Standards (OLES), one of NIJ's technology centers.

Before NIJ Standards can be identified/developed and adopted, a great deal of preparatory work has to be completed. The results of this work will be incorporated into a strategic plan that will guide the standards selection and adoption process. An ITS process plan delineates this work, which includes a review and analysis of:

- user requirements for wireless communications and information technology applications,

- current and planned assets legacy systems, replacement plans, and status of jurisdictions' systems for wireless communications and information technology,
- internal and external factors (such as state privacy laws on sharing of PS and CJ information gathered on individuals), and
- technologies appropriate to satisfying the requirements.

In addition, the formal structure and procedures of the AGILE standards organization is required to be thoroughly documented. ITS has completed the work detailing the user requirements for wireless communications and IT systems, and has produced the standards organization and procedures manual. The remainder of the work necessary to develop the strategic plan will be finished during the first half of fiscal year 2000. The formal AGILE standardization process will then begin.

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Railroad Telecommunication Planning

Outputs

- Radio infrastructure system planning for the Eugene OR – Vancouver BC rail corridor.
- Evaluation of the proposed railroad VHF band channel plan.

Newly designed land-mobile radio (LMR) equipment is beginning to incorporate narrowband technology solutions in order to more efficiently utilize radio spectrum resources. Since future radio systems and equipment will be narrowband, the railroads are currently addressing migration and compatibility issues associated with introducing narrowband equipment and systems into their existing LMR networks.

The Wireless Communication Task Force* (WCTF), an ad-hoc committee comprised of the railroads, radio manufacturers, and State and Federal Governments, is preparing to field test new narrowband digital radio equipment along the Eugene, Oregon, to Vancouver, British Columbia, rail corridor. This digital radio equipment complies with the Telecommunications Industry Association's TIA-102 series of standards.

That portion of the radio spectrum that comprises the railroad VHF band occupies a range of frequencies from 160.215 MHz to 161.565 MHz. This spectrum is divided into 181 channels spaced every 7.5 kHz. WCTF has proposed a VHF band plan for the railroads, depicted in Figure 1. This band plan will be utilized by the railroads during the Oregon Department of Transportation (ODOT) pilot test.

The WCTF band plan apportions the majority of these frequencies into 10 channel groups, each group comprised of 8 duplex frequency pairs, or channels. The remaining portion of the band is reserved for 5 duplex channels and 11 simplex frequencies. Each group of 8 channels could be collocated at a single site. These channels could then be trunked, allowing a much greater voice traffic handling capacity to local users than could be provided by an equal number of non-trunked channels.

The Federal Railroad Administration (FRA) tasked ITS to evaluate the efficacy of this plan. ITS' findings are documented in the NTIA Report listed below. This report investigated the proposed channelization scheme as it pertained to cochannel interference potential, adjacent-channel interference potential, intermodulation interference potential, trunking efficiency, and equipment costs.

During the course of that evaluation, a second, equally viable channelization scheme was suggested, shown in Figure 2. This alternate scheme proposes 13 channel groups of 6 duplex channels each. There are 5 duplex channels, as with the original plan, and 15 simplex frequencies available for other applications.

Figure 1. WCTF band plan.

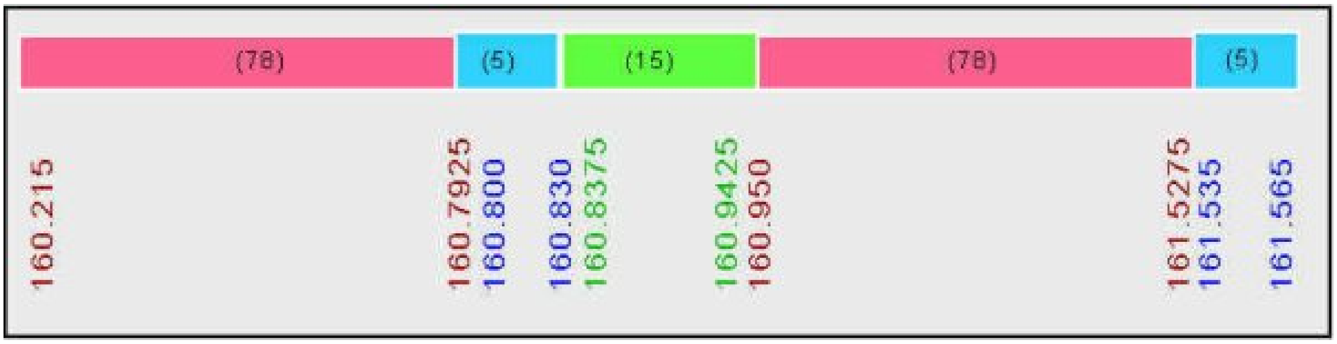

Figure 2. ITS band plan.

Comparison of WCTF and ITS Band Plans		
Parameter	WCTF	ITS
Spectrum	160.215-161.565	160.215-161.565
Total No. of Channels	181	181
No. of Trunked Duplex Channels	80	78
No. of Trunk Groups	10	13
No. of Control Channels per Trunk	1	1
No. of Traffic Channels per Trunk	7	5
Traffic Capacity @ 2% Blocking	2.6E	1.5E
No. of Non-Trunked Duplex Channels	5	5
No. of Simplex Channels	11	15
Transmitter Site Channel Spacing	75 kHz	97.5 kHz
Repeater Frequency Split	720 kHz	735 kHz
Support 7-Cell Topology with 15-kHz Channel Spacings?	No	Yes
Lowest Order of Intermodulation Interference that could occur within ± 6.25 kHz of receive frequency.	5th order	7th order

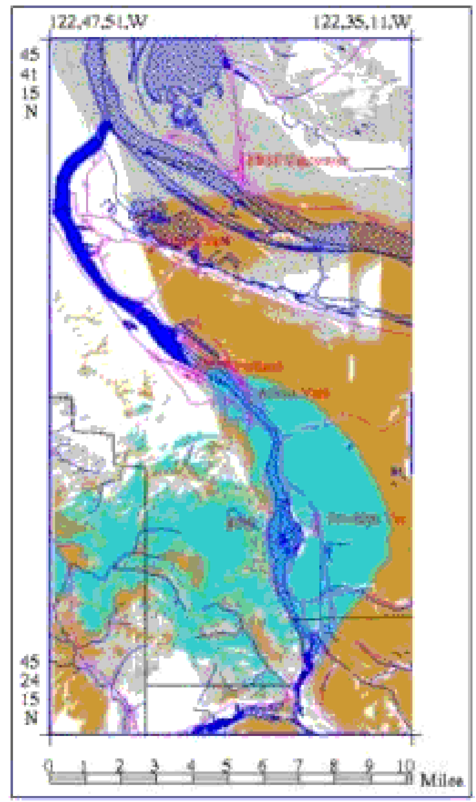

Figure 3. Terrain coverage for high-quality radio communications for both analog FM and digital TIA-102 systems.

The Table above compares the plans. While the former plan promises significantly better trunked voice traffic capacity, the latter offers better protection against intermodulation interference, more latitude in selecting cellular topologies in congested communications areas, particularly if adjacent cells require more than 7.5-kHz separation between their 12.5-kHz wide channels, and lower cost per trunking site.

ITS also performed propagation analyses to determine the radio coverage that could be obtained with the proposed TIA-102 system. Figure 3 shows an example of radio coverage that could be expected for high-quality speech intelligibility in the Portland OR area. Contours are shown where the power received by a base station site from an itinerant portable handheld radio exceeds -113 dBm, -102.9 dBm and -95.7 dBm, 90% of the time and at 99.9% of the locations. The latter two power levels are indicative of how strong a signal is required to yield a superior level of speech intelligibility, for both a TIA-102 compliant system and a legacy analog FM system, respectively.

Continued work in this area will assist railroads in evaluating the efficacy of TIA-102 equipment for such applications as positive train control and positive train separation.

*Formerly known as the North American Railroad Radio Network (NARRN).

Recent Publication

J.M. Vanderau and E.J. Haakinson, "An evaluation of the proposed railroad VHF band channel plan," NTIA Report 99-370, Sep. 1999.

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Satellite Studies

Outputs

- Control and analysis software developed and installed in the Transportable Video Quality Measurement System (TVQMS).
- Users' Guide and experiment plan prepared for the TVQMS.
- Paper describing the TVQMS presented at the 1999 International Symposium on Advanced Radio Technologies (ISART).

Satellite networks are an increasingly important and indispensable component of the globalized telecommunications industry, an industry that is responding to the convergence of computing and communications with exponential growth of the Internet and new multimedia applications such as worldwide web services and desktop videoconferencing. The infrastructure responding to this growth and demand for expanded services must be comprised of hybrid (integrated) networks—terrestrial, fiber-optics based networks with seamlessly-integrated, broadband satellite networks—to satisfy the rapidly-increasing demands for broadband mobile services and to achieve full connectivity with distant locations and isolated nodes of the terrestrial network. These

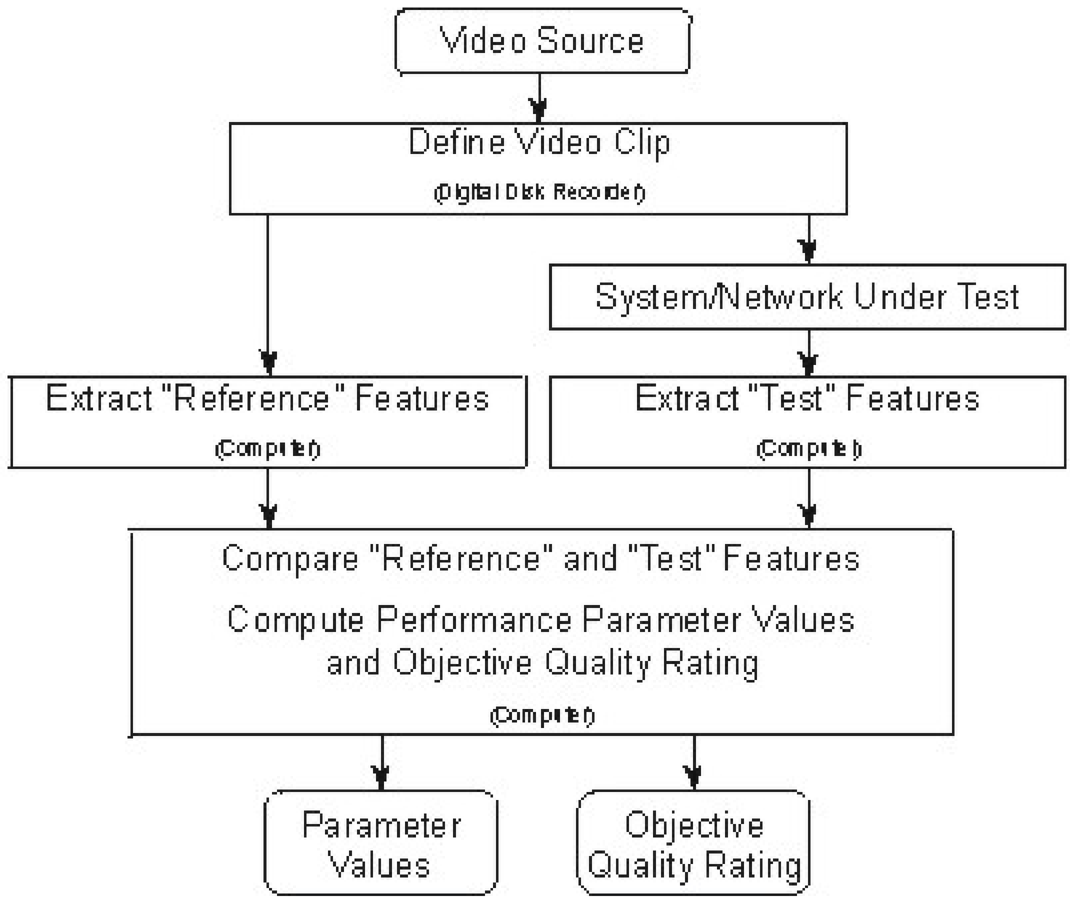

Figure 1. Functional process of the Transportable Video Quality Measurement System (TVQMS) illustrated.

integrated satellite/terrestrial networks will reduce traffic congestion, provide wider selections of available services to all users, and provide better quality of service to remote users where it simply is impossible or cost-prohibitive to extend fiber-optics based services.

Figure 2. Transportable Video Quality Measurement System (TVQMS) ready to perform digital video quality measurements.

Satellites that support multimedia technology are the next generation of communications satellites. These satellites, with inter-satellite links, will use on-board processing and switching and multiple, high-gain, spot-beam antennas to provide full two-way services to and from users with Earth terminals using antennas comparable in size to the direct-to-home receiving antennas commonly used today for satellite-broadcast television. The services these satellites will offer include high-data-rate Internet access and private intranets, as well as television broadcasting. Telephone and reduced Internet services will be available to users with mobile and hand-held terminals.

Many of these systems, that include low-Earth-orbit (LEO), medium-Earth-orbit (MEO), and geosynchronous-Earth-orbit (GEO) satellites, plan to use asynchronous transfer mode (ATM—transport protocol for transmission) technology in the on-board processing and switching capabilities and inter-satellite links. The ensuing technological challenges include interoperability between the satellite systems and the terrestrial networks and satisfying users' quality of service (QoS) requirements. Standards that address these challenges are being developed by the ATM Forum, the Telecommunications Industry Association (TIA), and the International Telecommunication Union Radiocommunication Sector (ITU-R).

The Institute's Satellite Studies Project contributes to satellite technology enhancement and interoperability through system and link performance analyses and measurements and technical contributions to national and international standards committees. The project's focus for the past year has been the development of a Transportable Video Quality Measurement System (TVQMS). This is a tool for measuring the quality, or performance, of digital video services, systems, and networks that use ATM over satellites. The tool can also be used to measure the quality of digital video services using the Internet protocol (IP) over ATM over satellites.

Functionality of the TVQMS is illustrated in Figure 1. Recorded video source material is used as the input video for the TVQMS—the "reference" video—and the system or network under test. Output video from the system under test becomes the "test" video. The TVQMS independently analyzes the reference and test video samples, or "clips," to compute, or "extract," selected summary statistics (e.g., mean, standard deviation) that are defined as "features." The features for the reference and test samples then are compared to compute the quality or performance parameters and composite video quality metrics, defined as objective quality rating values. These objective quality values correlate very well with subjective evaluations of video quality determined using well-defined and accepted techniques. Figure 2 is a photo of the TVQMS ready to perform measurements.

A Users' Guide and Experiment Plan for the Transportable Video Quality Measurement System was prepared that describes completely the components that comprise the system, explains how to use the system, and presents detailed plans for several experiments of video over ATM over satellites, intended to be the first conducted. Also, a paper describing the features and functions of the TVQMS and the experiments planned as its first application was presented at the 1999 International Symposium on Advanced Radio Technologies.

Limited measurements with the TVQMS of quality/performance for MPEG-2 video using ATM over satellites were started. The tool stands ready to be used in completing the validation measurements. Then it will be ready to use in experiments that produce measured results useful to several standards-developing organizations, including the TIA Working Groups that are developing standards for ATM and IP over satellites and Working Party-4B (WP-4B) of the ITU-R Study Group 4 that is developing similar international standards known as ITU-R Recommendations. The tool could and should be developed further to accommodate expanded measurements, e.g., performance measurements for systems and services where video is a component of multimedia services.

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Telecommunication Terminology Standards

Outputs

- CD-ROM of FED-STD-1037C with search engine.
- NTIA Report on the 1037C search engine.
- Mechanisms for on-line, Web revisions of FED-STD-1037C, *Glossary of Telecommunication Terms*.
- New Web pages of >1250 added terms for FED-STD-1037C-rev 1.

Common understanding of technical terminology is essential in a wide range of telecommunications planning functions, including the development of interoperable equipment, and the generation of precise product and procurement specifications. The Institute, under the sponsorship of the National Communications System (NCS), has spearheaded the development of telecommunications terminology standards for many years through its leadership and technical contributions in the development of the FED-STD-1037 series of telecommunications glossaries.

The ITS effort in the glossary standard in Fiscal Year 1999 included two thrusts: (1) developing and delivering a search engine for FED-STD-1037C, and (2) developing on-line mechanisms for submitting new terminology that addresses the latest in Web technology and computer-security terminology to be included in a revision of the Standard.

The Search Engine for FED-STD-1037C
During FY 99 ITS staff members delivered a 1999 release of the CD-ROM containing an HTML version of FED-STD-1037C and a custom-designed search engine for that glossary. The user of the search engine types a specific character string, and the search engine examines the complete text of the 5800-entry glossary to identify definitions associated with each hit of that character string. The search process requires 7 to 40 seconds, depending on the length of the input string. A significant advantage of the search engine is its ability to speed a user's access to particular entries in the glossary. The search engine also promotes more organized and systematic use of the glossary by giving users access to groups of related terms. The search engine and the document's on-line availability have also made possible a more efficient, and more timely, update of the glossary.

On-line, Web-based Updating of the Glossary
Although it is still valuable at present, FED-STD-1037C will become obsolete if it is not updated at regular intervals. Telecommunications terms describing new discoveries and technological advances must be communicated quickly and accurately to prospective users if those advances are to be used effectively in technical specifications. Obsolete terms must be deleted from the glossary promptly to ensure its continued credibility.

Growing concerns with critical infrastructure protection, reflected in the President's 1998 issuance of PDD-63, have created a particularly compelling need for clear, widely accepted definitions of computer security, network security, and associated information-assurance terms. The 1037C Standard is a natural medium for promulgation of these important specialized terms because of its broad acceptance and definitive treatment of related, more fundamental telecommunications concepts.

The staff at ITS have researched the technical literature and draft documents from expert committees to develop a body of more than 1250 definitions related to the new technologies associated with computer security and the Web. These definitions have been placed on the Web for consideration in the revision of FED-STD-1037C. To facilitate incorporating these definitions into the revision of the glossary, ITS has developed on-line, Web-based mechanisms using HTML codes—in lieu of face-to-face meetings—for developing the update. The process of using the Web-based revision is illustrated in the figure.

The HTML draft of the new-technology revisions can be seen at:

http://www.its.bldrdoc.gov/projects/fs-1037c-r1

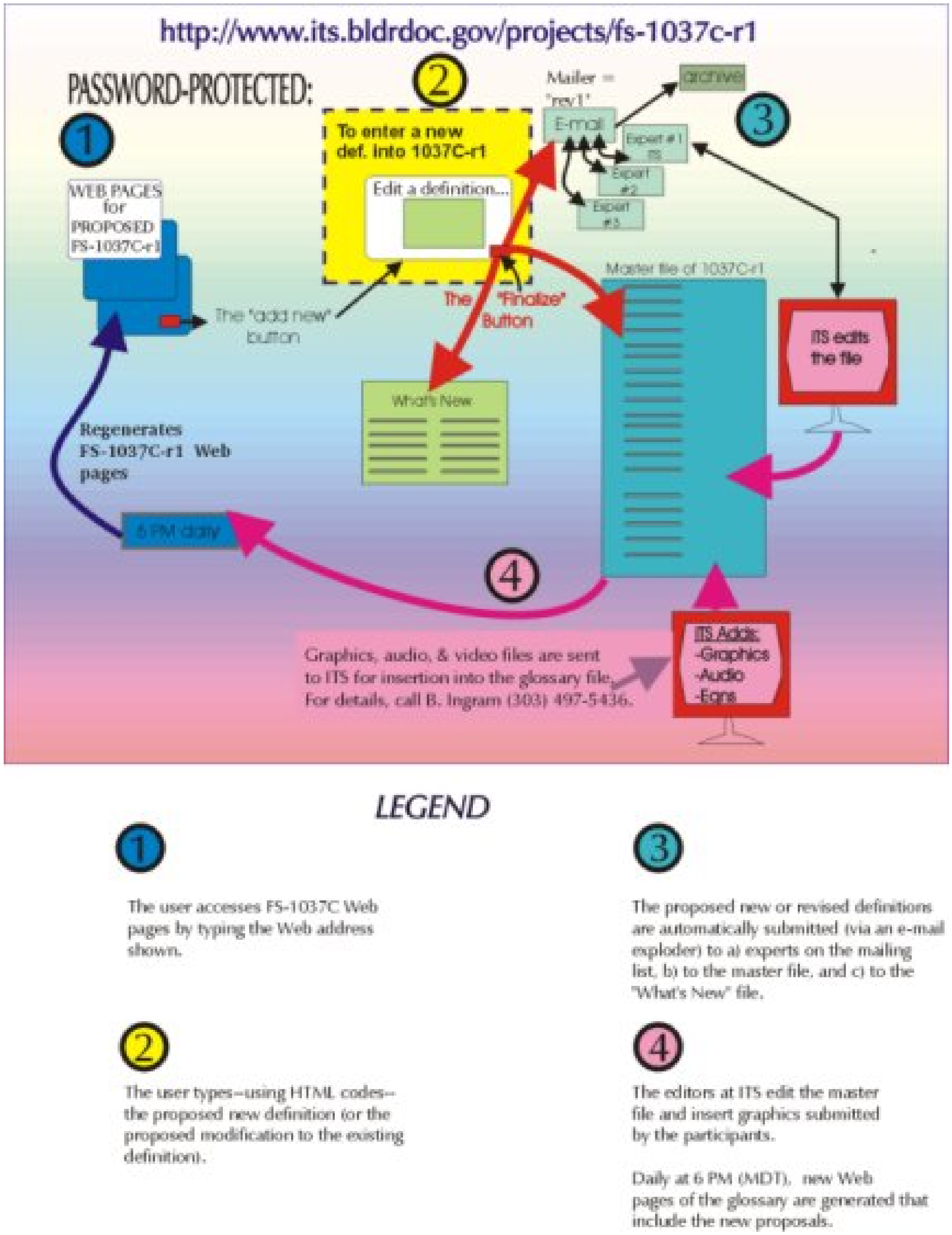
The on-line process being used to revise the glossary is shown in the figure.

In step 1 in the figure, the user accesses the Web pages of the glossary (using a password available from ITS), and then clicks either a) "[add new]" (to propose a new definition), or b) a letter of the alphabet in the rightmost frame of the computer screen, and then the word beginning with that letter, to propose a modification to an existing definition.

In step 2, the user types the proposed changes or new definitions directly on the Web page for that term name.

In step 3, the proposed new (or revised) definitions are automatically submitted via an e-mail exploder first to everyone on the mailing list, then to the archive file (a backup file) and the master file of the entire revised glossary, and then to the "What's New" file of new/ revised definitions. E-mail comments on the proposals are also automatically distributed to all experts on the e-mail mailing list.

In step 4, the editors at ITS edit the master file and insert graphics submitted by participants. Daily at 6 p.m. (MDT) new Web pages of FED-STD-1037C-rev 1 are generated that include the new proposals.



Web-based revision of FED-STD-1037C, Glossary of Telecommunication Terms.

Hard copy and a CD-ROM of the 1996 glossary (with a search engine) may be obtained at no cost from

National Communications System
Attn: Mrs. M. Parham or Mr. F. McClelland, N2
701 South Court House Road
Arlington, VA 22204-2198
Phone: (703) 607-6107

Recent Publications

W.J. Ingram and E.M. Gray, "A Federal Standard on electronic media," NTIA Report 98-350, Aug. 1998.

W.J. Ingram and E.M. Gray, "A search engine for Federal Standard 1037C," NTIA Report 99-365, Mar. 1999.

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Use of IP-based Networks in Real-Time NS/EP Applications

Outputs

- A report providing information to the sponsor concerning IP network protocols and operation of real-time applications on IP-based networks.

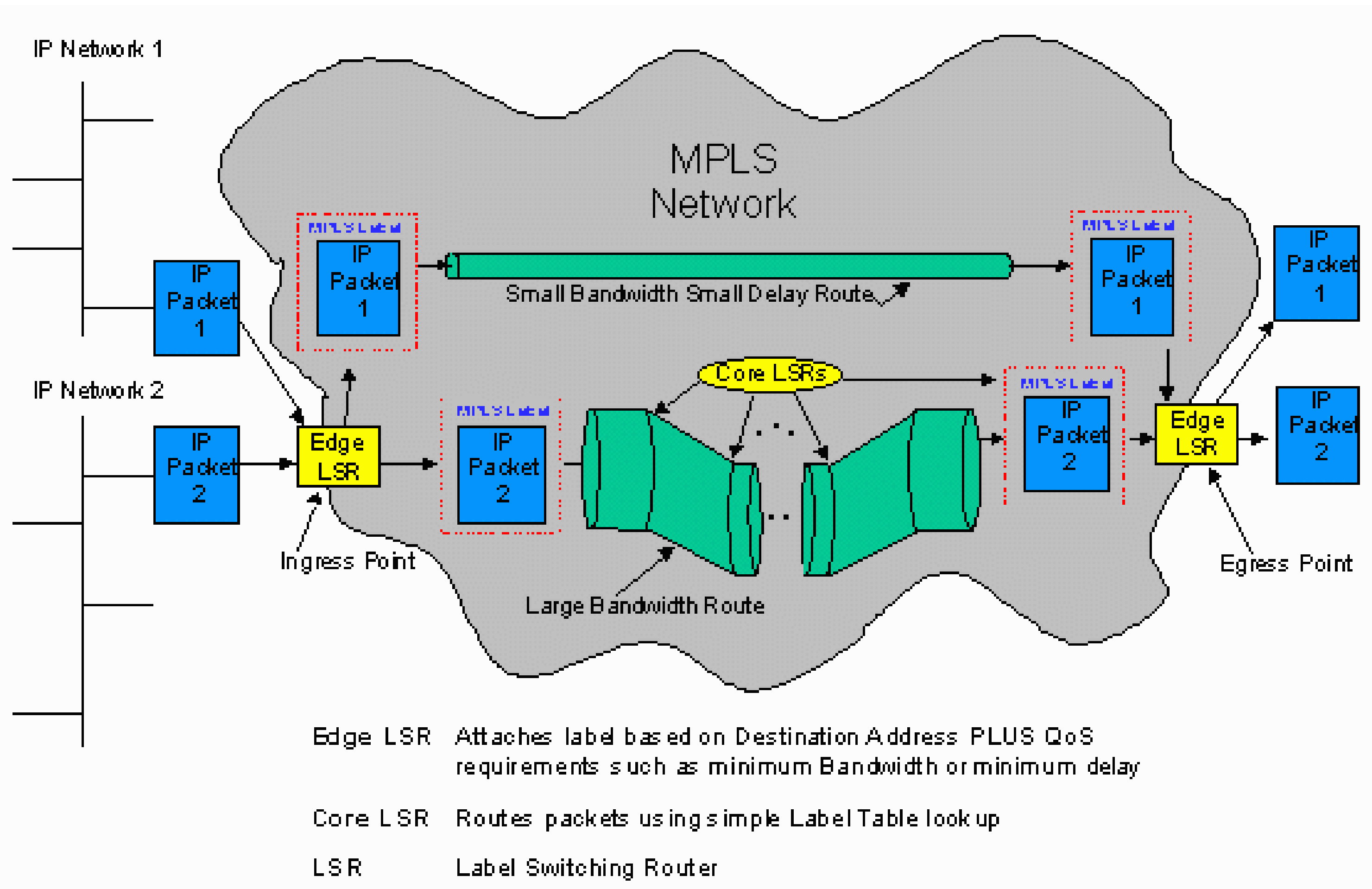
During FY 1999, ITS conducted research on behalf of the National Communications System (NCS) to describe the potential performance of real-time communication applications (e.g., voice over Internet Protocol or IP) that will use IP-based networks as their communication infrastructure. The report resulting from this research summarizes the current technological status of IP-based networks and real-time applications of interest and closes with a set of recommendations concerning actions that NCS should take to ensure the proper operation of these applications in NS/EP (National Security/ Emergency Preparedness) situations.

NCS, consisting of 23 Federal member departments and agencies, is responsible for ensuring the availability of a viable NS/EP telecommunications infrastructure. In particular, the NCS mission includes both "the exercise of the telecommunications functions and responsibilities as well as the coordination of the planning for and provision of national security and emergency preparedness communications for the Federal government under all circumstances, including crisis or emergency, attack, recovery and reconstitution."* Recent technological advances in high-speed telecommunications networks, computer systems, and software have helped the Government reengineer the way it does business. Electronic government uses all forms of telecommunications, including voice, data and imagery. In response, NCS has been investigating and testing new and complementary technologies and enhancements to its existing NS/EP telecommunications technology.

Several technological trends that are currently being proposed have the potential of revolutionizing the national communications infrastructure. It is important that Government planners understand the consequences and opportunities associated with the growth of IP-based networks and their possible use in supporting telephony and other real-time services in order to ensure that the Government's NS/EP needs are addressed.

NCS member agencies will surely have growing needs for audio and video/audio IP communications in support of NS/EP. Even today, the Federal Emergency Management Agency (FEMA) uses video teleconferencing in their Emergency Operations Vehicles assigned to the FEMA Mobile Emergency Response Support, which are deployed to disaster sites to provide an on-site operations base for FEMA emergency response teams. The Department of Defense (DoD) has indicated a need for video teleconferencing to provide an inexpensive training mechanism for its coordinated inter-agency Emergency Plan on Domestic Terrorism. In this effort, training to prevent and respond to domestic terrorist incidents involving weapons of mass destruction will be provided to local agencies in 120 cities over 3 years.

While circuit-switched networks will be used for at least another five to ten years, the unique characteristics of IP, with its distributed topology and ubiquity (Figure 1 illustrates the use of an important IP component technology —Multiprotocol Label Switching), make it the important technology for NS/EP applications. It seems highly likely that real-time communications over IP networks will become a very important addition to the current NS/EP communications methods. At some time in the future, IP communications (or perhaps some other packet switched service) will probably completely replace circuit switched networks.



Multiprotocol Label Switching – A technology integral to IP networks.

One proposal currently being considered by the Internet Engineering Task Force (IETF), the Differentiated Services (DIFFSERV) architecture, could profoundly impact the use of the Internet in NS/EP applications. The DIFFSERV plan is to allocate Internet resources, either by establishing priority-based per-hop forwarding behaviors, or by guaranteeing qualitative levels for performance parameters such as throughput, delay, delay variation, and loss probability. The DIFFSERV architecture holds great potential as a means of reserving resources for NS/EP applications, but the Government must make its needs known for this potential to be realized.

Depending on the success of DIFFSERV and other IP network resource allocation proposals, it is likely that the major telecommunications providers will move from the use of current circuit switching technology to a router-based network architecture relying on the Internet protocol. Voice-over-IP (and video over IP) technology could become common communication technologies during the next few years. The Government needs to understand how the special needs of emergency response teams would be affected by this historic migration, and how the resources of routing and transmission facilities could be allocated in NS/EP situations. The report delivered to NCS provides information that will lead to such an understanding. In addition, recommendations are provided that will help to ensure that future versions of the IP infrastructure and the real-time applications themselves will provide necessary performance to those who will depend on such communication facilities in times of NS/EP.

*NCS Web page, **http://www.ncs.gov/**

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Telecommunications Theory

The Institute is involved in research for both wireless and wireline telecommunications. The rapid growth of telecommunications in the last 50 years has caused crowding in the radio spectrum. New technology requires a new understanding of the behavior of radio waves in all parts of the radio spectrum. The Institute studies all frequencies in use, extending our understanding of how radio signal propagation is affected by the earth's surface, the atmosphere, and the ionosphere. This work is resulting in new propagation models for the broadband signals used in new radio systems. The Institute's historical involvement in radio-wave research and propagation prediction development provides a substantial knowledge base for the development of state-of-the-art telecommunication systems. In another area the Institute develops perception-based measurements for multimedia services. ITS transfers all of this technology to both public and private users, where knowledge is transformed into new products and new opportunities.

Areas of Emphasis

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

Advanced Radio Technologies Symposium
The Institute conducted the 1999 International Symposium on Advanced Radio Technologies. This second annual symposium focused on satellite communications. The project is funded by the Department of Defense.

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

Augmented Global Positioning System
The Institute provides technical support for the

design and implementation of a nationwide differential GPS service that will provide navigation and positioning information to surface users throughout the country. The project is funded by the Federal Highway Administration (FHWA).

ITS engineers performing objective video quality measurements in the audio-visual quality laboratory (photography by F.H. Sanders).

Electromagnetic Compatibility Research
The Institute conducts research involving the electromagnetic compatibility of a variety of communications systems. Projects are funded by NTIA and FHWA.

Impulsive Noise and Digital Systems
The Institute performs measurements to define the RF noise environment experienced by communication systems and develops models to predict the effect on digital communications. The project is funded by NTIA.

Software Defined Radio Technology
The Institute is involved in research on advanced radio systems including software defined radios and smart antennas. Projects are funded by NTIA and the Department of Defense.

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

Video Quality Research
The Institute develops and implements perception-based, technology-independent video quality measures and promotes their adoption in national and international standards. Projects are funded by NTIA and NCS.

Adaptive Antenna Testbed

Outputs

- Wideband radio channel sounding measurements.
- 8 simultaneous measurement channels (expandable to 16).
- Propagation loss, fading, delay, and Doppler statistics over a broad bandwidth.
- Antenna array diversity gain data.
- Angle of arrival input data for adaptive antenna schemes.

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

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

ITS has developed an adaptive antenna testbed (ATB) to serve as a common reference for testing adaptive antenna arrays and signal combining algorithms, as well as complete systems. The ATB builds on wideband channel measurement systems previously developed by ITS. These systems use a maximal length pseudo-random noise (PN) code generator to BPSK modulate a radio channel carrier frequency at the transmitter. The received signal is autocorrelated at the receiver with the known PN code producing an impulse-like response. The impulse response characterizes the channel over a wide bandwidth (up to 50 MHz) about the carrier frequency. Digitization of the received data allows for post processing to examine various combining algorithms and digital beam forming schemes. Channel sounding can be done continuously or in selected bursts.

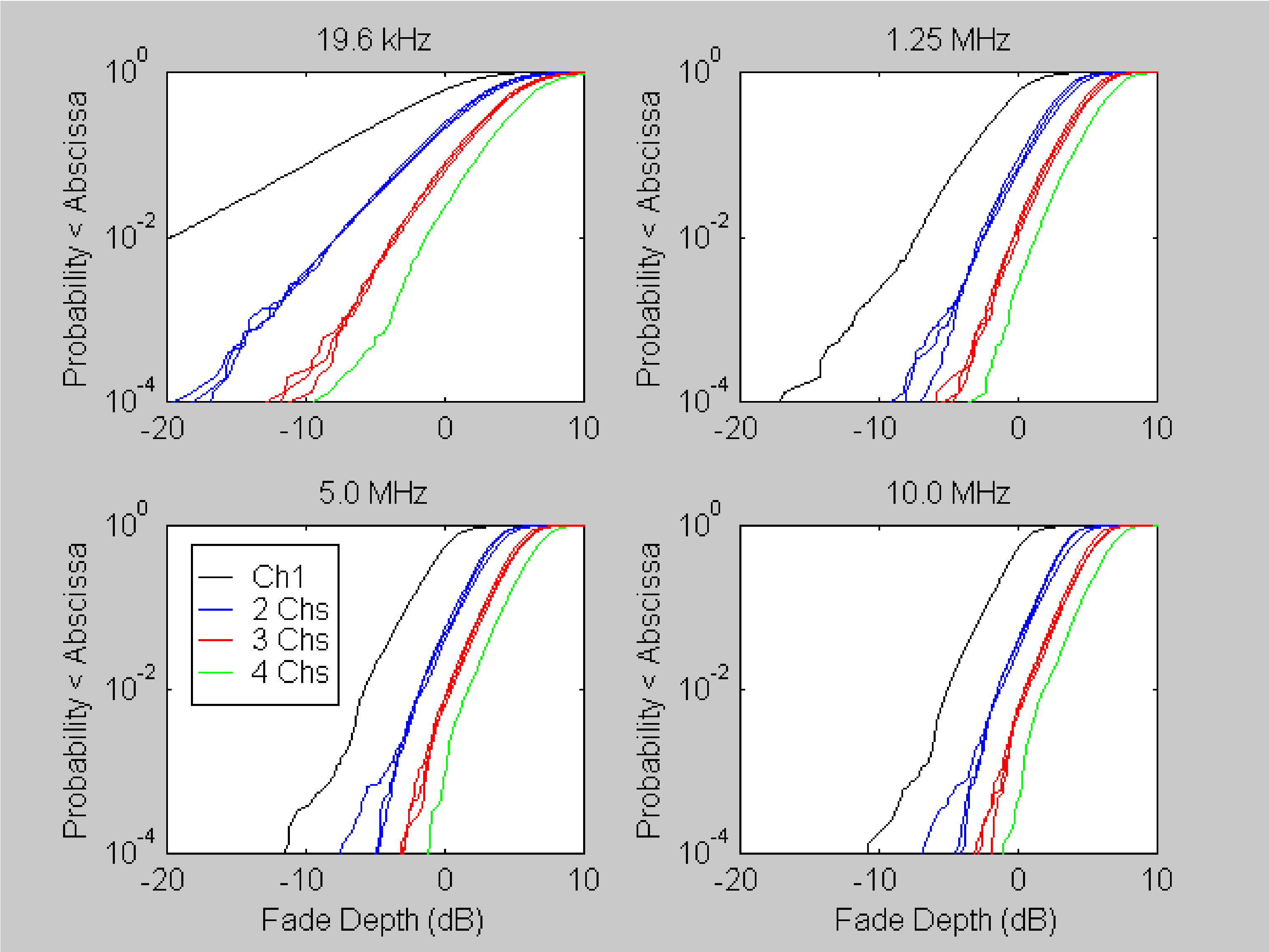

Figure 2. Fast fading cumulative distribution functions for various bandwidths (19.6 kHz to 10 MHz) versus array size (one to four channels using maximal ratio combining). Diversity gain is the difference between curves for a given fade probability level (along a horizontal).

A recent example of an ATB application is a multi-channel diversity experiment conducted in FY 99. A fixed, four-element PCS receiving array is shown in Figure 1. The antenna elements were spaced 2, 5, and 10 wavelengths with respect to the left end element. A mobile van-mounted dipole was used to transmit a 511-bit PN code on a 1.92-GHz carrier frequency. A 10 Mb/s transmitted code was sampled at a rate of 40 MHz at the receiver (oversampling was used to reduce noise). A total of 2044 samples per impulse were taken, yielding an impulse duration of 51 µs. Data were collected in the burst mode with a 3 s delay between bursts. A burst consisted of 128 impulses with a 3 ms delay between impulses, yielding a burst duration of approximately 400 ms. At normal suburban driving speeds (30-60 kph) a burst covered a 20-40 wavelength path length.

Channel sounding was undertaken in a suburban neighborhood. Multipath effects appeared as echoes in the impulse signal and frequency selective fading in the power spectral density. These channel data were used to determine fading and delay statistics, diversity gain, angle of arrival, and correlation bandwidth. Sample diversity gain data as a function of bandwidth are shown in Figure 2. The data indicate that diversity gain increases as the array size increases (from two to four elements) but decreases as the bandwidth increases (from 19.6 kHz to 10 MHz). The latter result is due to the averaging of frequency selective fading effects with increased bandwidth.

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

Recent Publications

P. Wilson, P. Papazian, M. Cotton, and Y. Lo, "Advanced antenna test bed characterization for wideband wireless communication systems," NTIA Report 99-369, Aug. 1999.

P. Wilson, P. Papazian, M. Cotton, and Y. Lo, "A comparison of 1920 MHz diversity gain using horizontally and vertically spaced antenna elements," in *Proc. 1999 IEEE Radio and Wireless Conference*, Denver, CO, pp. 243-246, Aug. 1999.

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Advanced Radio Technologies Symposium

Outputs

- Symposium proceedings.
- Exchange of ideas among leading experts in satellite communications.

The Institute hosted the 1999 Second Annual International Symposium on Advanced Radio Technologies on September 8-10, 1999 in Boulder, Colorado. This year's symposium focused on state-of-the-art and future trends in satellite communication technologies and applications. The Advanced Communications Technology Satellite (ACTS), shown in Figure 1, is an example of the synergism in modern satellite communications. The ACTS program has included participation by academia, industry, and government agencies, including the Institute.

Session presentations by leading experts from government, academia, and industry were followed by forward-looking open round table discussions on future directions in technologies and related issues. The symposium encouraged an interactive dialogue between the speakers and the audience so that participants could share their ideas and opinions on relevant technologies and future trends. Approximately 130 individuals from 10 countries attended the symposium.

The symposium was organized into five sessions: an opening session, applications, propagation aspects, hardware, and networking. These five sessions comprised 26 presentations.

The opening session consisted of three talks: an overview of satellite communications, a discussion of traffic management in satellite networks, and a talk on spectrum issues related to satellite communications.

The applications session began with an overview of low earth orbit (LEO) satellite systems presented by ITS engineer Christopher Redding. This was followed by talks on applications of the ACTS, Orbcomm, and TechSat 21 satellite systems. The session concluded with papers on a GPS radio occultation instrument and atmospheric-space networking. Figure 2, from Christopher Redding's talk, "Overview of LEO Satellite Systems," is a diagram of the orbital altitudes of six commercial LEO satellite systems.

The propagation session consisted of six talks: an overview of propagation concerns for satellite communications, papers discussing the effects of rain, foliage, and noise on satellite communications, and papers on adaptive impairment mitigation techniques and mobile satellite communication channel modeling. Figure 3 is from ITS engineer Dr. Roger Dalke's talk in this session, "Effects of Noise on VHF Satellite Communications." Dr. Dalke reported on the Institute's work conducting measurements of radio noise in satellite communication frequency bands. This radio noise was measured and simulated by ITS engineers in order to plan the link budget for a satellite communications link.

The hardware session comprised talks on Ka band hardware, phased array antennas, wideband multibeam antennas, laser communication requirements, adaptive hardware techniques for power management of radio transceivers, and system engineering for GOES satellites. The networking session consisted of five papers: terminal architecture and protocol software, an internet interface to NASA satellites, the internet over satellite networks, multimedia satellites, and return channel system architecture for multimedia over satellite.

After the presentations, the Institute conducted tours of ITS and NIST Boulder Laboratories, including the Telecommunication Analysis Services Laboratory, the Broadband Measurements Laboratory, the Antenna Measurements Laboratory, the Microelectronics Laboratory, and the Voice and Video Quality Measurements Laboratory.

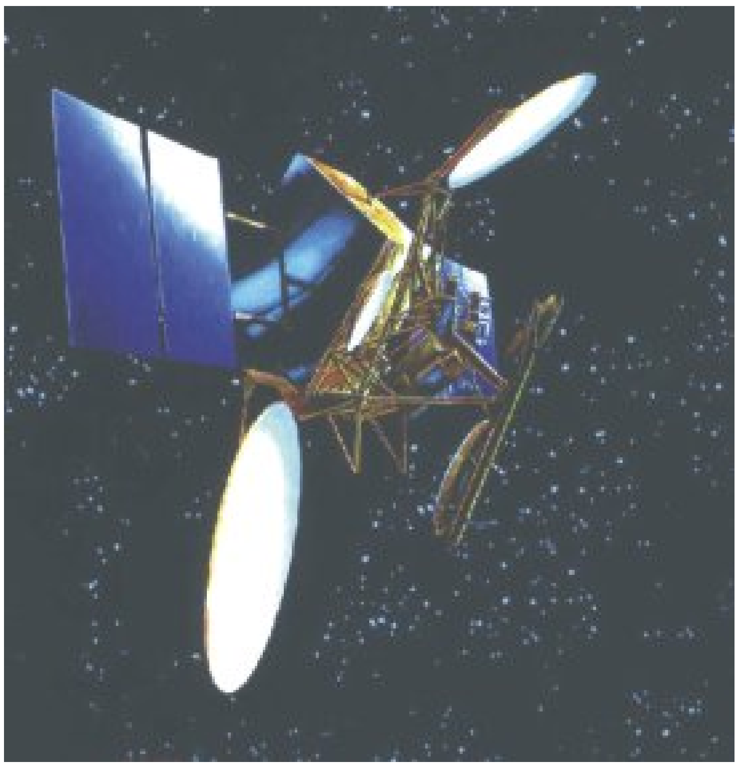

Figure 1. Advanced Communications Technology Satellite (ACTS).

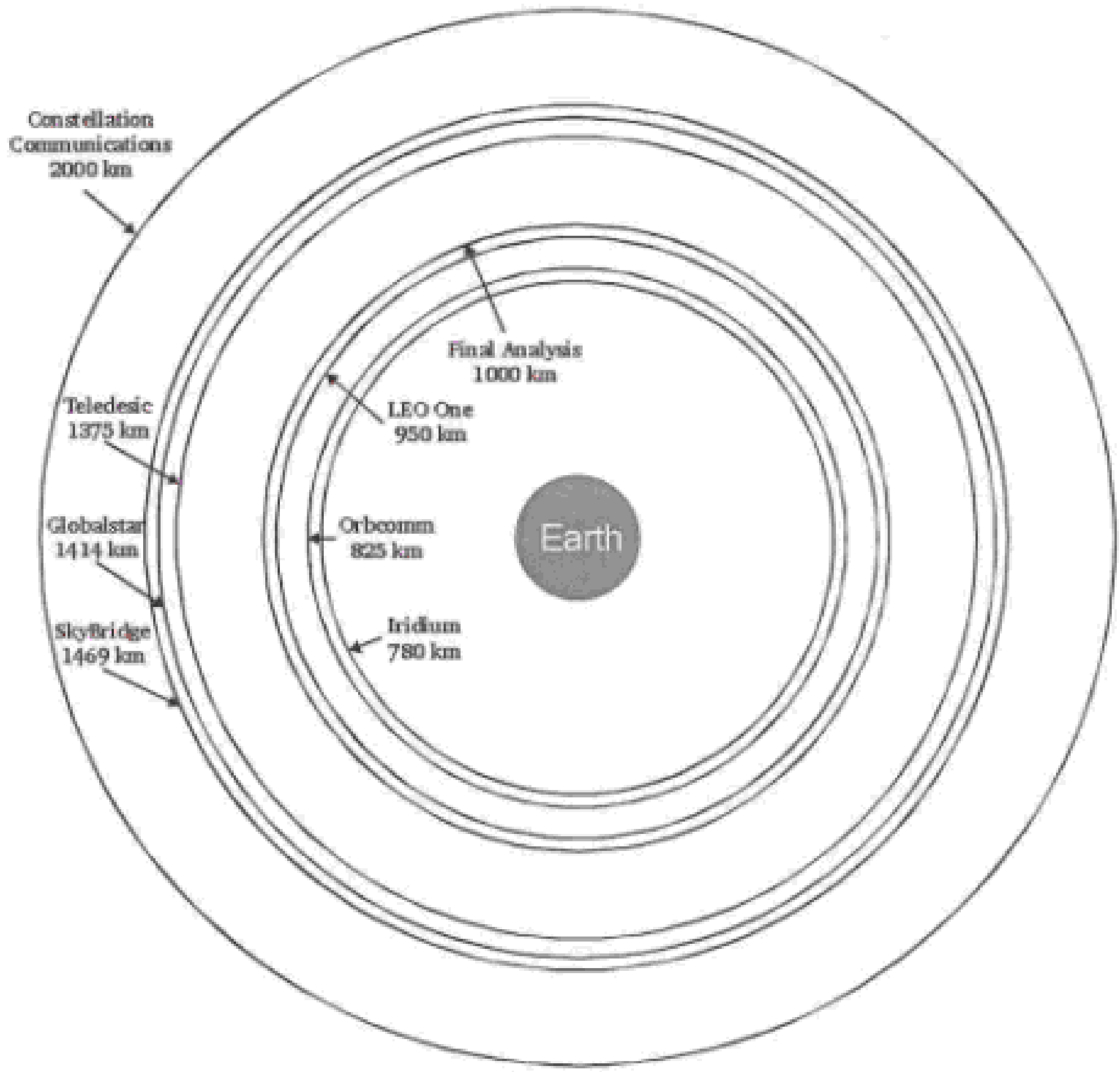

Figure 2. Orbital altitudes of some commercial low earth orbit (LEO) satellite systems.

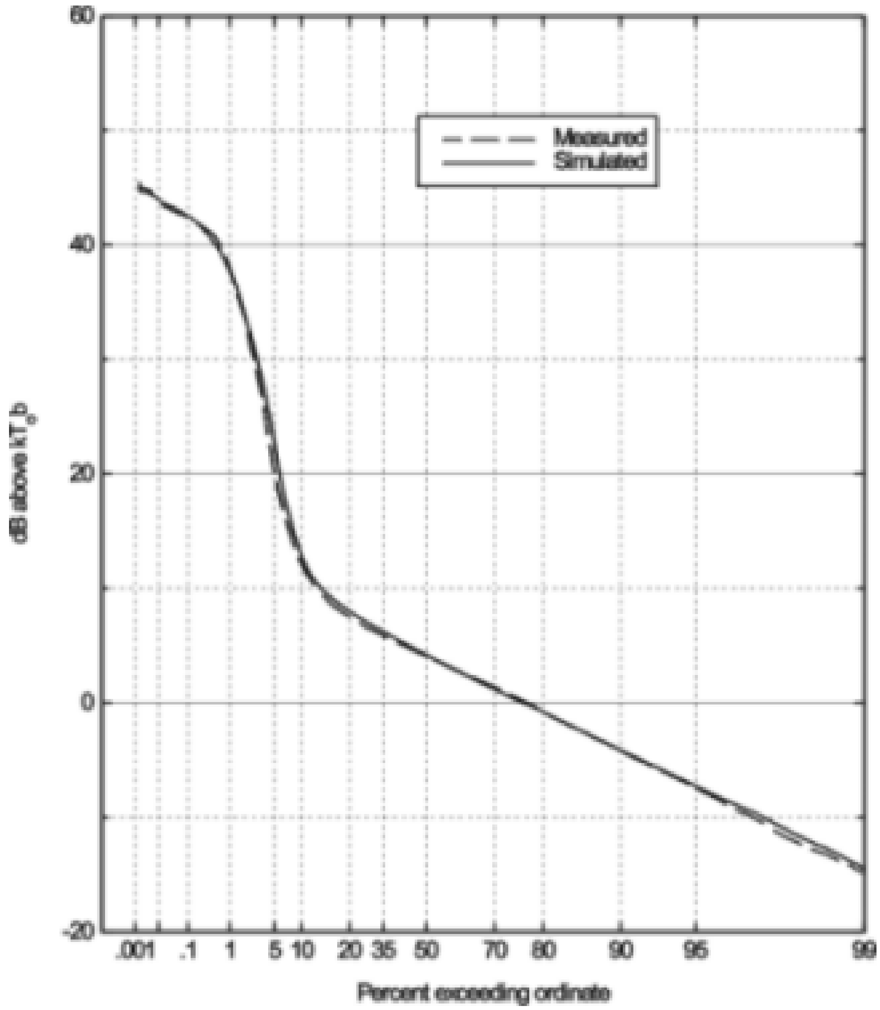

Figure 3. Cumulative probability distribution of radio noise emissions at 137 MHz near a rural power line.

Recent publication

Symposium proceedings can be found at the web site **http://ntia.its.bldrdoc.gov/isart/**

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Audio Quality Research

Outputs

- Algorithms and software for speech and audio quality assessment and coding.
- Technical papers and reports documenting new results.
- Presentations on speech and audio quality assessment issues.

Digital compression and transmission of speech and audio signals are two of the enabling technologies that have contributed to the current explosion of telecommunications and broadcasting offerings. Examples of these offerings include cellular telephones, personal communications systems (PCS), satellite telephony, digital audio broadcasting, voice messaging systems, voice over Internet protocol (VoIP) services, Minidisc equipment, Motion Picture Experts Group (MPEG) 1, Layer-3 (MP3) music files and MPEG Advanced Audio Coding systems. Digital compression allows these systems to deliver high-quality speech using bit rates between 4 and 64 kbit/s. Audio signals, including music and entertainment soundtracks, are typically delivered at rates between 16 and 256 kbit/s per channel. Compressed speech and audio signals can be transmitted as data packets, thus sharing channel capacity with other data streams. Some compression and transmission systems employ multiple streams of packets to increase robustness to transmission failures, or to allow for higher quality audio when and where bandwidth permits.

These digital compression and transmission techniques and the associated economic trade-offs have created important new speech and audio quality issues. Equipment manufacturers, service providers, and users all seek equipment and services that maximize delivered audio quality under applicable transmission channel constraints. But due to the increasingly complex time-varying interactions among audio signal content, source coding, channel coding, and channel conditions, it is becoming more and more difficult to define or measure audio quality. The ITS Audio Quality Research Program develops and verifies tools that assist with audio quality assessment and optimization.

The most fundamental and correct measures of audio quality come from subjective listening experiments. The Audio Quality Research Program uses these experiments to provide answers to pressing questions in the field. In order to generate the most useful and reliable results, this work is done in accordance with applicable recommendations from the International Telecommunication Union (ITU). In FY99, program staff designed, conducted, and analyzed an experiment that investigated the links between variable transmission delays and speech quality. Variable transmission delays can occur in packetized transmission systems, and are presently considered a major factor in the design of VoIP systems. The Figure shows how packet delay variation can lead to a unique sort of speech distortion. Results from the experiment will provide equipment designers with new guidance for their efforts to mitigate the effects of delay variation.

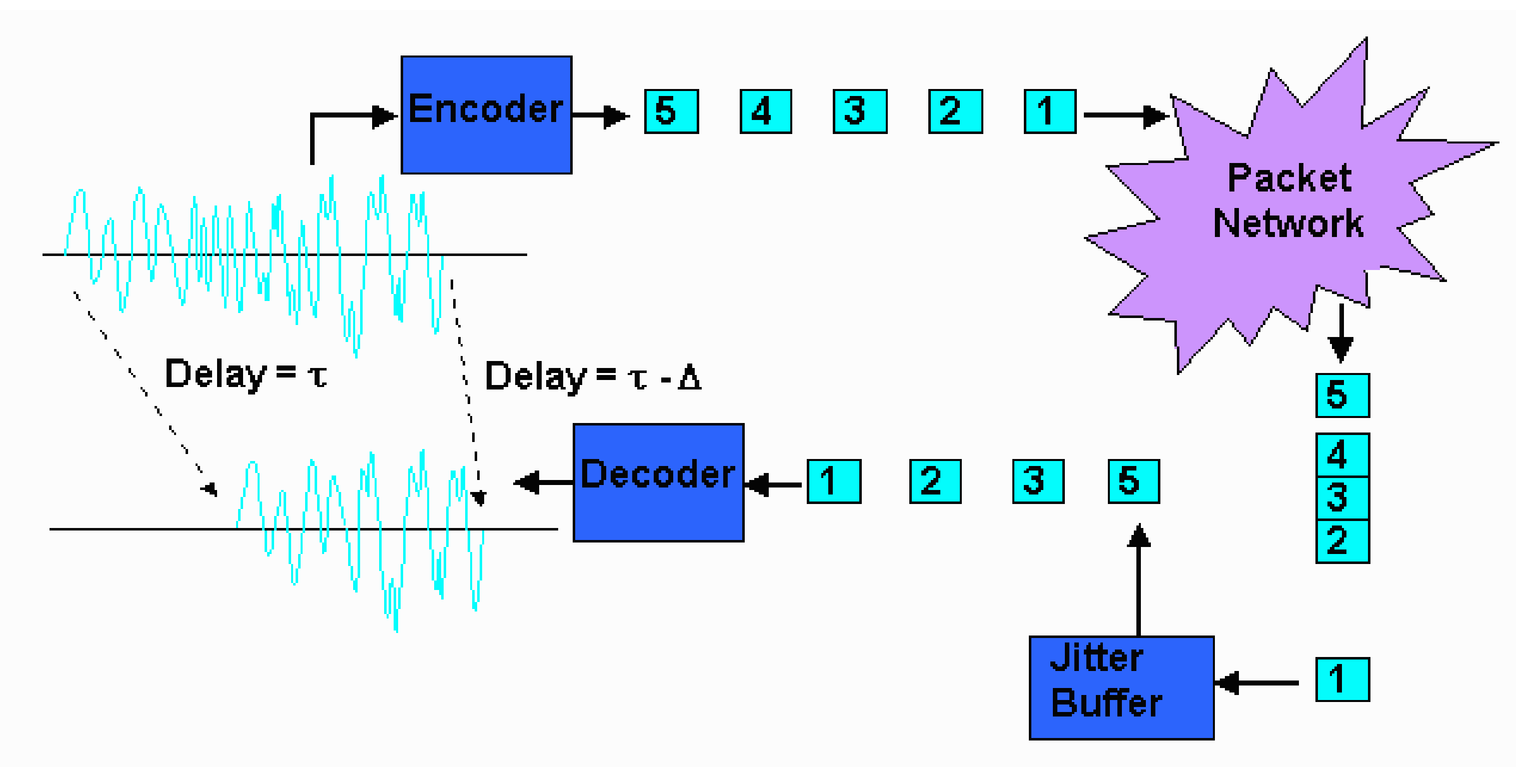
Carefully conducted subjective listening experiments tend to be fairly complex and time consuming, and the associated costs make them inappropriate for some applications. The Audio Quality Research Program continues to be involved in developing and evaluating practical alternatives to subjective listening experiments. The program has recently made a significant contribution in this area: the measuring normalizing block (MNB) algorithms for estimating the perceived quality of 4 kHz bandwidth speech. The MNB algorithms work because they model both human hearing and human judgement. A simple hearing model is followed by a more sophisticated judgement model. The judgement model involves measuring and normalizing spectral deviations at multiple time and frequency scales. To most realistically emulate listeners' patterns of adaptation and reaction to spectral deviations, the measuring normalizing blocks are combined so that analysis proceeds from larger scales to smaller scales.

When speech quality estimates from the MNB algorithms are compared with the results of subjective listening experiments, a good degree of correlation is found. Improvement over earlier algorithms is particularly evident for highly compressed speech transmission systems, and those suffering from bit errors and frame erasures. Thus these algorithms furnish industry, Government, and other users with valuable tools that provide rapid and reliable quality feedback in an increased number of application areas. The MNB algorithms form both the American National Standards Institute Telecommunications Standard T1.518-1998 (see **Publications Cited**) and ITU Recommendation P.861, Appendix II, 1998.

During FY99, program staff continued to apply the MNB algorithms to a variety of speech transmission systems, with an emphasis on emerging VoIP systems. These studies provided valuable information for the future refinement and extension of the MNB algorithms. One of these extensions is frame-energy plane partitioning, which allows separate estimators to be applied to different parts of speech signals. As an example, pauses in speech may be analyzed for background noise, while active speech is analyzed for distortion. This approach offers the potential of more reliable quality estimates in the presence of background noise. These improved estimates will be important for PCS, cellular, and satellite telephones operated in vehicles or other noisy environments.

In FY99, program staff also made significant efforts to track and analyze speech transmission delay in systems where that delay has significant variation. This work builds on the subjective listening experiment described above and is particularly applicable to VoIP systems. It is expected that this work will lead to tools that provide more effective quality feedback for VoIP systems. Other staff efforts included the application of quality assessment results in the coding and transmission areas, with a potential for improved audio quality and more robust transmission.

Throughout FY99, program staff disseminated program results to industry, Government, and academia through numerous technical publications, participation in workshops, conferences and symposia, submitted and invited talks and lectures, and laboratory demonstrations. Laboratory demonstrations often focused on subjective testing capabilities and issues, and on prototype audio quality test instruments that implement MNB algorithms in near real time.



Example of a speech waveform impaired by delay variation in a packet network.

Recent Publications

S. Voran, "Advances in objective estimation of perceived speech quality," in *Proc. 1999 IEEE Workshop on Speech Coding*, Porvoo, Finland, Jun. 1999.

S. Voran, "Objective estimation of perceived speech quality, Part I: Development of the measuring normalizing block technique; Part II: Evaluation of the measuring normalizing block technique," *IEEE Transactions on Speech and Audio Processing*, vol. 7, no. 4, pp. 371-382 and pp. 383-390, Jul. 1999.

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Augmented Global Positioning System

Outputs

- Planning of the number and location of GWEN differential GPS reference stations required to provide nationwide signal coverage.
- Recommended frequency assignments and transmitter powers for differential GPS reference stations.

The NAVSTAR global positioning system (GPS) is a space-based radionavigation system that consists of a constellation of 24 satellites in 6 orbital planes. GPS provides accurate three-dimensional position, velocity, and precise time to users worldwide, 24 hours per day. GPS was originally developed as a military force enhancement system. Although still used in this capacity, GPS also provides significant benefits to the civilian community. To make GPS service available to the greatest number of users while ensuring that national security interests are protected, two GPS services are provided. The precise positioning service (PPS) provides full system accuracy to military users. The standard positioning service (SPS) is available for civilian use but has less accurate positioning capability than PPS, approximately 100 meters.

Because the SPS accuracy of 100 m does not meet most civilian navigation and positioning requirements, various augmentations to GPS are used to provide higher accuracy positioning, as well as increased integrity and availability of the positioning information. One form of augmentation, differential GPS (DGPS), can provide 1- to 10-m accuracy for dynamic applications and better than 1-m for static users. In a 1994 report, the result of a study done for the Department of Transportation, ITS recommended implementation of a radio beacon system, operating in the 300-kHz band, modeled after the U.S. Coast Guard's (USCG) local area DGPS. This system would provide nationwide coverage of DGPS for surface applications (DeBolt et al., 1994; see **Publications Cited**).

For the past three years ITS researchers have been conducting a study, sponsored by the Federal Highway Administration, to determine the optimum location and operating parameters of the DGPS reference stations required to provide this civil navigation and positioning service to all surface users across the nation. This new service will be known as the nationwide differential global positioning system (nDGPS). The use of this service will have an enormous impact on a diverse set of activities, including ocean and land transportation, surveying and mapping, farming, waterway dredging, recreation, emergency location and rescue operations, and many others that have not yet been identified.

The foundation of nDGPS is the DGPS reference stations currently operating or planned by the USCG and the U.S. Army Corps of Engineers; this system provides coverage of the radiobeacon DGPS signal for coastal areas, harbors, and inland waterways. ITS added additional DGPS reference stations to this foundation to provide nationwide coverage of the DGPS signal. To achieve this additional signal coverage, ITS used the Ground Wave Emergency Network (GWEN) sites, owned by the U.S. Air Force Air Combat Command. The GWEN system is an existing Federal Government asset that provides a cost-effective method of implementing nationwide coverage of the DGPS signal. The GWEN sites were used at existing locations or moved to new locations as required to complete the nDGPS signal coverage. Installation of these GWEN DGPS reference stations has already begun.

In FY99, to verify the performance of the first GWEN DGPS reference station (near Appleton, WA), ITS engineers measured the DGPS signal strength at various locations around the GWEN site and compared the measurements to predicted signal strengths using ITS propagation models. Measured field strengths and background noise are shown in Figure 1. Figure 2 shows a signal coverage prediction plot for the Appleton GWEN site.

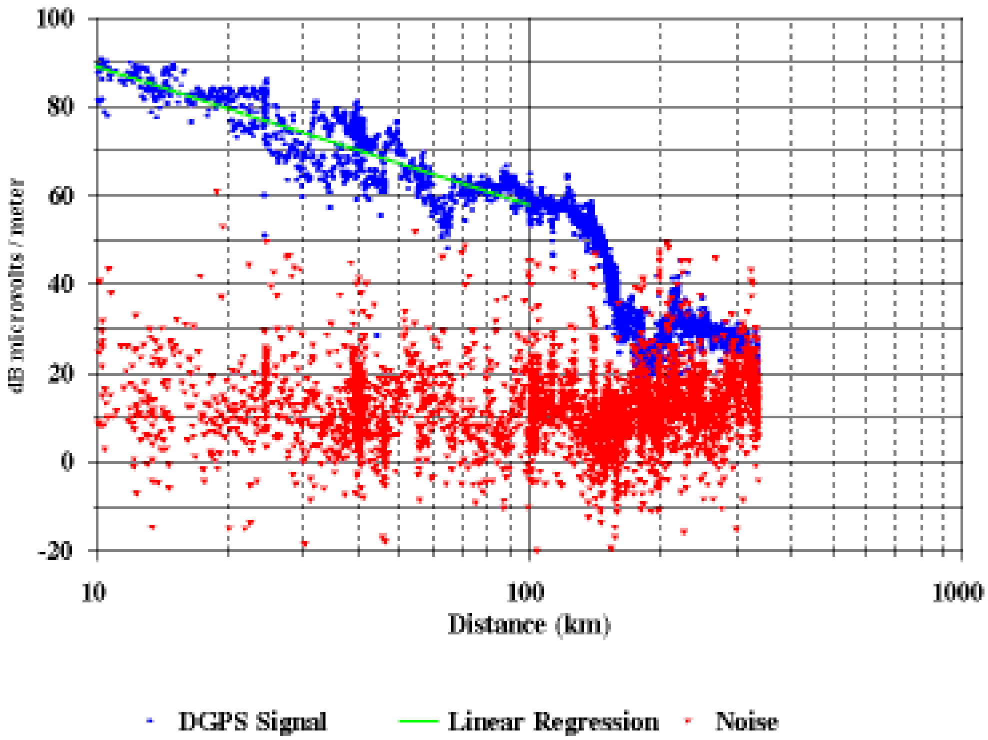

Figure 1. Measured field strengths and background noise at 300 kHz at the GWEN site near Appleton, WA.

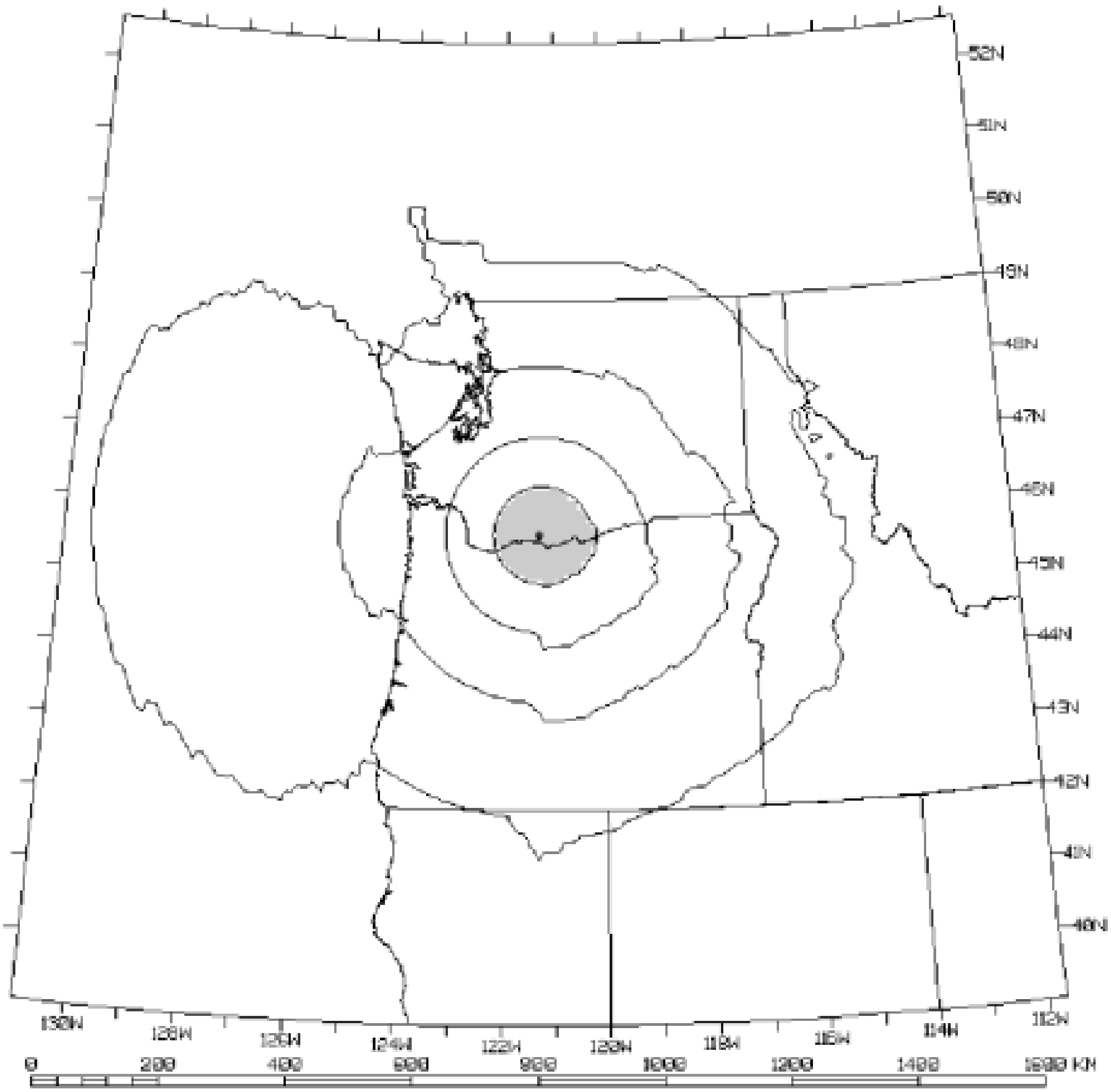

Figure 2. 300 kHz signal coverage prediction plot for the Appleton GWEN site, showing contours for field strengths of 37.5, 50.0, 60.0, and 70.0 dBµV/m.

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Electromagnetic Compatibility Research

Outputs

- Models of electronic system performance.
- Analysis of immunity and emission compliance.
- Models of advanced electromagnetic materials.
- Analysis of system interference and susceptibility.

Electromagnetic compatibility (EMC) and electromagnetic interference (EMI) analysis is crucial in the development of electronic and telecommunication devices for both domestic and international markets. The successful development and marketing of such devices is predicated on meeting both domestic and international regulations and requirements on both emission and immunity. In response to this national need, the Institute is involved in several research efforts in the areas of electromagnetic compatibility (EMC) and electromagnetic interference (EMI). In the past year our EMC/EMI efforts encompassed electromagnetic characterization of composite materials, absorbing materials, anechoic chambers, radiated emissions from printed circuit boards, rf interface for wireless communication systems, and standards activities.

Dedicated short-range communication (DSRC) systems have been proposed for automatic motor vehicle toll collection operations at locations across the United States in the 5850- to 5925-MHz band. Various high-power search and weather radars operate at or near this frequency band and are a source of potential interference. The Institute has performed a series of interference measurements to determine the electromagnetic compatibility of DSRC systems and high-power 5-GHz radars. From these measurements, the time (wait time) required for a successful transaction between a motor vehicle and a DSRC toll collection system in the presence of radar signals with various pulse characteristics and power levels was calculated. The table shows radar power levels that were found to yield unacceptable wait times for a typical radar signal.

Anechoic and semi-anechoic chambers provide an accurate and convenient environment for EMC/EMI testing and are important cost-effective tools for achieving EMC/EMI compliance. The Institute has developed finite-difference time-domain (FDTD) models for predicting the performance of these test facilities. The FDTD technique can be used to predict the performance of absorber-lined chambers for various testing scenarios. This allows for the validation of the performance of chambers with particular types of absorber prior to construction which provides a great cost effective tool for chamber manufacturers. Figure 1 shows typical results obtained from the FDTD model. Depicted here is the performance of a 3-meter semi-anechoic chamber with various absorber types.

Peak Pulsed Interference Power Levels Resulting in Excessive Wait Times		
Vehicle Speed km/hr (mph)	Max Allowable Wait Time s	Interference Power Level Resulting in Excessive Wait Times pulse width = 1 ms duty cycle = 0.1%
64.4 (40)	0.89	-68 dBm (0.5%)
48.3 (30)	1.19	-58 dBm (3.3%)
32.2 (20)	1.79	-58 dBm (0.4%)

(Percentage of trials exceeding the maximum is shown in parentheses.)

In the installation of ferrite tile absorbers on anechoic chamber walls, gaps between individual tiles are inevitable. These gaps have a detrimental effect on the overall performance of the ferrite tile absorber, which in turn can have a substantial effect on the overall chamber performance. In fact, gaps as small as 0.3mm can cause 1.5dB changes in the chamber performance. Since only ±1dB is usually budgeted for chamber imperfections these variations can have a dramatic effect on the ability of the chamber to meet its design specifications. We have recently developed a model that accurately predicts the performance of ferrite tiles with gaps. For example, Figure 2 shows the reflection coefficient of a ferrite tile absorber with various gap sizes. Notice that as the gap size increases, the performance of the ferrite tile absorber decreases (i.e., the reflection coefficient increases).

Other EMC/EMI efforts at ITS this year have been related to the development of an effective material property model for advanced fiber composites and for various other electromagnetic absorbing materials. For example, an effective material property model was developed for hollow pyramids this year. The variations of the material properties obtained from this model as the wave propagates into the hollow absorber are depicted in Figure 3.

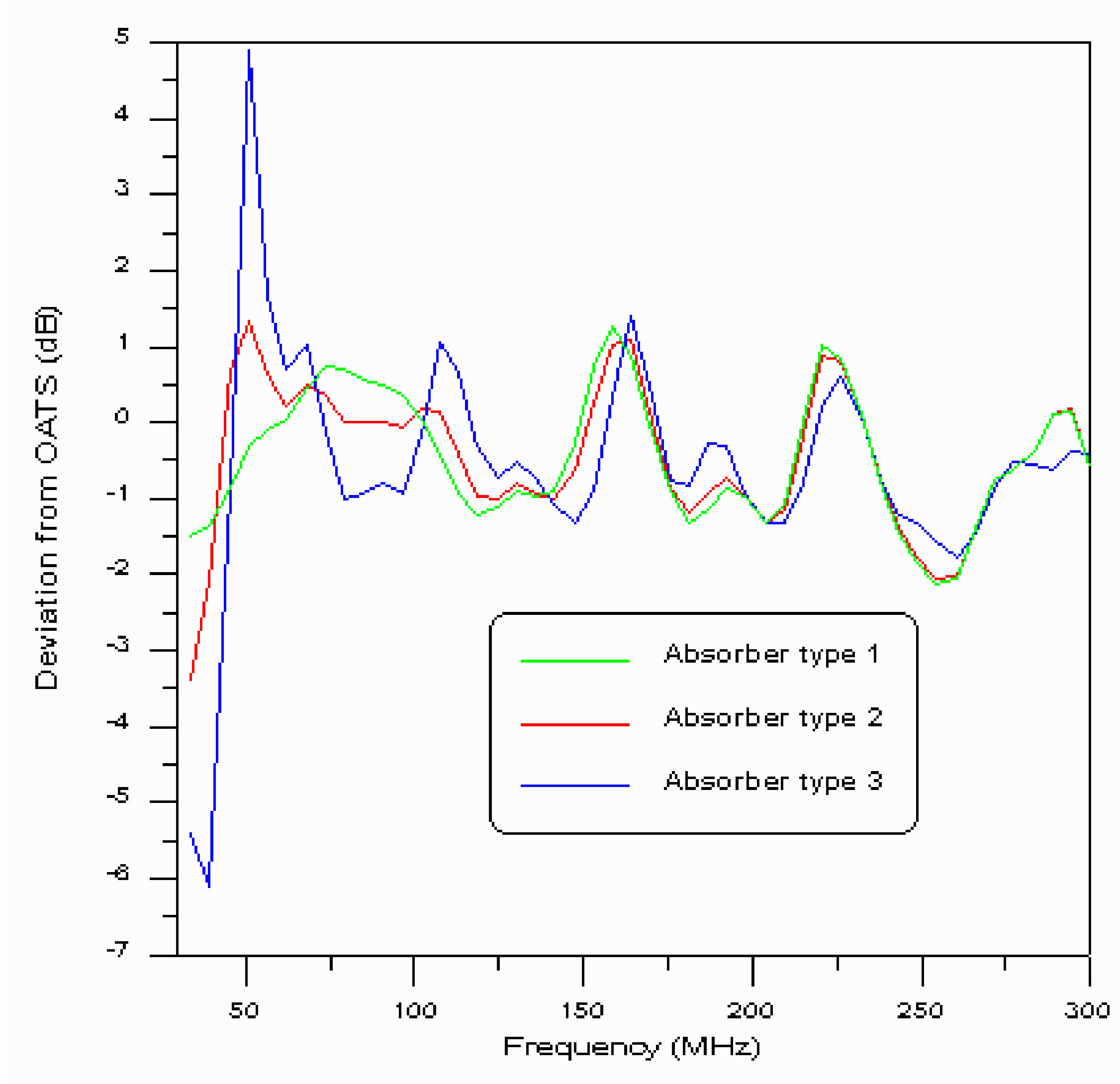

Figure 1: Predicted chamber performance using the FDTD technique.

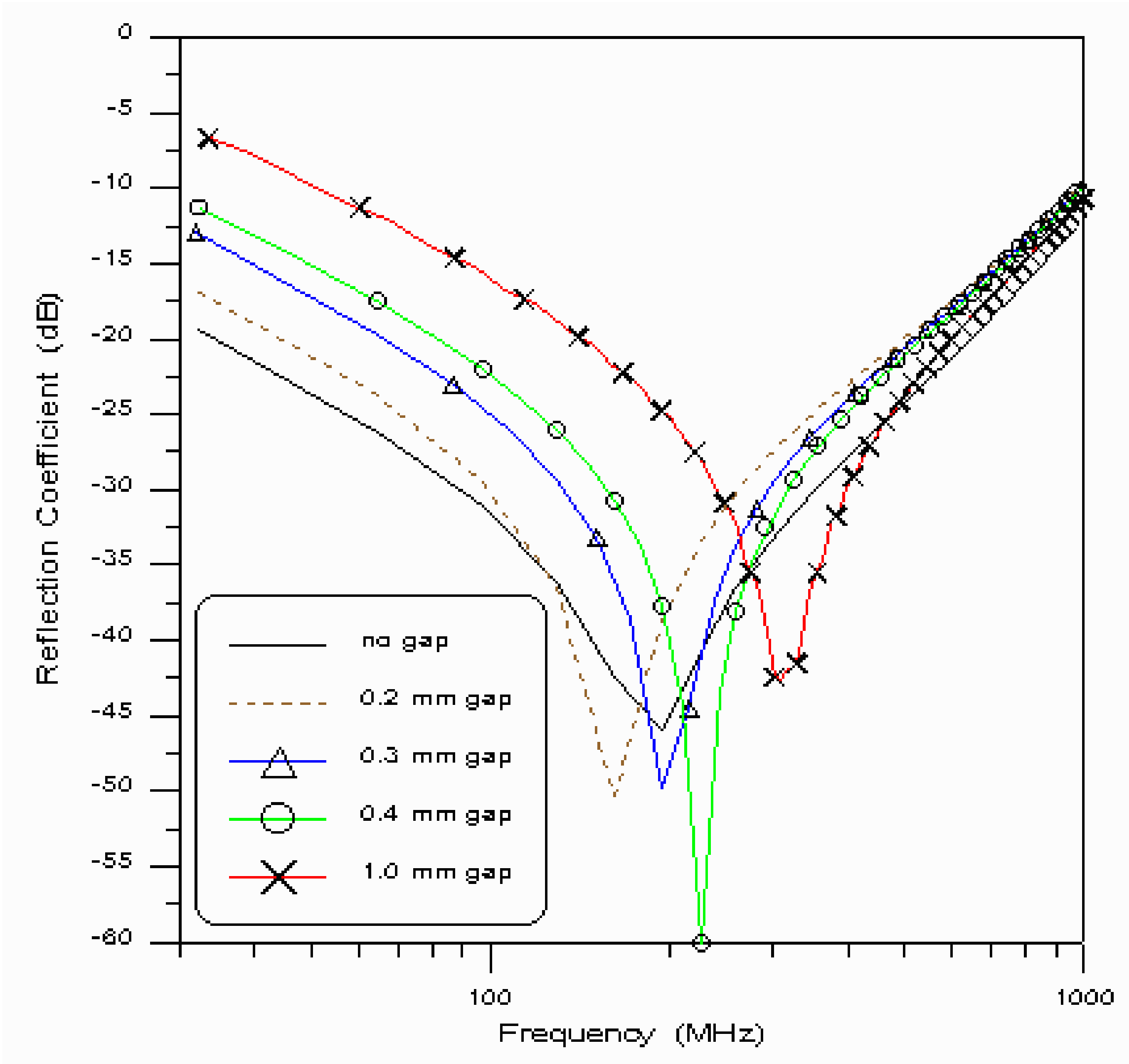

Figure 2: The effects of gaps in ferrite tiles on absorber performance.

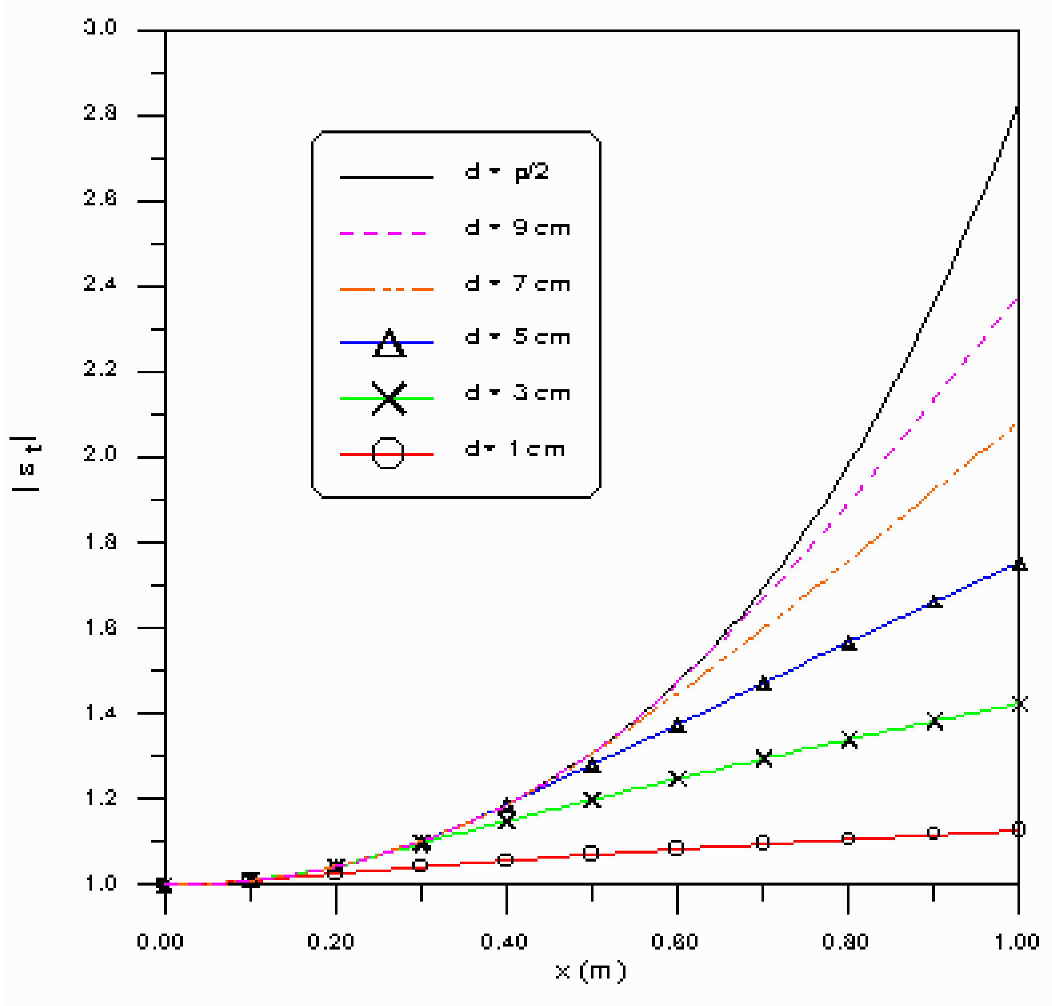

Figure 3. Effective material property as a function of x, where x is the depth into the absorber, for different hollow absorber parameters.

Recent Publications

R.A. Dalke, F.H. Sanders, and B.L. Bedford, "EMC measurement and analysis of C-band radars and dedicated short range communications systems," in *Proc. IEEE International Symposium on EMC*, Seattle, WA, Aug. 1999, pp. 974-979.

C.L. Holloway, J.R. Baker-Jarvis, R.T. Johnk, and R.G. Geyer, "Electromagnetic ferrite tile absorber," in *The Wiley Encyclopedia of Electrical and Electronics Engineering*, J.G. Webster, Ed., New York: John Wiley & Sons, Inc., 1999, vol. 6, pp. 429-440.

C.L. Holloway, M. Johansson, E.F. Kuester, R.T. Johnk, and D.R. Novotny, "A model for predicting the reflection coefficient for hollow pyramidal absorbers," in *Proc. IEEE International Symposium on EMC*," Seattle, WA, Aug. 1999, pp. 861-866.

C.L. Holloway, P. McKenna, and R.T. Johnk, "The effects of gaps in ferrite tiles on both absorber and chamber performance," in *Proc. IEEE International Symposium on EMC*, Seattle, WA, Aug. 1999, pp. 239-244.

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Impulsive Noise and Digital Systems

Outputs

- Noise power measurements at UHF frequencies in urban and residential locations.
- Draft NTIA Report on noise power measurements made at VHF and UHF frequencies.

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

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

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

Man-made noise power was measured comprehensively by ITS at many frequencies, locations, and times 25-35 years ago. These measurements were critical in the design of the many radio applications created by the rapid growth of semiconductor technology.

A new noise power measurement system using modern test equipment and data acquisition techniques has been developed at ITS. The measurement system organizes the noise power samples into histograms which represent the first order statistics of the noise random process over a 1-minute time interval. Currently ITS is using these first order statistics to investigate the effect UHF man-made noise has on the performance of a digitally modulated radio link. The information derived from this work will assist industry and government in efficiently utilizing our valuable spectral resources.

In FY 96 ITS conducted VHF man-made noise power measurements at 137 MHz in business, residential, and rural environments. These measurements were conducted to support the National Oceanic and Atmospheric Administration in converting their meteorological satellite radio links from analog to digital. The measurements showed that VHF man-made noise characteristics have changed over the past 25-35 years due to technological advances such as quieter automotive ignition systems. In particular, these measurements showed that residential noise has decreased, while urban noise has stayed at about the same level.

These results have prompted radio engineers to question published noise power levels at UHF frequencies based on measurements made 25-35 years ago. Predicting whether UHF frequencies would follow the same trend as VHF frequencies is difficult. For example, noise due to automotive ignition systems may have also decreased in UHF frequencies as it did at VHF frequencies; however, modern electronic devices such as personal computers and pulse-width modulated motor drives may have added noise not present when the earlier measurements were made.

In FY99 ITS conducted measurements of UHF noise to determine its effect on digitally modulated radio link performance. Noise power measurements were collected for 24 hours (or more) at 402.5 and 761.0 MHz in two residential and two urban locations, in two different cities, during the spring and summer of 1999. Such long duration measurements allowed for correlations of noise power with cultural rhythms such as working hours. The measurement receiver noise floor was approximately 2 dB above kTB where k is Boltzman's constant, T is 288K, and B is bandwidth. A Gaussian-shaped, 30-kHz 3-dB bandwidth filter limited the measurement bandwidth prior to digitization. Independent noise power samples were digitized once every millisecond.

Several results which may impact the performance of a digitally modulated radio link were drawn from the measured data. First, the mean noise power was close to the measurement system noise floor at most locations. The one exception to this was at one urban location at 402.5 MHz where mean noise power fluctuated on a hourly basis from 2 to 10 dB above kTB, as shown in Figure 1. Figure 2 shows the same location at 761.0 MHz, two days later.

Second, non-Gaussian noise was present in all urban locations. Peak noise power was 10 and 20 dB above the peak power that would be expected for Gaussian noise with the same mean power at 402.5 and 761.0 MHz, respectively. Third, non-Gaussian noise was absent at most residential locations. Lastly, the highest peak noise power levels were correlated with working hours in most locations.

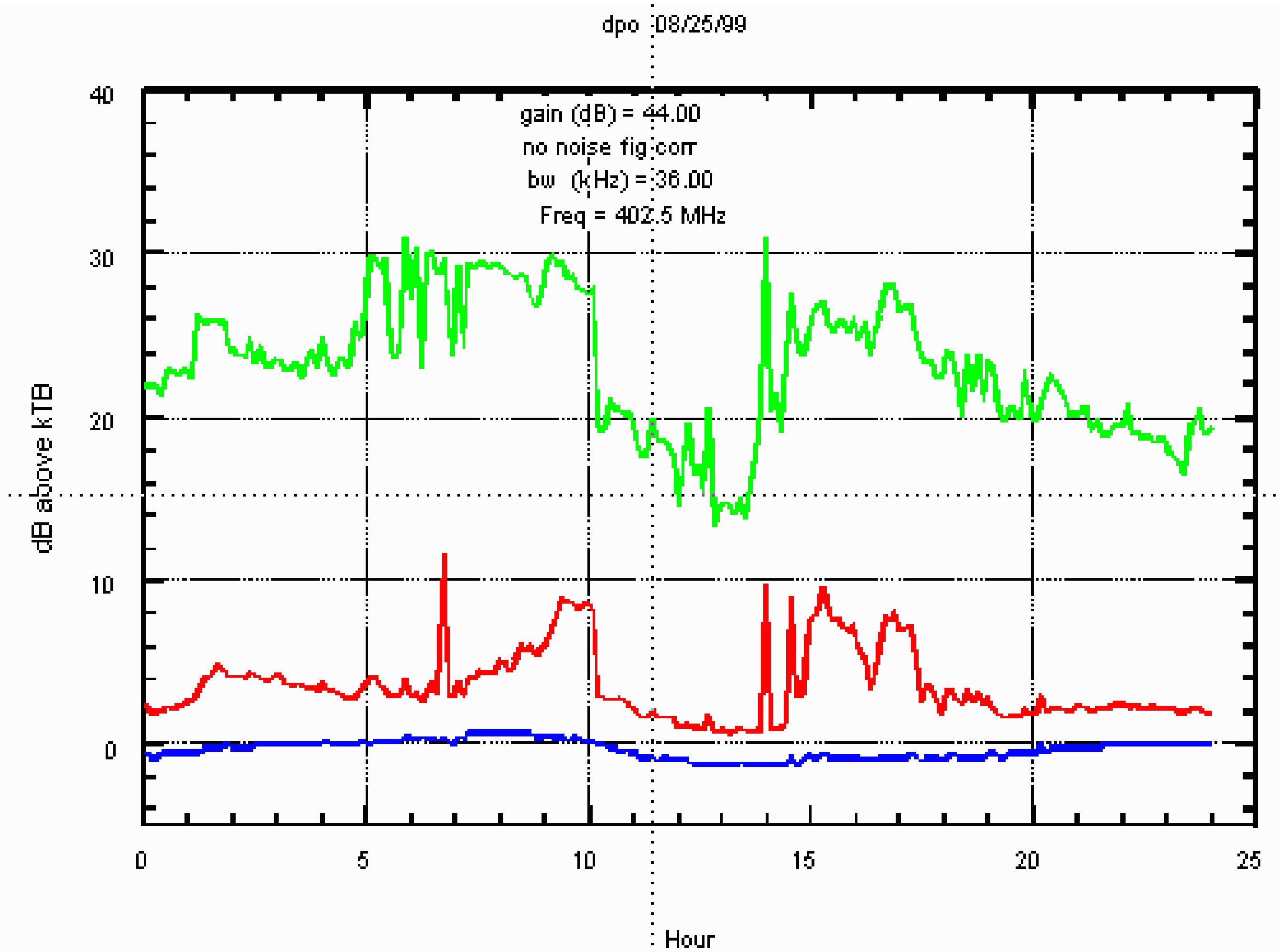

Figure 1. 402.5 MHz median, mean, and peak power at downtown Denver, Colorado on Wednesday, August 25, 1999.

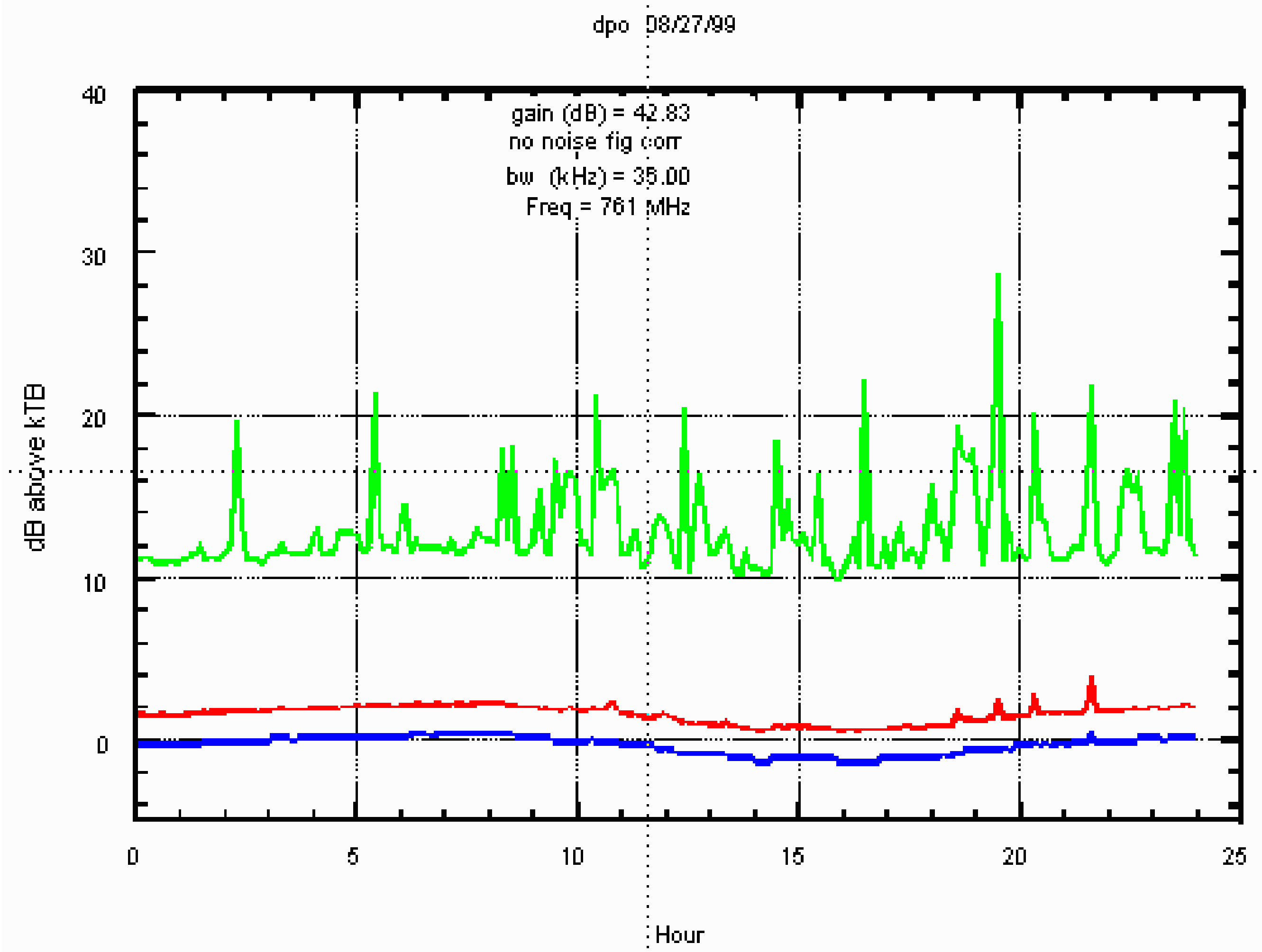

Figure 2. 761.0 MHz median, mean, and peak power at downtown Denver, Colorado on Friday, August 27, 1999.

Recent Publications

R. Dalke, "Radio noise," in *The Wiley Encyclopedia of Electrical and Electronics Engineering*, J.G. Webster, Ed., New York: John Wiley & Sons, Inc., 1999, vol. 18, pp. 128-140.

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Software Defined Radio Technology

Outputs

- Presentation to the Interdepartment Radio Advisory Committee (IRAC) on the activities of the Markets, Technical, and Regulatory Advisory Committees of the Software Defined Radio Forum.
- Encyclopedia article on wireless receivers using digitization at the RF or IF.
- Draft NTIA Report on implementation and testing of a software defined radio cellular base station receiver.

With software defined radios (SDR), the fundamental processes of radio transmission and reception familiar in traditional radios remain the same. SDR transmitters and receivers still need to perform modulation/demodulation, upconversion/downconversion, filtering, and amplification. Depending upon the specific applications, SDR's may also need to perform source and channel coding/decoding, multiple access processing, frequency spreading/ despreading, and encryption/decryption. While these basic functions are the same for SDR's and traditional radios, the implementation of these functions may be very different. The Figure shows a basic block diagram of an example SDR receiver.

In an SDR, many of the radio functions are implemented in digital signal processing. Digital signal processing offers a greater variety of ways of implementing the required radio functions than traditional radios. Some of the methods for implementing radio functions in SDR's are unique to digital signal processing. For example, in the SDR receiver, downconversion is not limited to the traditional heterodyne operation. Downconversion can be achieved as a byproduct of the sampling process without using a mixer or digital multiplication of a received signal with a local oscillator. An example of a filter implementation unique to digital signal processing is the finite impulse response (FIR) filter where steep rolloff in the magnitude response and linear phase can be achieved simultaneously. In analog filter implementations, as the magnitude response rolloff becomes steeper, the phase response generally becomes more nonlinear.

The primary distinction between SDR's and traditional radios is that SDR's possess some level of programmability or configurability whereas traditional radios either do not have this capability or have limited capability. The two issues concerning programmability (or configurability) in SDR's are (1) which radio functions can be programmed and (2) the method and ease of programmability or configurability. For each function, programmability can be limited to a fixed set of choices or it can allow variation over a wide range of values. Methods of programmability include over-the-air download, keypad entry, and serial or proprietary port download.

Programmability in SDR's permits the use of different modulation types, frequency bands, filtering, coding techniques, and other processing via software changes. This great flexibility provides a tremendous opportunity for solving interoperability problems between the many different existing standards, implementing new standards, and minimizing the amount of hardware necessary to perform required communications across these different standards. On the other hand, this very flexibility presents some significant challenges for spectrum management.

SDR is a rapidly evolving technology that ITS has contributed to for several years. ITS involvement has included a wide variety of activities ranging from research into SDR theory and concepts, implementation and testing of an example SDR, publication of various NTIA reports and open-literature articles, leadership and participation in the SDR Forum, and organization, chairmanship, and technical contributions to the 1998 International Symposium on Advanced Radio Technologies (focused on software defined radio and smart antenna technologies).

Work at ITS in SDR technology continued this year to support NTIA's Office of Spectrum Management (OSM) by closely following the progress of the SDR Forum. A presentation describing the activities and current status of the SDR Forum was given at a special meeting of the Interdepartment Radio Advisory Committee (IRAC) in an effort to keep OSM and the IRAC apprised of the latest SDR issues.

The SDR Forum is a non-profit organization that promotes the development, deployment, and use of open architectures for advanced wireless systems. The Forum includes participants from the commercial, government, and academic sectors and is comprised of three core committees: the Markets, Technical, and Regulatory Advisory Committees. Some key outputs of the Markets Committee are predictions of the SDR market size and business revenue and identification of key market characteristics and primary drivers for the commercial, military, and civil government sectors.

Emphasis in the ITS presentation to the IRAC focused on the Technical Committee progress including the status of the Mobile, Handheld, and Base Station Working Groups and the development of the mobile SDR architecture model. The definition of the mobile SDR is evolving rapidly as a result of the Department of Defense Joint Tactical Radio System (JTRS) program and the ensuing SDR development in industry.

In another effort, ITS drafted an NTIA Report (not yet published) based on the implementation and testing of an example cellular base station SDR receiver configured at ITS. The intent of the report is to illustrate an example SDR receiver implementation along with its performance in the presence of noise and interference. The example SDR receiver emulated an Advanced Mobile Phone System (AMPS) cellular base station receiver with digitization of the entire cellular B band (a 14-MHz bandwidth). The receiver was configured using a commercially available digital downconverter board that operates in a personal computer, a separate front end that includes an analog downconverter and digitizer, and a custom interface board. The architecture of the receiver allowed testing to be performed at the digitized IF output, the digitally downconverted and filtered baseband, the digital FM demodulator output, and the analog audio output.

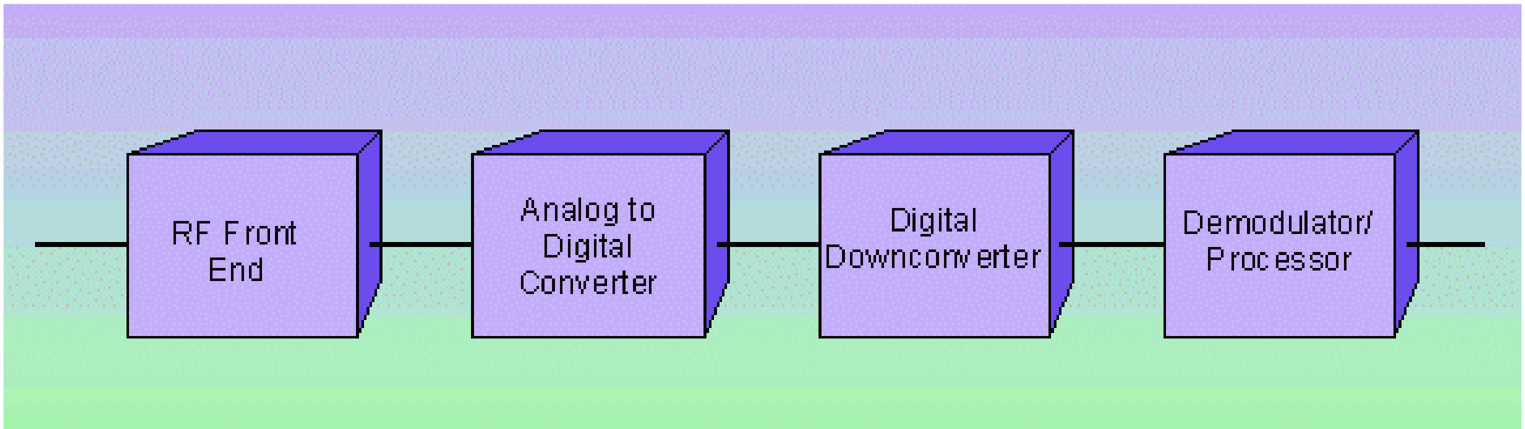

Figure 1. Basic block diagram of an example SDR receiver.

Recent Publication

J.A. Wepman, "Wireless receivers using digitization at the radio frequency or intermediate frequency," in *The Froehlich/Kent Encyclopedia of Telecommunications*, F.E. Froehlich and A. Kent, Eds., New York: Marcel Dekker, Inc., 1999, vol. 18, pp. 157-194.

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Video Quality Research

Outputs

- Digital video quality measurement technology.
- Journal papers and international video quality measurement standards.
- Technical input to development of U.S. policies on advanced video technologies.
- A national objective and subjective digital video quality testing laboratory.

Digital video systems are replacing all existing analog video systems and making possible the creation of many new telecommunication services (e.g., direct broadcast satellite, digital television, high definition television, video teleconferencing, telemedicine, e-commerce) that are becoming an essential part of the U.S. and world economy. Objective metrics for measuring the video performance of these systems are required by government and industry for specification of system performance requirements, comparison of competing service offerings, network maintenance, and optimization of the use of limited network resources such as transmission bandwidth. The goal of the ITS Video Quality Research project is to develop the required technology for assessing the performance of these new digital video systems and to actively transfer this technology to other government agencies, end-users, standards bodies, and the U.S. telecommunications industry. The increases in quality of service made possible with the new measurement technology benefit both the end-users and the providers of telecommunication services and equipment.

To be accurate, digital video quality measurements have to be based on perceived "picture quality" and have to be made in-service using the actual video being sent by the users of the digital video system. The primary reason for these requirements is that the performance of digital video systems is variable and depends upon the dynamic characteristics of both the input video (e.g., spatial detail, motion) and the digital transmission system (e.g., bit-rate, error-rate). To address this problem, ITS developed the revolutionary approach shown in Figure 1, based upon extraction and comparison of low bandwidth perception-based features (e.g., edges, motion) that can be easily communicated throughout the broadcast network. The new measurement paradigm has received two U.S. patents, been adopted as an ANSI standard (ANSI T1.801.03-1996; see **Publications Cited**), and is being used by organizations worldwide.

ITS continues to make refinements to the technology and to apply it to an ever-wider range of video scenes and systems. In FY99 ITS researchers developed a combined spatial-temporal distortion metric that is sensitive to perceptual losses and gains in the magnitude and angular direction of spatial gradient information. Losses in spatial gradient information result from impairments such as blurring, while gains result from impairments such as blocking or tiling. This combined parameter (denoted as *join*) was developed and tested over seven subjectively-rated data sets that spanned a total of 79 video scenes and 90 video systems. The 90 video systems used bit rates from 10 kb/s to 45 Mb/s, video teleconferencing coding technologies (e.g., proprietary, H.261, H.263), Motion Picture Experts Group (MPEG) coding technologies (e.g., MPEG-1, 2, 4), and digital transmission errors (e.g., burst errors, dropped ATM cells). Testing the combined metric *join* on each of the seven data sets produced the correlation coefficients shown in Figure 2, where this correlation was performed at the video clip level (i.e., each data point represented the response of a particular scene through a particular system). The combined metric *join* achieved an average correlation coefficient of 0.88 across the seven data sets. In view of the breath of the subjective data in these seven experiments, this result is quite significant.

A video quality measurement system specifically designed for MPEG-2 video systems was submitted to the ITU Video Quality Experts Group (VQEG) in FY99. Figure 3 shows the predicted objective quality from the measurement system versus the actual subjective quality for the 32 video systems in the test. Here, each point represents the average system quality level and is obtained by averaging the responses from the 10 video scenes that were sent through each video system. This test achieved a correlation coefficient of 0.95.

The Video Quality Research home page is located at **http://www.its.bldrdoc.gov/n3/video**

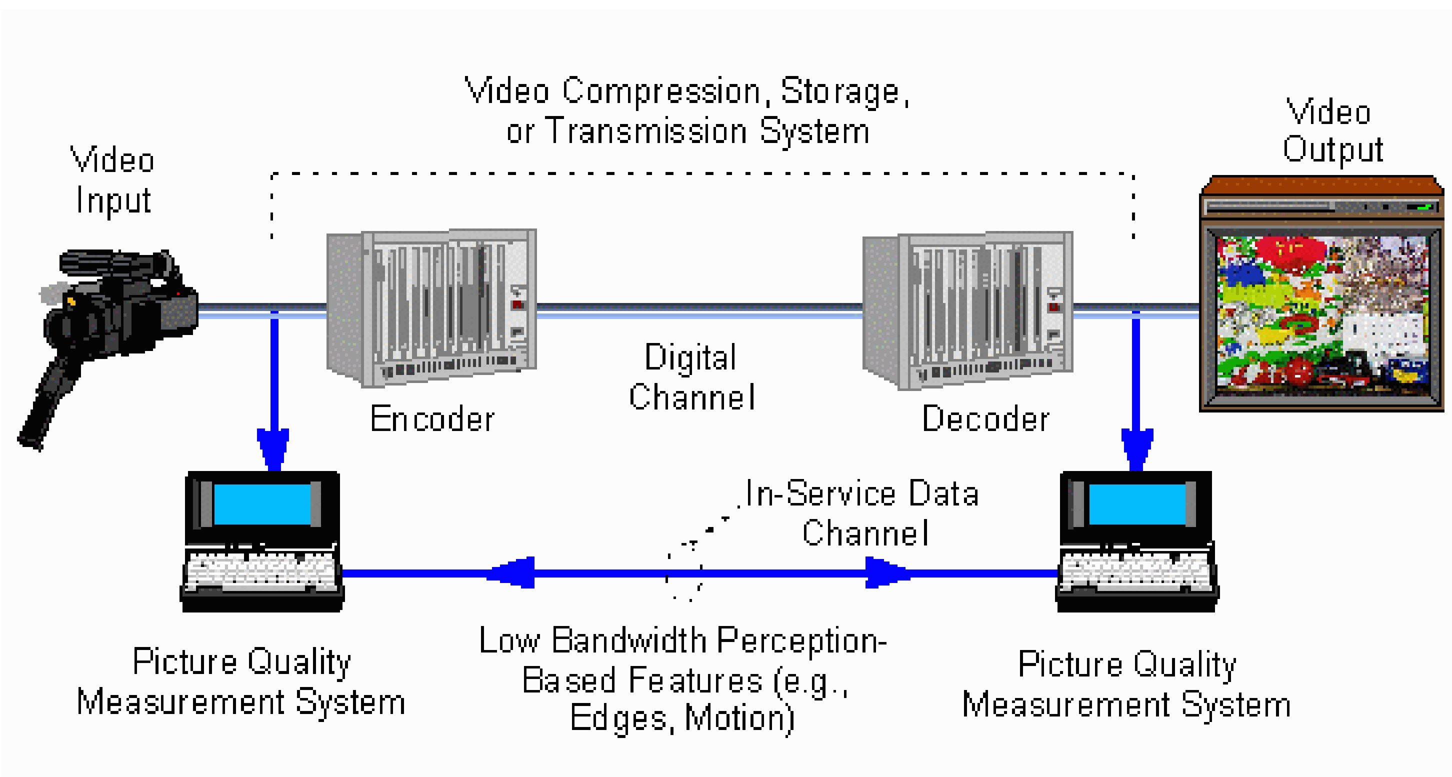

Figure 1. In-service perceptual picture quality measurement system.

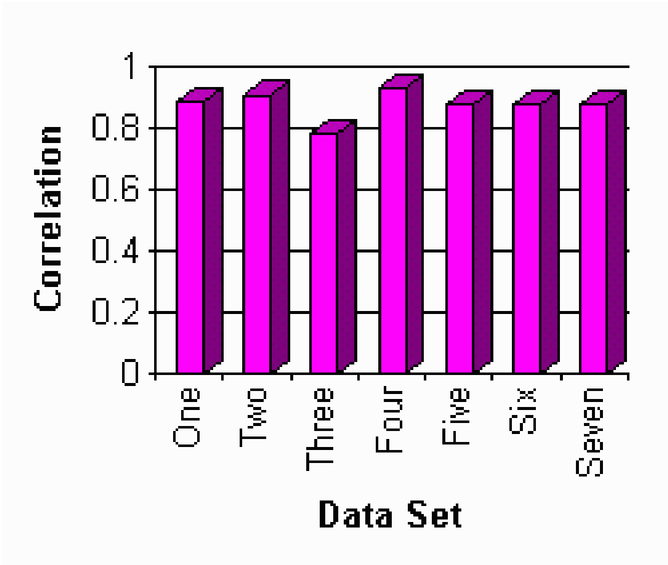

Figure 2. Correlation coefficient of the join parameter for seven data sets.

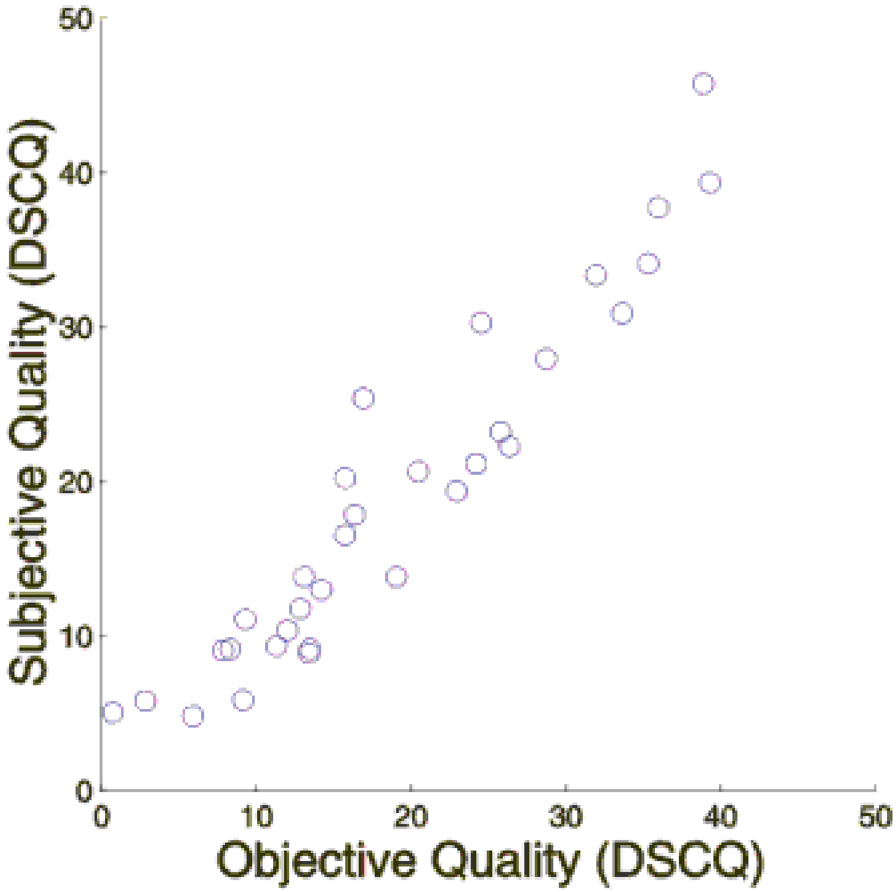

Figure 3. MPEG-2 system quality (objective versus subjective), expressed in terms of double stimulus continuous quality (DSCQ).

Recent Publications

P. Corriveau and A. Webster, "VQEG evaluation of objective methods of video quality assessment," *SMPTE Journal*, vol. 108, pp. 645-648, Sep. 1999.

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

S. Wolf and M.H. Pinson, "Spatial-temporal distortion metrics for in-service quality monitoring of any digital video system," in *Proc. SPIE International Symposium on Voice, Video, and Data Communications*, Boston, MA, Sep. 1999.

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

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Wireless Propagation Research

Outputs

- Indoor channel modeling for WLAN and WLCN applications.
- Methods of predicting the impulse response for an indoor propagation channel and the delay spread of the multipath channel.
- Algorithms to predict smart antenna performance.

For several years the Institute has been involved in research efforts related to wireless communication applications and theory. The majority of this work has been related to the outdoor propagation environment. Recently, with the emergence each year of new indoor wireless local area networks (WLAN) and wireless local campus networks (WLCN), we have concentrated our efforts on investigating the indoor propagation environment. The objective of this effort is to support new wireless technology development and help U.S. industry compete in the worldwide telecommunications marketplace. More specifically, ITS develops models and measurement systems to predict and measure propagation characteristics of various multipath environments. This work supports the advancement of new techniques and technologies (e.g., smart antennas and diversity) to overcome limiting factors for indoor communication systems.

The Institute has developed a geometric optics (or ray-tracing) model for calculating the field strength and impulse response of an indoor radio propagation channel. Figure 1 shows a typical calculated impulse response from this model. While the ray-trace technique is accurate, it can be time consuming. The Institute has also developed a simplified model for calculating the impulse response and delay spread for the indoor channel in a matter of seconds on a personal computer. Also shown in Figure 1 are results for this simple model. Notice that the simple model captures the delay characteristics of the ray-trace model.

In an attempt to access the validity of the ray-trace model, we have been investigating the accuracy of some assumptions used in ray-tracing. Using the exact Sommerfeld formulation for a source above a dielectric layer, a comparison to the geometric optics (GO) approximation was made. Figure 2 shows the difference between these techniques. This study demonstrated discrepancies associated with surface-wave and near-field effects and the use of plane-wave Fresnel reflection coefficients, as is common in ray-trace models.

The Institute is also investigating the use of a three-dimensional finite-difference time-domain (FDTD) approximation to Maxwell's curl equations to determine the impulse response of the indoor channel. Figure 3 shows results of the predicted impulse response of two different rooms. While this numerical approach is capable of high accuracy, it can be very time consuming. We are presently investigating a new hybrid numerical technique to reduce the computational run time.

The Institute is involved in many other efforts in measurement techniques for various indoor propagation scenarios. In an attempt to understand antenna polarization and directivity effects indoors, impulse response measurements were acquired in a wide range of indoor environments employing different types of antennas. The results of one set of these measurements are presented in Figure 4. Additionally, we recently finished work addressing propagation characteristics of radio waves penetrating reinforced concrete structures.

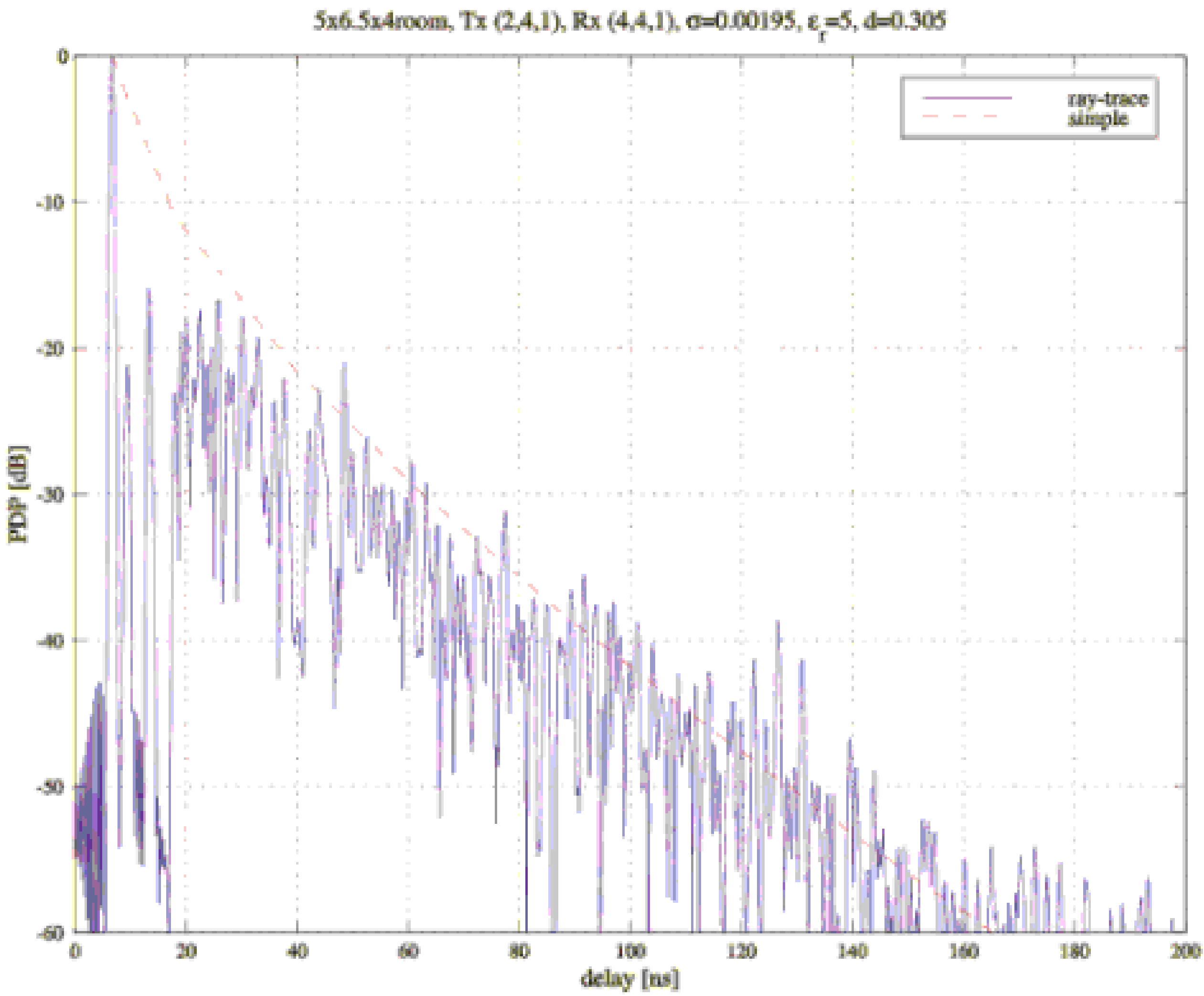

Figure 1. Calculated power delay profile from both ray-tracing and the simple model.

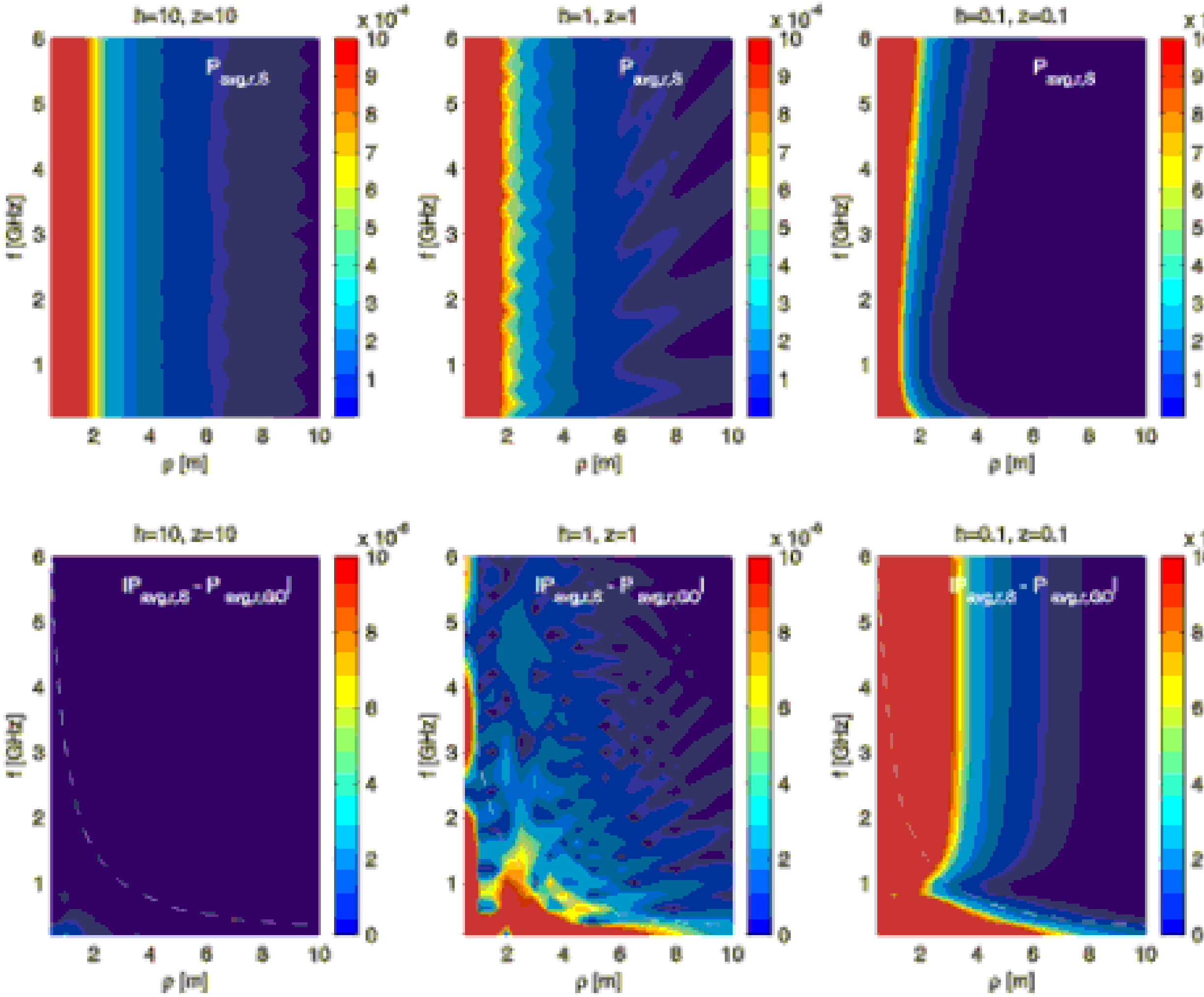

Figure 2. Sommerfeld solution (top) and GO error (bottom) for an elementary vertical electric dipole above a half-space ($\varepsilon_r = 5$, $\sigma = 0.00195$ S/m) versus frequency and horizontal separation. Source and observation points are at equal heights. $R_0 = 10\ \lambda$ curve (dashed line) is shown.

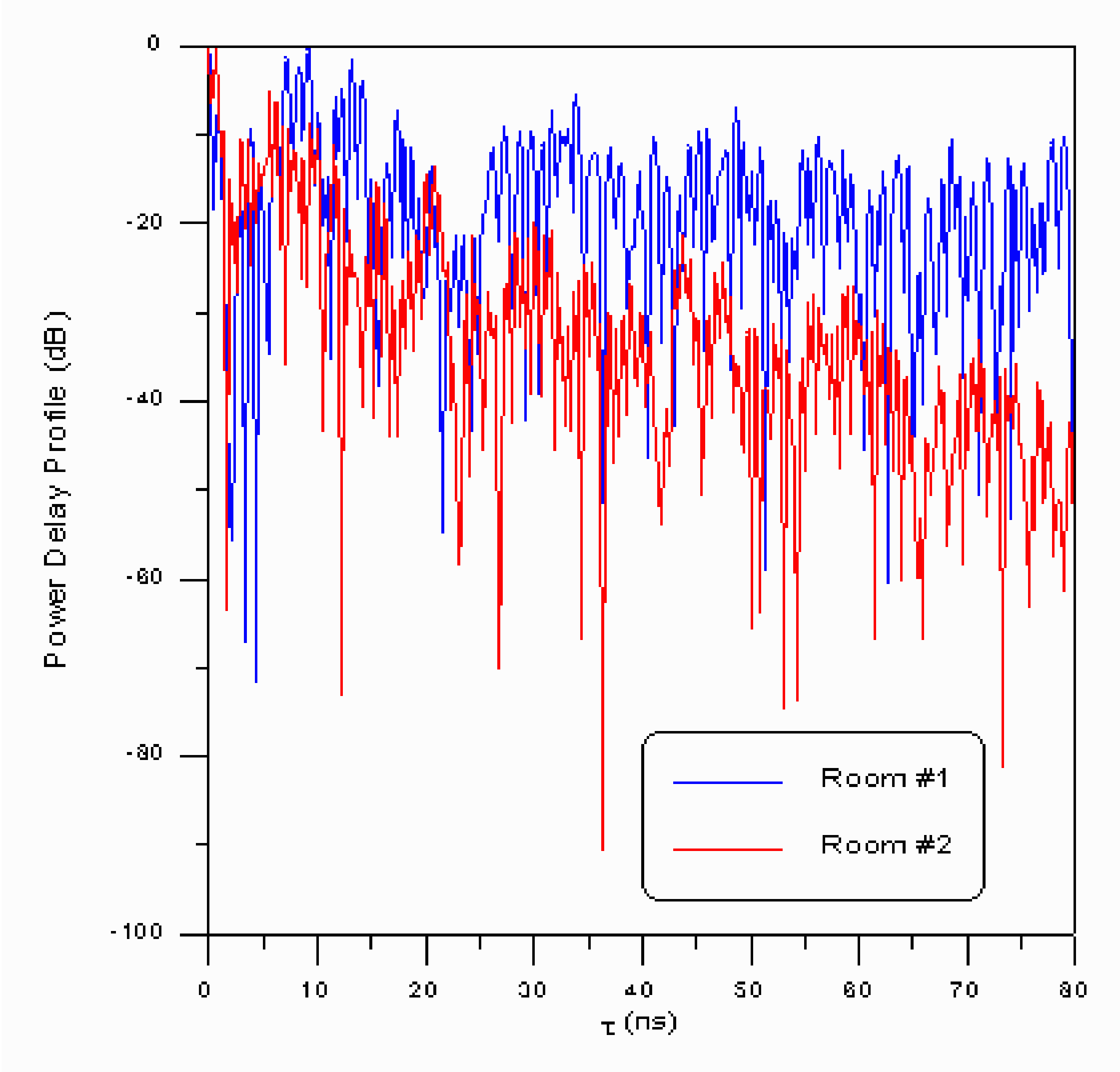

Figure 3. Calculated power delay profile relative to direct path, from the FDTD model.

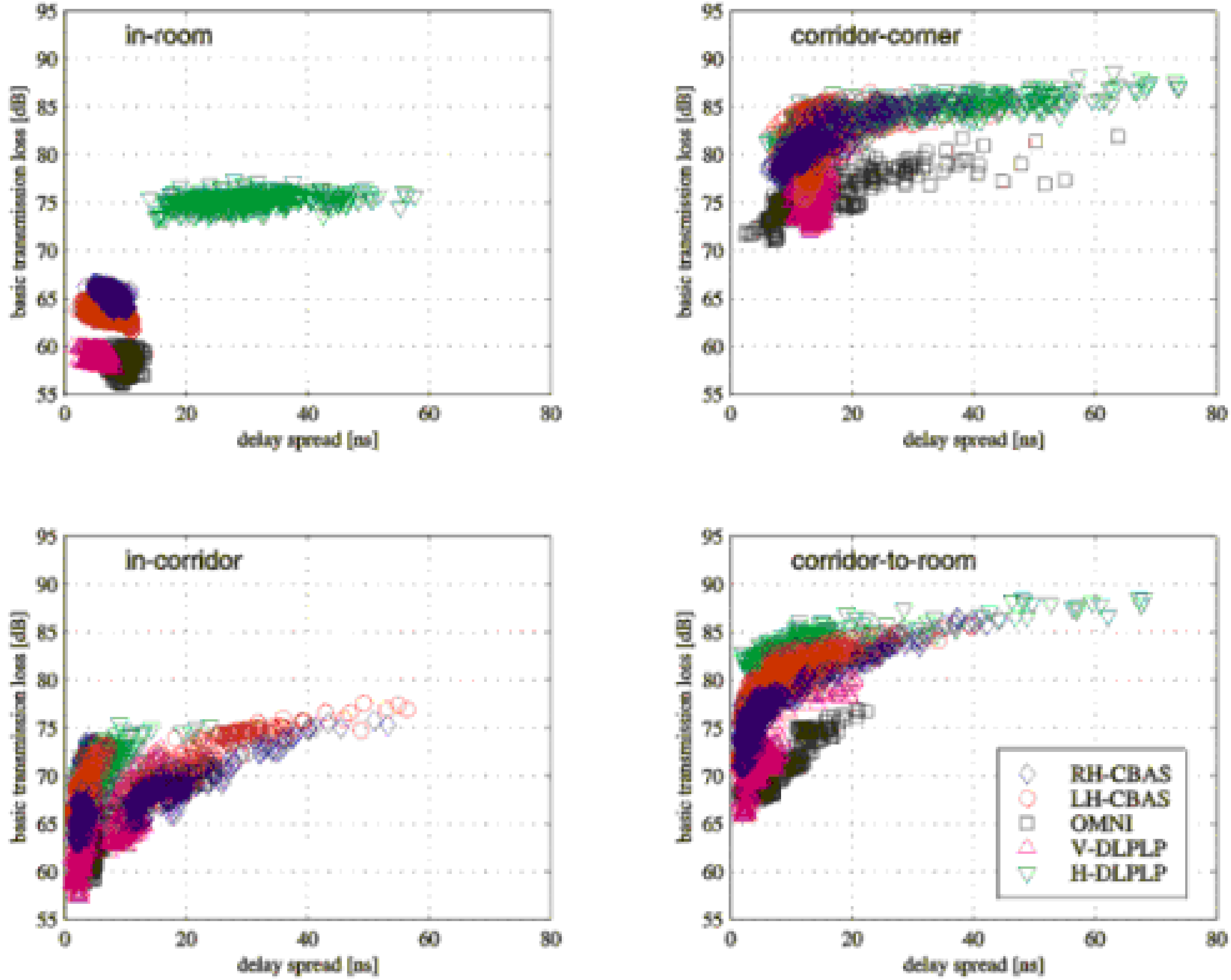

Figure 4. Scatter plots of basic transmission loss versus delay spread of individual impulses for a V-OMNI transmit antenna and various receive antennas.

Recent Publications

R. Dalke, C.L. Holloway, and P. McKenna, "Reflection and transmission properties of reinforced concrete walls," in *Proc. 1999 IEEE AP-S International Symposium*, Orlando, FL, Jul. 1999, pp. 1502-1505.

C.L. Holloway, M.G. Cotton, and P. McKenna, "A model for predicting the power delay profile characteristics inside a room," *IEEE Trans. on Vehicular Technology*, vol. 48, no. 4, pp. 1110-1120, Jul. 1999.

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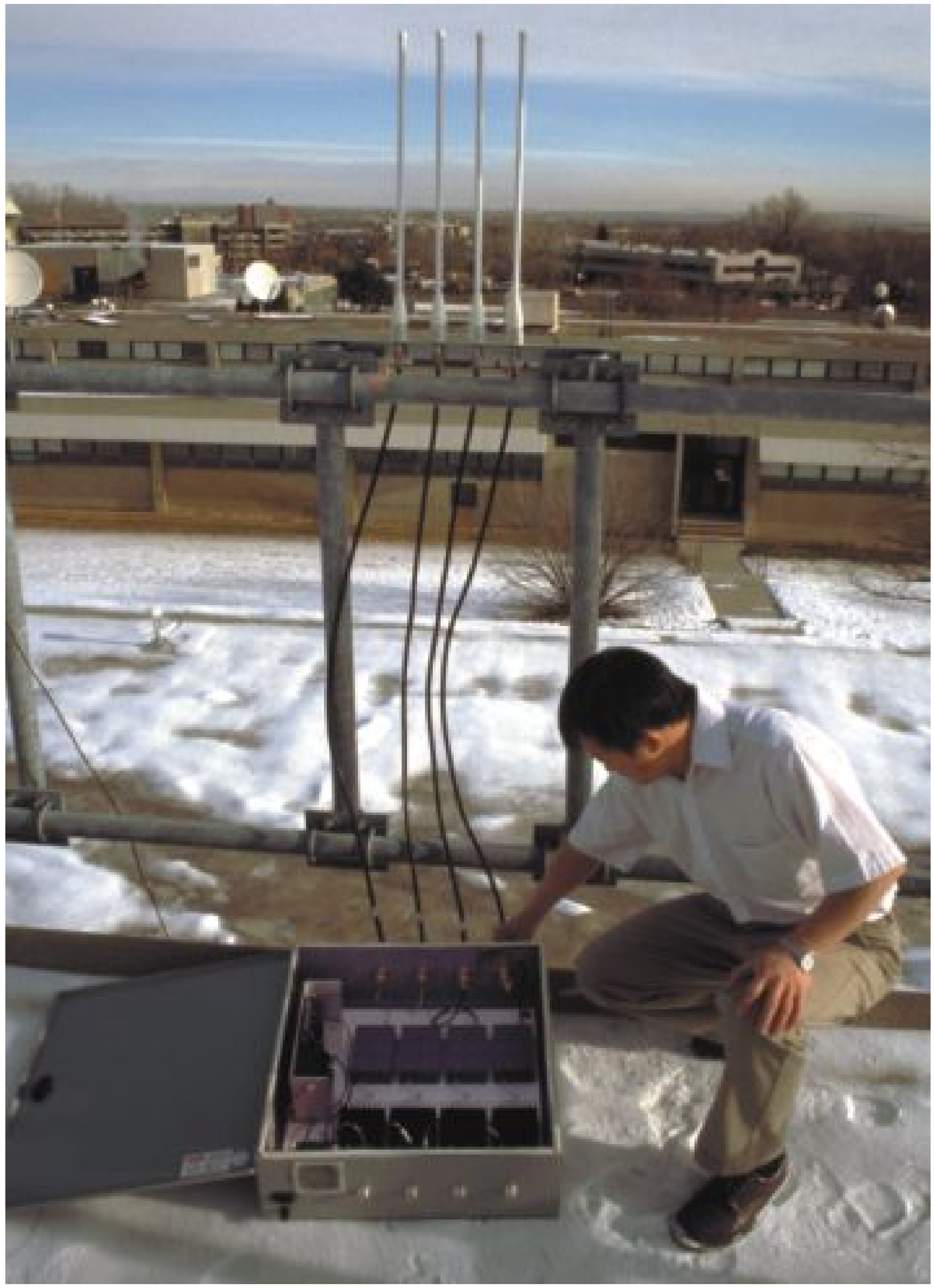
ITS Tools and Facilities

- Adaptive Antenna Testbed
- Advanced Communications Technology Satellite Test Facility
- Audio Visual Laboratories
- Digital Sampling Channel Probe
- FED-STD-1037C Web Page
- HF Communications System Test and Evaluation Facility
- Integrated Networks Simulation Environment
- Integrated Networks Test Bed
- ITS Internet Services
- ITS Local Area Network
- Mobile Radio Propagation Measurement Facilities
- Mobile Radio Communication Performance Measurements
- Radio Noise Measurement System
- Radio Spectrum Measurement System
- RFIMS Development Lab
- Spectrum Compatibility Test and Measurement Sets
- Table Mountain Radio Quiet Zone
- Telecommunications Analysis Services



An ITS engineer adjusts a four-channel preselector-preamplifier box used as part of the ITS antenna testbed (photograph by F.H. Sanders).

- **Wireless Link Simulation Laboratory**

ITS Projects in FY 1999

ITS Outputs in FY 1999

Publications Cited*

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

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

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F.H. Sanders, B.J. Ramsey, and V.S. Lawrence, "Broadband spectrum survey at San Francisco, California," NTIA Report 99-367, July 1999.

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

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

*Publications cited in the report that are not Fiscal Year 1999 reports.

Abbreviations/Acronyms

AAMA	American Automobile Manufacturers Association
ACTS	Advanced Communications Technology Satellite
AGILE	Advanced generation of interoperability for law enforcement
ALE	automatic link establishment
AM	amplitude modulation
AMPS	advanced mobile phone service
ANSI	American National Standards Institute
APCO	Association of Public Safety Communications Officials
APD	amplitude probability distribution
ARQ	automatic repeat request
ATB	antenna testbed
ATCRBS	Air Traffic Control Radar Beacon System
ATIS	Advanced Traveler Information System
ATM	asynchronous transfer mode
ATR	automatic target recognition
BAWT	broadband arbitrary waveform transmitter
BBNG	broadband noise generator
BER	bit error ratio
B-ISDN	broadband integrated services digital network
BPSK	binary phase shift keying
BW	bandwidth
CAI	common air interface
CARS	cable relay service
CCIR	International Radio Consultative Committee
CCS	common-channel signalling
CD	compact disk
CDMA	code division multiple access
CDPD	cellular digital packet data
CD-ROM	compact disk read-only memory
CJ	criminal justice

C/(N+I)	carrier to noise and interference
CPW	coplanar waveguide
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory (a precursor of ITS)
CRSMS	Compact Radio Spectrum Measurement System
CSPM	Communications System Performance Model
dB	decibel
DGPS	differential global positioning system
DIFFSERV	differentiated service
DMA	designated market area
DOC	Department of Commerce
DoD	Department of Defense
DOT	Department of Transportation
DSCP	digital sampling channel probe
DSP	digital signal processing
DSRC	dedicated short-range communication
DTV	digital television
EHF	extremely high frequency
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EOV	emergency operations vehicle
ES	Earth station
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDDI	fiber distributed data interface
FDMA	frequency division multiple access
FDTD	finite-difference time domain
FED-STD	Federal Standard
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIR	finite impulse response
FM	frequency modulation
FRA	Federal Railroad Administration
FSK	frequency shift keying
FTP	file transfer protocol

FTSC	Federal Telecommunications Standards Committee
FTSP	Federal Telecommunications Standards Program
FTTA	Federal Technology Transfer Act
FWA	fixed wireless access
FY	fiscal year
GEO	geosynchronous (or geostationary) earth orbit
GHz	gigahertz
GIS	geographic information systems
GLOBE	global land one-km base elevation
GMSK	Gaussian minimum shift keying
GOES	geostationary operational environmental satellite
GPS	Global Positioning System
GSM	Global System for Mobile communications
GWEN	Ground Wave Emergency Network
HDTF	high definition television
HF	high frequency
HFRS	High Frequency Radio Subcommittee
HMMWV	high mobility multipurpose wheeled vehicle
HP	Hewlett-Packard Company
HRR	high resolution radar
HTML	hypertext markup language
HTTP	hypertext transfer protocol
ICEPAC	Ionospheric Communications Enhanced Profile Analysis and Circuit prediction program
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IEP	Integrated Electronic Package
IETF	Internet Engineering Task Force
IF	intermediate frequency
INFOSEC	information system security
IONCAP	Ionospheric Communications Analysis and Prediction program
IP	Internet protocol
IPDP	indoor power delay profile
IRAC	Interdepartment Radio Advisory Committeev
ISART	International Symposium on Advanced Radio Technologies

ISDN	integrated services digital network
ISM	industrial, scientific, and medical
ISSI	inter-RF subsystem interface
IT	information technology
ITAC-T	International Telecommunications Advisory Committee Telecommunications
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences Intelligent Transportation System
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radiocommunication Sector
ITU-T	International Telecommunication Union-Telecommunication Standardization Sector
JEM	Jammer Effectiveness Model
JTRS	Joint Tactical Radio System
kHz	kilohertz
LAN	local area network
LEO	low earth orbit
LMDS	local multipoint distribution service
LMR	land mobile radio
LOS	line-of-sight
LULC	land use/land cover
Mb	megabyte
MCM	multicarrier modulation
MCS	Measurement Control System
MEO	medium (or middle) earth orbit
MHz	megahertz
MIL-STD	military standard
MNB	measuring normalizing block
MOS	mean opinion score
MPEG	Motion Picture Experts Group
MSK	minimum-shift keying
MSTV	Association for Maximum Service Television, Inc.

NARRN	North American Railroad Radio Network
NASA	National Aeronautics and Space Administration
NASTD	National Association of State Telecommunications Directors
NATO	North Atlantic Treaty Organization
NBW	necessary bandwidth
NCS	National Communications System
nDGPS	nationwide differential global positioning system
NGDC	National Geophysical Data Center
NII	national information infrastructure
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPRM	Notice of Proposed Rule Making
NRZ	non-return to zero
NSA	National Security Agency
NS/EP	National Security and Emergency Preparedness
NTC	National Training Center
NTIA	National Telecommunications and Information Administration
NTSC	National Television Standards Committee
NVESD	Night Vision Electronic Sensors Directorate
OBW	occupied bandwidth
ODOT	Oregon Department of Transportation
OFDM	orthogonal frequency division multiplexing
OLES	Office of Law Enforcement Standards
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTAR	over-the-air rekeying
P25	Project 25
PAL	phase alternating line
PAWSS	Ports and Waterways Safety System
PBS	Public Broadcasting System
PC	personal computer
PCS	Personal Communications Services
PDA	personal data assistant
PDD	Presidential Decision Directive

PDO	Program Development Office
PDP	power delay profile
PN	pseudo-random
POC	proof of concept
PPS	precise positioning service
PS	public safety
PSK	phase shift keying
PSNR	peak signal to noise ratio
PSP	Public Safety Program
PSTN	Public Switched Telephone Network
PSWAC	Public Safety Wireless Advisory Committee
PTC/PTS	positive train control/positive train separation
QoS	quality of service
RDBMS	relational database management system
RF	radio frequency
RFIMS	Radio Frequency Interference Monitoring System
RISC	Reduced Instruction Set Computer
RMS	root mean square
RP	range profile
RSMS	Radio Spectrum Measurement System
SDH	synchronous digital hierarchy
SDR	software defined radio
SG	study group
SINAD	signal to interference noise and distortion
SIPRNET	secret Internet protocol router network
SMPTE	Society of Motion Picture and Television Engineers
SMTP	simple mail transfer protocol
SNR	signal-to-noise ratio
SONET	synchronous optical network
SPS	standard positioning service
STANAG	standards agreement
STRICOM	Simulation, Training, and Instrumentation Command
S-VHS	super VHS (Video Home System)
TA Services	Telecommunications Analysis Services
TAC	Technical Advisory Committee

TCP	transmission control protocol
TDMA	time division multiple access
TEAM	Telecommunications Engineering, Analysis, and Modeling Division
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TSB	Telecommunications Systems Bulletin
TVQMS	Transportable Video Quality Measurement System
UHF	ultra high frequency
USCG	U.S. Coast Guard
US WEST	US West Advanced Technologies, Inc.
UWB	ultrawideband
VHF	very high frequency
VME	Versa Module Eurocard
VOACAP	Voice of America Communications Analysis and Prediction program
VoIP	voice over Internet protocol
VQEG	Video Quality Experts Group
VTC	video teleconferencing
VTS	Vessel Traffic Service
WCTF	Wireless Communication Task Force
WLAN	wireless local area network
WLCN	wireless local campus network
WP	working party
WWW	worldwide web