Institute for Telecommunication Sciences

2000 Technical Progress Report

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2000 Technical Progress Report

U.S. Department of Commerce
Donald L. Evans, Secretary

John F. Sopko, Acting Assistant Secretary for Communications and Information

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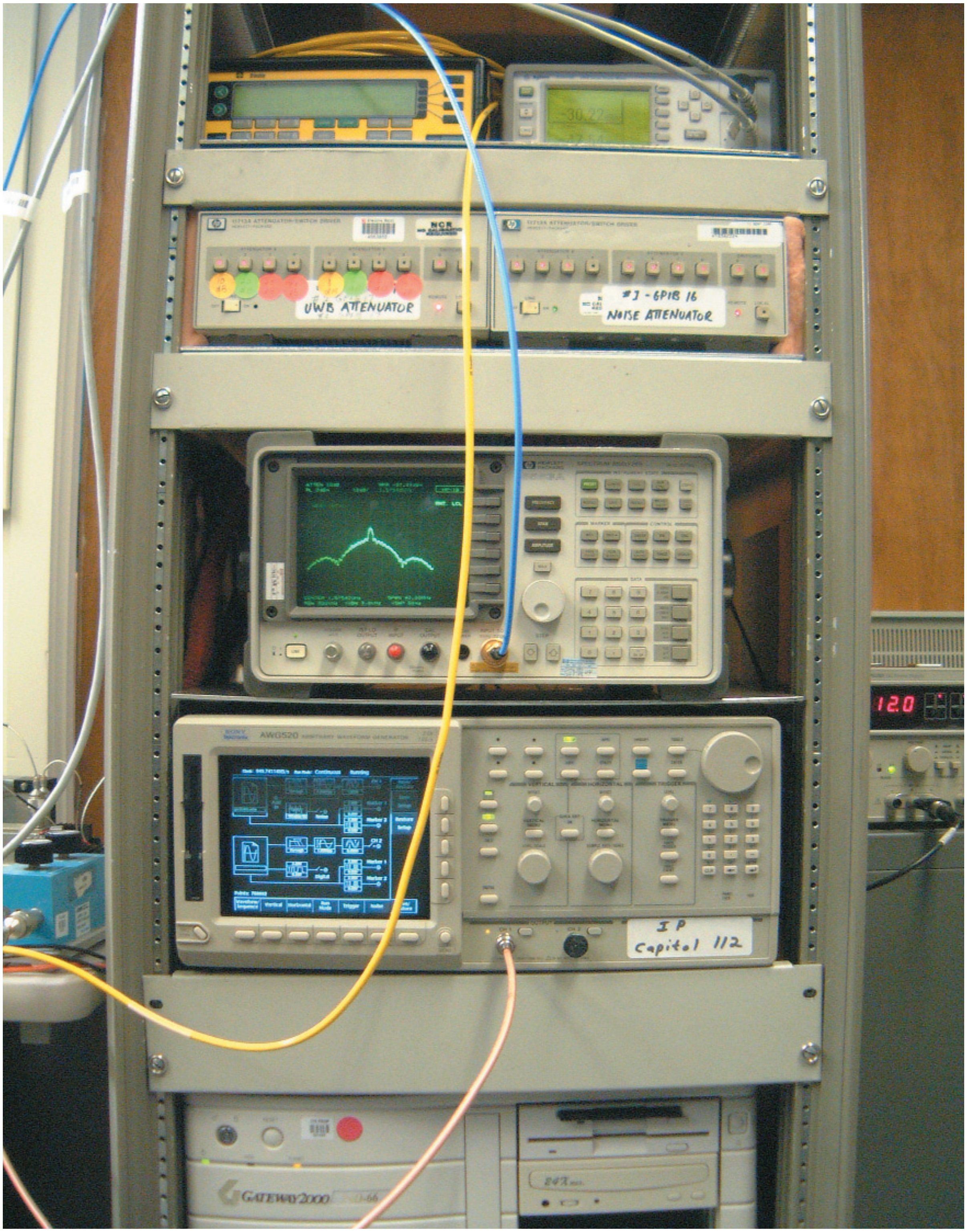
Certain commercial equipment, components, and software are identified in this report to adequately describe the design and conduct of the research and experiments at ITS. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration,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

Contents



Assuring compatibility among new and existing telecommunication systems is an important part of the ITS mission. Pictured here is a measurement system developed at ITS for assessing compatibility among newly developed ultrawideband transmitters and existing Global Positioning System (GPS) receivers (photograph by F.H. Sanders).

The ITS Mission

The Institute for Telecommunication Sciences (ITS) is the research and engineering laboratory of the National Telecommunications and Information Administration (NTIA). ITS provides technical support to NTIA in advancing telecommunications and information infrastructure development, enhancing domestic competition, improving U.S. telecommunications trade opportunities, and promoting more efficient and effective use of the radio spectrum.

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

ITS supports private sector telecommunications activities through cooperative research and development agreements (CRADAs) based on the Federal Technology Transfer Act of 1986. The Act encourages sharing of Government facilities and expertise as an aid in the commercialization of new products and services. ITS is a member of the Federal Laboratory Consortium for Technology Transfer, formally chartered by the Act in 1986.

ITS also maintains an Office of Research and Technology Applications (ORTA), established as a result of the 1980 Stevenson-Wydler Act. The ORTA assesses research and development projects for potential commercial applications, and makes information on Federal technologies available to State and local governments as well as private industry.

ITS provides leadership and technical contributions in national and international telecommunication standards committees under OMB Circular A-119, which provides ground rules and encouragement for Federal agency involvement in voluntary consensus standards development.

The ITS mission often involves technical leadership of interagency projects. Here, engineers from (left to right) the NTIA Office of Spectrum Management, ITS, and the Federal Aviation Administration inspect a radar circuit card during interference measurements in Oklahoma City (photograph by F.H. Sanders).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the research and engineering arm of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce. ITS employs individuals, all of whom are Federal employees, with strong 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, and computer scientists. ITS' support during Fiscal Year 2000 consisted of $3.6 million of direct funding from the Department of Commerce and approximately $5.4 million for work sponsored by other Federal 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, Department of Commerce. In 1965, CRPL joined the Environmental Science Services Administration (ESSA) and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, ITSA split into two labs within ESSA, the Aeronomy Laboratory and the Institute for Telecommunication Sciences (ITS). In 1970, Executive Order 11556 established the Office of Telecommunications (OT) within the Department of Commerce and the Office of Telecommunications Policy (OTP) in the Executive Office; at the same time, ITS was transferred from ESSA to OT. Finally, under the President's Reorganization Act #1 of 1977, OT and OTP 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 and Organization

ITS' technical activities are organized in four program areas:

- ***Spectrum and Propagation Measurements:*** ITS designs, develops, and operates state-of-the-art, automated spectrum measurement and propagation measurement systems; measures spectrum occupancy trends and patterns; measures emission characteristics of 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:*** ITS plans and analyzes existing, new and proposed telecommunications and information technology systems and services, in order to improve the efficiency and enhance the technical performance and reliability of those resources.
- ***Telecommunications Engineering, Analysis and Modeling:*** ITS evaluates and enhances the technical performance characteristics of existing, new and proposed individual telecommunication systems, to improve their efficiency and enhance their technical performance.
- ***Telecommunications Theory:*** ITS develops and enhances 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.

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 maintains 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 research and engineering mission. The Institute also maintains an NTIA 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.

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.

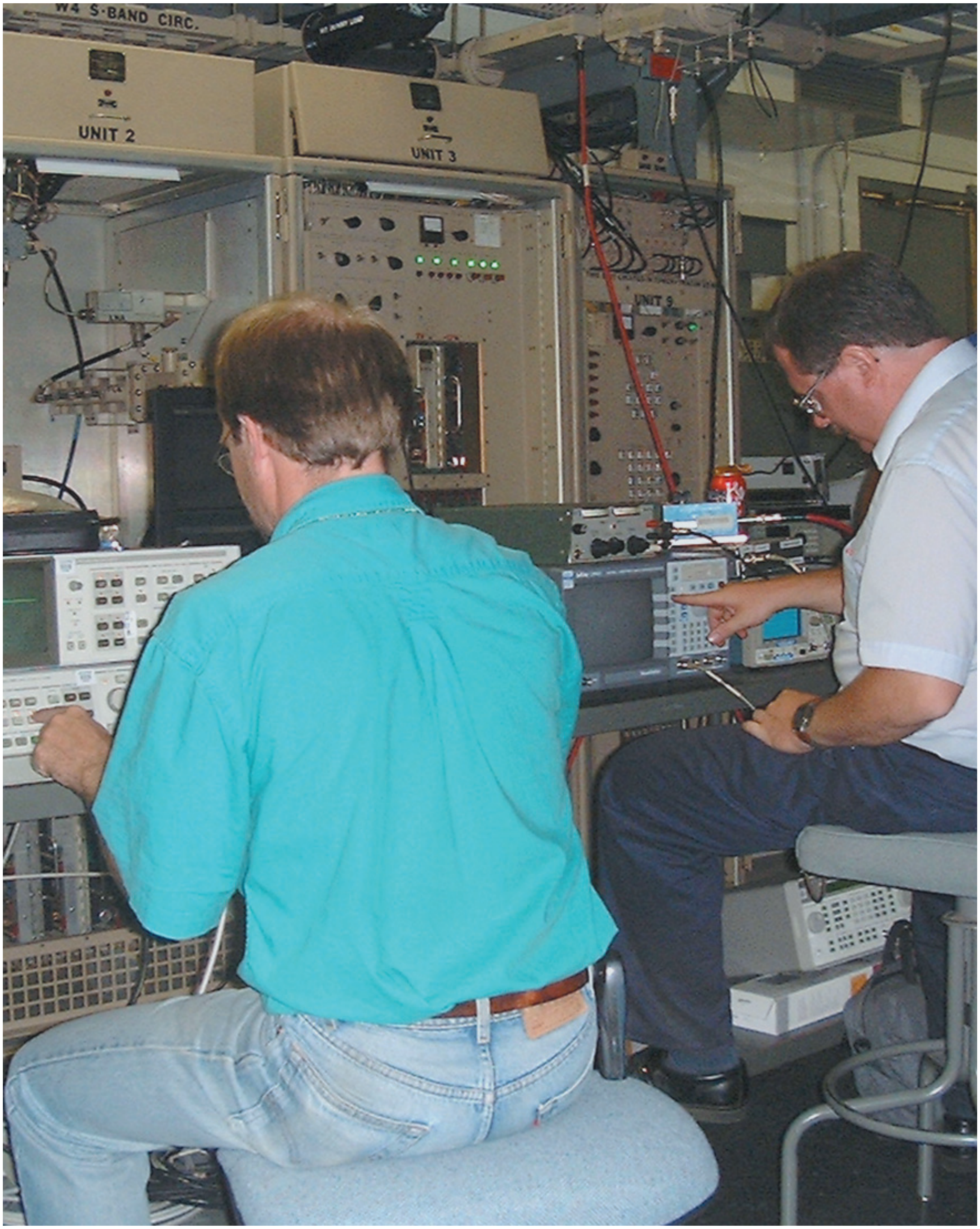
- Expert Services: Training courses and workshops to communicate technology advances and applications to industry and Government users.

Sponsors

Activities at the Institute are undertaken through a combination of programs sponsored by the Department of Commerce and other Federal agencies, and through cooperative research agreements with the private sector. The Institute's policy stipulates that research sponsored by other agencies must contribute to and reinforce NTIA's overall program and must be directed toward supporting the goals of the Department of Commerce. Agencies within the Department of Defense provide a significant portion of the Institute's other agency funding. Other major sponsors include the Department of Transportation, the Federal Aviation Administration, and the National Institute of Standards and Technology.

Cooperative research and development agreements (CRADAs) 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 CRADAs 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 role, ITS is able to provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides 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 2000 to both the public and private sectors.



ITS engineers from the Spectrum and Propagation Measurements Division performing measurements on interference signals in an air traffic control radar (photograph by F.H. Sanders).

Spectrum and Propagation Measurements

The radio spectrum is a natural resource that offers benefit to all of humanity by supporting all radio and wireless applications for communications and 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.

The Spectrum and Propagation Measurements Division performs measurements of radio signals to support research and engineering promoting more efficient and effective use of the spectrum, and opening 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

Spectrum Compatibility Measurements

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.

Spectral Assessment of Government Systems

The Institute performs measurements on new and established Federal 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 Spectrum Measurement System Upgrades

The Institute uses its Radio Spectrum Measurement System (RSMS) to make spectrum occupancy measurements, and to help assess interference and compatibility issues. To keep pace with technological changes in radio systems, the RSMS is being upgraded with hardware and better signal processing to support faster measurements, higher frequencies, and new modulation methods. The project is funded by NTIA.

Ultrawideband Signal Characterization

The Institute performs measurements of both the temporal and spectral characteristics of the time-domain-modulated radio technology called ultrawideband (UWB). Measurement methods are developed to identify the technical characteristics of UWB signals when received (observed) in various bandwidths. The project is funded by NTIA.

Effects of Ultrawideband Signals on GPS Receivers

The Institute identifies and analyzes the effects that a variety of UWB signals may have on various critical receiver systems used with the Global Positioning System (GPS). The resulting information is used to develop frequency management criteria (e.g. coordination distance) or new rules and regulations. The project is funded by NTIA, the U.S. Air Force, and the Federal Aviation Administration.

Spectrum Compatibility Measurements

Outputs

- Measurements on maritime mobile radio compatibility with the automatic identification systems (AIS) used by marine traffic at New Orleans.
- Measurements of ultrawideband (UWB) transmitter emissions as a function of measurement bandwidth at Columbia, MD.
- Measurements of EMC between a UWB transmitter and a variety of air traffic control radionavigation systems at Oklahoma City, OK.

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.

In FY 2000, ITS used suitcase measurement systems in New Orleans to determine EMC parameters between marine mobile radiotelephones and automatic identification systems (AIS) used by marine traffic. Interference-to-noise (I/N) protection ratios were measured, and the results were forwarded to the NTIA Office of Spectrum Management (OSM) for use in a report that is currently in a draft form.

Ultrawideband (UWB) transmitter emissions were measured at the Federal Communications Commission (FCC) laboratory in Columbia, MD. These initial measurements were performed to determine how UWB signals coupled into traditional radio receivers would change as a function of receiver bandwidth. New measurement techniques were developed for this task, utilizing a newly available wideband intermediate frequency (IF) section for a spectrum analyzer. Data results from the measurements were forwarded to OSM and to other ITS personnel for use in the development of theoretical models for coupling between UWB transmitters and non-UWB radio receivers.

Figure 1. An ultrawideband (UWB) transmitter antenna mounted on top of a mast on the Radio Spectrum Measurement System (RSMS) van with an ARSR-4 radar tower in the background. The UWB transmitter emission effects were monitored at the ARSR-4 receiver (photograph by F.H. Sanders).

Figure 2. The ARSR-4 radar antenna feed, which received the UWB emissions transmitted from the RSMS system shown in Figure 1 (photograph by F.H. Sanders).

UWB emissions are also a concern to Government spectrum managers, due to the possibility that such systems might have the potential to cause interference to air traffic control systems such as radars and air traffic control beacon interrogators (ATCBI). To quantify the maximum UWB emission levels that might be allowed in the vicinity of such receivers without causing interference effects, ITS used the Radio Spectrum Measurement System (RSMS) at the Federal Aviation Administration (FAA) center at Oklahoma City, OK. The RSMS performed quantitative tests and measurements on several FAA receivers at that location. The receivers were the ASR-8, ASR-9, and ARSR-4 air traffic control radars, and the ATCBI-5 beacon system. A programmable UWB test transmitter with a custom-controllable output was used to couple signals into these receivers, both via cables and via radiation from various distances outdoors.

For these measurements, techniques were developed to monitor the levels at which UWB signals were occurring within the receivers. A technique was also developed to measure the coupling factors between the radar and beacon receivers and the UWB transmitter as a function of distance between the transmitter and receivers. It was determined that the coupling factors did not increase without limit as the distances between the transmitter and the receivers were reduced. Rather, a maximum coupling level was achieved within a non-zero distance from all of the receivers, and this level decreased as the UWB transmitter moved in closer (and into the “dead spot” underneath the receiver antenna pattern).

Measurements on receiver performance were performed with the UWB transmitter located within the maximum coupling zone for each receiver. The UWB emission levels were varied to determine the levels at which degradation to receiver performance was minimized. The results were summarized and forwarded to OSM for incorporation into NTIA Reports on this and other UWB compatibility studies by NTIA.

Recent Publication

W. Kissick, Ed., “The temporal and spectral characteristics of ultrawideband signals,” NTIA Report 01-383, Jan. 2001.
http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

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Spectral Assessment of Government Systems

Outputs

- Spectrum emission measurements on tactical and anti-tactical ballistic missile (ATBM) military radars.
- Draft New Proposed Recommendation on radar emission spectrum measurement techniques to the ITU-R, in support of the U.S. Administration.

Increasing demands are being placed upon radio spectrum worldwide to accommodate new-technology systems such as International Mobile Telecommunications 2000 (IMT-2000). Such spectrum demands can result in electromagnetic compatibility (EMC) problems that threaten Government radio operations. Further, in the event that new or existing Government systems do create or experience 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.

A number of Administrations in the International Telecommunication Union (ITU) have recently proposed that spectrum bands used by various U.S. radars and radionavigation systems may be shared with the new communications technologies. In support of the U.S. Administration, ITS has undertaken a technical effort to determine the nature of and the extent to which EMC problems may occur when bands are shared between radars and other services. Further, to ensure that radars continue to be provided with a sufficient amount of spectrum, ITS has undertaken a significant effort to ensure that foreign Administrations accurately and adequately measure the spectrum emissions from their own existing radar systems.

Figure 1. ITS measurements in progress on maritime surface-search and navigation radars at a Ministry of Defense facility at Funtington, UK. A suitcase version of the Radio Spectrum Measurement System (RSMS) was used inside the loaned van. The collapsible parabolic antenna is trained on radars, located about 1/8 mile away (photograph by F.H. Sanders).

Figure 2. Detail of the Figure 1 measurement system, showing the measurement system as configured within the van (photograph by F.H. Sanders).

In FY 2000 ITS performed emission measurements on Department of Defense (DoD) radar transmitters at Syracuse, NY. These measurements were intended to show both the extensive nature of the emissions from these radars, and also the desirability of performing the measurements in accordance with techniques previously developed by ITS. These data were used to support the U.S. Administration position at the ITU.

The measured DoD transmitters included radars designated AN/FPS-117 and AN/TPS-59. The radars are used for long-range air surveillance, and one (the TPS-59) incorporates anti-tactical ballistic missile (ATBM) capabilities. The measurements were performed with the NTIA/ITS Radio Spectrum Measurement System (RSMS). The radar was allowed to radiate and scan the sky in normal operational modes while the RSMS received its signals at a distance. A variety of measurement parameters were used to demonstrate the effect on measurement results. In addition, measurements of pulse shapes were performed in different bandwidths to demonstrate the time waveforms to which receivers near such radars will be subjected at selected frequencies, including GPS bands.

In June 2000, a suitcase radar measurement system was transported to Funtington, UK, to demonstrate those measurement techniques to selected ITU members (France, Japan, Germany, and the UK), as shown in Figures 1 and 2. The suitcase system was used to perform measurements on maritime navigation radars with the delegates in attendance. A seminar on ITS radar measurement and calibration techniques was provided by NTIA Office of Spectrum Management (OSM) personnel at Southampton, UK, in connection with this effort.

In October, ITS personnel traveled to the ITU-R Working Party 8B meeting in Geneva, Switzerland to support a Draft New Proposed Recommendation for the measurement of radar emission spectra. Its final approval as an ITU Recommendation is pending, subject to additional efforts by the French and other Administrations to develop the measurement techniques demonstrated at Funtington, UK, and used earlier at Syracuse, NY.

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Radio Spectrum Measurement System Upgrades

Outputs

- Determination of wideband configuration and digitizer requirements.
- Design of preselector and RF control unit.
- Preliminary revision of RSMS software.

For over 25 years, the U.S. Department of Commerce Radio Spectrum Measurement System (RSMS) program has kept track of radio spectrum usage and resolved interference problems involving Government radio systems in the United States. Since 1973, this mobile Government facility (and sometimes its suitcase-transportable variants) has performed its mission at dozens of locations across the lower forty-eight states, as well as at Anchorage, AK; Adak, AK; Guam; Diego Garcia (BIOT); and Scotland (UK).

The RSMS program is a result of the ongoing commitment of NTIA's Office of Spectrum Management (OSM) to accomplishing three critical spectrum management missions: (1) Determine the extent, patterns, and amounts of usage of U.S. radio spectrum (particularly through broadband spectrum surveys between 30 MHz to 20 GHz); (2) Analyze emissions from Government and non-Government transmitters to prevent electromagnetic compatibility problems (interference) from occurring; and (3) Resolve radio interference problems if they involve one or more Government systems.

The RSMS is a state-of-the-art spectrum measurement and analysis capability that incorporates automated, semi-automated, and manual techniques for the measurement and analysis of radio emissions from the following types of transmitters: high-power radars; mobile radios and associated base stations; navigation beacons and transponders; point-to-point microwave links; earth station transmitters; and low power device emissions, such as those generated by FCC Part 15 (low power) and FCC Part 18 (Industrial, Scientific, and Medical (ISM)) units.

The RSMS is now in its third generation of design and operation by ITS. Although RSMS III is a powerful measurement tool, its effectiveness as a state-of-the-art spectrum measurement system is being eroded by rapid advances in radio technology. Therefore, a fourth-generation upgrade has been proposed: RSMS IV. This upgrade is intended to provide flexibility for different system configurations as well as for future expanded capabilities. It will provide a soft transition between the current and future systems, adding to the present capabilities rather than creating an entirely new system. The goals of

Radio Spectrum Measurement System (RSMS) III, parked outside Wing 4 of the Department of Commerce Boulder Laboratories (photograph by F.H. Sanders).

the upgrade and progress made in FY 2000 are described below.

Expansion of measurement system bandwidth.

The RSMS has a bandwidth of 3 MHz, wide enough for most applications. However, there is a need to expand to wider bandwidths to measure some of the newer spread spectrum systems and proposed ultrawideband (UWB) systems. To meet this goal requires expanding the bandwidth of the measurement spectrum analyzer to 100 MHz, redesigning the front end preselector module, and modifying the acquisition software. The spectrum analyzer upgrade is to be accomplished in two steps. The first step is the replacement of the spectrum analyzer IF section with an IF section capable of 100-MHz bandwidth (accomplished in FY 2000). The second step (planned for FY 2001) will complete the expansion through the purchase of an RF unit capable of 100-MHz bandwidth. An internal spectrum analyzer tracking filter in the RF unit can be used for bandwidths up to 35 MHz. For bandwidths greater than 35 MHz, external broadband YIG tracking filters are required which have been designed into the next generation front-end preselector module. RF coverage for the spectrum analyzer is 100 Hz to 26.6 GHz. Software modifications are further required to incorporate the capabilities of the wide bandwidth spectrum analyzer into the current and future proposed acquisition software.

Digital signal processing (DSP) capabilities.

Real-time DSP capabilities will be incorporated into RSMS IV to allow signal processing in ways not possible through traditional analog means (e.g. sharp filtering with flat group delays). The first step was the purchase of a vector signal analyzer (VSA), a high speed, wide dynamic range digitizer which interfaces through the spectrum analyzer. The VSA is VXI based, has a 40-MHz baseband bandwidth, a 100-MHz sample rate, with a 15 equivalent bit digitizer. To achieve the full 80-MHz equivalent RF bandwidth, as well as obtain phase and time domain information, both the co-phase and quadrature-phase channels are required. This year, only a single channel was purchased, but the second baseband channel is slated for a future acquisition. To complete the system requirement for digital signal processing, both hardware and software changes are required. For phase and time domain information it has been necessary to design the hardware with minimal phase distortion and to utilize special calibration techniques to deconvolve the system effects. Modifications to the current acquisition software will also be required to incorporate the VSA.

Front-end hardware upgrade.

Upgrade of the RSMS has required additional hardware upgrades, including new preselector and RF controller modules. The preselector module has been designed with particular attention given to versatility for inclusion into suitcase applications. In addition, a wideband YIG tracking filter has been added, along with provisions for 18-26 GHz and 26-40 GHz block down-converters, and direction finding (DF) capabilities. The RF controller design has been modified for versatility, so it can be used in a suitcase application.

Software upgrade.

Objectives of the software upgrade project include transitioning to Windows® based software, expanding measurement capabilities, revising the file output format, allowing for growth and multiple programmer input, and providing a soft transition for processing software. To transition to Windows® the choices were: (1) rewrite the current software, (2) modify software developed for the Radio Frequency Interference Monitoring System (RFIMS), or (3) start from scratch. The decision was made to modify both the current acquisition software (better suited for suitcase applications and flexibility) and the RFIMS software (which has expanded capabilities and enhanced record keeping of calibrations and equipment states). Several tasks were identified for modification of the RFIMS software, including (1) incorporating hardware changes, (2) increasing flexibility, (3) adding key procedures to the scheduler, (4) incorporating a modulation domain analyzer, (5) changing the file structure, (6) adding multiple antenna port selection, (7) adding a file translation program for analysis tools, and (8) upgrading analysis tools for the new file structure. In FY 2000 the following tasks were completed: Global changes were made to the current RFIMS software to transform it into RSMS software. The recommended file structure was determined. Development of the modulation domain analyzer software was begun. The scheduler and the swept / m3 were added.

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Ultrawideband Signal Characterization

Outputs

- A description of time and spectral characteristics of UWB signals based on analysis, simulation, and measurements.
- Development of UWB measurement and modeling techniques
- Measurements of UWB interference to three Federal systems.

Because the radio spectrum is a limited resource, a wide variety of creative approaches have been proposed for increasing the number of users that can occupy it. Recently, an approach called ultrawideband (UWB) technology has been developed, which employs very-short-duration electrical impulses to provide sensing and communications functions. Although the UWB pulses contain energy that spreads across wide stretches of spectrum already containing many licensed radio systems, UWB proponents claim minimal interference to existing users, due to the very low spectral power density of UWB signals. However, many users of traditional radio systems fear that UWB signals may cause massive interference.

ITS performed a major study to assist with assessing these claims. The results of this study provide critically needed data and modeling tools for decision-making regarding the deployment and potential ubiquitous use of UWB transmitters. A theoretical analysis of UWB signals was performed to provide insights into how UWB signals affect various types of RF systems. The analytical results are also useful for the validation and interpretation of measurements. An analysis of proposed UWB pulse position modulation schemes yielded the power spectrum and some band-limited signal statistics. From the signal statistics, a method was developed for predicting when a UWB signal is approximately Gaussian.

UWB signals were measured as full-bandwidth pulse shapes, showing temporal characteristics such as the peak voltage and pulse widths (Figure 1). Since these pulses contained sub-nanosecond features, these measurements were technically challenging and required specialized expertise and facilities. Fast Fourier Transforms (FFTs) were performed on the pulse shapes to yield power spectra and field strength graphs (Figure 2). These graphs provided a reference set for comparison of spectrum measurements made with bandwidth-limited equipment.

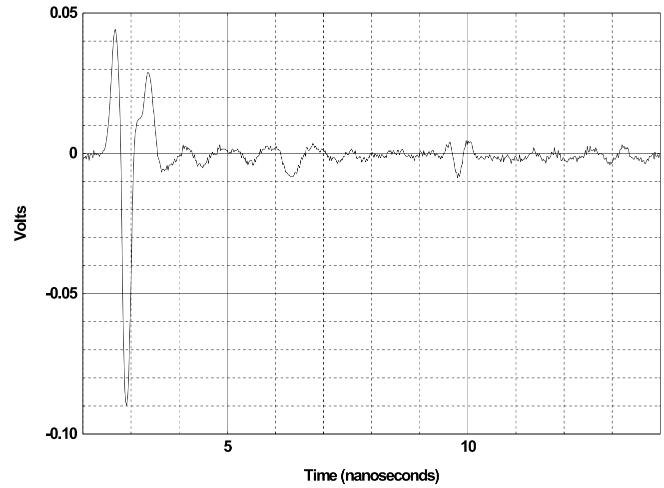

Figure 1. Full bandwidth pulse shape.

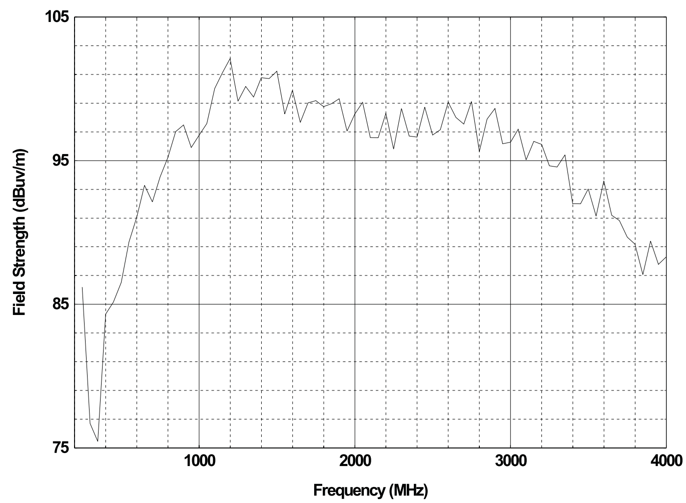

Figure 2. FFT spectrum from full bandwidth pulse shape.

Measurements were also performed using commercial-off-the-shelf (COTS) bandwidth-limited equipment like spectrum analyzers. These bandwidth-limited COTS measurements are important for several reasons: They provide a more realistic measurement approach for many commercial test laboratories; they give a more realistic indication of how UWB signals interact with traditional narrowband radio systems; and they permit a realistic study of the effects of various UWB modulation techniques such as dithering and gating. A major aspect of UWB signal characterization is that UWB signal amplitude and characteristics are highly dependent on measurement conditions, especially receiver bandwidth. Measurement techniques were developed for determining UWB signal characteristics as a function of the measurement bandwidth, the pulse repetition frequency, pulse modulation, gating, etc. One important conclusion was that the COTS measurements gave emission spectrum results very similar to the full-bandwidth FFT results.

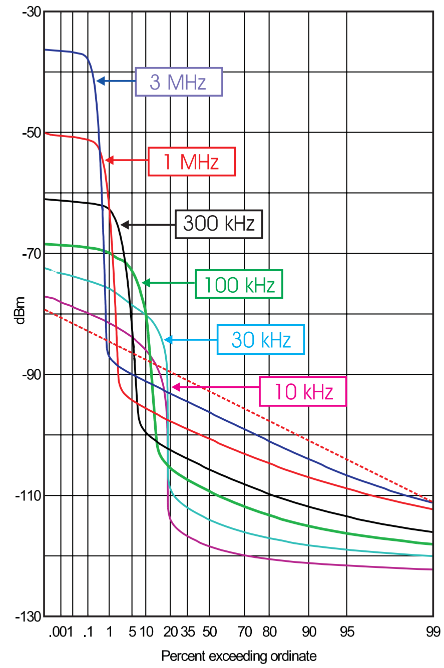

Figure 3. APDs measured in various bandwidths.

Amplitude probability distributions (APD) were developed as a useful way to describe UWB signals as a function of measurement bandwidth (Figure 3). APDs also were used to compute the values equivalent to several detector functions commonly found in measurement equipment (e.g., peak, RMS, average voltage, average log). The wide range of values for computed detector results (Figure 4) clearly show the importance of tightly specifying the correct measurement procedures for compliance with future UWB regulations. They also suggest that modifications to the proposed FCC Part 15 measurement procedures would provide more useful answers for UWB devices.

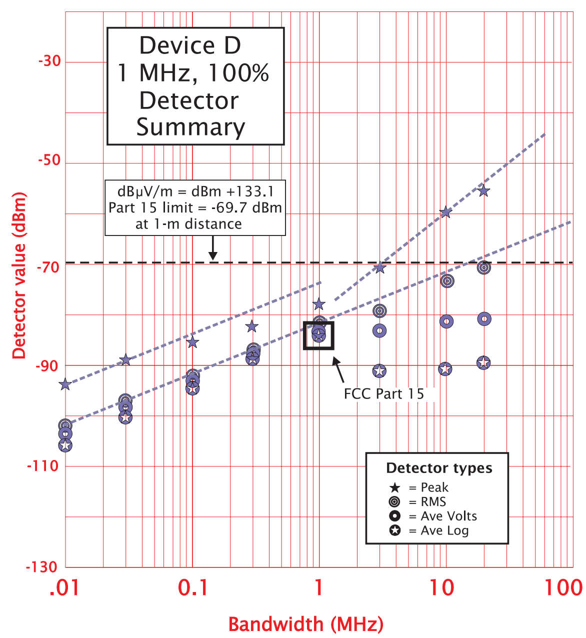

Figure 4. Detector summary, UWB device with 1-MHz average PRR.

Due to a potentially large proliferation of UWB devices, it is important to understand the effects of an aggregation of such devices. A statistical model was developed that can be used to calculate the power received from UWB devices randomly distributed over the surface of the Earth. This model is useful for predicting UWB interference power for terrestrial and airborne receivers.

A most important aspect of UWB devices involves their effect on existing receivers. ITS investigated this by introducing UWB signals into three different Federal radar receivers, as well as a much more detailed series of measurements on GPS systems. These tests are described on pages 14-15 of this technical progress report.

Recent Publication

W. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001. http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383

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Effects of Ultrawideband Signals on GPS Receivers

Outputs

- Development of GPS/UWB compatibility test plan.
- Design and development of GPS laboratory, including control and data acquisition software and RF hardware.
- Results of tests on GPS receivers (to be completed in FY 2001).

In FY 2000, the Institute has investigated the general characteristics of ultrawideband (UWB) transmitters, with particular emphasis on how measured characteristics of UWB systems relate to interference to conventional radio systems. This general UWB effort is described in the preceding section (see pp. 12-13). In addition to the general UWB work, a separate project was established to investigate Global Positioning System (GPS) vulnerability to UWB interference, starting with the measurement techniques developed in the general UWB work. To accomplish this we monitored the behavior of several GPS receivers when exposed to various UWB signals in a controlled (i.e., conducting) environment. A secondary objective was to develop measurement methodologies to assess interference effects on the weak GPS signal. This work is expected to be finished in FY2001.

The Global Positioning System is a dual-use, space-based, broadcast-only, radio navigation satellite service that provides universal access to precise position, velocity, and time information on a continuous worldwide basis. The GPS constellation consists of twenty-four satellites that transmit an encrypted code, which is used by U.S. and allied military forces, and an unencrypted code, which is used in a myriad of commercial and consumer applications. GPS is presently used by aviation for en-route and non-precision approach landing phases of flight. Precision-approach runway incursion, and ground traffic management services are currently being developed. On our highways, GPS assists in route guidance, vehicle monitoring and identification, public safety and emergency response, resource management, collision avoidance, and transit command and control. Non-navigation applications may be grouped into geodesy and surveying; mapping, charting, and geographic information systems; geophysical; meteorological; and timing and frequency. Planned systems, such as Enhanced 911 (E911), personal location, and medical tracking devices are soon to be commercially available. The U.S. telecommunications and power distribution systems are also dependent upon GPS for network synchronization timing. In summary, GPS is a powerful enabling technology that has created new industries and new industrial practices fully dependent upon GPS signal reception. Given the importance of this critical government radiocommunication system, NTIA is concerned with the susceptibility of GPS to interference that can severely degrade the system. GPS vulnerability to conventional interference types (e.g., noise, continuous wave) is well documented; this work addresses interference from UWB signals.

In principle, an interference test is performed by applying a known amount of “foreign” signal to an operational radio system and noting any functional degradation in the radio performance. GPS interference testing includes the same basic elements, but the complexity of the system makes GPS testing quite different. The GPS operational system normally includes signals from multiple satellites, whose positions are constantly changing (including appearing and disappearing from view behind the Earth’s horizon). To maintain a repeatable test situation, a complex GPS simulator is used to provide a known and controllable sample of multiple GPS signals. These signals appear as though they had been transmitted from multiple moving satellites, but the simulated satellite positions can be reset to a selected standard configuration at the beginning of each test.

The typical GPS receiver provides some challenges also. The receiver usually does not exist as a piece of hardware with easily accessible test points, but rather is mostly software implemented on highly specialized ASICs and DSP chips. These programs process information from GPS signals, according to proprietary adaptive algorithms, and maintain a

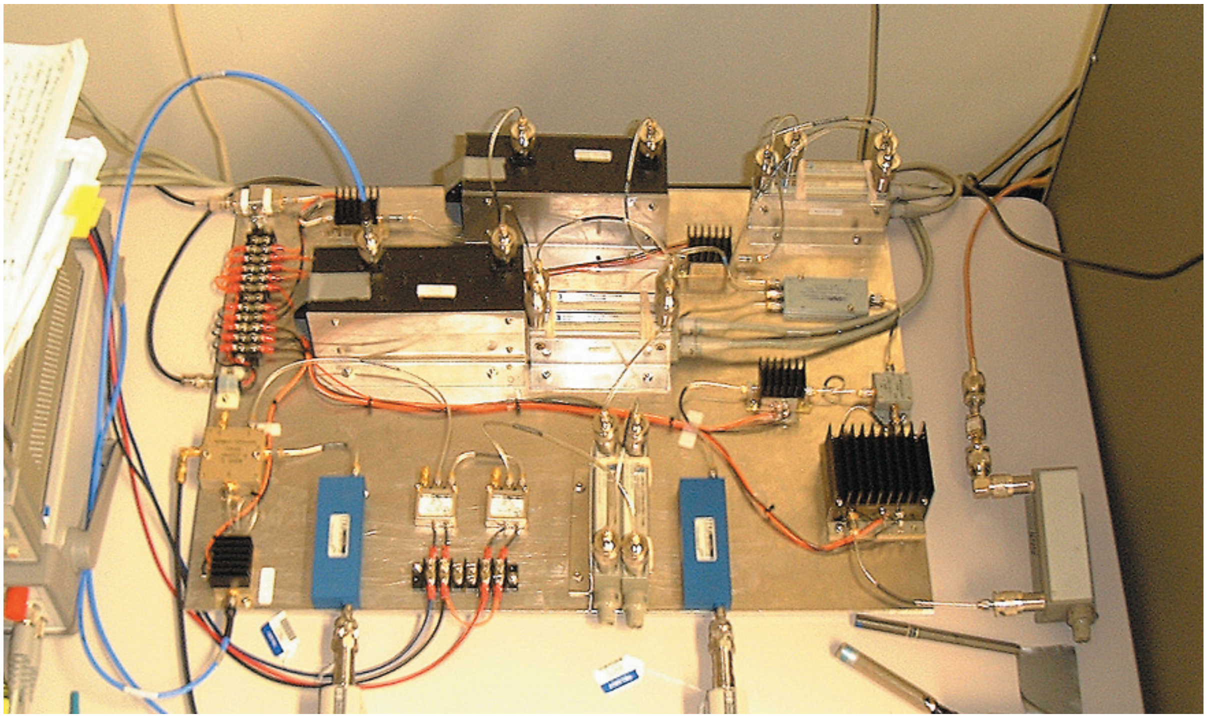

Figure 1. RF test fixture for GPS/UWB compatibility test (photograph by F.H. Sanders).

desired level of accuracy. Each different GPS receiver has its own functionality; therefore, each receiver may generate different failure modes from interference and may recover from interference in different ways. Finally, it is not obvious what measures should be used to identify unacceptable receiver degradation. Some GPS applications (e.g., surveying) require very high position accuracy. A cellular site requires high time accuracy. An aircraft application requires accurate position, velocity, and fast recovery from outages.

A collection of receivers was chosen for these tests which encompass a broad range of GPS technologies and applications (e.g., agriculture, surveying, aviation, public safety). Since we were unable to observe much of the internal workings of these receivers, we were limited to those results that were available outside the receivers. Given those limitations, we pursued our objectives with both radiated and conducted tests. The goal of the radiated tests was to measure the transfer function of each GPS antenna, including the phase linearity within the passband of a specific receiver. Conducted tests were divided into two parts: single-source and aggregate. In the single-source test, we were able to assess GPS susceptibility to a representative range of UWB signals. The aggregate tests will demonstrate how 2-6 UWB signals combine and what effect those signals will have on the chosen GPS receivers.

The basic GPS testing involves inserting an increasing level of UWB interference until a functioning GPS receiver loses lock on a given satellite signal. Having lost lock, the interference is decreased in various amounts, and the respective times until lock is reacquired are measured. In order to obtain high confidence in our results, a long simulation time is needed to completely measure each test point (i.e., approximately 45 minutes per interference level, for each UWB source, for each GPS receiver). Consequently the UWB/GPS test station is being run via computer control on a 24-hour/day basis.

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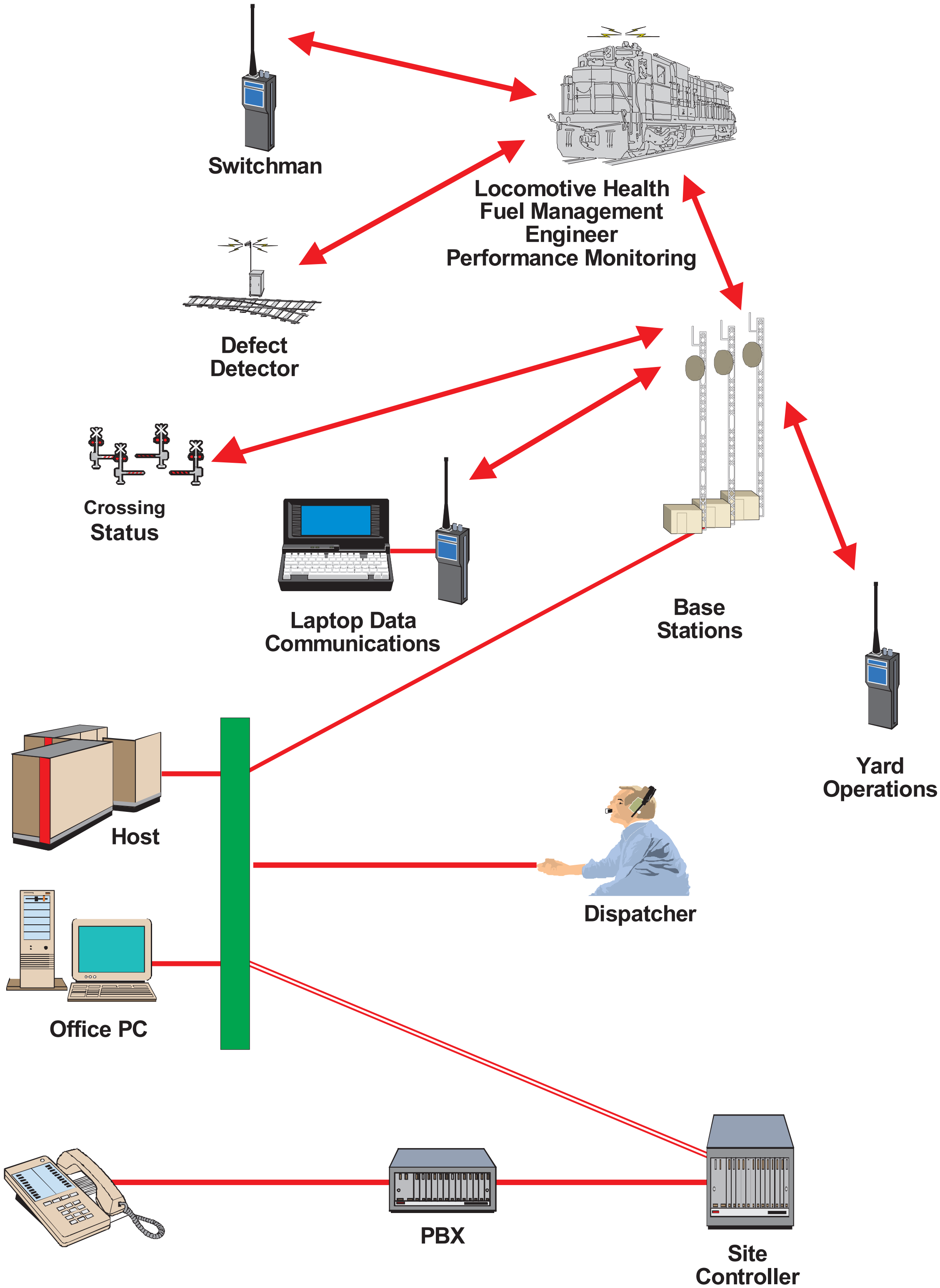

As part of the process involving network planning, analysis, or improvement actions, a thorough understanding of existing and future functional needs is developed. Typical elements of a railroad telecommunications network are outlined here. Red lines with arrows denote wireless communications; red lines without arrows denote wireline communications.

Telecommunications and Information Technology Planning

The telecommunications and information technology planning function represents the highest-level system or network perspective of the Institute. 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 this work for both wireline and wireless applications. This portion of the ITS technical program encompasses work that is frequently referred to in industry as "systems engineering."

All phases of strategic and tactical planning are conducted under this work area; problem solving and actual implementation engineering also are done. ITS engineers identify or derive users' functional requirements and translate them into technical specifications. Telecommunication system designs, network services, and access technologies are analyzed, as well as information technologies (including Internet and Internet-related schemes). Associated issues, such as network management and control and network protection and privacy, also are 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.

Network Interoperability The Institute identifies and provides unbiased perspectives for network interoperability problems of particular significance to U.S. interests and provides candidate approaches useful for resolving the problems. The project is funded by NTIA.

Network Survivability and Restoration The Institute uses traditional methods as well as network modeling and simulation tools to develop practical and effective ways to specify and assess the survivability performance and reliability of both wireline and wireless communications networks. This project is funded by the National Communications System (NCS).

Networking Technology The Institute defines a structured process for telecommunications and information technology planning and assessment studies, uses this process to identify needs for automated tools that aid in producing solutions that satisfy users' requirements, and prepares a handbook for performing the entire planning or assessment study process. This project is funded by NTIA.

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 Telecommunication Planning The Institute performs radio infrastructure system planning in support of a high-speed rail pilot program, and demonstrates newly designed digital land mobile radio technology and infrastructure, compliant with TIA-102 standards, along the Pacific northwest rail corridor. The Federal Railroad Administration funds this project.

Telecommunication Terminology Standards The Institute develops automated web-page and e-mail procedures for updating FED-STD-1037C, *Glossary of Telecommunication Terms* (1996) and uses the procedures to produce a revised draft of the standard, now known as Proposed ANS *Telecom Glossary 2000*. This project is funded by NCS.

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 more and more new users begin using wireless services. Figure 1 and Table 1 below provide industry data and projections on U.S. deployment of wireless services by subscriber numbers and penetration.

As users expect better quality voice service and more features such as caller ID and call forwarding, 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.

Table 1. Growth in Subscriber Penetration for Wireless Services

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

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. Besides the number of users increasing, the types of services (beyond just voice communications) are increasing, with more emphasis on Internet-type uses. These new services 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

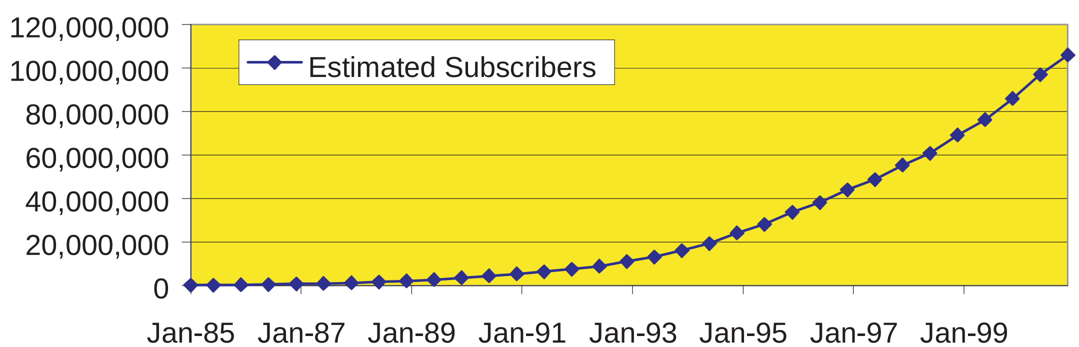

Figure 1. Growth in estimated number of wireless subscribers.

In order to predict wireless signal coverage more accurately, ITS and other research organizations are developing and evaluating propagation models that are more responsive to the needs of cellular and private land mobile radio service providers. A common model used by system planners is the ITS Irregular Terrain Model (ITM), 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 databases to predict losses due to man-made objects. Another common model is the Okumura-Hata model. It is a good predictor in urban and suburban environments, but it does not handle irregular terrain nor does it handle changing environments, e.g., from urban to suburban to rural.

Figure 2. Predicted field strength values versus distance for mobile and broadcast systems over land at 2000 MHz for 50% of the time and 50% of locations.

Radio propagation predictions made using land-use, land-cover databases should estimate signal losses due to objects on a propagation path more accurately than predictions calculated without knowledge of the obstacles. The improved predictions allow service providers to better evaluate locations for base stations and to predict where additional base stations might be needed to fill in areas 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.

Another effort supported by ITS is the international development of propagation prediction models that can be used by spectrum managers and system planners of both land mobile and terrestrial broadcast services. As the two services are becoming more similar in terms of RF equipment characteristics, it is appropriate to use the same propagation model for both services. The ITU-R Study Group 3 on Radio Propagation is developing such a model, which blends features that the two services have previously used independently of one another. Figure 2 shows an example prediction of field strength for various land mobile base station or broadcast transmitter antenna heights. The model, for example, can be used to effect coordination between services, countries, or systems in the same service.

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Network Interoperability

Outputs

- Identification and assessment of emerging network interoperability issues.
- Resources supporting telecommunication and information technology system planning efforts.

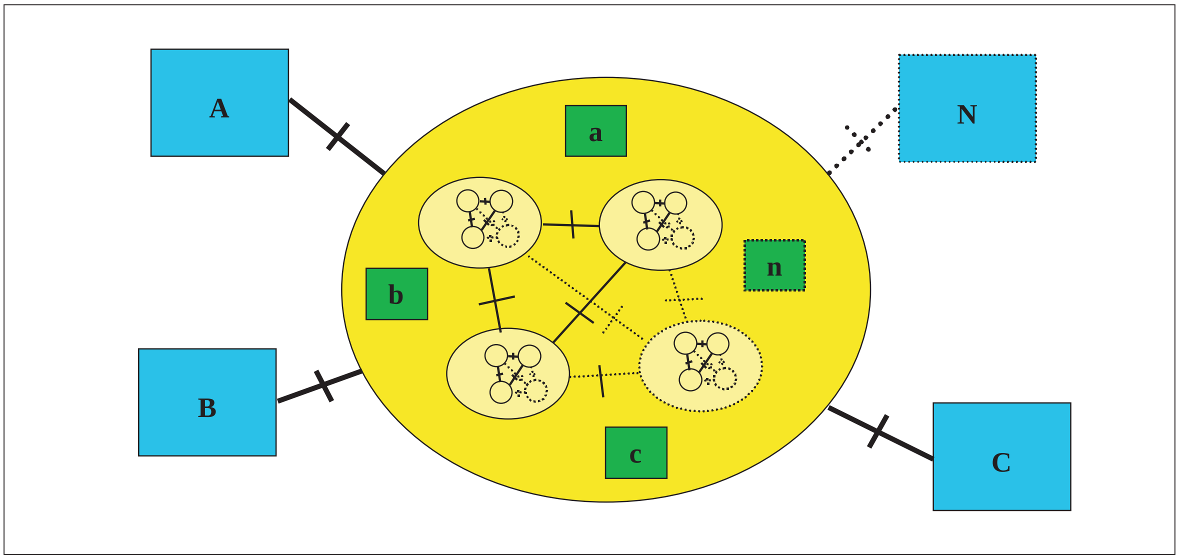
A nationally critical need exists for *interoperable* telecommunication services and equipment. Domestic economic and social growth depends greatly on emerging telecommunication and information technologies (IT). Interoperability is required to perform a variety of telecommunication functions that meet user needs, including the end-to-end transport of user information involving multiple, heterogeneous network technologies and supported multimedia applications.

The current lack of interoperability among systems is a serious concern in the public safety community, whose members may experience difficulties communicating with others from different jurisdictions. But this problem also occurs more subtly throughout many other systems worldwide, especially due to unprecedented innovation in technology and demand for advanced services and equipment. Federal agencies (and state and local governments) need guidance regarding the most effective way(s) to interoperate among dissimilar systems. This guidance also will be of value in matching customer needs with offered telecommunications and IT service and equipment in both the public and private sectors.

The problem of interoperability has become an increasingly important technical challenge in the design, procurement, and operation of advanced wireless systems, including those systems that rely on terrestrial (wireline) elements to provide a large network configuration. This is essentially the networking problem associated with wireless communications: How can wireless communication networks interoperate? Can transmission or signaling technologies such as transmission control protocol (TCP), Internet protocol (IP), Internet control message protocol (ICMP), asynchronous transfer mode (ATM), and signaling system no. 7 (SS7) be used to facilitate interoperability?

In consideration of such needs and challenges, the Institute recently established a long-term program to address — from an unbiased perspective — network interoperability problems of particular significance to U.S. interests and to provide candidate approaches useful for resolving those problems. For the short term, the program's focus is on conducting studies of the wireless-to-wireline incompatibility dilemma involving not only the protocols involved with the transfer of traffic across different networks but also the performance and migration path implications. Because the understanding of critical interoperability-related problems requires ongoing technical efforts, continuing studies in a variety of technical areas will be necessary. Collectively, these studies will enable the timely dissemination of relevant research results in support of both public and private sector interoperability efforts, and will involve (1) technology forecasting and assessment, (2) consideration of design, operation, maintenance, and migration issues associated with public and private networks, (3) evaluation of standards-related processes and products, (4) research, development, and application of promising new communication technologies, and (5) interoperability characterization, including the analysis and testing of specific communication systems (i.e., requirements and implementations). Overall, the program is intended to promote deployment of interoperable public safety and criminal justice hybrid communication systems, broadband wireless technologies to rural areas, and public and private telecommunication systems that meet national security and emergency preparedness needs.

Interoperability issues involve two basic facets: the *exchange* and *use* of information, as illustrated in the Figure. An initial study framework has been established, taking into account the mutually interacting related aspects of *plans*, *infrastructures*, and *practices*. The planning process involves consideration of both endogenous and exogenous factors that affect the users' and providers' development of business plans (strategic and tactical), interoperability requirements (technical and process), technical architectures (system and component), service definitions and implementations, and standards (technical and process), taking into account infrastructures and practices. The infrastructure development process



Interoperability involves consideration of how information is exchanged (through networks of networks) and used (through user-based (A, B, C, ..., N) and network-based (a, b, c, ..., n) applications and services). Interoperability issues involve, for example, specification of protocol suites, provision of basic and enhanced services, secure information exchange among authorized users, user selection of transit networks and content providers, connection admission control, end-to-end quality of service, network management, and user data element format, processing, and storage/retrieval.

involves the users' and providers' development and implementation of prototype and operational systems, taking into account plans and practices. A key perspective in assessing infrastructures is to analyze services, architectures, and implementations, extant and planned. Practices are users' and providers' short- and long-term activities (offering and use of services and equipment), taking into account plans and infrastructures. Importantly, practices provide the operational and management experiences essential for the planning process. Collectively, the framework recognizes the complexity of issues affecting the rate at which innovative new candidate technologies are adopted while legacy systems are retired (i.e., forces affecting system migration).

During FY 2000 a preliminary framework, including a broad survey of supporting concepts and industry activities, useful for the characterization and analysis of interoperability issues was developed (highlighted above). Additionally, a preliminary assessment of techniques and technologies that may be effective in facilitating interoperability was conducted. Initial results have been disseminated with the primary audience being ITS telecommunication/IT system planners.

During FY 2001 an emphasis will be placed on advancement of the initial results including evaluation of candidate techniques and technologies that address interoperability issues in defined baseline and operational telecommunication/IT systems. Specific areas of interest include the identification and assessment of interoperability-related issues as they affect multi-network (e.g., wireless and wireline) provision of dynamically requested end-to-end quality of service associated with emerging multimedia applications, internetworking of IP-based and telephony-based networks, and technology forecasting of the increasingly diverse set of networking technologies that collectively compose the rapidly evolving global information infrastructure .

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Network Survivability and Restoration

Outputs

- Technical Contributions to ANSI Working Group T1A1.2.
- Technical report to NCS defining traffic engineering techniques to enhance network survivability performance.

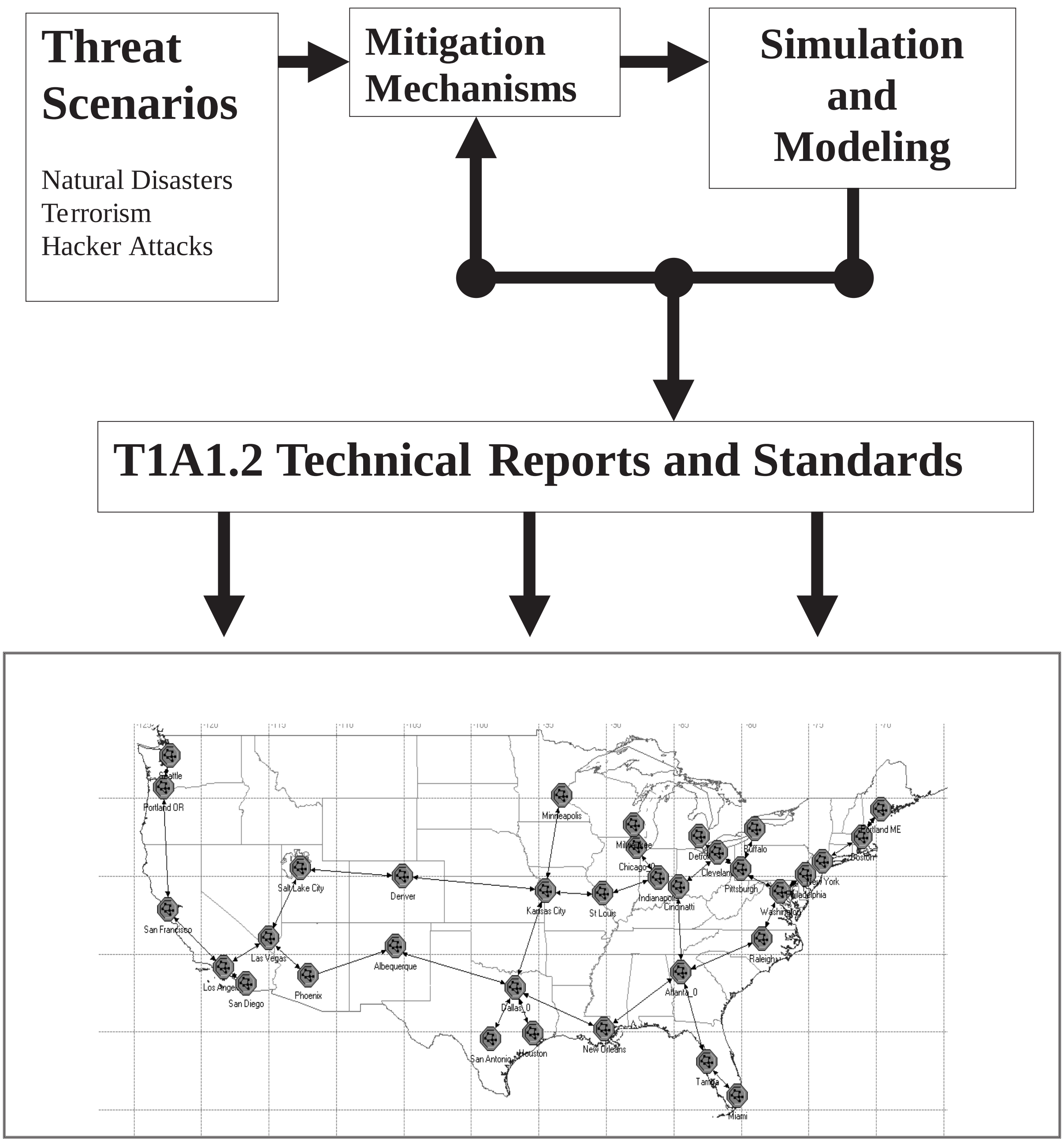
As the world becomes more dependent on communications and computer networks, there is a growing concern about the potentially devastating effects of network failures. Failures can occur as the result of natural disasters (flooding, hurricanes) or as the result of human action (war, terrorism, hacker attacks) or even by unintentional failures in software or control systems. The need for voice, video, 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 can break down under heavy traffic loads. Multi-vendor environments create the potential for interoperability problems as well. The ANSI-accredited Standards Committee T1 (Telecommunications) Working Group T1A1.2 (Network Survivability Performance) is working 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 both wireline and wireless communications networks. ITS is helping to 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.

Since modern networks have become so complex, traditional analysis methods are not adequate to predict the effects of service outages. Therefore, in addition to traditional methods, ITS is using network modeling and simulation tools to address the needs of T1A1.2, NS/EP, and the nation. While modeling and simulation are powerful tools for the assessment of threats and mitigation techniques, the simulations need to be well-grounded in the physical measurement of important parameters. This is an area where other project work at ITS can be utilized to help meet the needs of this project. The Figure shows one approach taken in the Network Survivability and Restoration project.

During FY 2000 ITS presented several technical contributions to T1A1.2. These included inputs to the T1 Technical Report on Enhanced Network Survivability Performance — now out for T1 Letter Ballot. Recent contributions to T1A1.2 focused on the new Draft Technical Report on Reliability/Availability of IP-based Networks and Services. These contributions covered several topics including historical perspectives on network survivability, traffic engineering and queueing theory as it relates to packet networks, and terms and definitions for the new report. An ITS engineer currently serves as the editor of this Technical Report.

In FY 2001 ITS will continue 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 2001 will focus on survivability of IP and other packet-based networks as well as address NS/EP concerns in wireless networks. Network modeling and simulation tools will be used extensively to validate proposed methods for network survivability enhancement.



Survivable Networks

System diagram for Network Survivability and Restoration project.

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Networking Technology

Outputs

- Definition of structured planning process for telecommunication and information technology networks.
- Identification and description of automated tools to assist network planners.
- Handbook for telecommunication and information technology network planning.

The Institute has a rich history of performing telecommunication planning and assessment studies for other organizations – our customers. But, the complexity of today's telecommunication and information technology (hereafter referred to as "telecom and IT") requirements, and the technology available to satisfy those requirements, create demands for enhanced sophistication in the methodologies and tools used to perform these studies. The Networking Technology project has defined a structured planning process for such studies, examined many automated tools that *could be used* in conducting such studies, and identified those tools determined most likely to provide the greatest benefits. The results, conclusions, and recommendations are contained in a document entitled *A Telecommunication and Information Technology Planning Process*, intended to become an NTIA Report.

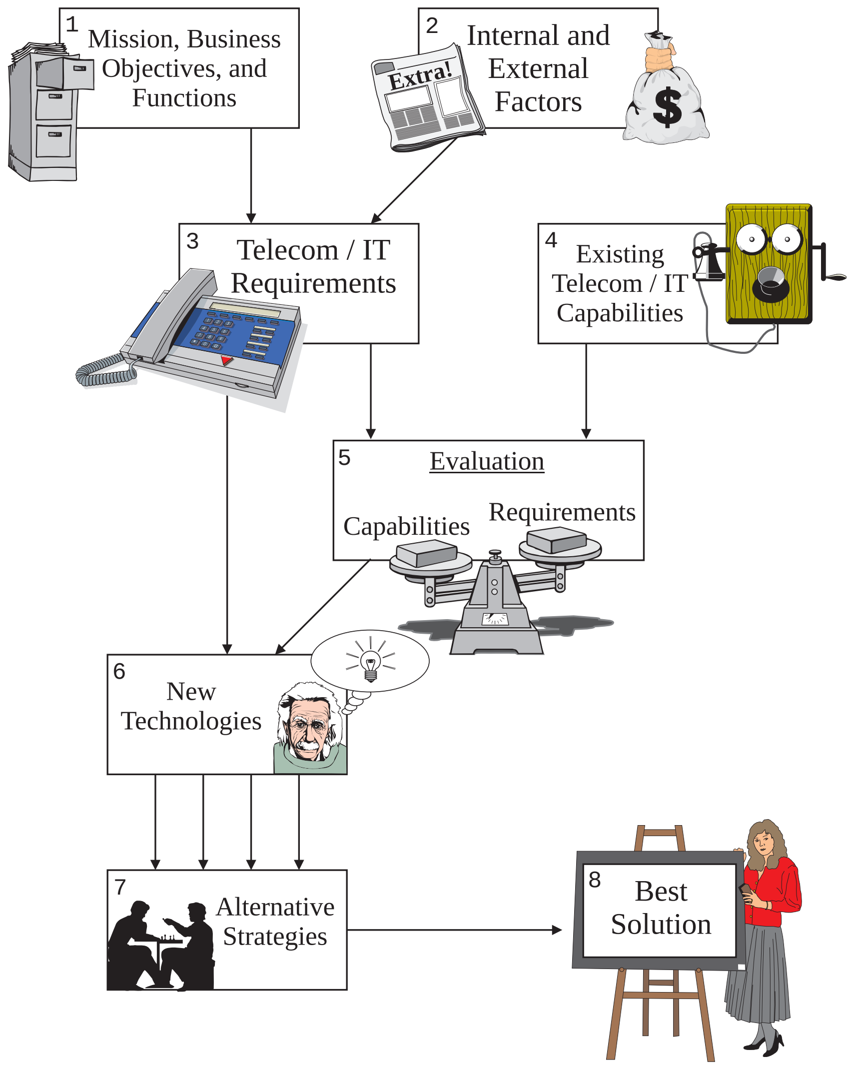
The eight steps of the structured planning process are illustrated in the Figure. The first step is to identify mission, business objectives, and functions of an organization for which planning is being undertaken. This information *about* an organization must be obtained from the organization, working with its managers. The second step is to identify and assess all internal and external factors that will influence the organization's telecom and IT requirements. There may be constraints such as available funds, internal policies, or external regulations (local or governmental). The third step is to use the information from the first two steps to define the organization's functional requirements (requirements for *types of capabilities*, not *specific capabilities* which are defined in step 7).

Next, the organization's existing telecom and IT capabilities – systems, networks, services – and practices must be identified and defined. The fifth step is to evaluate the existing capabilities and determine if the requirements *can be satisfied* – through modified utilization and practices, perhaps. The likely conclusion is that the requirements *cannot be satisfied* with existing capabilities. Step 6, then, is identification of (new) technologies that can satisfy the organization's telecom and IT requirements. In step 7, alternative strategies/solutions for satisfying the requirements are constructed and evaluated. Finally, step 8 is the selection and recommendation to the organization of the "best" solution for satisfying their telecom and/or IT requirements. This solution, with an Implementation Plan, must be presented to the organization's managers for approval.

There are many automated tools available to assist planners in the work they must do to identify and evaluate existing capabilities (steps 4 and 5) and while constructing and evaluating alternative solutions (step 7) to satisfy requirements. These automated tools are of two general types: (1) tools for discovering the topology of existing networks and monitoring utilization, availability, and traffic features of these networks, and (2) tools for modeling a network and predicting its performance. Evaluations of expected network performance may be based on discrete-event simulation, analysis-based modeling, or a combination (hybrid) of these technologies.

Much of the research done in FY 2000 has been to identify available tools for the purposes noted, select a subset of those tools considered most likely to enhance ITS' capabilities for network analysis (particularly as a part of planning and assessing networks to satisfy requirements for telecom and IT services), and research information to more thoroughly understand and describe (evaluate) the capabilities of this subset of tools. Nearly 70 prospective tools were identified and studied briefly. Detailed technical information has been prepared for 26 tools (representing 16 tool-developing organizations) – 20 network modeling and simulation tools and 6 network discovery and monitoring tools. The results of this research will be published as an ITS handbook.

Telecom / IT Planning Steps



Steps that define a structured telecommunication and information technology planning process.

As a result of various synergistic relationships in ITS projects and programs, the Institute has operational software for three of the tools identified (not necessarily the best – nor the worst – tools to satisfy the Institute's goal of developing enhanced capabilities for network analysis). The first tool has extensive capabilities for creating a network model and conducting a discrete-event simulation to predict the network's performance. The second is a network discovery and monitoring tool purchased to assist in monitoring and managing the ITS LAN. The third is the Communication System Planning Tool (CSPT, described on pp. 46-47), developed at ITS for modeling and predicting the performance of modern wireless systems and networks as part of our research work to develop improved propagation models and enhanced capabilities for assisting our customers in solving their telecom and IT problems.

The Institute is considering acquiring two additional types of tools to further enhance its capabilities for telecom and IT network analysis and planning. These are as follows: (1) an analysis-based (or hybrid technology) network modeling and analysis tool (to complement the discrete-event simulation tool that the Institute currently owns) and (2) a network monitoring tool to measure the characteristics of traffic in an existing network.

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Public Safety Telecommunications Interoperability Standards

Outputs

- Voice and data encryption standards.
- User requirements documents for wireless telecommunications 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 fail to communicate with each other during multi-jurisdictional events. Even when calamities do not occur, however, daily interoperability problems continue to plague public safety agencies nationwide. ITS is conducting a technical program aimed at providing effective interoperability and information sharing among dissimilar public safety telecommunications and information technology systems. The key to the program is the identification and/or development of interoperability standards to allow local, State, and Federal agencies to exchange information, without requiring substantial changes to internal systems or procedures. The ITS program is sponsored by three Federal agencies: the National Communications System (NCS), NTIA, and the National Institute of Justice (NIJ) (through its Advanced Generation of Interoperability for Law Enforcement (AGILE) Program). The three projects are 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, in progress, is developing a set of interoperability standards for narrowband (6.25 kHz) digital LMRs; standards defining TDMA radios with an equivalent 6.25 kHz/channel efficiency may be developed. ITS efforts have mainly supported Phase 2. Phase 3 (sometimes referred to as "Project 34") has also begun, and is focused on the development of standards for wideband mobile data applications.

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 ITS 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 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

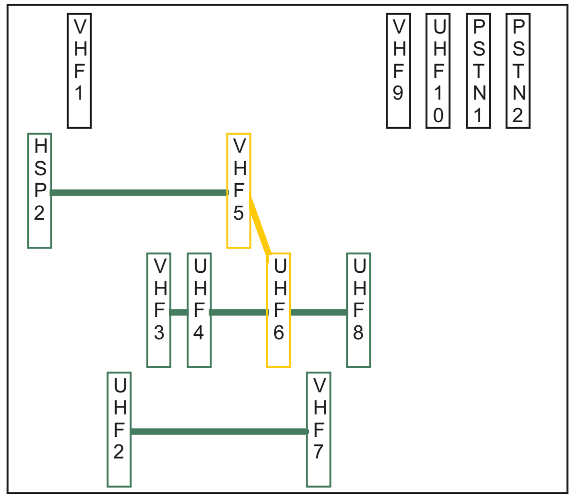
As a result of the findings from the NTIA and FCC Public Safety Wireless Advisory Committee's (PSWAC) Final Report, NTIA established the Public Safety Program (PSP) to follow up on the PSWAC recommendations. ITS has provided some of the technical engineering support to develop standards and specifications 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 the data aspects of OTAR for encryption. ITS is presently developing the test specifications for Data Services, and Trunking. ITS has also provided technical support to the development of the Inter-RF Sub-System 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.

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 standards development organizations 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 NIST's Office of Law Enforcements Standards (OLES), one of NIJ's technology centers.

Before NIJ Standards could be identified/developed and adopted, a great deal of preparatory work was necessary. The results of the work to date have been incorporated into two strategic plans for wireless and information technology that will guide the standards selection and adoption process. An ITS process plan delineates the work, including review and analysis of: (1) user requirements for wireless communications and information technology applications; (2) current and planned assets — legacy systems, replacement plans, and status of jurisdictions' systems for wireless communications and information technology; (3) internal and external factors (e.g., State privacy laws on sharing PS and CJ information gathered on individuals); and (4) technologies appropriate to satisfying the requirements. In addition, the formal structure and procedures of the AGILE standards organization must be thoroughly documented. ITS has reviewed and analyzed the four items listed above, and has produced the standards organization and procedures manual. The formal AGILE standardization process will now begin.

While formal NIJ standards are being adopted (over several months), interim interoperability measures (including devices) are also being considered and analyzed. One such device used to assist neighboring jurisdictions and agencies with differing land mobile radio equipment is an audio gateway switch that allows wireless communications to be combined at a common denominator, namely the audio baseband. Thus, radios that operate within different parts of the radio spectrum, that use different modulation and access techniques, or that use analog versus digital encoding, can interoperate by exchanging the received audio from one radio technology and using it as the source audio for one or more other transmitters of differing technologies. An example of the utility of such a gateway is shown in the Figure. Three radio networks were created by the gateway in the Figure. Radios on UHF2 and VHF7 comprise one network; radios on VHF3, UHF4, UHF6, and UHF8 comprise a second network; radio VHF5 and the local dispatcher or commander console-handset interface on HSP2 comprise a third network; and finally, radios VHF1 and VHF9 as well as Public Switched Telephone Network interconnect devices are presently unused in the example configuration. This example shows how a gateway can be used to bridge different radio networks to provide more interoperability among the radio systems and the agencies that use the radios. ITS conducted a series of laboratory evaluation measurements on one commercially available audio gateway and provided the results to the PS/CJ community through AGILE. More evaluations are planned on similar telecommunications devices and equipment.



An audio gateway switch that has bridged different radio networks for interoperability purposes.

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Railroad Telecommunication Planning

Outputs

- Demonstration of new advanced radio technology and infrastructure along the Pacific northwest rail corridor in support of the Federal Railroad Administration's and Oregon Dept. of Transportation's high-speed rail pilot program.

Newly designed digital land mobile radio (LMR) equipment, complying with TIA-102 standards, employs narrowband strategies and radio channel trunking solutions in order to more efficiently utilize radio spectrum resources. The railroads are currently addressing migration and compatibility issues associated with introducing this new equipment 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, has commenced testing this new narrowband digital radio equipment along the Pacific northwest rail corridor (Figure 1). Audio samples were transmitted over the new system between base station and locomotive, and received transmissions recorded in both conventional analog FM and new digital C4FM modulation formats for analysis. These audio samples were cataloged by the geographic location of the locomotive and can be aurally reviewed by visiting this website:
http://www.its.bldrdoc.gov/FRA6380/odot/testdata1

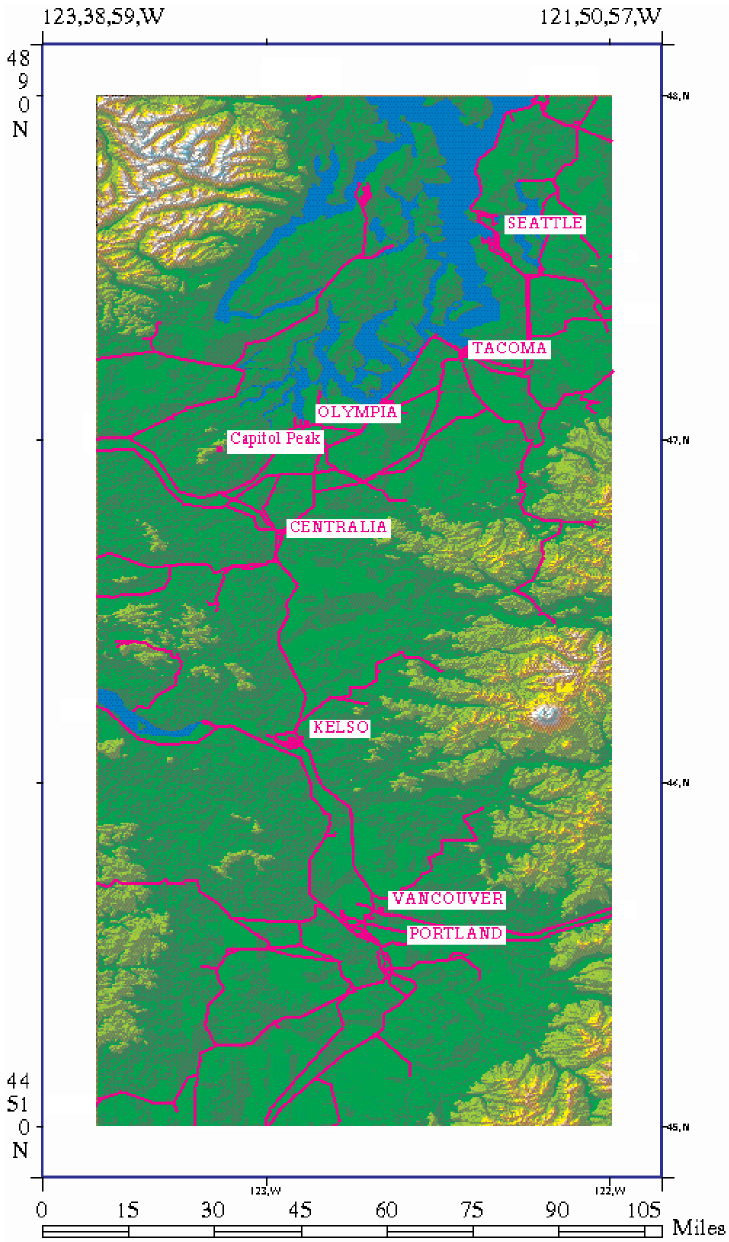

Figure 1. Pacific northwest rail corridor.

Several towns and cities are indicated on the map, along with the location of the Capitol Peak base station site utilized during this test. Audio samples can be reviewed by clicking on the map at a railroad track location. If a set of audio samples was collected at that location, textual and graphical information pertinent to the site, and additional hyperlinks to launch the audio files, will be displayed. An example web page is shown in Figure 2.

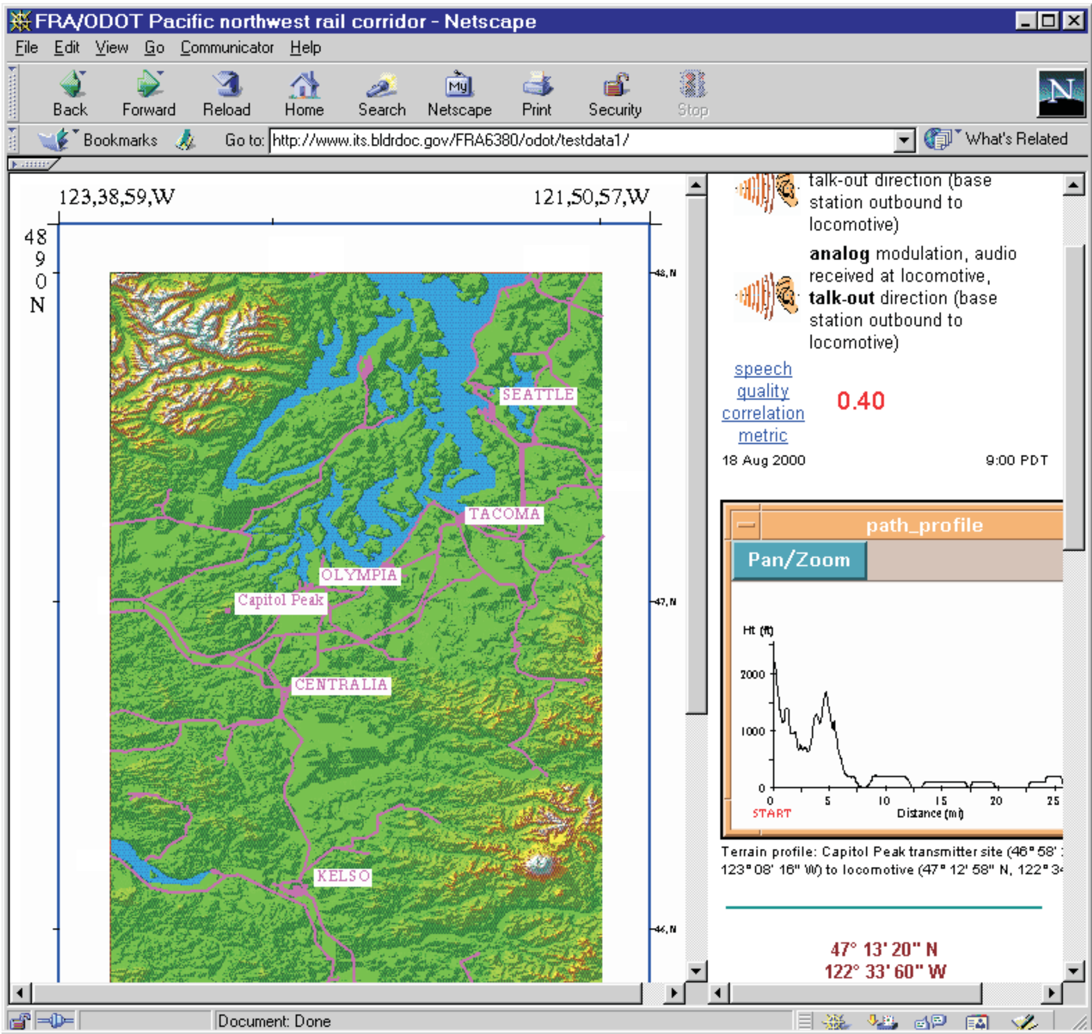

Figure 2. Example web page. Clicking on the map at a railroad track location where audio samples have been collected causes links to those audio files and other pertinent information to display on the right of the screen.

Some of the audio files were evaluated for audio quality, utilizing the measuring normalizing blocks (MNB) algorithm described in NTIA Report 98-347, “Objective estimation of perceived speech quality using measuring normalizing blocks” (Voran 1998; see Publications Cited, p. 102). A numeric score for audio quality is given. In addition, the website visitor is provided an opportunity to listen to the relative quality of traditional analog FM transmissions versus the newer digitally-modulated transmissions.

Other work in FY 2000 included channel occupancy measurements of the railroad VHF band in the Portland, Oregon area. Upon implementation of trunking within the Portland railroad arena, a comparison between the channel usage statistics in trunked and non-trunked modes will demonstrate the improvements in spectrum efficiency that are achievable by incorporating trunking technology in LMR networks. Analysis of this data is ongoing, and results of this work will be posted at the web site mentioned above, and documented in a formal NTIA publication, anticipated to be published in FY 2001.

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

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Telecommunication Terminology Standards

Outputs

- Draft of Proposed ANS *Telecom Glossary 2000*, on the web.
- Automated web-page and e-mail procedures for updating FED-STD-1037C, *Glossary of Telecommunication Terms* (1996).
- Draft NTIA Report, "Committee Development of an Interactive Web Glossary."

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. ITS, under 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 telecommunication glossaries.

FY 2000 work involved three major activities: (1) coordinating a standards project proposal and related agreement with Committee T1 (Telecommunications) and its sponsoring organization, the Alliance for Telecommunications Industry Solutions (ATIS), (2) developing techniques for updating the glossary using the web, e-mail, and "virtual meetings," in lieu of the traditional face-to-face standards meetings, and (3) preparing new entries to update the glossary's contents on security, Internet/web technology, and photonics, and to incorporate T1-standardized telecommunication terms.

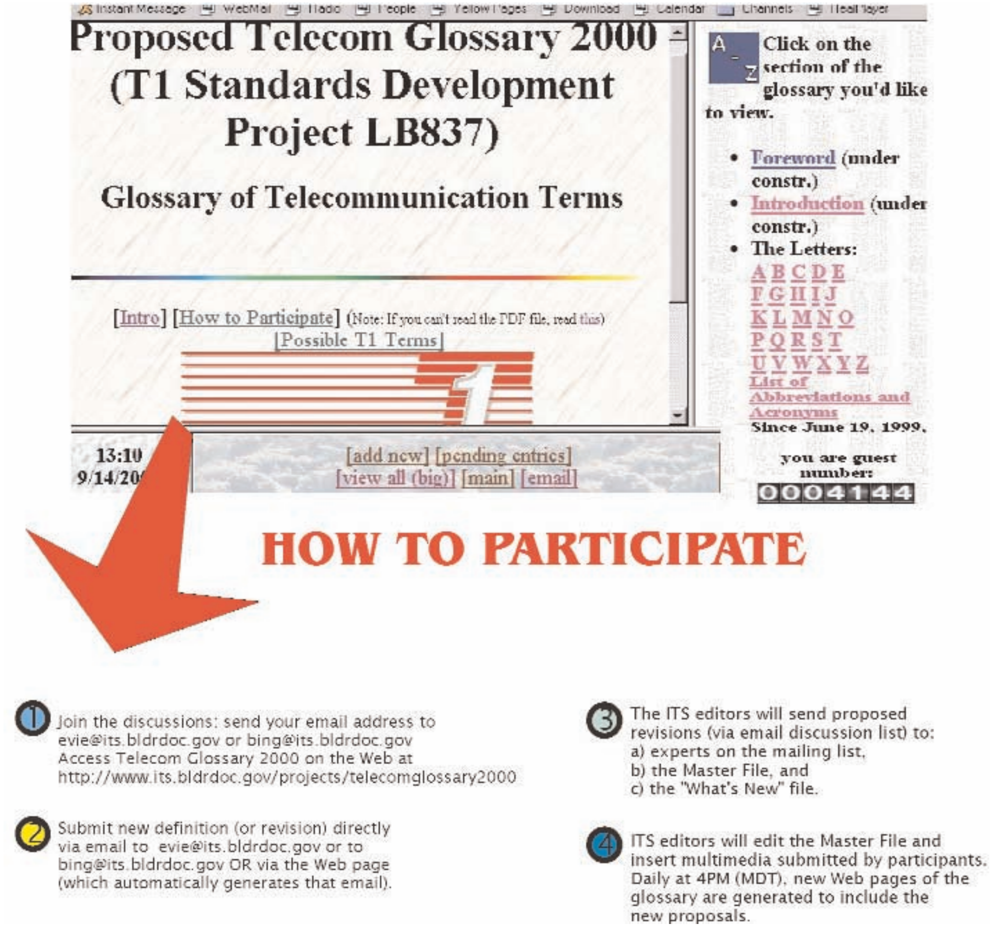
At the suggestion of NCS, ITS explored with three ANSI-accredited industry standards organizations their possible cooperation in joint industry/government development of the revised glossary and its proposal as an American National Standard (ANS). ITS selected Committee T1 as its preferred industry partner in the development and coordination of the revised glossary. After coordination with ATIS and the Committee T1 Advisory Group, ITS participants formally presented a Standard Project Proposal on the glossary project to Technical Subcommittee T1A1 for action at its January 2000 meeting. T1A1 approved the proposal for T1 Letter Ballot at that meeting, and Committee T1 approved the Letter Ballot on March 3, 2000. Reflecting this commitment, ITS updated the glossary Home Page as indicated in the Figure, and ATIS updated its Home Page to indicate links to the *Telecom Glossary 2000* project web site. ATIS also announced the project via a press release. Technical Subcommittee T1A1 formed an Ad Hoc Group, convened by an ITS staff member, to coordinate and advance the project.

The proposed ANS, *Telecom Glossary 2000*, will enhance FED-STD-1037C by adding terminology addressing new technology areas and will eliminate government-specified material and obsolete terms (e.g., "Mosaic"). The ANS will also add more than 900 terms defined in T1-developed standards, requirements, and reports.

The project is being accomplished using web-based processes, including on-line HTML revision of definitions, e-mail communication and data entry, and "virtual meetings." Instructions on how to participate in the project were provided to participants in the *Telecom Glossary 2000* project on the website, as summarized in the lower portion of the Figure. During FY 2000, ITS staff members developed and presented to the revision committee several innovative techniques for automated e-mail and web entry of proposals for draft definitions. These electronic revision methods have several advantages:

- **Wider reach:** The revision achieves a broader exposure due to the web-review techniques.
- **Cheaper:** The cost is less because participants are not required to travel to meetings.
- **Faster:** Revision is faster and participation is more efficient because participants can review terms intermittently, between other tasks.
- **Focused participation:** Participants can focus their revision efforts on only those fields of interest and expertise.

During FY 2000, ITS developed a draft NTIA Report that describes and evaluates the on-line standards development process.



Web-based development of the draft of Telecom Glossary 2000.

In addition to the 5800 entries already in FED-STD-1037C, more than 2100 new entries have been proposed, including 1250 new entries of (1) web/Internet terms (e.g., cookies, portal, web browser); (2) security terms (including INFOSEC definitions from NSTISSI No. 4009); and (3) photonics terms (e.g., photonic computer, photonic switching); as well as 900 entries from T1 standards and reports. During FY 2000, ITS also upgraded the website to bring it into compliance with the World Wide Web Consortium's (W3C) Web Content Accessibility Guidelines for producing web pages with accessibility to people with disabilities. These additions and enhancements will keep the standard abreast of rapidly changing technologies, make it more accessible, and augment its contents to reflect both industry and government needs.

The end product of the work will be a proposed ANS, in the form of a web-based HTML document comprising more than 7500 hyperlinked terms and definitions. The document will be equipped with its own search engine, optimized for glossary application, similar to that provided in the web-accessible version of FED-STD-1037C. That earlier version will continue to be available during the revision process at:
http://www.its. bldrdoc.gov/fs-1037/
The draft of the newer, updated glossary, *Telecom Glossary 2000*, can be viewed on the Web at
http://www.its.bldrdoc.gov/projects/telecomglossary2000/
The revised standard will be made accessible free of charge at the ATIS/T1 web page and at
http://www.atis.org

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ITS engineers from the Telecommunications Engineering, Analysis, and Modeling Division discuss the predicted coverage of wireless communications using the most recent propagation models developed at ITS by Telecommunications Analysis (TA) Services. Models developed at ITS are made available through analysis programs located online at TA Services at http://www.its.bldrdoc.gov/tas/ (photograph by F.H. Sanders).

Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis and Modeling Division conducts studies in these three areas for wireless and wireline applications.

Engineering work includes assessment of the components of telecommunications systems; evaluation of protocol and transport mechanism effects on network survivability and performance; and assessment of the impact of access, interoperability, timing, and synchronization on system effectiveness in a national security/emergency preparedness environment.

Analysis work is often performed in association with Telecommunications Analysis (TA) Services, which offers analysis tools online via the Internet. In addition, ITS can provide custom tools and analyses for larger projects or specific organizations.

Modeling has been one of ITS's greatest strengths for many years. Propagation models include various terrain databases and other data. Adaptations of historic models, and those for more specialized situations have been developed and enhanced.

Areas of Emphasis

ENGINEERING

NS/EP Requirements for Wireless Networks The Institute promotes technology advancement in the telecommunication industry and improvements to the access and interoperability of wireless systems supporting NS/EP needs. Sponsors include the National Communications System (NCS).

Third Generation HF Modem Testing As part of its HF Program, the Institute develops effective ways of evaluating and assessing telecommunications equipment. The project is funded by NCS and NTIA.

Tandem Vocoder Testing The Institute tests the performance of vocoders, both singly and in different combinations of tandem configurations, to evaluate overall voice quality. 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.

Mobile IP Network Access Technologies The Institute examines the application of Internet protocol (IP) to wireless terrestrial and satellite links, 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 access to its research results, models, and databases supporting applications in wireless telecommunications system design and the evaluation of systems. These services are funded by fee-for-use and fee-for-development charges.

Geographic Information System Applications The Institute has developed a menu-driven propagation model using geographic information system (GIS) formats. This work was funded by DOD and ARINC.

MODELING

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

Time-hopped UWB Simulation Analysis for BWCF In coordination with NTIA/OSM, the Institute models and simulates ultrawideband (UWB) systems from an analytic description to determine bandwidth correction factor (BWCF) and the interference effects of these devices on victim receivers. Projects are funded by NTIA.

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.

NS/EP Requirements for Wireless Networks

Outputs

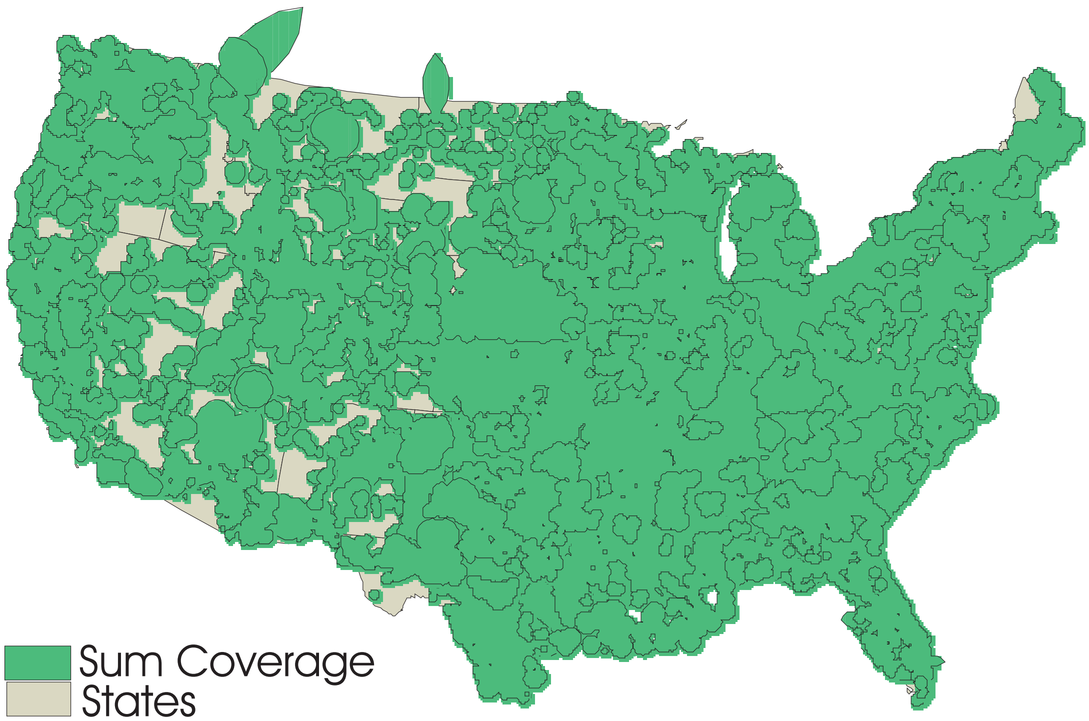
- Technical assessment of wireless priority services for NS/EP users.
- TIA TR45 Standard Requirements Document.

The National Communications System (NCS) is responsible for planning and implementing initiatives to enhance national security and emergency preparedness (NS/EP) telecommunications under a wide range of operational scenarios. To fulfill this responsibility effectively, NCS must have a systematic process for defining comprehensive NS/EP telecommunications needs, evaluating relevant communications technologies, and specifying those technologies that economically meet the defined NS/EP communications requirements. One such requirement is priority access service. Currently, priority access service exists in the wireline public switched telephone network (PSTN) via the Government Emergency Telecommunications Service (GETS) program. The wireless augmentation of priority access service is the objective of the current ITS tasking, which will provide mobile users with the same capability as their wireline counterparts.

During FY 2000, ITS participated in two efforts pertaining to NS/EP requirements for wireless networks. The first effort was to perform a technical assessment of the wireless priority services for NS/EP users. This consisted of researching a wide range of wireless technologies. The report produced from this assessment illustrates both the comprehensive technologies, and the physical system specification of essential NS/EP wireless communications capabilities. The report addresses the technology baseline, the status of the technology, some relevant forecasts, and the issues of priority integration for each of the related wireless technologies.

The report begins by examining several possible disaster scenarios requiring priority access service, and assigns a degree and duration of congestion to each scenario. Each scenario is then related to appropriate technologies that would provide NS/EP communications. Wireless technologies presented include commercial wireless telephony, mobile satellite systems, land mobile radio, personal digital assistants/pagers, high altitude communication technologies, multimode handsets, software-configurable radios, telephony over wireless IP networks, wireless ATM (asynchronous transfer mode), HF radio, and security. The Figure shows a coverage plot for CDMA (code division multiple access), TDMA (time division multiple access), and GSM (global system for mobile) technologies in the contiguous United States. From this plot, NS/EP users can determine areas where wireless coverage exists, as well as areas where other wireless technologies may be needed to augment the commercial wireless network in the aftermath of an NS/EP event.

The report provides advice and guidance for NCS on a strategy for achieving wireless priority access service. ITS concluded that NCS should continue to promote the basic GETS call program in both the wireline and wireless PSTN. For commercial wireless networks, the Wireless Intelligent Network (WIN)-based radio channel access and egress queuing should be pursued, since this is a good tradeoff of increased wireless high probability of connectivity (HPC) call functionality and, potentially, a vendor-independent standard for NS/EP responders. In addition, ITS concluded that the Service Control Point (SCP)-based GETS PIN database can be used to provide HPC functionality for both today's commercial land-based wireless networks and future wireless networks that will interwork with the PSTN. Each of these approaches can help to satisfy a pressing, near-term need for wireless and wireline priority access service.



Total wireless computed coverage (800 MHz) in the contiguous United States.

ITS' second major effort in this area during FY 2000 was to assist NCS in developing a Standard Requirements Document (SRD) for standardizing a priority access service in commercial wireless networks employing a WIN-based approach. This standardization effort will be accomplished through the Telecommunications Industry Association (TIA) TR45 standards committee.

Under TR45, ITS will participate in the TR45.2.5 WIN Working Group to standardize the WIN implementation of priority access service. This group is standardizing the event and trigger detection points at which transfer of control from the mobile switching center (MSC) to a WIN service logic can occur, in the WIN Basic Call State Model (BCSM). The WIN BCSM's provide a high-level vendor independent abstraction of call and connection processing. This, in turn, implies uniform call and connection processing across multiple vendors' implementations of these functions. As such, this group provides a forum for NCS to achieve the goal of providing a uniform wireless priority access service.

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Third Generation HF Modem Testing

Outputs

- Results of modem performance testing published in an industry journal.
- Software system for the automation of multiple repetitive tests.

During national security/emergency preparedness (NS/EP) situations, terrestrial communication systems may be unavailable or inoperable due to damage or overloading. High frequency (HF) systems offer the capability of voice or data communications over long distances without the restrictions of higher frequency systems. Data communication has increased in importance due to the complexity of information and the need for reduced probability of misunderstanding (information corruption). Since the government traditionally has depended on the large reserve of HF operators and systems in emergency situations, a common, efficient, HF data exchange method is needed. The National Communications System (NCS) sponsored ITS to test and compare the newest HF modem protocols. The Federal Emergency Management Agency (FEMA) will use the test results to determine which protocols could be used to serve as a common exchange with the amateur community in the event of a national emergency.

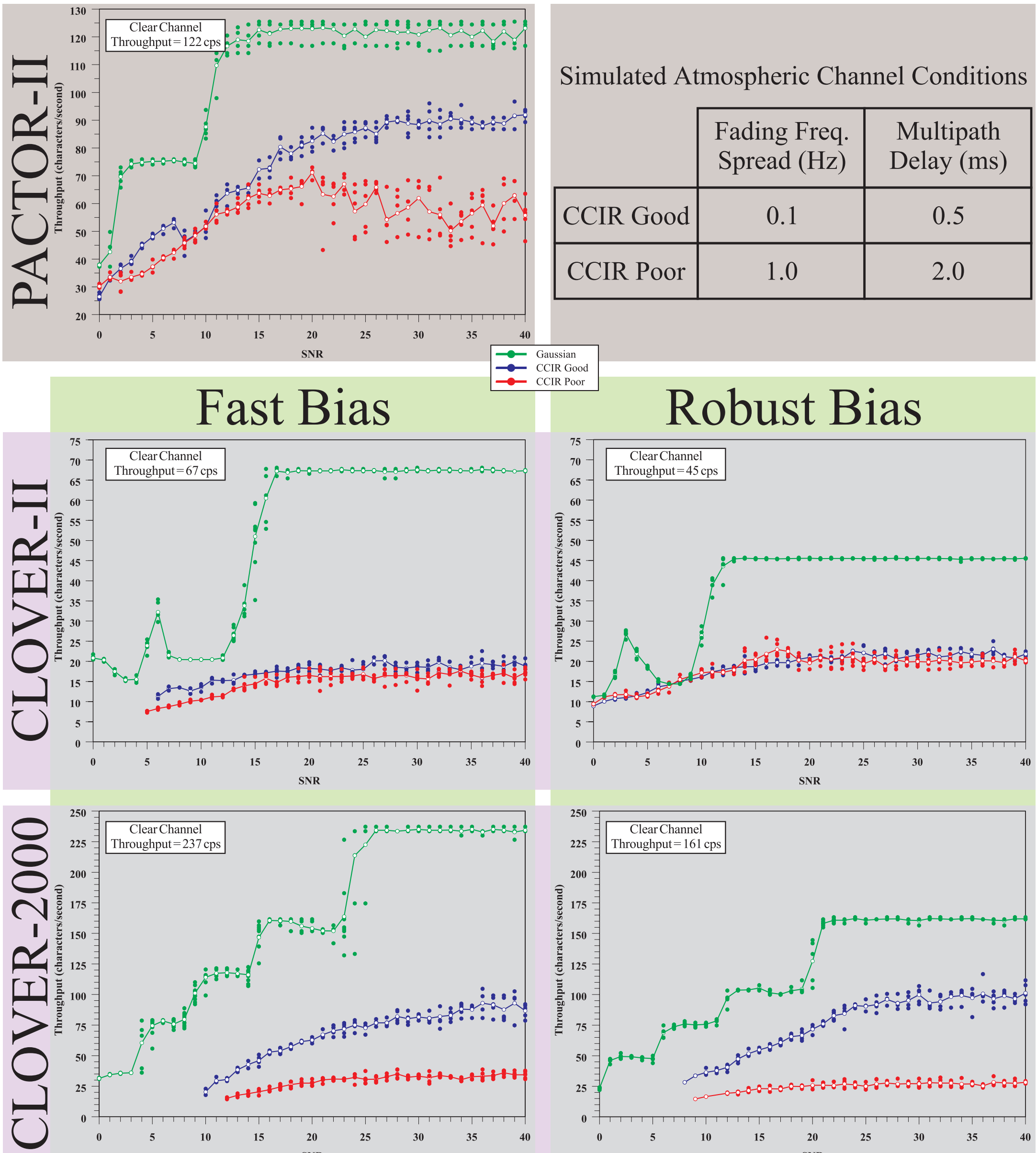
To obtain greater data throughput and higher bandwidth efficiency, HF digital modem protocols have been enhanced with better error correction and more advanced modulation schemes, resulting in reduced data errors and less susceptibility to atmospheric degradation. PACTOR-II improves on the widely used PACTOR protocol, while CLOVER-2000 is the newest generation of the CLOVER family of protocols. In previous testing (Riley et al., 1996; see Publications Cited, p. 102), ITS tested what could be considered the second generation of protocols (PACTOR, AMTOR, G- TOR, and CLOVER-II) as well as the then newly released PACTOR-II.

In the time elapsed since those first tests, much had changed in terms of available computing power and software capabilities. Consequently, the test environment was significantly different than when the first tests were performed. To verify the consistency of results between the two tests, two protocols from the first tests, PACTOR-II and CLOVER-II, were re-tested during the second series of tests. PACTOR-II can be considered a third-generation protocol, comparable to CLOVER-2000. CLOVER-II was re-tested because it was implemented in new hardware.

The test configuration consisted of two modems connected back-to-back through two atmospheric simulator channels. The HF channel simulator consisted of the Watterson channel model implemented in two digital signal processing (DSP) cards plugged into one personal computer. The two modems and the channel simulator all are controlled by a second, test controller, computer. The modems were configured to operate in automatic repeat request (ARQ) mode to assure error-free data transmission and eliminate the need to measure bit-error-rate. A 15,183 byte file was passed between the two modems, under a variety of simulated atmospheric conditions, to calculate throughput. The file was transmitted five times for each channel simulator setting to assure statistical reliability. Clear channel conditions were used to confirm the test setup. Gaussian noise of varying levels (0 to 40 dB in 1 dB steps) was used to confirm the modem's operation, and to enable comparison with other published test results. Finally, CCIR* Good and Poor conditions, with varying levels of Gaussian noise, were used to approximate actual atmospheric conditions.

Unique to the CLOVER protocol was a bias setting. Robust bias implemented 60% data transmission and 40% error correction coding; fast bias implemented 90% data transmission and 10% error correction coding. Fast bias offered the highest raw data throughput, but corrected the fewest errors and required more packet retransmissions during degraded conditions. As a result, the robust bias mode occasionally exhibited higher throughput than the fast bias mode.

*CCIR stands for the International Radio Consultative Committee, now known as the International Telecommunications Union Radio Communications Sector (ITU-R); however, the acronym CCIR is still used in certain situations



	Fading Freq. Spread (Hz)	Multipath Delay (ms)
CCIR Good	0.1	0.5
CCIR Poor	1.0	2.0

Throughput testing results under varying atmospheric channel conditions

The Figure shows the throughput results of all three protocols under Gaussian noise, CCIR Good, and CCIR Poor channel conditions. All three protocols use multiple modulation schemes which are dynamically selected depending on the detected re-transmission demand. This is exhibited in the Gaussian noise curves. As the channel becomes more degraded, simpler modulation techniques are chosen and lower throughput is measured. Note that, for the sake of readability, a different vertical scale was used for each of the three protocols. In comparing the results, the fact that CLOVER-2000 uses a 2 kHz bandwidth, while CLOVER-II and PACTOR-II both use a 500 Hz bandwidth, should be considered if bandwidth efficiency is a concern.

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Tandem Vocoder Testing

Outputs

- Quality evaluation of widely used vocoder technologies.
- Tandem vocoder test results.

Vocoders are used to minimize transmitted bit rate (and the associated transmission bandwidth) in digital voice communication systems. Bandwidth is an especially precious commodity in wireless communication systems, since wireless service providers must normally accommodate many users within a fixed spectrum allocation. Vocoders allow voice to be transmitted efficiently over circuit-switched or packet-switched digital networks. Vocoders also make spectrum-efficient wireless voice communications possible, and they allow the digitized voice stream to be encrypted. It is a goal of vocoders to transmit the highest quality speech using the least amount of bandwidth. This should be accomplished using the lowest possible complexity to reduce implementation cost and vocoder processing delay.

There are many different types of vocoders, designed to work with the many different types of communication systems. The various types of public safety communication systems require speech decoding and encoding at system interfaces to enable interworking. A vocoder will be required for each digital system; and, in addition, it will be required that the vocoders be connected in various “tandem configurations.” Vocoder manufacturers generally focus their testing on individual products, often with little consideration of tandem configurations. The objective of this program, sponsored by the National Communications System (NCS), was to test the voice quality of commonly-used vocoders in different tandem configurations.

Tests were performed first on individual vocoders, and then on pairs of vocoders in tandem. The latter testing allowed the degradation from tandem vocoder combinations to be evaluated. Several commonly used vocoder technologies were investigated during this test. These technologies included: code excited linear prediction (CELP), vector-sum excited linear prediction (VSELP), Qualcomm code excited linear prediction (QCELP), improved multi-band excitation (IMBE), advanced multi-band excitation (AMBE), and algebraic codebook excited linear prediction (ACELP). All of the vocoders tested were hardware implementations with the exception of the ACELP vocoder, which was a software implementation.

Figure 1 shows a block diagram of the test setup used to evaluate the vocoders. A standardized objective voice quality assessment algorithm, developed (and patented) by ITS, was used in this testing. The algorithm was implemented using the ITS-developed Audio Play, Record, and Estimate (APRE) software tool. APRE estimates the voice quality of a device under test (DUT) by playing a digital voice input file to the DUT and recording the DUT input and output signals in digital voice files on a personal computer. It then performs a comparison of the voice files and provides an auditory distance (AD) score that indicates the degradation introduced by the DUT.

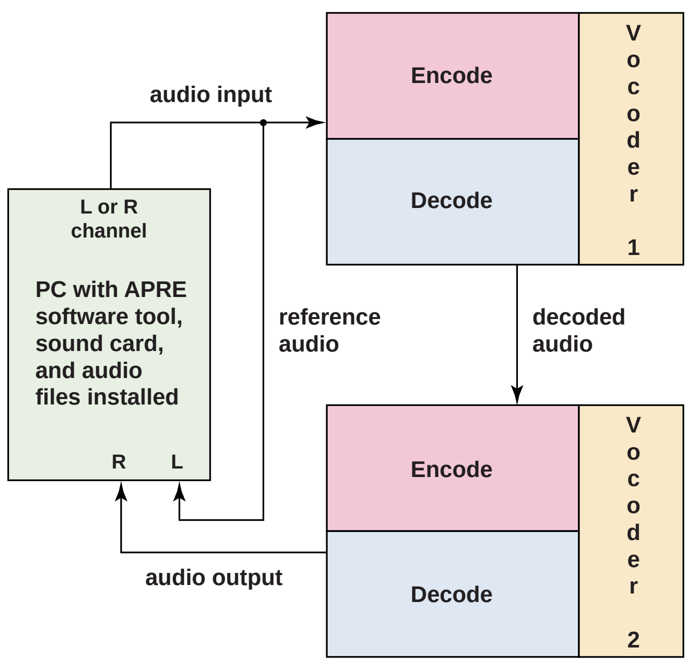

Figure 1. Block diagram of the test setup used to evaluate the vocoders.

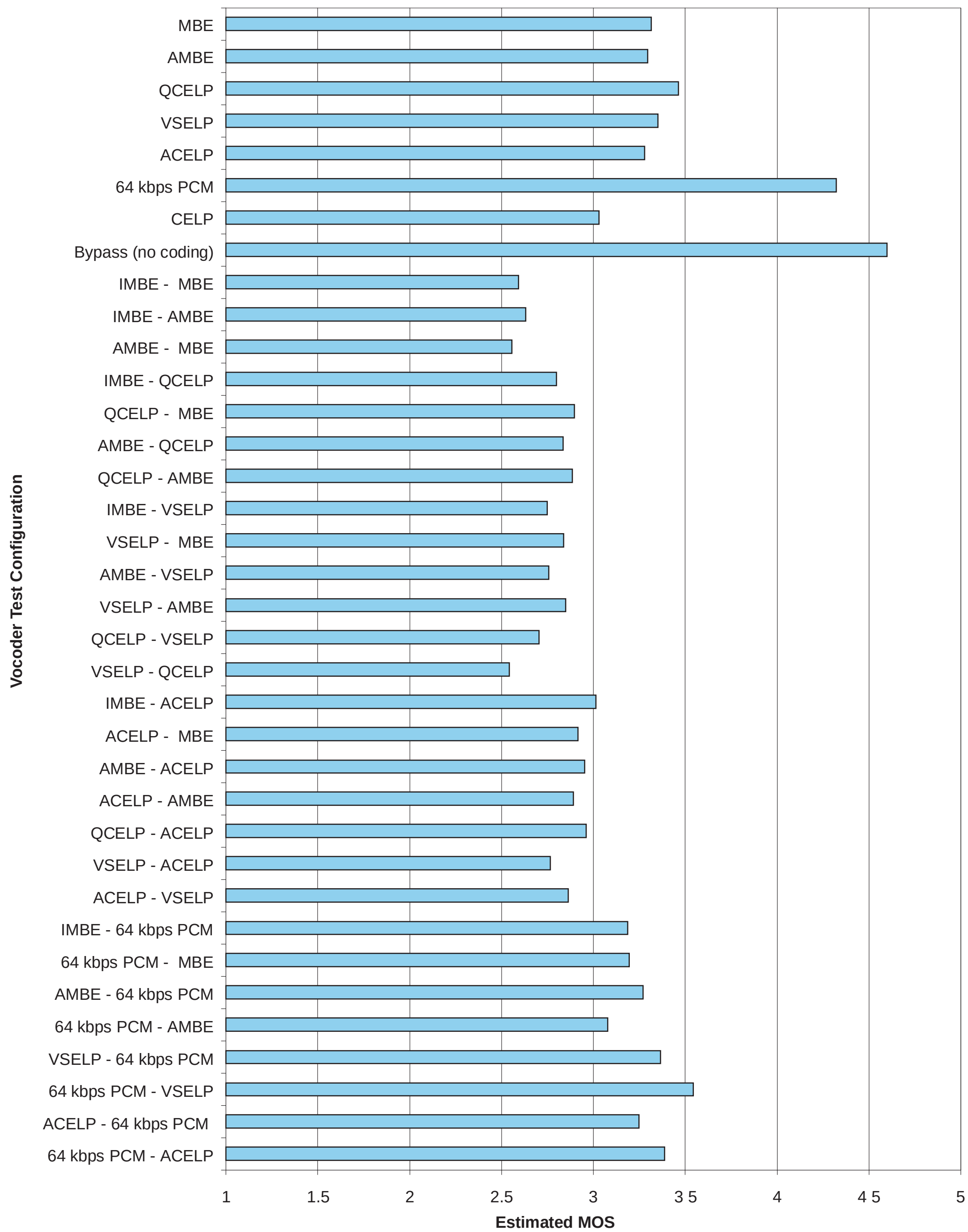

Figure 2. Estimated MOS for tested vocoder configurations.

An APRE parameter called L(AD) was used to compare the various vocoder configurations. L(AD) can be converted to estimated Mean Opinion Score (MOS), which is a common method for subjectively rating vocoder voice quality. It has been demonstrated that MOS estimates developed by APRE correlate well with subjective test results for a wide variety of conditions, although they cannot be considered to be replacements for formal subjective tests. Figure 2 shows the MOS values for the tested vocoder configurations.

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PCS Applications

Outputs

- Interference model for the various PCS technologies currently in use, as well as proposed technologies for two and a half generation (2.5G) and third generation (3G) systems.
- Contributions to industry-developed inter-PCS interference standard for predicting, identifying, and solving interference related problems.

Personal communications services (PCS) has become the choice for mobile voice and data communication and is a significant resource for emergency recovery of telecommunication services following a natural disaster. PCS networks of varying technologies from many providers cover a majority of this nation's area. Most areas are serviced by multiple, non-interoperable systems which function independently but use the same radio frequency bands and infrastructure (base station sites and towers). This joint use of spectrum is one source of interference. When damage occurs to the terrestrial telecommunication system, users tend to migrate to cellular resources, resulting in another source of interference. This sudden influx of traffic by private, commercial, civil, and Federal users results in wireless system overloads, interference, and disruption of service in the affected area. National security/ emergency preparedness (NS/EP) planners and network operators must understand these interference effects to operate effectively in an overloaded environment. To facilitate their understanding, it is necessary to characterize the interfering environment caused by large numbers of active users and competing technologies.

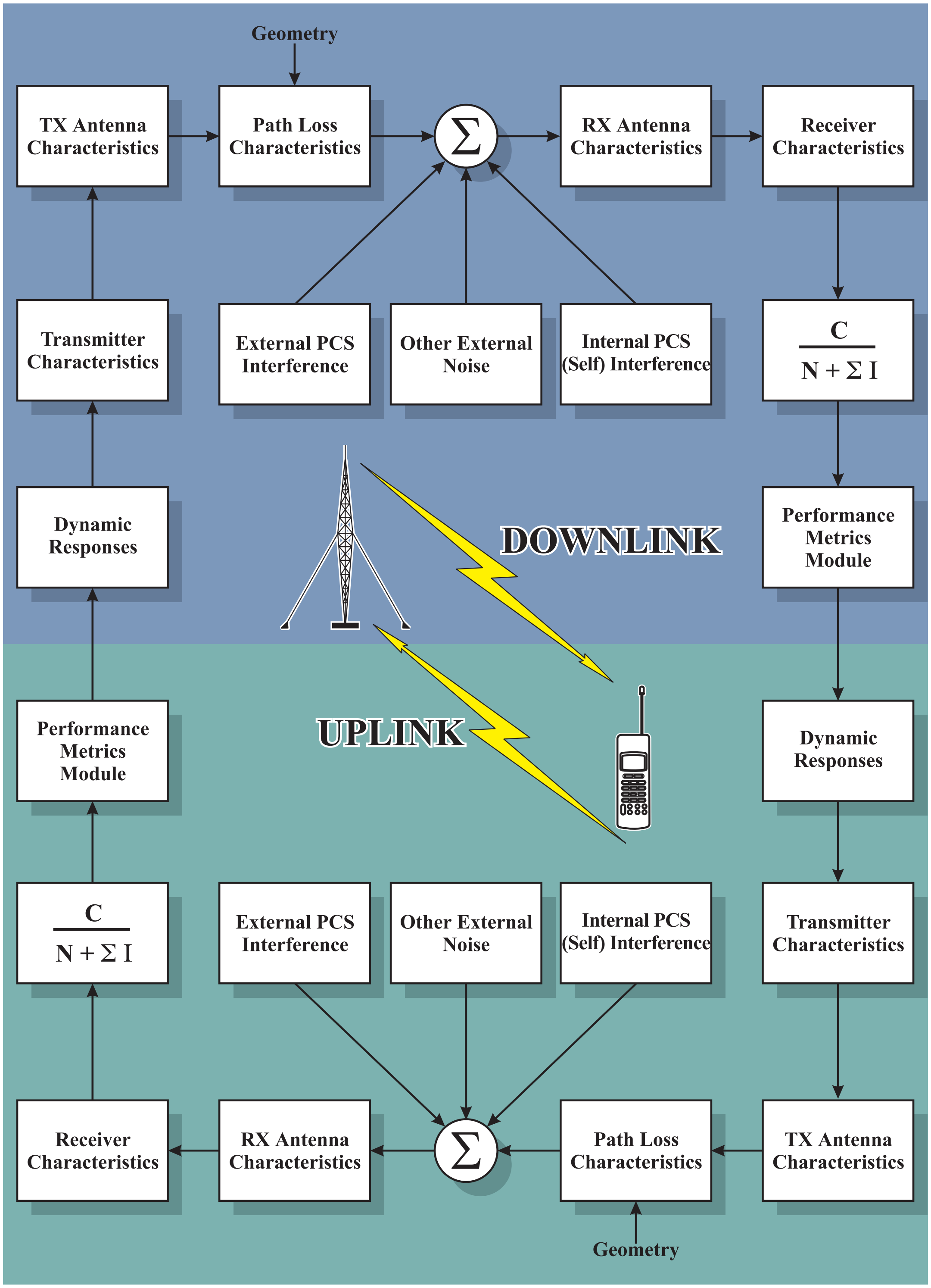
ITS has contributed to inter-PCS interference understanding through its participation in the development of an inter-PCS interference handbook developed by the Telecommunication Industry Association (TIA) committee TR46.2 (Telecommunications Systems Bulletin TSB-84A, *Licensed PCS to PCS Interference*). Since the handbook was released in July of 1999, the communications industry has developed and proposed new technologies to address system limitations such as system capacity and coverage, and data transfer rates.

In the near term, 2.5G systems such as EDGE (Enhanced Data Rates for Global Evolution) and GPRS (General Packet Radio Service) are enhancements to current technologies designed to improve current services without requiring extensive changes to the existing infrastructure. In the long term, 3G systems such as code division multiple access (CDMA) 2000 and wideband CDMA (W-CDMA)* have been proposed to support the goals established by the International Telecommunication Union (ITU) with International Mobile Telecommunications 2000 (IMT-2000). In addition, high-altitude platform systems such as HAPS (high altitude platform station), HALO (high altitude long operation) fixed-wing aircraft, HELIOS (a NASA experimental high altitude long endurance solar-powered aircraft), and other unmanned air vehicles (UAVs) will have an effect on existing systems due to their large signal footprint and effective radiated power.

As a result of these advances, and in an effort to promote higher visibility of the inter-PCS interference problem, TR46.2 has begun work on the next version of the handbook as a draft American National Standard. While the basic interference estimation process (see the Figure) will remain unchanged, it will be expanded to include future technologies.

In support of this work, ITS is enhancing its multi-user, multi-network PCS interference model (described in Ferranto 1997; see Publications Cited, p. 102) to cover 2.5G and 3G PCS. The model currently profiles the signals generated by the base and mobile stations in the cell under study, in addition to the base and mobile stations in adjacent cells. 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. To further enhance the model's usefulness, ITS is expanding it to determine the effects that co-located or adjacent PCS systems have on one another.

* W-CDMA is called UTRA (Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access) in Europe



Process used to estimate interference between PCS systems (from TSB-84A).

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Mobile IP Network Access Technologies

Outputs

- Wireless laboratory and field testing of PCS data transport mechanisms.
- Tools and techniques to help understand wireless IP access issues.

In times of national emergency, wireless network access is becoming a primary necessity to insure the uninterrupted service of many Government agencies. It is perhaps unknown to the typical Federal wireless data user, but throughput can depend as strongly on the computing platform as it can on the underlying wireless network. The radio and computing hardware elements, in conjunction with the software protocols that make data communication possible, create a multi-dimensional environment. The ITS wireless data test bed facilitates experiments to identify and analyze the effect of wireless propagation characteristics on data access in these diverse networking environments.

Wireless impairments, such as flat fading and cochannel interference, create problems that are not handled well by networks designed for wired transmission. For instance, fading on wireless links can cause the error rate of the data channel to increase momentarily. Algorithms present in TCP interpret this effect as incipient congestion and back off on the data transmission rate. This behavior is correct over short time intervals, but is incorrect over longer time frames because wireless channel impairment can change very rapidly. The net result of this wired network designed protocol behavior, as applied over wireless links, severely decreases the effective throughput of the data channel. Not only are wired protocols inappropriately applied to wireless connections but present generation cellular and PCS networks can act in unexpected ways when propagating data. The PCS networks were designed for voice communication, which demands low latency and can operate tolerably for relatively large error rates. This kind of network may not be applicable for data communication, which is quite tolerant to varying degrees of latency but is very sensitive to bit error rate (BER).

From the point of view of these Federal users, the most salient network parameter is application speed. At the system engineering level a multifaceted measurement is warranted. Throughput measurements exist within a continuum from the session to the individual IP packet. At the user level, gross measurements representing data services of a given session are sufficient. A more detailed look, suitable to the system engineering point of view, involves measurement of transport times on a packet by packet basis. Both measurements are complicated by the wireless user access to only the end points of the linkage. The intermediate portion of the network remains invisible to the user. These intermediate links may encompass base station to PSTN connections. In either event ITS has the ability to examine complexities of wireless data connections from the low level protocol management signaling to the propagation phenomena that impair wireless data communication.

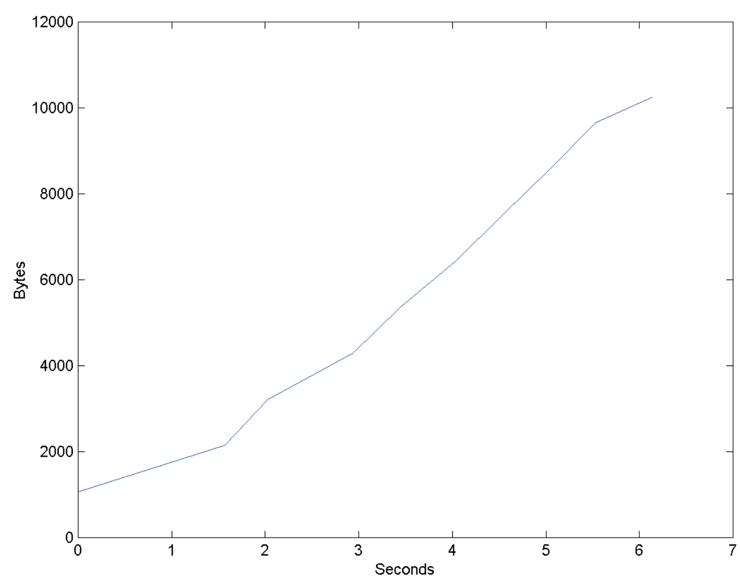

Figure 1. GSM Channel with 10 kB file transfer.

Examples of the capabilities of the ITS wireless data access test bed are displayed in the following Figures. Figure 1 shows a 10 kilobyte file transfer over a GSM channel. In this experiment the maximum transfer rate observed was 19.1 kilobits/sec but the average rate was only 7.2 kilobits/sec. This average data rate is 75% of the 9.6 kilobits/sec expected rate for GSM, whereas the burst rate is almost twice that. Figures 2 and 3 illustrate the effect of different file sizes on the transfer rate over a CDMA channel. In Figure 2, a 10 kilobyte file transfer is measured. Here, the maximum burst rate observed was 16.6 kilobits/sec but the average was 13.5 kilobits/sec. This average data rate is 94% of the 14.4 kilobits/sec expected rate for CDMA, but the burst rate exceeds the expected rate by 15%. Figure 3 shows the result obtained using the same CDMA channel with a larger file, 100 kilobytes in this case. At this larger scale the transfer rate appears much more constant, 8.6 kilobits/sec in this measurement, although we have observed average transfer rates as high as 12 kilobytes/sec over CDMA channels.

As these three graphs indicate, effects due to differences in PCS technologies as well as differing file sizes can be studied using the ITS test bed. Existing tools allow investigation down to the packet level of parameters such as throughput, delay and latency. Future projects include the collection of time statistics for wireless networks, investigation of PCS network discovery tools and verification/validation of propagation models. In addition, the test bed will be augmented with new third and fourth generation technologies as they are brought online.

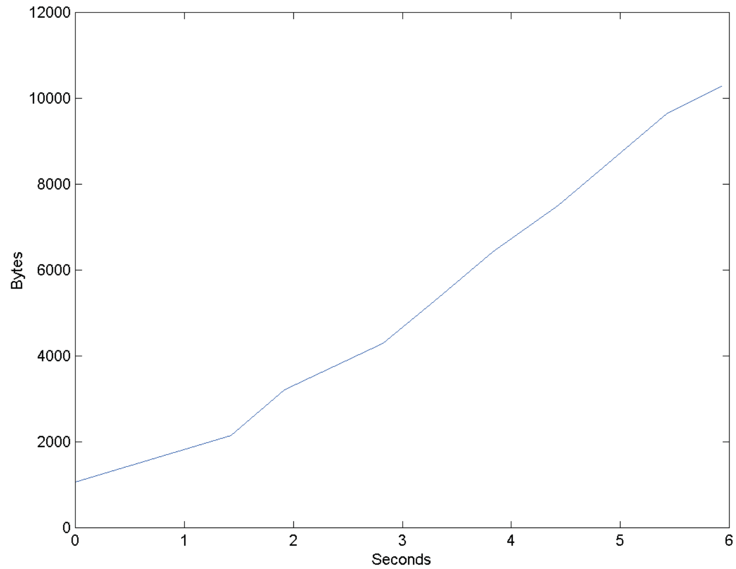

Figure 2. CDMA Channel with 10 kB file transfer.

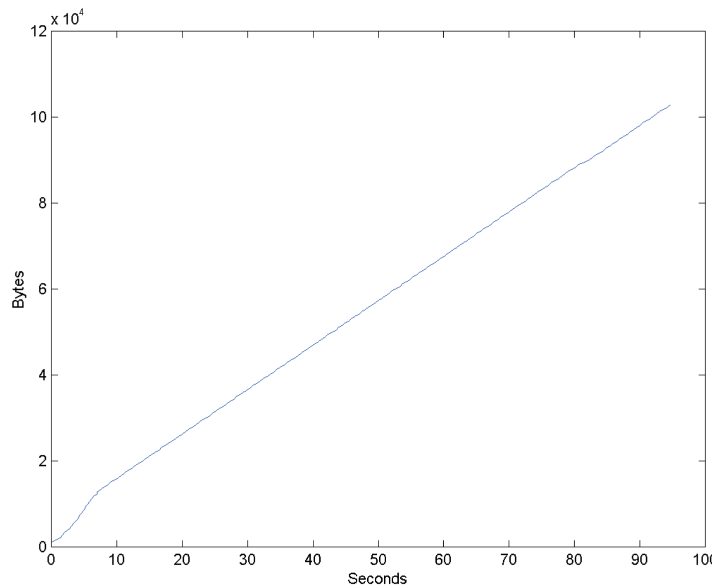

Figure 3. CDMA Channel with 100 kB file transfer.

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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.
- Contributions to the 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 the latest ITS research and engineering on a cost reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

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 GLOBE (Global One-km Base Elevation) 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 (p. 85–87) 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

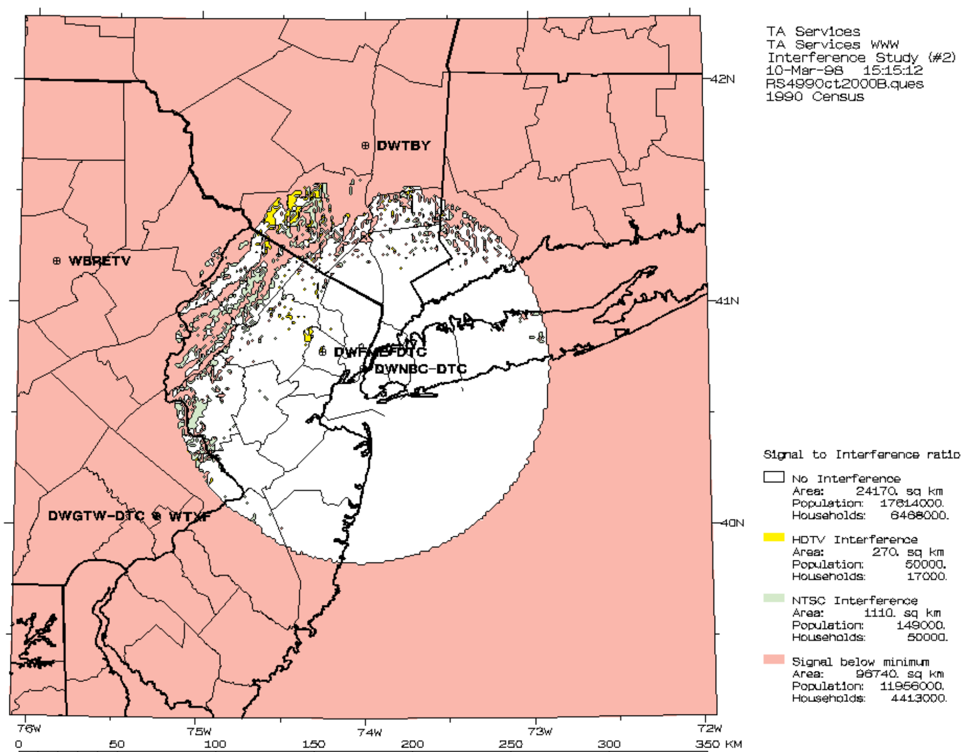

Figure 1. Interference analysis for a proposed digital station in New York.

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 New York. In addition to determining the contribution to interference from other stations to a selected station, the model can tell the user the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and determine the effect these modifications have on the interference that 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.

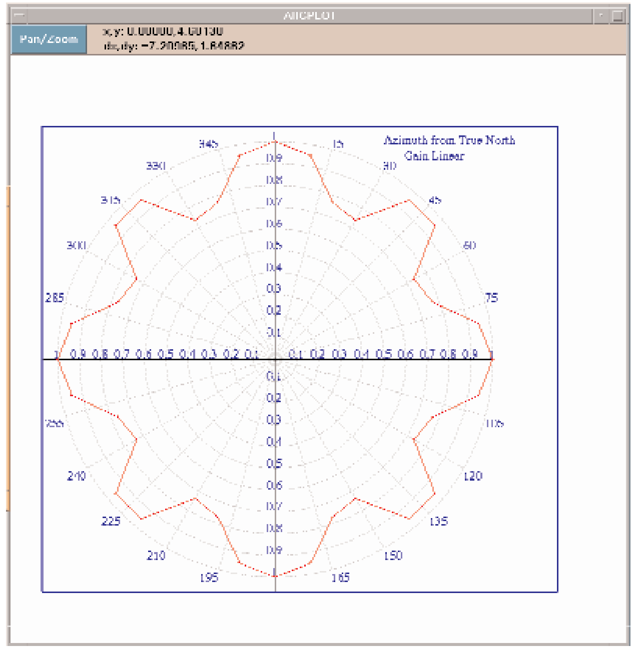

Figure 2. Antenna pattern from the user catalog in the TA Services PCS/LMDS model.

TA Services continues to develop models in the geographic information systems (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, including 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 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 three 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 two or three 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 under development by two prominent U.S. universities.

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Geographic Information System Applications

Outputs

- Two- and three-dimensional propagation coverages for one or more transmitters.
- Interference and overlap coverages of multiple transmitters.
- Ray tracing analyses for urban environments.

The Communication Systems Planning Tool (CSPT) is a menu driven propagation model developed by ITS to give industry and government agencies access to the latest ITS research and engineering tools at frequencies as high as 50 GHz. The accuracy of the results and the usefulness and flexibility of the presentation of the results are enhanced by the power of a geographic information systems (GIS) background. CSPT allows the user to import digital stereo photographs or other remote sensing data converted to 3-dimensional models of the region. This environment is then taken into consideration as the model calculates the results of the desired analysis. Contained within CSPT are propagation “engines” valid at frequency ranges used by cellular, personal communications services (PCS), radio, TV, pagers, microwave and other communication links. A GIS efficiently captures, stores, manipulates, analyzes, and displays all forms of geographically referenced information in a user-friendly way. Databases include terrain, roads, communications infrastructure, building locations and footprints, land type and use, water bodies, streams, population densities and many others. These are maintained in commonly used relational database management systems (RDBMS).

A graphical description of CSPT is shown in Figure 1. The output shows an analysis area in Washington D.C. made from an imported digital elevation model and color image at 1 meter resolution. There are eight transmitters defined for this particular analysis.

The general flow of CSPT is as follows. The user defines an area, graphically or with latitude/longitude, anywhere in the world, and then imports desired GIS information such as political boundaries, roads, rivers, etc. Then the user creates or imports (from the Federal Communications Commision (FCC) database) transmitter, receiver, and antenna data. Multiple transmitters can be defined for each area. Each transmitter can be made active or inactive for any particular analysis calculation. If the user chooses to perform an interference study (one of the analysis options), then one transmitter must be designated as the “desired” transmitter and others as the interferers. CSPT allows the user a great deal of flexibility in defining antenna patterns. Many vertical and horizontal patterns are included with the software. Their formats include: linear, log relative, log dBi, and log dBd. In addition, the user may create his own pattern using any one of the above formats.

After creating the transmitter database, receivers, and antennas, and after selecting a set of these for a particular study, the user defines the type of analysis to be performed. The analysis can be a propagation prediction of one of the following types:

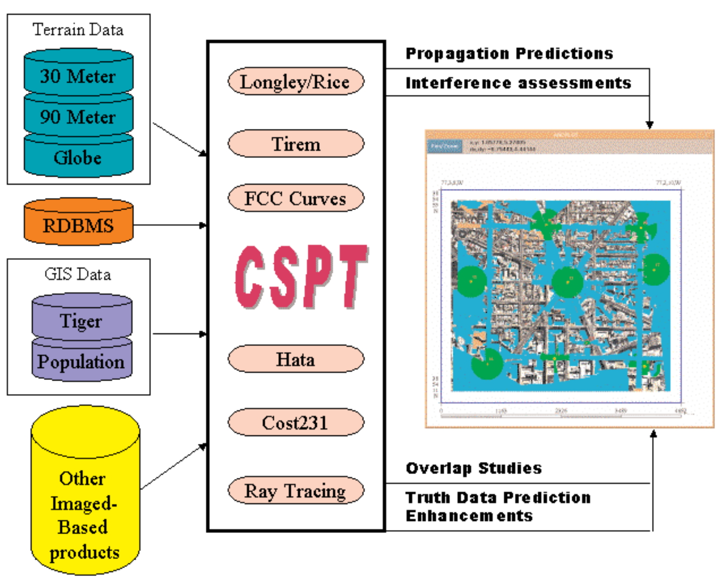

Figure 1. Overview of the CSPT model.

1. Create a line of sight (LOS) coverage only.
2. Calculate signal strength within the LOS region.
3. Calculate signal strength based upon terrain diffraction.
4. Calculate signal strength along a single path.
5. Perform ray tracing analysis (urban environments).
6. Add rain loss to any of the above.

Propagation predictions can be augmented with "truth data" provided by the user, and can be overlayed to determine locations of redundant coverage. The output from a propagation prediction analysis can be displayed in any one of the following forms: field intensity (dBuv/m); available power (dBm); basic transmission loss (dB), or signal/noise power ratio (dB). In addition to running a propagation prediction, the user can select a set of transmitters to use in an interference analysis. Signal strength calculations are performed by one of several prediction models according to the user's choice. The models included are:

- Longley/Rice - for analysis options based upon terrain diffraction.
- Tirem - for analysis options based upon terrain diffraction.
- Hata - for urban or suburban environments without detailed environments.
- Cost231 - for urban/suburban environments without detailed environments.
- Ray Tracing - for detailed urban environments.
- FCC Curves - for areas larger than 5 kilometers.

Analysis results are draped on top of the analysis area image. These results can be shown in two or three dimensions (shown in Figures 2 and 3). Figure 2 shows a single railroad transmitter (white area in upper right) with field strength contours of 50, 60, and 70 dBuV/m. The coverage of the transmitter is good near the transmitter, but not for the railroad tracks (magenta lines) heading south. Figure 3 shows the same analysis as Figure 2 in 3D. Notice that the impact of the mountains on the coverage can be clearly seen. Also, the user can zoom into any region of the analysis area and look at individual cell values of signal strength or interference.

CSPT is available on a UNIX or Windows® NT platform. CSPT contains an extensive help system. Most menus have a "help" button which displays an explanation of the options on that menu. A user's manual is currently being written. We suggest that users have an account with ITS on our TA Services computer so that we may provide phone support.

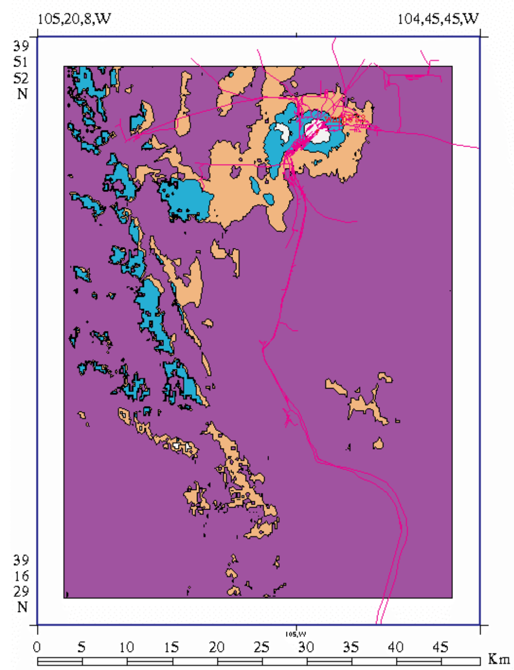

Figure 2. CSPT analysis showing a 3-contour coverage in 2D.

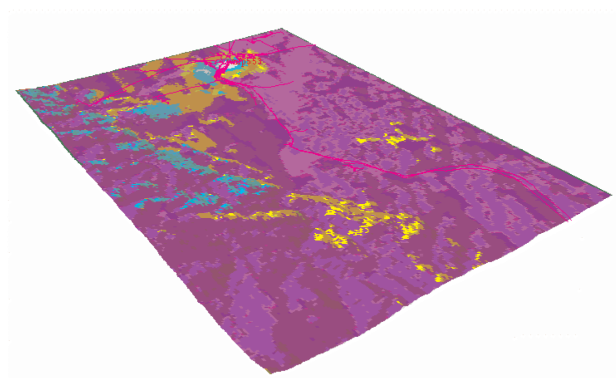

Figure 3. Same coverage shown in Figure 2, in 3D.

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Propagation Model Development

Outputs

- Methodology for prediction of site-specific RF electromagnetic wave propagation.
- Intercomparison/harmonization of ITM and TIREM.

ITS' work on propagation model development focused on two primary areas in FY 2000: enhanced development of a Fresnel-Kirchhoff based methodology for the prediction of site-specific (i.e., point-to-point) radio frequency electromagnetic wave propagation; and intercomparison/harmonization of the two radio frequency electromagnetic wave propagation models employed by NTIA, the Irregular Terrain Model (ITM) and the Terrain Integrated Rough Earth Model (TIREM). This work was sponsored by NTIA's Office of Spectrum Management (OSM). Progress in each area is described below.

Fresnel-Kirchhoff Methodology

The particular attraction of the Fresnel-Kirchhoff methodology is that it provides for the accurate prediction of diffraction by terrain (or other) obstacles with arbitrary shapes and separations, thereby obviating the need to approximate this diffraction as some assumed combination of knife edges, wedges, smooth spheres and/or cylinders. The theoretical basis for the method is Green's Theorem and is, in principle, exact. The development uses approximations, appropriate for the VHF-UHF radio propagation regimes, which are described or implied below. In view of this, we approximate the Green's function for our problem by the free space propagator plus its image in a finitely conducting ground plane. Next, we assume all angles of incidence are nearly grazing. Finally, we assume that variations in the coordinate perpendicular to the plane of incidence are ignorable. Future work in this area will address these limitations.

For a given path's distance, effective earth's curvature and transmit and receive antenna heights above ground, the method proceeds by identifying the sequence of locations on the terrain profile which have direct ray (or its convex hull, in cases where the terrain profile intrudes into the direct ray) clearances less than a specified fraction of a first Fresnel radius, subject to a specified minimum horizontal separation. Horizon points, if present, are always included in the sequence. For each of the locations identified above, consecutively, starting from the location nearest to the transmitter, the total field above the ground, relative to free space, is computed as a function of height. This is done by integration, roughly speaking, from the ground to infinity, over the total field and its image, as a function of height above the ground, at the preceding location. On the first surface, the total field is found by taking the sum of the direct ray from the transmitter and its image into the finitely conducting ground plane presented by the terrain. Currently, the image term is computed using the appropriately polarized plane wave (i.e., Fresnel) reflection coefficient for a finitely conducting ground plane. The last location, corresponding to the receiver, only requires calculation of the total field at a single height, i.e., the receiver's antenna height above ground.

The integrations of the total field and its image over a given height interval are accomplished by piecewise fits, at three discrete heights containing the height interval, of the integrands' amplitudes and phases to quadratic height dependencies. (As a practical matter, it is important to ensure that the phases are on the same Riemann sheet.) However, in some intervals it can happen that one or both of the phase variations under consideration would be better characterized, from a numerical standpoint, as having either linear or constant variation with height. If this occurs, the phase variation is then treated as piecewise linear or constant on the interval in question. For the step to infinity, though, physical considerations require that both integrands' phases vary in height quadratically, with positive second derivatives. This requirement imposes ancillary conditions on the height at which the total field computation can be terminated. That is, the top three heights for which the total field is computed, at a given location, must be great enough to capture a sufficient portion of the contributions to weakly convergent integrands (see below), as well as have the desired phase arrangements amongst the total fields and their corresponding images, for all heights of interest at the next location where the total field as a function of height is to be computed, for the step to infinity.

For quadratic phase variation with height, the integrals thus obtained on a height interval evaluate to a combination of Fresnel integrals and complex exponentials, after a suitable change of variable. For the linear or constant phase variation, the resulting integrals on a height interval are even simpler. The total field at any given height at a new location is then obtained by summation of the results over all height intervals at the preceding location, including the step to infinity. Note, also, that both the amplitude and the phase of the total field strength are available as byproducts of the methodology. (Indeed, both are required at the intermediate steps in the solution.) Phase information can be useful, for example, in propagation predictions for some broadband electromagnetic excitations.

The Fresnel-Kirchhoff prediction methodology has been tested for paths which have analytic solutions. This testing approach was adopted, in part, because it permitted examination of the accuracy of the intermediate results, as well as the final result. Since the accuracy of the final result will depend heavily on the accuracies of the intermediate results, on any given path, it is possible to get information on error propagation due to finite precision arithmetic, horizontal and vertical discretizations, quadratic vs. linear vs. constant phase variation decision conditions and termination conditions. Thus far, indications are that accurate results require double precision arithmetic for paths requiring roughly ten or more intermediate integrations. Given the comments above, accurate results are also strongly dependent on height termination choices and the phase variation choice decision conditions. Current and future work continues on finding robust choices for these for many different path lengths, ray clearances, etc.

ITM & TIREM Intercomparison/Harmonization

During FY 2000, a study was launched to assess the comparison of ITM v1.2.2 and TIREM v3.14 predictions to several measured radio propagation datasets. TIREM v3.14 is the most recent version of that model, containing several bug fixes and improvements over earlier versions that had been used in the past. In all, the measured data considered in the study numbered over 41,000 measurements. The datasets contained results for a wide range of frequencies (approximately 20 MHz - 10 GHz), antenna heights, path lengths and terrain. Ostensibly, the goal of the study is to attempt to make some quantitative statement concerning the relative quality of the prediction error of ITM as compared to TIREM. However, this task is complicated by the fact that a great deal of the measurements and, hence, the predictions, within each individual dataset considered in the study are correlated. Given this, current and future work will focus on methods of removing the effects of the correlations from the measurements and predictions. Preliminary results of the study are shown in the Table below. However, due to strong correlations within each dataset, the reader is cautioned against imputing great significance to these statistics.

Comparison of the Overall Dataset Prediction Errors' Statistics for ITM and TIREM

Dataset	No. of meas.	ITM mean (dB)	TIREM mean (dB)	ITM std. dev. (dB)	TIREM std. dev. (dB)
CO. MTNS.	550	-17.1 +/- .7	-4.4 +/- .6	16.2 +/- .5	13.7 +/- .4
CO. PLNS.	1983	-14.9 +/- .2	-4.4 +/- .2	10.2 +/- .2	9.9 +/- .2
NE OH.	1787	-10.1 +/- .2	0.0 +/- .2	9.2 +/- .2	9.6 +/- .2
R-1	6780	2.0 +/- .2	1.2 +/- .1	13.9 +/- .2	12.0 +/- .1
R-2	2458	-7.5 +/- .5	-18.4 +/- .4	25.7 +/- .3	20.8 +/- .3
R-3	5149	1.9 +/- .2	2.8 +/- .2	11.6 +/- .2	11.4 +/- .1
R-4	9498	-12.8 +/- .2	-14.1 +/- .2	16.6 +/- .2	16.6 +/- .1
VA.	1655	-.9 +/- .3	-.2 +/- .4	13.2 +/- .3	15.6 +/- .3
ID.	435	-17.5 +/- .7	-10.9 +/- .6	14.5 +/- .4	11.9 +/- .4
WA.	892	-2.4 +/- .4	5.1 +/- .4	12.8 +/- .3	12.0 +/- .3
WY.	704	-11.9 +/- .6	-6.8 +/- .5	14.6 +/- .4	12.5 +/- .3
Ft. Hua.	372	-3.0 +/- .6	11.4 +/- .3	11.5 +/- .3	6.0 +/- .2
TASO	8865	-3.2 +/- .1	-1.2 +/- .1	12.5 +/- .1	14.0 +/- .1

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Time-hopped UWB Simulation Analysis for Bandwidth Correction Factor

Outputs

- Peak and average power as a function of victim receiver IF bandwidth from 0.3 to 100 MHz for time-hopped or pulse-position-modulated (PPM) ultrawideband (UWB) systems.
- Transmitter block diagram, simulation and power calculation process for time-hopped UWB systems.
- Received UWB spectra, time waveform, and envelope for no dither and 50% dither in victim receiver narrow IF bandwidth of 3 MHz.

Interest by the Government and private sector in the potential application of ultrawideband (UWB) devices has stimulated a measurement and analysis program to determine the interference effect of these devices on victim receivers. Results are shown for a class of time-hopped (time-dithered) UWB systems modeled and simulated from an analytic description

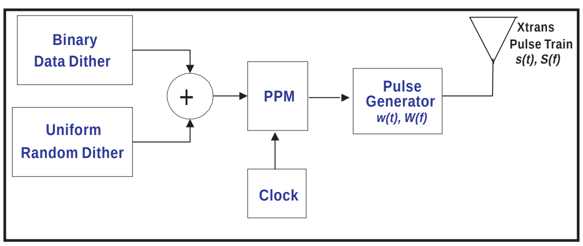

Figure 1. PPM ultrawideband system model.

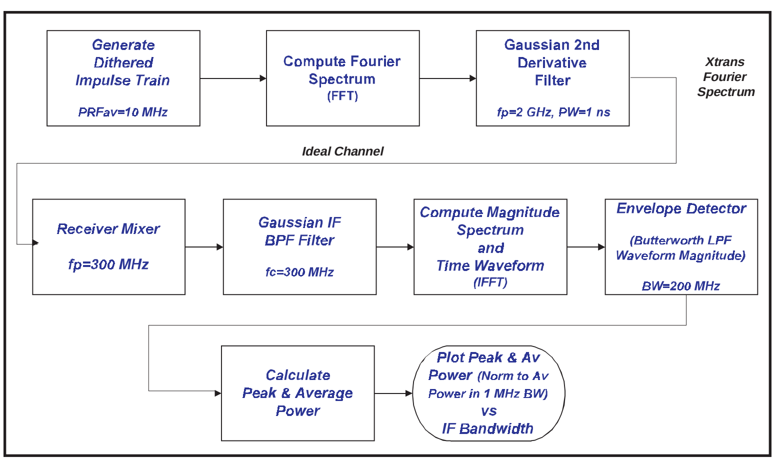

Figure 2. Simulation and power calculation process.

of the system. These simulated time waveforms and Fourier spectrum results are analyzed to show the effect of a receiver intermediate frequency (IF) bandwidth (BW) on peak and average power. These peak and average power curves provide the basis for establishing a normalized bandwidth correction factor (BWCF) curve and equation. The BWCF is used to estimate peak power over a range of BWs from average power measurements made in a 1-MHz BW. This BW is prescribed by the Federal Communications Commission for Part 15 devices. Simulation of the UWB devices complements measurements and other analytic model results for these devices.

The simulated time-hopped UWB system block diagram is shown in Figure 1. The system transmits a quasi-periodic, very low duty cycle, dithered pulse train s(t) where delta functions are shaped with a Gaussian 2nd derivative filter. The shaping filter for a specific hardware configuration depends on the transmit and receive antennas, and may deviate somewhat from this model. The specific pulse shape is probably not as important a factor in determining a receiver's narrow IF BW response as the pulse width and corresponding BW. The receiver IF filtering will remove pulse shape details if the pulse is sufficiently narrow and corresponding BW sufficiently wide, compared to the receiver IF BW. In this system the dither consists of two components: a pseudo-random time-hopping dither and a data dither. Usually the time-hopping dither is large compared to the data dither. In our case the time-hopping dither was uniformly distributed between 0 and 0.5T (50% dither); whereas the data dither represented binary 0s and 1s with 0 or 0.045T (4.5% dither). The time-hopping dither values are commonly generated from a pseudo-noise sequence. An undithered pulse repetition frequency (PRF) of 10 MHz was used which made the nominal pulse train period T= 100 ns. Simulation results were also obtained for the non-dithered case where the waveforms are periodic with a period T=100 ns and corresponding line spectra with a fundamental frequency equal to the PRF.

The simulation and power calculation process are shown in the flow diagram of Figure 2. A periodic impulse train is dithered by the combined amount of dither and then Fourier transformed. Then the spectrum is shaped using the Gaussian 2nd derivative filter transfer function W(f). The receiver mixer and IF filter are simulated next, followed by an envelope detector used in a spectrum analyzer. The final step calculates and displays peak and average power.

Figure 3 shows an example received output for a 3 MHz IF filter at the receiver. This case is particularly interesting since output pulses (IF - middle and envelope - bottom) are smeared together for this narrow BW. At a BW of 30 MHz the pulses out of the IF just touch each other. For wider BWs they are completely separated and for narrower BWs they are overlapped, causing peaking in the envelope. It is particularly interesting to compare the 50% and 0 dither cases. With the periodic (no dither) pulse train, the IF filter gets pinged by pulses at a regular interval and just provides periodic pulses out of the detector without peaking. At a BW of 3 MHz the 50% randomly dithered pulse train creates significant peaks and valleys (1 down to 0), whereas the periodic pulse train has a constant envelope coming out of the IF filter.

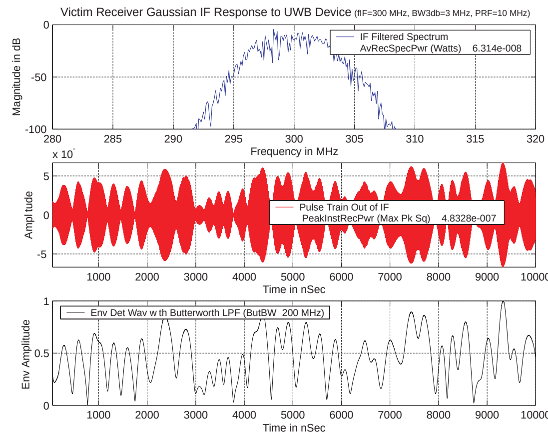

Figure 3. Receiver 3 MHz IF BW output spectrum, pulsetrain, and envelope detected pulsetrain (50% dither).

Figure 4 shows the received instantaneous peak and average power computed from the simulated time waveforms for receiver IF BWs ranging from 0.3 MHz to 100 MHz. These powers were normalized to the average power in a BW of 1 MHz. Consequently, the average power curves all go through 0 dB at 1 MHz. These curves provide the basis for which to develop BWCFs. The BWCFs are used to estimate the amount of peak power at a given BW from measuring the average power in this 1-MHz BW. In addition to peak and average power curves, a third guideline is provided. This straight line on a log-log plot is the 10 log (BW) average power trend. It follows the average power quite well for 50% dither (both pre- and post-detection); however, for the non-dithered case it follows only for BWs greater than or equal to the PRF.

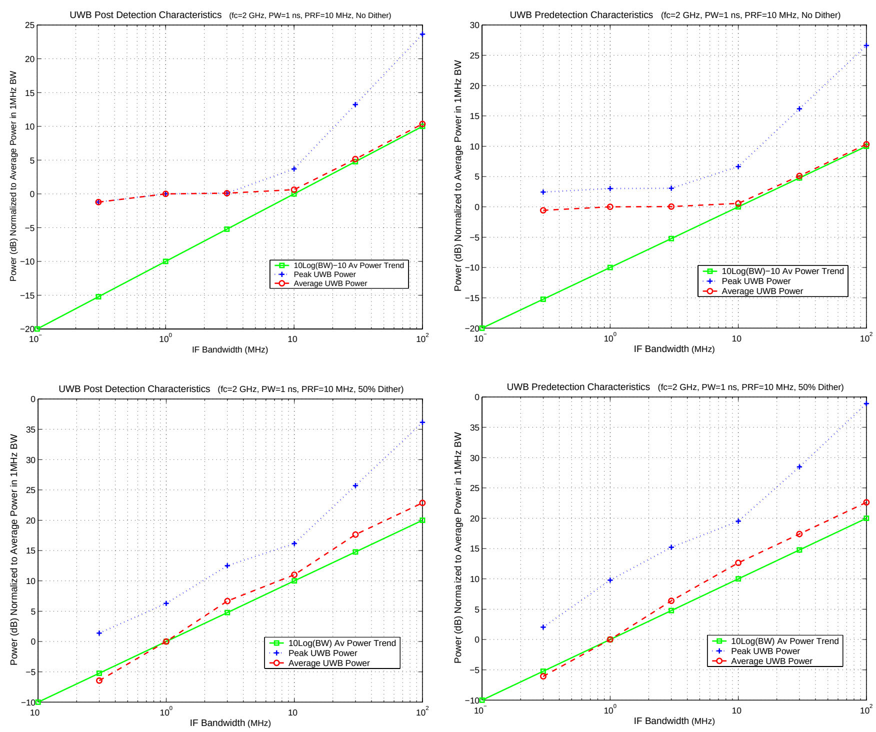

Figure 4. Receiver peak and average power dependence on IF bandwidth (Top no dither: Left— postdetection; Right—predetection; Bottom 50% dither: Left— postdetection; Right—predetection).

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Jammer Effectiveness Model

Outputs

- Windows® 95/98/NT version of Jammer Effectiveness Model for communications and radar systems analysis in use by the U.S. Army and other Federal agencies.
- Multiple jammer and interferer analysis capability on a wireless network for use in performance evaluation in an electronic warfare or interference electromagnetic environment.

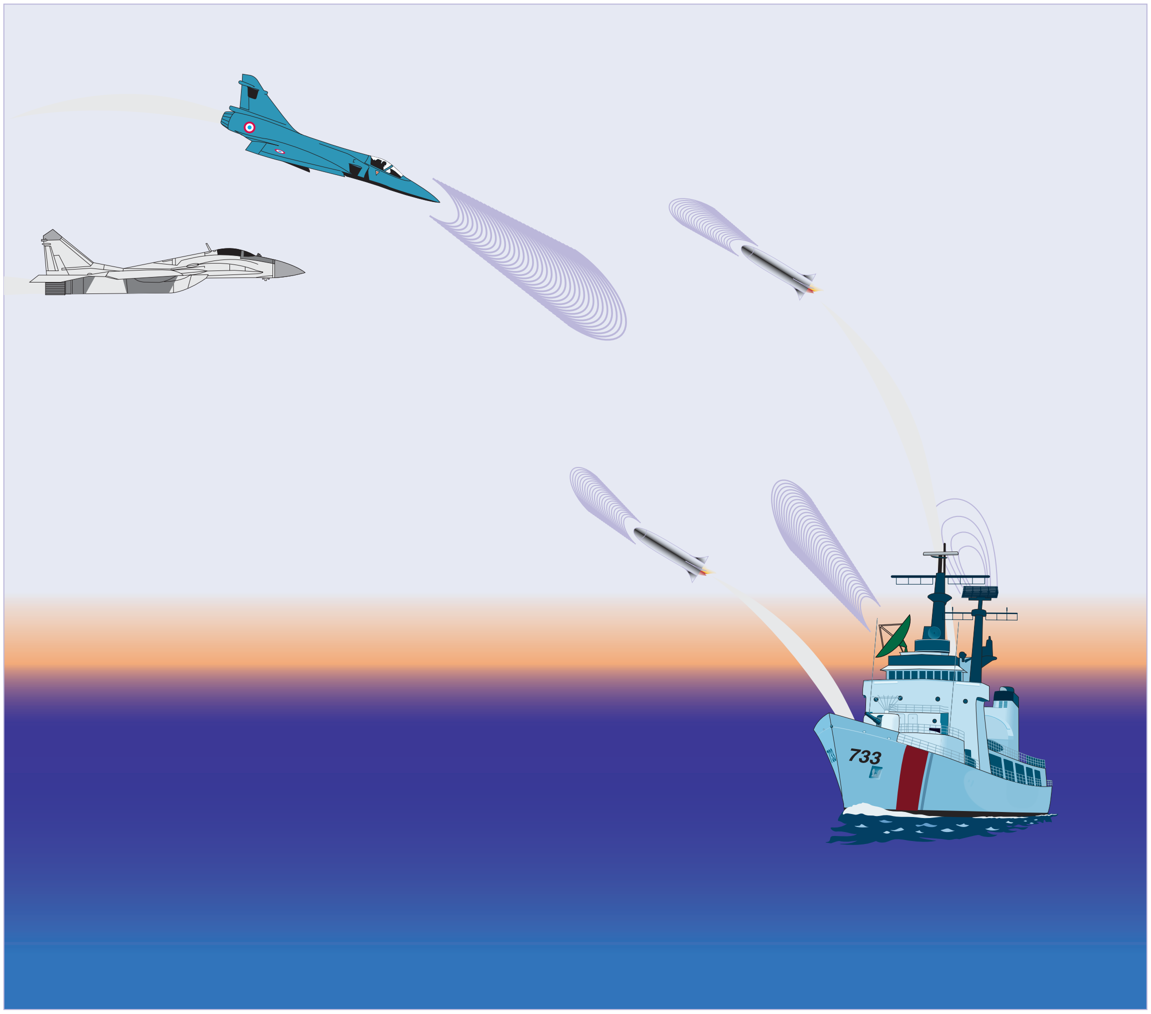
In FY 2000, ITS completed the conversion of the Jammer Effectiveness Model (JEM) to operation in the Windows® 95/98/NT environment. JEM was developed by ITS for the U.S. Army in order to evaluate electronic warfare scenarios on a personal computer. Other programs with similar capabilities require mainframe computers. 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 for systems performance evaluation in an electronic warfare environment: 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. 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 scenario descriptions to completely characterize a communication link or radar configuration with or without a jamming situation. Data entry to create a scenario description is simplified by the use of user-friendly menus and options. Each scenario description is saved in a database, and includes: ground or airborne station location, three-dimensional geometry description, equipment characteristics, and physical factors such as climate and terrain. JEM contains an inventory of specific analyses that can be performed on the physical configurations represented by the scenario description data.

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. In FY 2000, three-dimensional antenna pattern capability was added to JEM.

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 scenario analyses consist of evaluating the performance of a radar trying to detect and track a target. The analyses can be performed both with and without the presence of a jammer. A 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. The three-dimensional geometry of these radar scenarios requires three-dimensional antenna patterns, included in the analysis models.



Aircraft with standoff and self-screening jammers avoiding detection by a shipboard fire-control radar and radar-guided missiles (illustration by A. Romero).

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 two aircraft, a stand-off jammer and a self-screening jammer, attempting to avoid detection by a shipboard fire-control radar and a radar located in the guided missiles. The shipboard fire-control radar will detect the aircraft and inform the missiles of its location. The radar guidance systems on the missiles will provide terminal guidance to the missiles to destroy the aircraft targets. The stand-off jammer is protecting other airborne targets by jamming both the shipboard and missile radars. The self-screening jammer is protecting itself from detection by the shipboard radar and the missile radar guidance systems. The JEM software allows performance prediction of the jammers' ability to avoid detection in this scenario.

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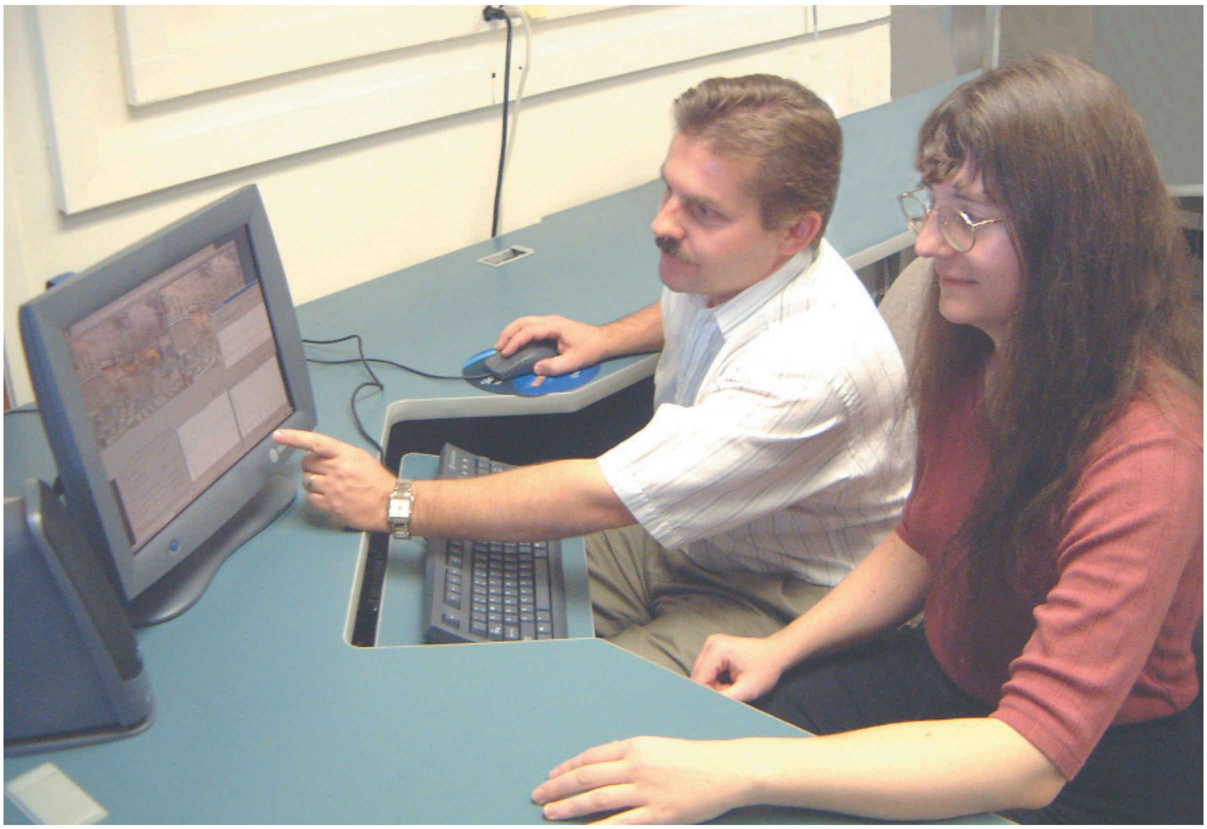

ITS engineers from the Telecommunications Theory Division performing objective video quality measurements in the audio-visual quality laboratory (photograph by F.H. Sanders).

Telecommunications Theory

The Institute is involved in research in 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 2000 International Symposium on Advanced Radio Technologies. This third annual symposium focused on broadband wireless communications technologies and applications. The project is funded by the Department of Defense.

Advanced Telecommunications in Rural America The Institute conducted research for a report evaluating the technologies available to provide advanced telecommunications to rural America. The project was funded by NTIA.

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).

Mobile Network Modeling The Institute is involved in research on the performance of wireless communications networks. The project is funded by NTIA.

Narrow Pulse System Characterization The Institute conducts research to characterize and model the narrow pulse systems used in ultrawideband communications systems and radars. Projects are funded by NTIA and the Department of Defense.

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.

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

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. Projects are funded by NTIA and Lucent Technologies.

Adaptive Antenna Testbed

Outputs

- Wideband radio channel sounding measurements.
- 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, and 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.

ITS has developed an advanced 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 (PN) code generator to BPSK modulate a radio channel carrier frequency at the transmitter. The received signal is correlated 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 1. A four element antenna array. The elements are spaced at $\lambda/2$ intervals (photograph by P. Papazian and E. Gray).

A recent example of an ATB application is a beam steering experiment conducted in FY 2000, which demonstrated the value of the ATB's continuous acquisition capability. A linear, four-element PCS receiving array with λ/2 element spacing is shown in Figure 1. A mobile van-mounted dipole was used to transmit a 511-bit PN code on a 1.92-GHz carrier frequency. The drive route consisted of a suburban area as well as some high rise offices in Boulder, CO. The 10 Mb/s transmitted code was then sampled at each receiving antenna at a rate of 40 MHz. This data could then be post-processed to determine the channel impulse response for each array element. 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 5 s delay between bursts. A burst consisted of 16 impulses with a 3 ms delay between impulses.

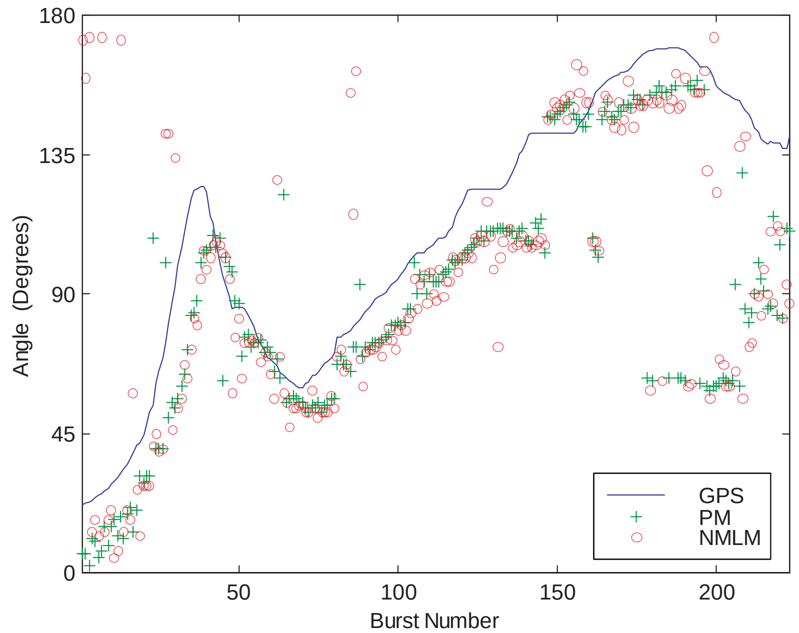

Figure 2. Direction of arrival as determined by the GPS location, the maximum of the PM estimate and the maximum of the NMLM estimate.

These data were then forward/backward averaged before post-processing using several beam steering algorithms. Figure 2 shows direction-of-arrival (DOA) data using two of these algorithms: a parallelogram method (PM) and the normalized maximum likelihood method (NMLM). Results of the experiment showed that the PM better estimates the line-of-sight direction and the DOA of the main signal power, while the NMLM better identifies isolated spokes in the signal power.

Comprehensive frequency translation data were also collected for several military training ranges using this system with multi-frequency transmitters. Results of this project are described in NTIA Reports 00-380 and 00-381 (see list of Recent Publications at right).

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 the Tools & Facilities section, p. 81, for more information about the ATB.)

Recent Publications

P. Wilson and P. Papazian, "PCS band direction-of-arrival measurements using a 4 element linear array," in *Proc. Vehicular Technology 2000*, Boston, MA, Sep. 2000.

P. Papazian, P. Wilson, M. Cotton and Y. Lo, "Flexible interoperable transceiver (FIT) program test range I: Radio propagation measurements at 440, 1360 and 1920 MHz, Edwards Air Force Base, CA," NTIA Report 00-380, Oct. 2000.

P. Papazian, P. Wilson, M. Cotton and Y. Lo, "Flexible interoperable transceiver (FIT) program test range II: Radio propagation measurements at 440, 1360 and 1920 MHz, Ft. Hood, Texas," NTIA Report 00-381, Oct. 2000.

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Advanced Radio Technologies Symposium

Outputs

- Symposium proceedings.
- Exchange of ideas among leading experts in broadband wireless technologies.

The Institute hosted the Third Annual International Symposium on Advanced Radio Technologies on September 6-8, 2000 in Boulder, Colorado. This year's symposium focused on state-of-the-art and future trends in broadband wireless technologies. The symposium featured a keynote address by the Assistant Secretary of Commerce for Communications and Information, Mr. Greg Rohde, shown in Figure 1.

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 120 individuals from 13 countries attended the symposium.

The symposium was organized into six sessions: an opening session, two sessions on broadband wireless technologies, broadband wireless networks, broadband wireless standards, and next generation Internet. These sessions comprised 36 presentations.

After welcoming remarks by Dr. Christopher Holloway of NIST (Figure 2), the opening session, chaired by Dr. John Lemmon of ITS, began with the keynote address by Assistant Secretary Rohde, followed by an overview of broadband communications by ITS engineer Frank Sanders, discussions of spectrum issues and standards, and perspectives on broadband wireless systems by agencies from the Department of Defense.

Figure 1. Assistant Secretary Greg Rohde delivering the keynote address at the International Symposium on Advanced Radio Technologies (photograph by E. Gray).

The sessions on broadband wireless technologies included an overview presentation on broadband wireless technologies, presentations by ITS engineers Dr. Roger Dalke and Robert Achatz on performance modeling of multichannel multipoint distribution services (MMDS) and broadband wireless local area networks, and presentations on optical wireless systems, smart antennas, space-time signal processing, neighborhood local multipoint distribution services (LMDS), propagation modeling for broadband millimeter wave channels, low noise active receiver feeds, third generation wireless security, and high performance broadband spread spectrum systems.

The broadband wireless networks session consisted of talks on laws that govern the Internet, asynchronous transfer mode (ATM) traffic management in wireless LMDS networks, broadband wireless network architectures, broadband local access, and a presentation by ITS engineer Val Pietrasiewicz on the effect of evolving information technology (IT) applications on broadband wireless requirements.

The standards session comprised talks on the role of standards in advancing wireless access technologies, enabling broadband wireless through standardization, standards for multiprotocol air interfaces, fixed broadband wireless access standards, the influence of information theory on wireless architecture standards, and the business and social implications of telecommunications standards.

The session on the next generation Internet, chaired by ITS engineer Ken Allen, included presentations on large scale networking programs, the interplanetary Internet, broadband wireless access for the next generation Internet, very high spectral efficiency wireless communications, satellite and terrestrial network architectures, and optical spread spectrum for Internet operation at terabit rates.

Figure 2. Dr. Christopher Holloway welcoming symposium participants (photograph by E. Gray).

The symposium allowed participants to interact in a friendly and informal atmosphere that included numerous breaks, luncheons (Figure 3), lively dialogues among the speakers and the audience, and tours of the Boulder Laboratories.

Figure 3. Lunch on the lawn at the Boulder Laboratories (photograph by E. Gray).

Recent Publication

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

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Advanced Telecommunications in Rural America

Outputs

- Report on status of broadband deployment in rural vs. non-rural areas in the United States.

ITS engineers worked in concert with other NTIA Offices and the Rural Utilities Service (RUS) to respond to a request by ten U.S. Senators on the status of broadband deployment in rural versus non-rural areas in the United States. The results of the analysis were published in April 2000 as a report, *Advanced Telecommunications in Rural America: The Challenge of Bringing Broadband Services to All Americans*. This report also responds to a call by President Clinton and Vice President Gore to bridge the digital divide and create digital opportunities for more Americans. The rate of deployment of broadband services will be key to the future economic growth of every region, particularly in rural areas that can benefit from high-speed connections to urban and world markets.

The results of the research show that rural areas are currently lagging far behind urban areas in broadband availability. Deployment in rural towns (populations of fewer than 2,500) is more likely to occur than in remote areas outside of towns. These latter areas present a special challenge for broadband deployment. Only two technologies, cable modem and digital subscriber line (DSL), are being deployed at a high rate, but the deployment is occurring primarily in urban markets. Broadband over cable has been deployed in large cities, suburban areas, and towns. It was found that cable modem service was offered in less than 5% of towns with 10,000 or less population, while it is offered in portions of more than 65% of cities with populations over 250,000.

DSL technology also has been deployed primarily in urban areas. The Regional Bell Operating Companies (RBOCs) are providing DSL service primarily in cities with populations above 25,000 according to public RBOC data. While more than 56% of all cities with populations exceeding 100,000 had DSL available in some areas, less than 5% of cities with populations less than 10,000 had such service. Deployment of both cable modem and DSL service in remote rural areas is far lower.

The primary reason for the slower deployment rate in rural areas is economic. For wireline construction, the cost to serve a customer increases the greater the distance among customers. Broadband service over cable and DSL is also limited by technical problems incurred with distance and service to a smaller number of customers. Both technologies, however, promise to serve certain portions of rural areas. Cable operators promise to serve smaller rural towns, and smaller, independent telecommunications companies and competitive providers may soon be able to offer DSL to remote rural customers on a broader scale.

Advanced services in rural areas are likely also to be provided through new technologies, which are still in the early stages of deployment or are in a testing and trial phase. Satellite broadband service has particular potential for rural areas as the geographic location of the customer has virtually no effect on the cost of providing service. Several broadband satellite services are planned. Their actual deployment remains uncertain, especially in light of the recent entry into Chapter 11 bankruptcy of two satellite service companies. Wireless broadband services are also planned for rural areas. More immediately, multipoint multichannel distribution service (and potentially local multipoint distribution service) fixed service capabilities may provide a solution for some rural areas. In as little as five years, third generation mobile wireless services providing data rates as high as two megabits/second may be operational.

In order to support advanced services in rural areas, NTIA and RUS recommended a number of actions. We recommended the continued support and expansion of those government programs, such as the E-rate program, that ensure access to new technologies including broadband services. We also urged the Federal Communications Commission to consider a definition of universal service and new funding mechanisms to ensure that residents in rural areas have access to telecommunications and information services comparable to those available to residents of urban areas. Support for alternative technologies will also be crucial to the deployment of advanced services in rural America. The Administration is committed to increasing investment in research and development to promote the next generation of broadband technologies.

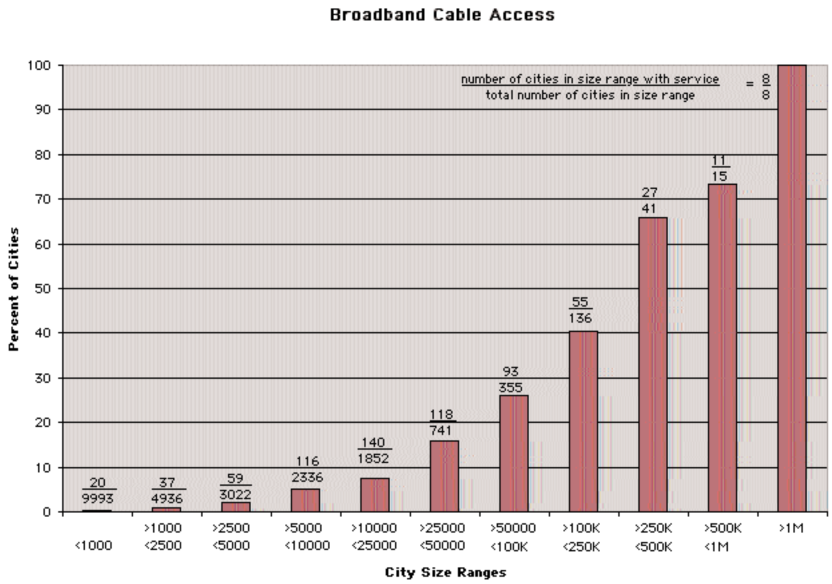

Figure 1. Percent of cities with cable modem service offered in at least some portions of the city in the early part of year 2000.

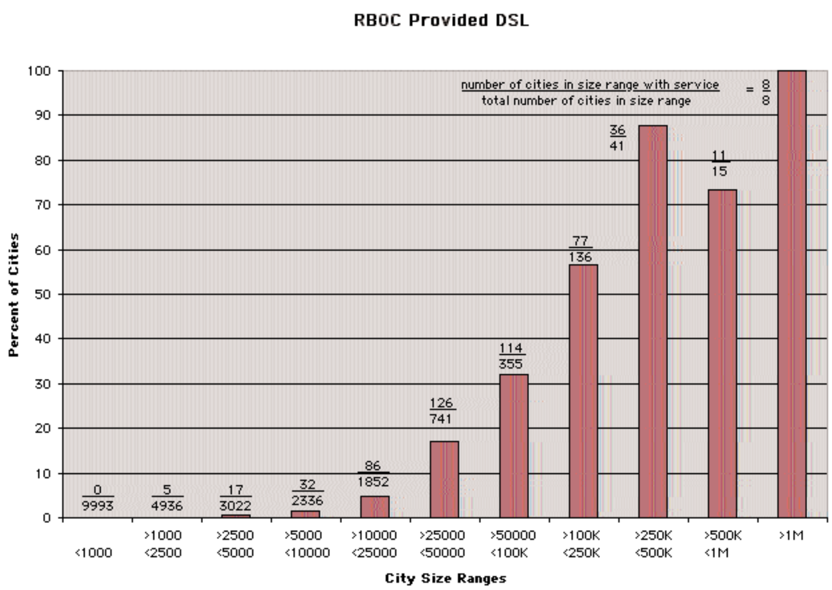

Figure 2. Percent of cities with DSL service offered in at least some portions of the city in the early part of year 2000.

Recent Publication

National Telecommunications and Information Administration and Rural Utilities Service, "Advanced telecommunications in rural America: The challenge of bringing broadband service to all Americans," April 2000.

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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 have helped make possible the current explosion of telecommunications and broadcasting offerings, which include digital cellular telephone services, voice over Internet protocol (VoIP) services, voice messaging systems, digital audio broadcasting, Motion Picture Experts Group (MPEG) 1, Layer-3 (MP3) music files and MPEG Advanced Audio Coding systems. Digital compression allows these systems to deliver good-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 and possibly radio spectrum with other data streams and hence with other users.

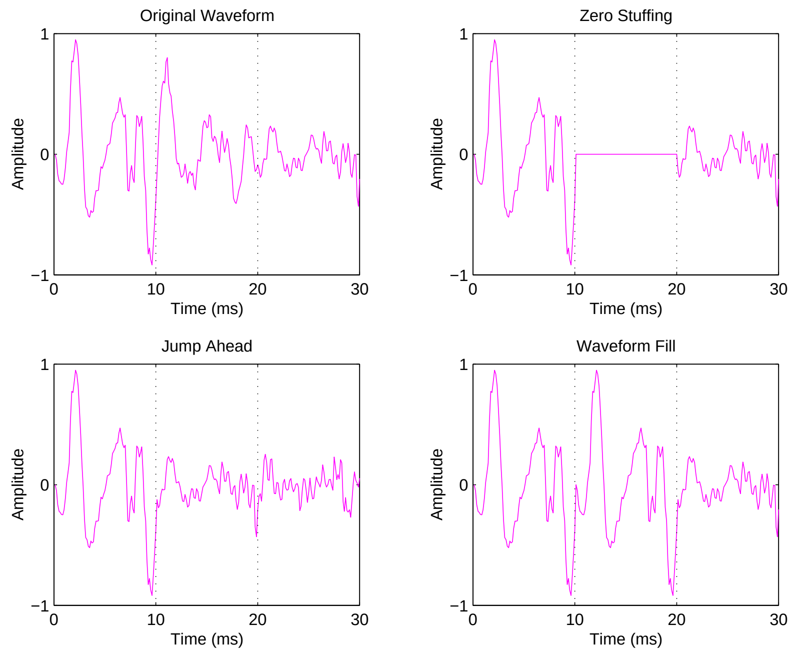
These digital compression and transmission techniques and the associated economic trade-offs are closely coupled to issues of speech quality and audio quality. Equipment manufacturers, service providers, and users all seek equipment and services that maximize delivered speech or audio signal quality under applicable transmission channel constraints. The complex time-varying interactions among signal content, source coding, channel coding, and channel conditions are making it increasingly difficult to define or measure speech or audio quality. The ITS Audio Quality Research Program studies quality issues in speech and audio compression and transmission, and develops and verifies tools that assist with quality estimation and optimization.

The most fundamental and correct measures of audio quality are provided by subjective listening experiments. However, properly conducted subjective listening experiments tend to be complex, time consuming, and expensive. To provide a practical alternative, the Audio Quality Research Program developed the measuring normalizing block (MNB) algorithms for estimating the perceived quality of 4 kHz bandwidth speech. The MNB algorithms include a simple hearing model followed by a more sophisticated judgment model. When speech quality estimates from the MNB algorithms are compared with the results of subjective listening experiments, a good degree of correlation is found. These algorithms furnish industry, Government, and other users with valuable tools that provide rapid and reliable quality feedback. The MNB algorithms form both the American National Standards Institute Telecommunications Standard T1.518-1998 and ITU Recommendation P.861, Appendix II, 1998. During FY 2000, program staff continued to respond to wide interest in the MNB algorithms from industry and academia. The MNB patent was issued to ITS on July 18, 2000. Much of the ongoing program work is ultimately aimed at extending the usefulness and accuracy of the speech quality estimates generated by MNB-type algorithms.

In FY 2000 the Audio Quality Research Program conducted numerous studies. One study addressed the problem of calibrating subjective test results. Subjective tests gather users' opinions of speech or audio quality, but results of different tests in different laboratories are not generally directly comparable. Program staff developed an iterated nested least-squares algorithm to map subjective test results to a common scale. Program staff also studied the causes and implications of a specific type of distortion that occurs in low-rate codebook-based speech compression devices. Extensive speech quality tests were performed on an automated two-way radio and telephone interconnection system.

Program staff also collaborated with National Institute of Standards and Technology (NIST) staff who recently developed a new magnetoresistive microscope. In support of the NIST effort, program staff prepared magnetic tape samples and formatted magnetoresistive microscope images of those samples into digital audio files for playback. Through this work it was determined that microscope images of severely abused tape fragments contain usable audio signals.

Another continuing program activity centers on the packet loss concealment (PLC) algorithms used for voice over Internet protocol (VoIP) systems. In most VoIP situations, at least some fraction of the transmitted data packets are not received in time to be decoded and played as speech waveforms. These unavailable packets are considered to be lost. PLC algorithms attempt to conceal the fact that some packets (and the corresponding portions of a speech waveform) have been lost.



Simplified examples of three packet loss concealment (PLC) approaches.

Many PLC approaches have been proposed. The Figure provides highly simplified operational descriptions of three basic PLC approaches in the case where a single packet is lost. The first waveform in the Figure is a portion of an original speech waveform to be transmitted. The packet boundaries are indicated by dotted lines. The "zero stuffing" algorithm simply substitutes a string of zeros for the information in the lost packet. The "jump ahead" algorithm works only when the network behavior and the receiver jitter buffering are such that when it is time to play the lost packet N, packet N+1 is already available. The "jump ahead" algorithm simply plays packet N+1 instead of packet N. This effectively contracts the speech signal in the time dimension. Thus it is necessary to later dilate the speech signal in the time dimension by an equal amount. The "waveform fill" algorithm preserves the time dimension of the speech signal and generates an estimated waveform to fill in for the missing information. This estimate is usually based on the contents of the last received packet. Estimation may be a complex process, or it may amount to simply repeating a previously received portion of the waveform as shown in the Figure.

Numerous variants of these three basic approaches exist, and fundamentally different approaches exist as well. The case of multiple lost packets adds additional complexity. program staff are studying PLC algorithms in terms of quality of concealment, algorithmic delay and complexity, and the amount of side information required by the algorithm. As expected, results are strongly dependent on packet size: shorter losses are easier to conceal than longer losses.

Technology transfer and literature dissemination efforts in the program were enhanced in FY 2000 through the development of a significantly expanded web presence located at www.its.bldrdoc.gov/home/programs/audio/audio htm. Program results were also disseminated to industry, Government, and academia through technical publications and presentations, participation in workshops, conferences and symposia, and laboratory demonstrations.

Recent Publication

S. Voran, "Results on reverse water-filling, SNR, and log-spectral error in codebook-based coding," in *Proc. 2000 IEEE Workshop on Speech Coding*, Delavan, WI, Sept. 2000.

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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, p. 102).

For the past four 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

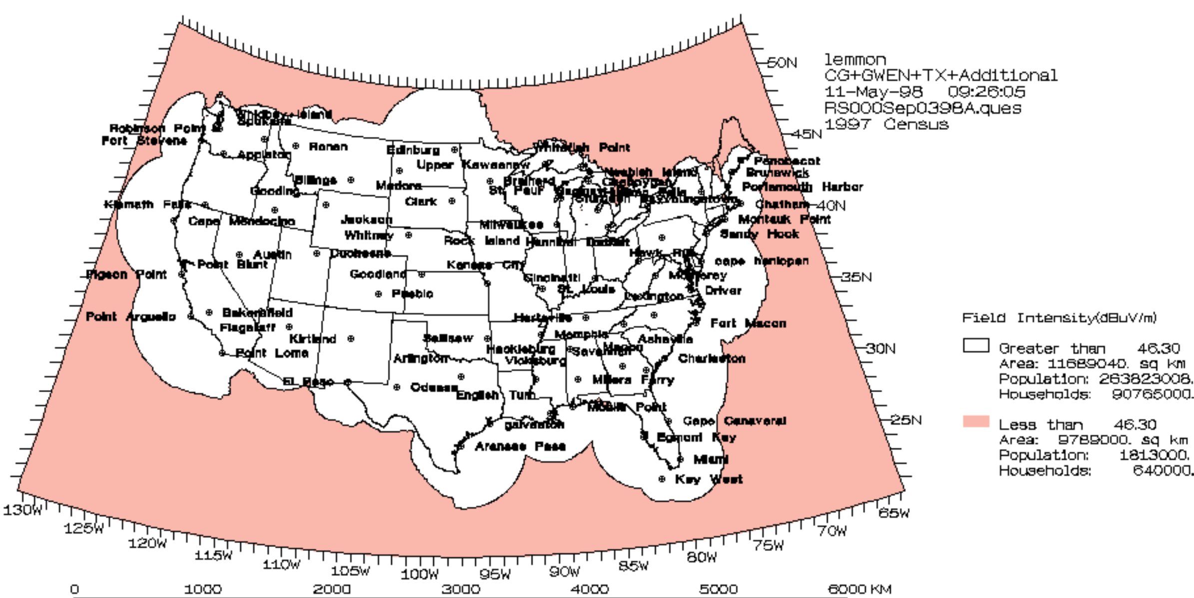

Figure 1. Signal coverage prediction plot showing nationwide coverage of the planned nDGPS service.

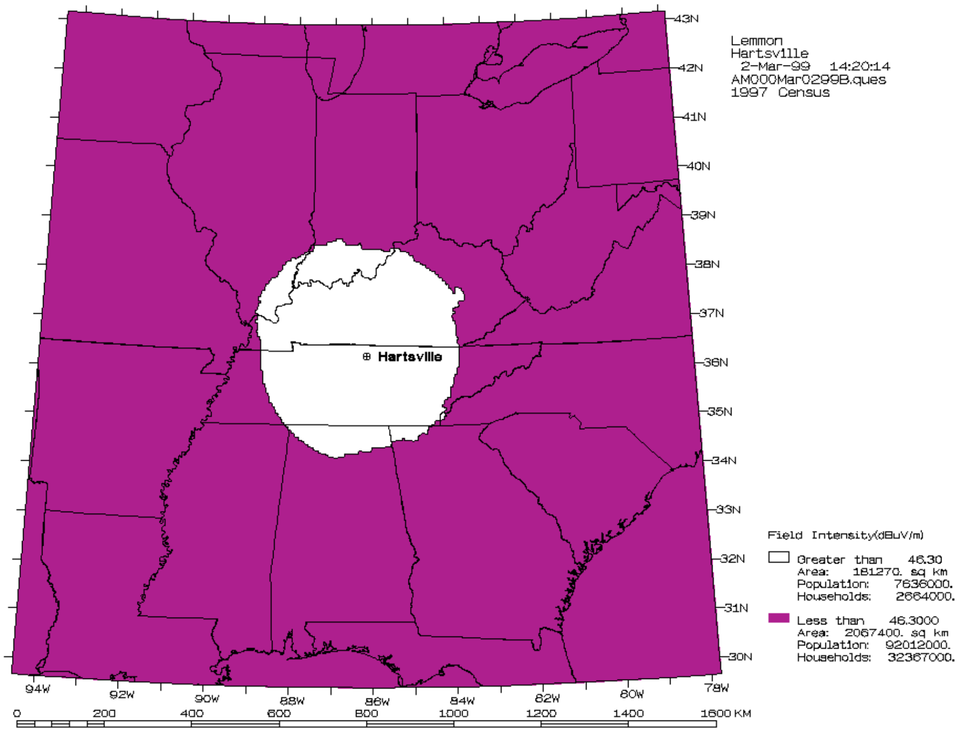

Figure 2. Signal coverage prediction plot for the DGPS reference station at Hartsville, TN.

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. Figure 1 shows a signal coverage prediction plot of this nationwide coverage. Installation of the GWEN DGPS reference stations is currently underway.

In FY 2000, ITS has provided technical support to the Department of Transportation that has been required for the implementation of the nDGPS. Much of this support has been in the form of interference analyses required to assess the impact of newly installed DGPS reference stations on existing aviation beacons in the 300-kHz frequency band. These analyses are particularly important for those stations whose transmitter powers have been increased from the recommended levels to provide signal coverage in unanticipated coverage gaps. A signal coverage prediction plot for one such station, at Hartsville, TN, is shown in Figure 2.

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Mobile Network Modeling

Outputs

- Discrete radio link models.
- Markov channel models.

In the past, businesses have provided data services to their mobile workforce with proprietary, low speed mobile packet data networks. Today, businesses and individuals are accessing the information-rich worldwide web with laptop computers, personal digital assistants, and mobile phones. The mobile packet data network now consists of a mobile link terminating in a wireless local area network access point or a personal communications service base-station which interworks with the ubiquitous, standards-based Internet.

Signal distortion introduced by radio channel multipath, noise, and interference causes mobile link speed and reliability to be considerably less than those of a fixed link operating over fiber, cable, or twisted wire pairs. These effects are accentuated when the mobile terminal is used while walking or driving. Advanced signal processing techniques will undoubtedly improve mobile link speed and reliability. However, for the foreseeable future, the performance of a mobile link will always fall short of the performance of a fixed link.

Standardized network protocols such as asynchronous transfer mode (ATM) or transmission control protocol/Internet protocol (TCP/IP) used in the worldwide web were designed for routes composed of reliable fixed links. Accessing the Internet with these protocols from a mobile terminal has been found to degrade network performance. For example, packet errors are expected to be rare for reliable fixed links. Therefore these network protocols have eliminated error checking at the link level to decrease delay. As a result, mobile packets in error are retransmitted across the entire route instead of over the unreliable link alone. This decreases network efficiency.

In the future, network protocols must be developed that can remain efficient when the route includes an unreliable mobile link. Accurate mobile radio channel and radio link models are needed for this important task. In FY 2000 ITS developed custom discrete radio link simulator software to fulfill this need. The software is unique in that it easily accepts ITS radio channel measurement data and models. The software is also unique in that it provides detailed packet error statistics needed for accurate network performance prediction.

The ITS discrete radio link simulator software processes data in the following manner. The transmitter converts discrete information bits to a signal that can be propagated through the radio channel.

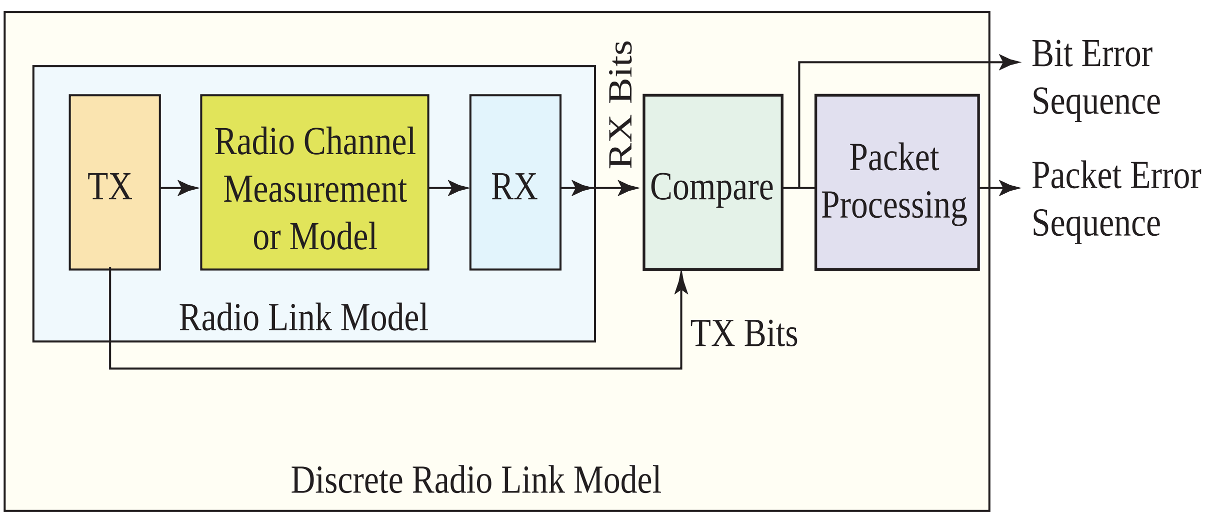

Figure 1. Block diagram of ITS discrete radio link simulation software processing.

The mobile radio channel, consisting of ITS measurements or models, distorts the signal with multipath, noise, and interference. The receiver converts the distorted signal back to discrete bits. A bit error sequence is obtained by comparing transmitted bits to received bits. With knowledge of the packet length and error correction capabilities, the bit error sequence is converted to a packet error sequence. The relationships between radio channel model, radio link model, bit error sequences, packet error sequences, and discrete radio link model are depicted in Figure 1.

Mobility introduces time variability in the channel. The rate at which the radio channel varies determines the amount of correlation between bit errors. If the variation is faster than the transmission speed, there is little correlation between bit errors, and the bit errors are considered independent. On the other hand, if the variation is much slower than the transmission speed there is correlation in bit errors, and measures such as bit interleaving are needed to restore bit error independence. First order error statistics, such as error rate, do not convey error correlation information. Second order error statistics, such as the probability of an error burst length, do.

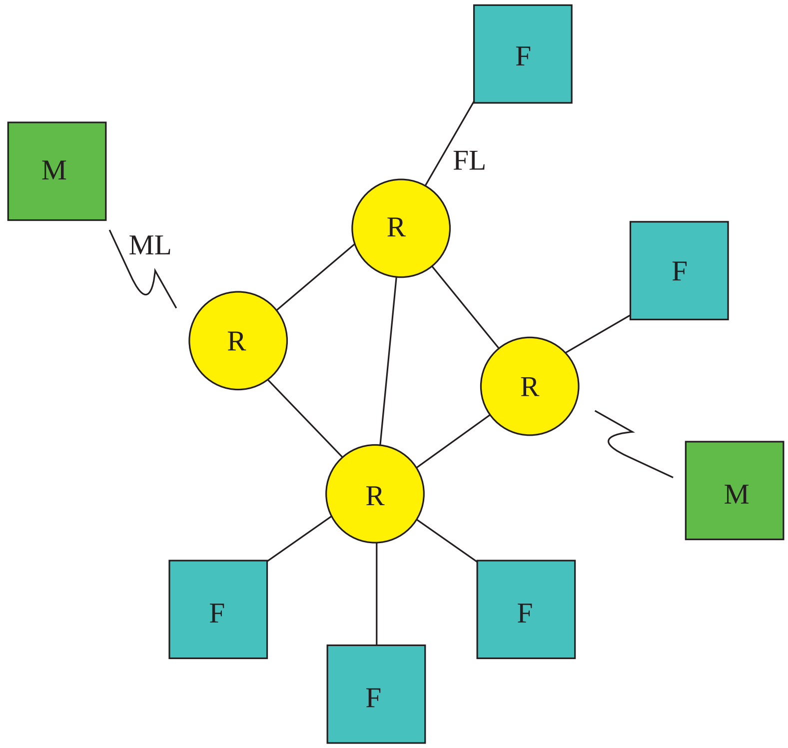

Figure 2. Mobile network.

Many radio channel models assume that the second order bit-error statistics are determined by independent, identical, Poisson distributed random processes with exponentially distributed error burst lengths. Additive white Gaussian noise introduced by the receiver causes Poisson distributed bit errors. However, multipath attenuation and frequency selective fading and interference from other electrical or electronic devices cause the bit errors to arrive with more complex second order statistics. Bit errors may be clustered, for example, by an extended fade caused by driving behind a large building.

The bit and packet error sequences provided by the discrete radio link simulator contain all the information needed to compute first and second order error statistics. These statistics are used in tandem to develop Markov error models capable of generating packets with error statistics corresponding to those generated by the simulation (J.J. Lemmon, "Wireless link statistical bit error model," to be published as an NTIA Report in FY 2001).

In FY 2001 ITS will use these error models to predict the performance of the simple network shown in Figure 2. The network consists of routers (R), fixed (F) and mobile (M) terminals, and fixed (FL) and mobile (ML) links. Each router has a queuing discipline and a routing table. The terminals have traffic models and the links have packet error models. The results of this performance prediction will only be as accurate as the radio channel and corresponding error models. Because of its long history of radio channel measurement and modeling, ITS is poised to assist industry and government in designing and evaluating network protocols that optimize performance of networks with mobile links.

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Narrow Pulse System Characterization

Outputs

- Theoretical analysis of emission spectrum and signal statistics.
- Technical support for spectrum managers, regulators, and system designers.

A wide variety of existing and proposed electronic systems emit short duration pulses for purposes of radar detection, communications, and other applications. The emission spectra for such systems have an extremely wide bandwidth. Such devices are often referred to as ultrawideband (UWB) systems. The proliferation of UWB systems throughout the United States has been predicted by many industry sources. Hence, it is important that the effects of such devices on RF spectrum users be well understood by regulators, spectrum users, and system designers. ITS has analyzed the emissions spectra of a number of such systems in support of efforts to assess their effects on more traditional radio spectrum users.

The theoretical analysis of UWB communications and radar systems provides important insights into how their emissions will affect various types of RF communications devices. In addition to allowing for direct calculation of interference effects, theoretically derived results can be used to aid in the planning, design, and validation of measurements. Perhaps the most important quantity for understanding the potential for interference to RF systems is the power spectral density. The power spectral density is the average power in the signal per unit bandwidth and hence provides important information on the distribution of power over the RF spectrum. As part of an ongoing research effort, ITS has developed methods for predicting the power spectrum for various archetypal UWB systems. Typically such systems utilize repeated random (in time) very short duration pulses for both communications and radar applications.

The theoretically derived power spectrum can be used to calculate the mean power in the bandwidth of a narrowband victim RF receiver at its operating or center frequency, and hence provides important information regarding the interference potential. For example, Figure 1 shows the power available to a receiver with a nominal 10 kHz bandwidth as a function of frequency. This result is based on a proposed UWB communications system where periodic short duration pulses are transmitted at a nominal rate. The pulses are randomized over some fraction of the pulse repetition period. As shown in Figure 1, the system emits both a discrete and a continuous spectrum. The discrete spectrum is not a factor for RF frequencies above a few hundred MHz. For narrowband victim receivers where gains due to the UWB transmitter filters/antenna, propagation channel, and receiver are fairly constant over the receiver bandwidth, the received interference power can easily be calculated by applying the appropriate gain factors to the power in the receiver bandwidth at the center frequency of the receiver.

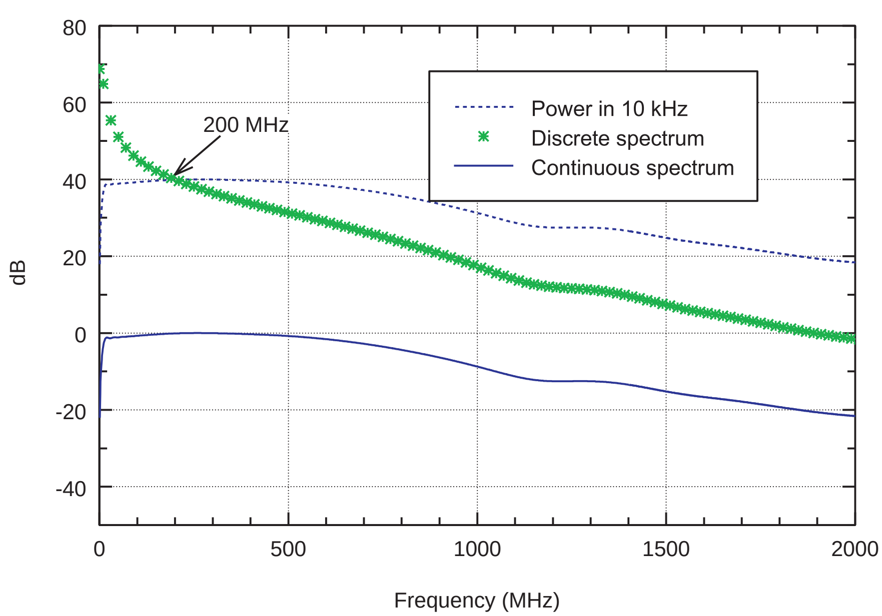

Figure 1. Calculated power spectrum for a UWB communications system.

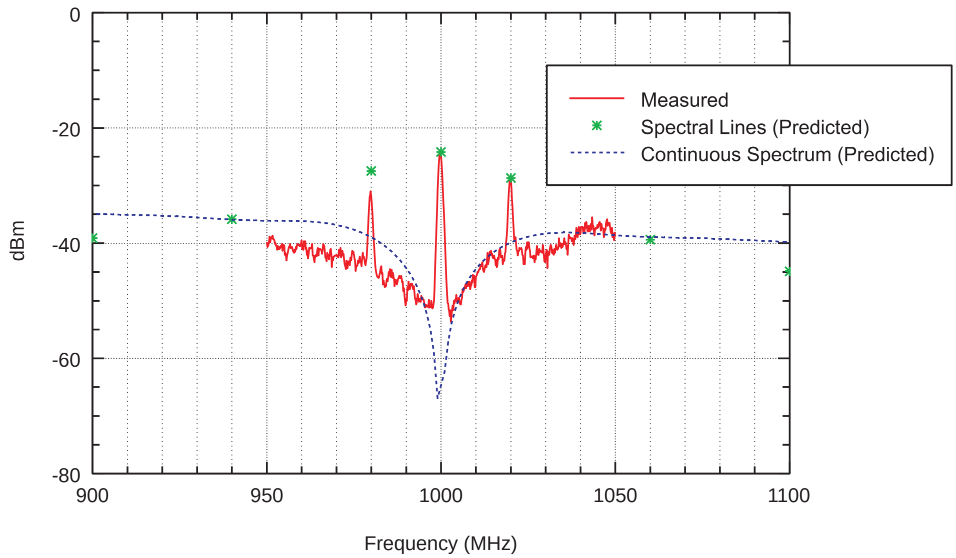

Figure 2. Comparison of measured and predicted results.

Of particular importance to spectrum managers and regulators is the fact that the spectrum contains both *continuous* and *discrete* components. The relative amplitude of both spectral components as well as a potential victim receiver's bandwidth must be used in electromagnetic compatibility (EMC) analysis. The analytical results developed at ITS are quite general and easily applied to EMC analysis. In particular, the analytical results can be used to predict the power spectral density at various points in the radio link between an interfering UWB transmitter and a victim receiver (e.g., at the output of the UWB transmitter, the UWB signal radiated from a particular antenna, or in the IF section of a narrowband RF receiver). When dealing with linear systems, the various pulse shapes are simply related by convolutions with the appropriate impulse response functions.

Since the UWB emissions are often perceived by a victim receiver as a random process, it is important to characterize the signal as viewed by a victim receiver. A knowledge of the statistics of such a process is important in predicting how interference affects the performance of a receiver. When the UWB pulse repetition frequency is larger than the receiver bandwidth, it may be expected that the received signal would appear to be indistinguishable from Gaussian noise. Since receiver performance in a Gaussian noise environment is well understood, quantifying conditions for which the received UWB interference resembles Gaussian noise is important in predicting receiver performance and developing emissions requirements. Also, when the received signal is Gaussian, only one parameter (mean power) is required to characterize the process. Analytical methods have been developed to determine the statistical character of fixed time base dithered signals. In particular, these methods can be used to determine when UWB signals are perceived by a victim receiver as Gaussian noise, and hence, are important tools for spectrum regulators and system designers.

The analytical results developed as part of this effort are also essential to the design and validation of interference testing and measurements. Figure 2 shows a comparison of the calculated and measured power spectra for UWB emissions that were used to test interference effects for an RF communications system. The good agreement between measurements and predictions lends credibility to the testing methodology. By comparing test equipment emissions and theoretical predictions, the test procedures and methodologies can be properly validated.

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Software Defined Radio Technology

Outputs

- Survey of tools and methodologies for implementation of software defined radio (SDR) signal processing algorithms in field programmable gate arrays (FPGA).
- Development of methodology to implement system-level signal processing algorithms in FPGA's.
- Implementation of a wireless local area network (LAN) despreader in an FPGA and performance verification at 25 Msamples/second.

A software defined radio (SDR) consists of an SDR receiver and/or an SDR transmitter. In an SDR receiver, the received signal is digitized and then processed using software-programmable digital signal processing techniques. Digitization may occur at the RF, IF, or baseband. In an SDR transmitter, the modulated signal to be transmitted is generated as a digital signal using software-programmable digital signal processing techniques. The digital signal is then converted to an analog signal for transmission. The conversion to analog may also occur at RF, IF, or baseband.

Awareness of the viability of, potential market for, and potential spectrum management impact of SDR's continues to grow as evidenced by an increasing number of SDR development efforts and actual products, the significant growth of the SDR Forum membership, and the recent Federal Communications Commission (FCC) Notice of Inquiry on Software Defined Radios. Because of the increasing importance of SDR's in wireless communications, the Institute has been involved in SDR research over the past five years.

Key areas of research in SDR's include data conversion (analog-to-digital and digital-to-analog), digital signal processing, and linear power amplification. Research in SDR's at the Institute in FY 2000 focused on the digital signal processing aspects of SDR's. Digital signal processing in SDR's can be accomplished by the use of application specific integrated circuits (ASIC), digital signal processing integrated circuits, field programmable gate arrays (FPGA), or general purpose processors. A combination of these types of devices can also be used to perform the digital signal processing in an SDR.

Digital signal processing research in SDR's at the Institute specifically focused on implementation of system-level SDR signal processing algorithms in FPGA's. The rapid advances in the gate capacity and operating speed of FPGA's has opened up an opportunity for performing real-time digital signal processing on a single FPGA that was not possible several years ago. The impact of research on implementation of system-level signal processing algorithms in FPGA's is not only significant in its own right, it actually encompasses many other major research areas such as hardware/software co-design, rapid prototyping, system-on-a-chip (SOC), reconfigurable computing, and electronic design automation.

There is a large gap between a system level or algorithmic description of signal processing and the implementation of algorithms in an FPGA. System level signal processing is easily carried out with high-level programming languages (such as C) or with system-level simulation block diagram tools. Tools for design with FPGA's are abundant and include both schematic capture and hardware description language synthesis tools. The problem is in traversing from the world of system-level processing to the FPGA design world. Traditionally, this "bridging of the gap" has been done by using a manual translation of the system-level design into a design suitable for implementation in FPGA's.

The goal of the research at the Institute was to develop an efficient methodology (design process) for implementing SDR signal processing algorithms in FPGA's. A methodology in which a system level or algorithmic description of the processing can be implemented in an FPGA in the most efficient and automated manner was desired.

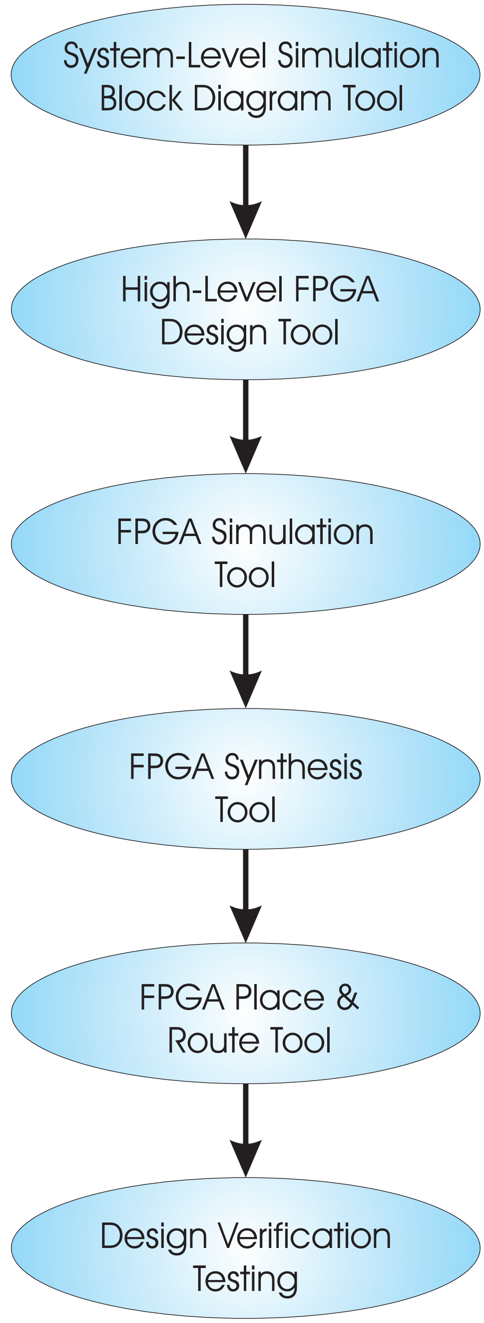
The level of abstraction at which the FPGA design is carried out is a metric for research in the field of implementation of signal processing algorithms in FPGA's. The goal is to be able to carry out the FPGA implementation at the highest level of abstraction possible, ideally right at the system level. Traditional FPGA design uses a fairly low level of abstraction by designing at the hardware architecture level. Raising this level of abstraction is a goal that is being addressed by many research efforts at this time.

A wide variety of tools were examined to assess their potential usefulness in the process of implementing signal processing in FPGA's. The tools examined fell into the following general categories: 1) system-level simulation block diagram tools, 2) automatic translation tools that convert code from high-level programming languages into a hardware description language such as VHDL, 3) object-oriented system design tools such as the specification and description language (SDL), 4) a high-level FPGA design environment tool, and 5) an object-oriented hardware description language.

While many tools exist to aid in the process of implementing system-level signal processing in FPGA's, and there have been and continue to be efforts to automate the process, our research revealed that automation has only been successful under certain limited and simple circumstances. Full automation of the process is indeed in its infancy.

Since an efficient, fully-automated process was not yet available, a design methodology was developed that utilizes a commercially available, high-level FPGA design environment tool and a commercially available system-level simulation block diagram tool. The combination of these tools along with FPGA simulation, synthesis, and place and route tools provides an efficient semi-automated design methodology. A high-speed pattern generator and logic analyzer are used for design verification by providing real-time stimulus and response testing of the FPGA. The block diagram in the Figure summarizes the design methodology and verification.

Verification of the design methodology was initially accomplished by demonstrating the implementation of a matched filter correlator for a wireless LAN in an FPGA. Real-time performance of the matched filter correlator FPGA implementation at 25 Msamples/second was demonstrated. A wireless LAN despreader was also implemented in an FPGA and successfully tested at 25 Msamples/second.



Design methodology and verification for implementation of system-level signal processing algorithms in FPGA's.

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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, p. 102), and is being used by organizations worldwide.

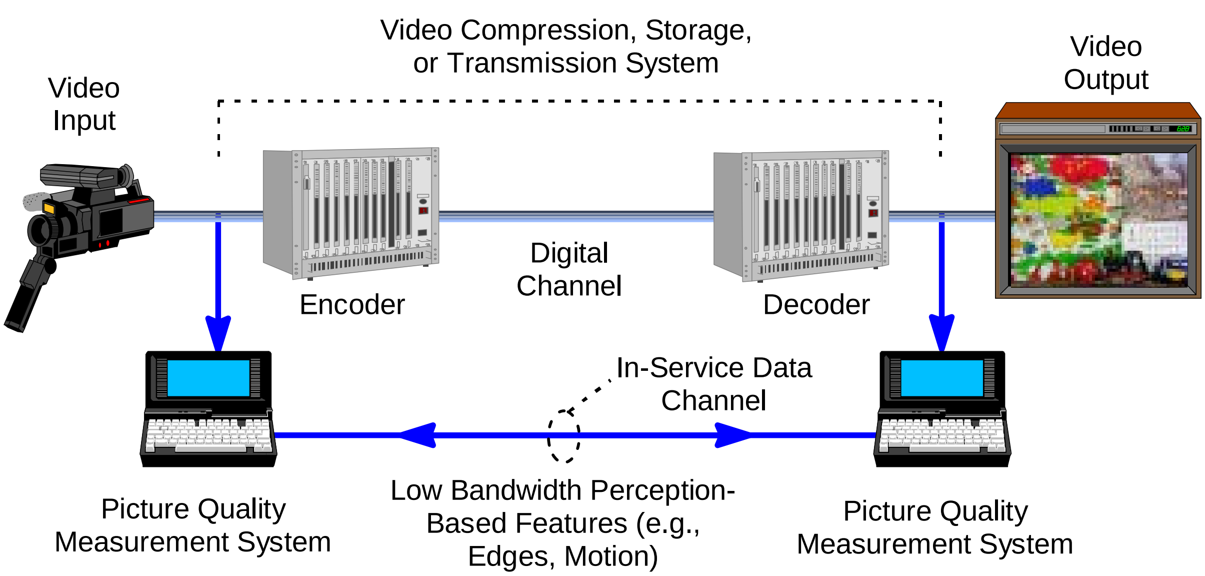

Figure 1. In-service perceptual picture quality measurement system.

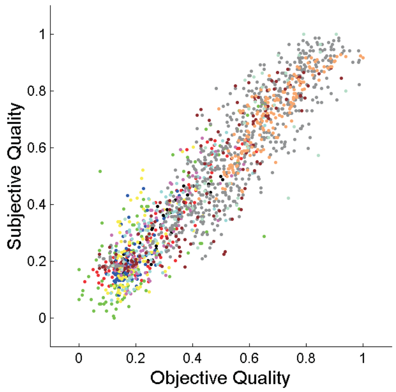

Figure 2. Objective predictions versus subjective data for each video clip.

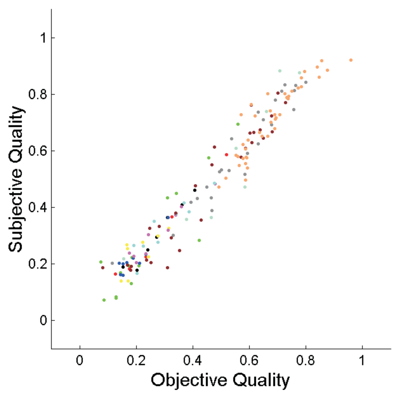

Figure 3. Objective predictions versus subjective data for each video system.

ITS continues to make refinements to the technology and to apply it to an ever-wider range of video scenes and systems. In FY 2000, eleven subjective (i.e., rated by viewers) and objective (i.e., rated by quality metrics) data sets were combined using a newly developed least squares fitting algorithm. The eleven video data sets covered 158 video systems operating at bit rates from 10 kbits/sec to 45 Mbits/sec and 115 video test scenes. ITS objective quality metrics produced the scatter plots shown in Figures 2 and 3. The horizontal axis gives the objective quality predictions while the vertical axis gives the subjective mean opinion scores. Each data set is plotted in a unique color and the scale of the plot is normalized such that 0 is no perceived impairment while 1 is maximum perceived impairment. Figure 2 gives the results for each clip (i.e., a given scene sent through a given video system) while Figure 3 gives the results for each video system (i.e., averaged results for a given video system). Figures 2 and 3 achieved correlation coefficients between the objective data and the subjective data of 0.94 and 0.98, respectively.

To facilitate the transfer of this promising technology to private industry, both UNIX-based and Windows®-based automated video quality measurement software has been developed. This software includes (1) video calibration, including video system gain/level correction and spatial/temporal registration of the input and output video streams, (2) four objective video quality metric calculations, optimized for specific digital video applications (TV, Videoconferencing, General – wide range of quality, Developer – wide range of quality + fast computation), and (3) root cause analysis summaries that give the perceptual relations between the objective metrics and specific digital coding artifacts (e.g., blurring, block distortion, jerky or unnatural motion, added noise, error blocks). Figure 4 is a photograph of the graphical display presented to the user by the Windows®-based automated video quality measurement software.

Further information and a list of recent publications can be found on the Video Quality Research home page at http://www.its.bldrdoc.gov/n3/video

Figure 4. User display presented by Windows-based video quality measurement system (photograph by F.H. Sanders).

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Wireless Propagation Research

Outputs

- Methods of predicting the impulse response for an indoor propagation channel and the delay spread of the multipath channel.
- Assessment of the geometric optics approximation for indoor ray-trace models.
- Identification of a pseudo-lateral wave phenomenon.

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 of new indoor wireless local area networks and wireless local campus networks, 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, characterization of an anechoic chamber, and analyzing the coupling mechanisms between rooms. 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 assess the validity of the ray-trace model, we have investigated the accuracy of some assumptions used in ray-tracing. Using the exact Sommerfeld formulation for a source above a dielectric half space, a thorough investigation into the geometric optics (GO) approximation was performed. 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. Figure 2 shows fields from an elementary horizontal dipole close to a dielectric surface calculated from the GO approximation (with and without the Norton surface-wave term added) and numerical evaluation of Sommerfeld's formulation. A discernable pseudo-lateral wave phenomenon was identified that produces an interference pattern in the Sommerfeld solution with respect to the GO plus Norton term approximation at relatively high frequencies when the source and observation points are near the surface.

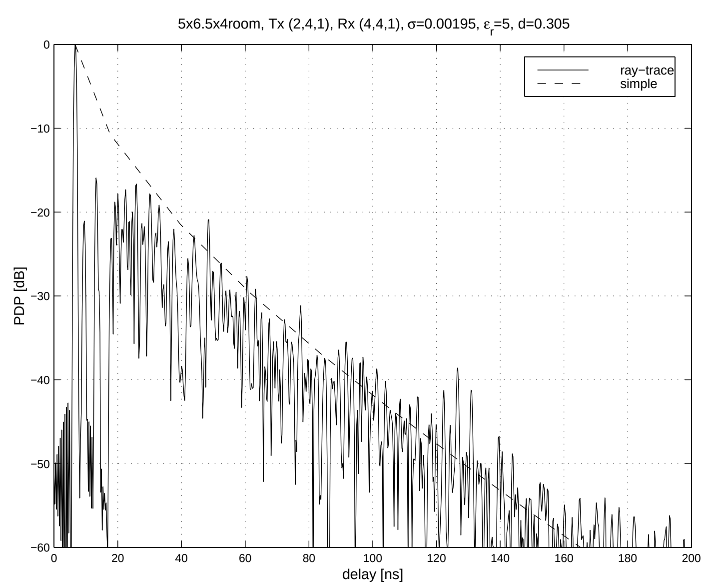

Figure 1. Calculated power delay profile from both ray-tracing and the simple model.

The Institute is also involved in measurement efforts 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 3.

Results indicated less linearly-polarized (LP) basic transmission loss than circularly-polarized (CP) basic transmission loss for both line-of-sight and obstructed channels. Also, LP rms delay spread was similar to CP rms delay spread in both line of sight (LOS) and obstructed (OBS) paths. The apparent advantage of using LP signals over CP signals indoors may be attributed to the relatively high degree of circular depolarization measured. Results also supported the use of omnidirectional antennas indoors to improve signal coverage. Omnidirectional measurements, however, demonstrated large delay spreads for some extraneous cases.

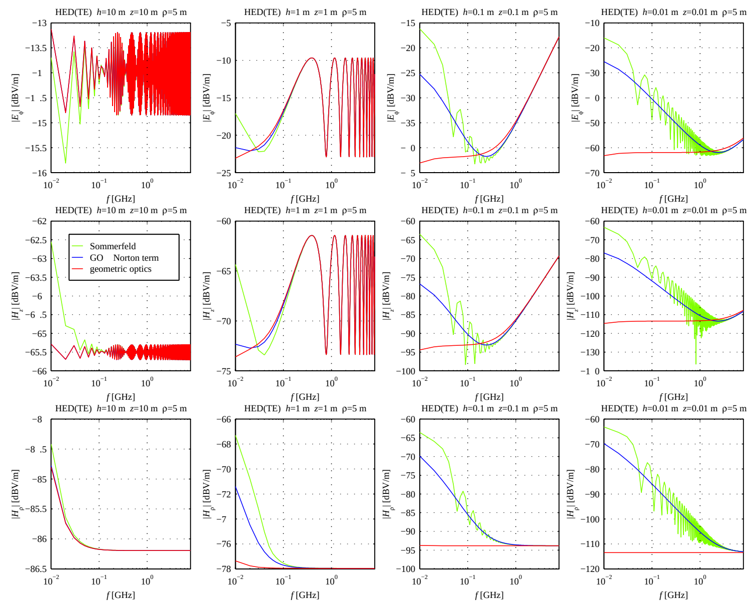

Figure 2. Near-surface effects on field strength of an elementary horizontal electric dipole above a concrete half space.

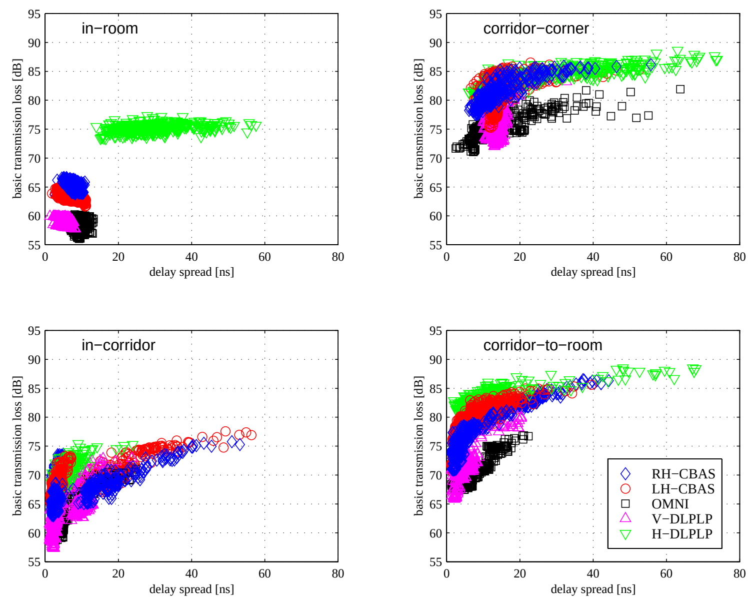

Figure 3. Scatter plots of basic transmission loss versus delay spread of individual impulses for a V-OMNI transmit antenna and various receive antennas.

Recent Publications

M.G. Cotton, E.F. Kuester, and C.L. Holloway, "A frequency- and time-domain investigation into the geometric optics approximation for wireless indoor applications," NTIA Report 00-379, Jun. 2000.

M.G. Cotton, R.J. Achatz, Y. Lo, and C.L. Holloway, "Indoor polarization and directivity measurements at 5.8 GHz," NTIA Report 00-372, Nov. 1999.

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Cooperative Research with Industry

Outputs

- PC-based tools that measure the quality of audio and video signals that have 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.

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; Lucent Digital Radio; Intel Corporation; and the American Automobile Manufacturers Association (AAMA). Not only does the private industry partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do. Recent CRADAs are described below.

- Intel Corporation and ITS have entered into a CRADA to conduct cooperative research and development in the area of telecommunications and multimedia for development of test equipment and products. The areas of interest include subjective and objective video quality, subjective and objective audio quality, and wireless communications.
- 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.

ITS Video Quality Assessment System (photograph by F.H. Sanders).

- 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. 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.

- Lucent Digital Radio and ITS entered into a CRADA to conduct research on a digital audio broadcasting (DAB), in-band on-channel (IBOC) radio system. The IBOC system permits the simultaneous transmission of a digital signal and an analog signal within an AM and FM station's current spectral allocation. DAB will have the capability to provide higher-quality audio than is currently available from existing analog FM and AM broadcasting. ITS served as an objective evaluator during testing of this system.

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.

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ITU & Related National 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.

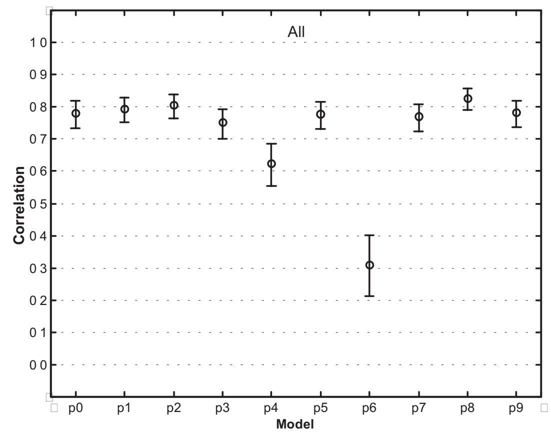
The Institute has a long and distinguished history of leadership, technical contributions, and advocacy of U.S. government and industry proposals in international and related national telecommunication standards committees. These activities have been focused in the International Telecommunication Union (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 Radiocommunication 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. 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. During FY 2000, an ITS staff member assumed a new ITU-R leadership role as Chair of Task Group 3/2 on Broadcast and Land Mobile Point-to-Area Propagation Predictions.

The Institute's ITU-R activities support international efforts to advance existing radio wave propagation, noise/interference, and coverage prediction techniques to substantially better levels of accuracy and resolution. In prior work, ITS 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. During FY 2000, ITS developed and standardized algorithms for extracting path profiles from such terrain databases. To support the use of the new terrain databases, ITS is providing algorithms to the ITU-R that utilize terrain characteristics to make point-to-point propagation predictions. ITS participates in the Correspondence Group that will evaluate the point-to-point prediction methods and develop a new Recommendation on the topic. Finally, ITS has provided material for a new ITU-R Handbook that will guide users in the application and interpretation of propagation calculations used in the Land Mobile Radio Service. The material includes information on radio and man-made noise in the Mobile Service bands and on the topics of ray-tracing, geometric theory of diffraction-uniform theory of diffraction (GTD-UTD), and parabolic and integral equation methods.

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 — is 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 integrated IP-based networks, and are developing objective, perception-based quality metrics for voice, video, and multimedia services.

The Institute's ITU-T activities in 2000 were focused in two groups: Study Group 13 Working Party 4 and Study Group 12 Working Party 2. The former group develops performance Recommendations for high-speed synchronous digital hierarchy (SDH), broadband integrated services digital network (B-ISDN), asynchronous transfer mode (ATM), wave division multiplexing (WDM), and Internet protocol (IP)-based technologies. The latter group defines performance parameters and



Correlation of objective video quality metrics (models) with subjective perception.

objectives for end-to-end transmission networks and terminals. ITS also provides leadership and technical contributions to related work in the American National Standards Institute (ANSI) accredited T1 (Telecommunications) Committee's T1A1 (Performance) Subcommittee and its three Working Groups. During FY 2000, ITS leadership in Study Group 13 contributed to the completion or substantial revision of ten ITU-T Recommendations: I.356 (ATM cell transfer performance); I.355, I.357, G.827, and G.827.1 (availability performance); G.828 and G.829 (broadband network transmission error performance); G.824 and G.825 (network time and frequency distribution performance); and I.351 (structure, content, and relationships among ITU-T performance Recommendations). The Institute's leadership in Study Group 12 assisted the Video Quality Experts Group (VQEG) in completing a comprehensive multi-laboratory evaluation of video quality assessment technologies proposed for international standardization. The Figure shows the correlations with subjective perceptions (and associated 95% confidence intervals) for each of the ten objective video quality metrics (models) evaluated by VQEG. The Institute's continued leadership in T1A1 advanced U.S. voluntary consensus standards and contributions to ITU-T in these and several other technology areas. A particular focus of ongoing T1A1 work is the standardization of QoS objectives for voice over Internet protocol (VoIP) and other real-time IP network services.

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An ITS engineer from the Telecommunications and Information Technology Planning Division performing maintenance and upgrade of a local area network at the Boulder laboratory (photograph by F.H. Sanders).

ITS Tools and Facilities

Adaptive Antenna Testbed

The adaptive antenna testbed (ATB) is a multi-channel test facility based on ITS digital sampling channel probe technology (see also "Adaptive Antenna Testbed," pp. 56–57). The VMEbus-based system can simultaneously characterize eight wideband radio channels (expandable). The received signals are digitized for flexible post processing. The Table below summarizes the range of permissible values for the ITS channel sounding system, as well as giving an example of a personal communications services (PCS) band configuration.

Data Acquisition and RF Parameters used for Diversity Tests

Configurable System Parameters

Parameter	PCS Band Example	ITS System
Receiver Channels	4	1-8 (expandable to 16)
Carrier Frequency	1 92 GHz	45 – 6 GHz
Bit Rate	10 Mb/s	1 – 50 Mb/s
Resolution	100 ns	10 µs – 20 ns
Code Type	Maximal Length	Programmable
Code Length	511 bits	Programmable
Acquisition Mode	Burst	Continuous or Burst
Positioning	GPS/Dead Reckoning	GPS/Dead Reckoning
Transmitters	1	Multiple
Data Processing	Post	Post or Real Time

The ATB provides a common reference for evaluating next-generation PCS antenna systems. Data from multiple channels can be used to test the diversity gain resulting from various signal combining algorithms. Digital beam forming techniques may also be examined.

A well-characterized cell site in Boulder, CO, serves as a known platform for evaluating existing and new PCS components and systems. Alternately, the ATB transmitting and receiving systems may be van-mounted for site mapping studies at any required location.

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Audio-Visual Laboratories

The ITS Audio-Visual Laboratories offer a wide range of audio and video recording, storage, processing, reproduction, objective quality assessment, and subjective testing capabilities. These capabilities in turn support the development and verification of new quality estimation techniques for compressed digital audio and video, and the development of novel subjective testing techniques for audio and video signals. Signals are acquired with high-quality microphones and cameras. Recording and playback devices include studio-quality analog and digital video tape recorders with two to four audio channels, video disk systems, digital audio tape machines, CD players, and analog audio cassette machines. These systems are augmented with several computer-based digital audio and video systems. One system offers the ability to record and playback video streams that conform with International Telecommunication Union, Radio Communication Sector (ITU-R) Recommendation BT.601 and synchronized digital audio streams to and from a high-speed workstation with a 500 GB Fibre Channel disk array. Video processing is performed in the digital environment using several high-performance video workstations. These workstations are supported by storage peripherals that include an 80-GB read/write optical jukebox, a 12-GB 4mm tape drive, an 8 GB 8mm tape drive, and a 40 GB digital linear tape drive. Analog audio mixing, filtering, and equalizing equipment is available, and the most intensive audio processing is done in the digital domain on PC platforms. An array of digital audio and video encoders and decoders are available as well. An audio-video routing switcher and numerous patch-panels allow for nearly arbitrary interconnections between the various pieces of equipment in these laboratories.

Reproduced signals are presented through studio-quality video monitors, monitor loudspeakers, headphones, or handsets. Two separate rooms with controlled acoustic and visual environments are available for the subjective testing of audio and video signals. These environments are specified in International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) Recommendation P.800 and ITU-R Recommendation BT.500 respectively. These specifications address background noise levels, wall colors, light levels, room dimensions, among others. Finally, the labs feature an array of audio and video signal generators and analyzers to support laboratory measurement and calibration activities. Lab activities are mainly focused on objective estimation of audio and video quality, and subjective testing of audio and video quality. Random access digital audio-video playback systems coupled with electronic data entry systems greatly facilitate many of the subjective testing activities. Because two separate subjective testing rooms are available, the laboratory can support conversation, teleconferencing, and video teleconferencing tests as well as viewing and listening tests.

Objective video quality estimation software, written in C++, processes video signals in accordance with American National Standards Institute (ANSI) T1.801.03-1996 and other more recently developed metrics, resulting in estimates of video quality that show good correlation with subjective test results. Objective audio quality estimation is performed by software implementations of the Measuring Normalizing Block algorithms, standardized in ANSI T1.518-1998, and ITU-T Recommendation P.861, Appendix II, 1998. The labs support both batch-mode and real-time objective quality estimation.

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Digital Sampling Channel Probe

The digital sampling channel probe (DSCP), designed and patented at ITS, is used to characterize the wideband propagation characteristics of the radio communication channel. The probe, consisting of both a transmitter and receiver, is used to make complex impulse response measurements. Unlike the analog sliding correlator equivalent, the DSCP digitizes the received signal at an IF frequency and then processes the data, thus providing the advantages of digital processing. Relative to the sliding correlator, the time over which the impulse is generated is also less, and therefore, can characterize the communication channel over a shorter period of time. Historically the DSCP has been employed extensively for channel characterization of cellular and personal communications services. ITS has included new features such as a quad channel capability used to perform spatial and polarization diversity experiments. Recently developed is a wide-bandwidth, high-frequency probe, particularly suited for high resolution requirements such as indoor wireless local area network (LAN) applications. For a more detailed description of the measurement systems and applications, see the following ITS web site: http://flattop.its.bldrdoc.gov/rcirms/

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ITS Internet Services

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

- Information about ITS programs and projects. Available at http://www.its.bldrdoc.gov/home/projects html
- An ITS organization chart and a complete listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/home/organization html
- Recent ITS publications including NTIA Reports, special publications, and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs html
- The on-line version of FED-STD 1037C, Glossary of Telecommunication Terms featuring over 5800 technical definitions linked together in hypertext. Available at http://glossary.its.bldrdoc.gov/fs-1037/
- Telecommunications Analysis Services. Available at http://www.its.bldrdoc.gov/tas/
- Information about ITS-sponsored symposiums such as ISART. Available at http://www.its.bldrdoc.gov/meetings/art/index html
- Anonymous FTP distribution of some ITS developed software programs. Available at ftp.its.bldrdoc.gov

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ITS Local Area Network

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

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Mobile Radio Communication Performance Measurements

ITS maintains a test capability for determining the performance of land-mobile radio systems that comply with the Telecommunications Industry Association's TIA-102 and TIA-603 series of specifications.

The measurement capabilities include the usual TIA-603 type of measurements for analog systems, such as receiver sensitivity, adjacent-channel and cochannel interference. In addition, with TIA-102 (Project 25) capable test equipment, various aspects of the link control format information, such as network access code, talk group identification, emergency bit and message opcode, can be viewed. Demodulated speech samples can also be collected for an assessment of audio clarity by ITS' audio laboratory.

The primary use for this capability is interoperability testing between TIA-102 radios of different manufacture and backward-compatibility testing between TIA-102 radios and legacy analog FM systems. Other applications may be possible, such as routine performance measurements. This capability is available on a first-come, first-serve basis by both NTIA and other agencies.

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Mobile Radio Propagation Measurement Facilities

ITS maintains a measurement vehicle capable of radio channel characterization over a wide frequency range. The vehicle is equipped with on-board power, a telescoping mast, azimuth elevation controllers, and global positioning systems with dead-reckoning backup. A suite of measurement equipment also is available for use in this vehicle. This includes wideband systems for measuring radio channel impulse response at 450 MHz, 1350 MHz, 1920 MHz, 5.8 GHz and 30.3 GHz. Impulse response measurement capability at 30 GHz with 2ns resolution has been enhanced with the addition of a digital wideband recording system. During the past year ITS increased its mobile channel measurement capability with the addition of a phased array antenna system. Multi-channel synchronous acquisition can be used for antenna array measurements or multi-frequency broadband measurements. Mobile measurement capability allows space division multiple access (SDMA) algorithms to be studied using data collected in typical mobile environments. This data can then be used to simulate and model radio systems.

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Radio Noise Measurement System

The ITS noise measurement system hardware consists of an omnidirectional antenna mounted on a ground plane, preselector filter, low noise preamplifier, off-the-shelf spectrum analyzer, digitizer, and computer. Noise samples are digitized prior to spectrum analyzer detection just after spectrum analyzer log amplification. Spectrum analyzer demodulation circuits are used for aural noise identification during measurements. The measurement system noise figure is nominally 2 dB above kT_0b. Noise is measurable approximately 15 dB below and 60 dB above system noise. The noise measurement system uses custom data acquisition software written and maintained at ITS. The software graphical user interface allows the user to customize and notate each measurement. It also displays noise samples and their corresponding first-order statistics. The statistics are shown as an amplitude probability distribution (APD) function (complement of the amplitude cumulative distribution function). The APD is plotted on a Rayleigh graph that represents the amplitude statistics of Gaussian noise as a straight line with a negative slope. Non-Gaussian noise is easily identified during measurements as a deviation from the straight line or a change in slope. Non-Gaussian noise exists throughout the radio spectrum. ITS has used the noise measurement system to measure noise at 137.5 MHz, 402.5 MHz, and 761.0 MHz. The noise measurement system can also be used to measure noise at higher frequencies. For example, the noise measurement system can be used to measure noise at 2.4 GHz in spectrum occupied by unlicensed Part 15 low power communication devices such as wireless local area networks and Part 18 industrial, scientific, and medical devices such as microwave ovens. The noise measurement system can be run from a building or a measurement van. A direct current converter with noise suppressor is used to power the van mounted equipment if 120 V alternating current is not available. Calibration measurements in radio quiet zones have shown that noise contributed by the noise measurement system and power conversion equipment is negligible.

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Radio Spectrum Measurement Systems

ITS has designed, constructed, and currently operates a number of automated spectrum measurement systems. The Radio Spectrum Measurement System (RSMS), ITS' primary system, is a vehicularly mounted, self-contained facility for measurements between 1 MHz and 24 GHz. ITS also has available a number of suitcase-deployable systems called Compact Radio Spectrum Measurement Systems (CRSMS). RSMS and CRSMS facilities incorporate a combination of commercial off-the-shelf hardware, hardware custom-designed by ITS, and control software written by ITS. The RSMS is RF-shielded, and includes two 30-ft masts, an on-board 10-kW generator, air conditioners, four full-height equipment racks, and storage space. CRSMS capabilities utilize the same software but typically include only as much hardware as is required for any given measurement task. Local arrangements must be made for CRSMS shelter and power. Both RSMS and CRSMS rely extensively upon computer control of measurements. These systems can be operated in fully automatic, semi-automatic, and fully manual modes. Mobile radios, fixed communication links, radars, personal communication systems, earth station uplinks, industrial, scientific, and medical devices, broadcast signals, and special-purpose transmitter systems can be measured. For a complete description of the RSMS, go to ITS on-line publications (http://ntia.its.bldrdoc.gov) and download applicable appendices from any RSMS measurement report (e.g., Appendix C of NTIA Report 99-367; see Publications Cited, pp. 102).

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RFIMS Development Lab

The Radio Frequency Interference Monitoring System (RFIMS) Development Lab is a facility that is used to provide support to the Federal Aviation Administration's (FAA) RFIMS program. 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 eleven systems. The lab contains a measurement system that is identical to the measurement system that is found within RFIMS vehicles. The lab is capable of making the same measurements that can be made with the vehicles. These include measurements of spectrum signature, radar prf and spectragraph, among others. In the RFIMS Development Lab, ITS engineers develop and test measurement concepts that will become part of the RFIMS. Newly created software is tested for both functionality and user friendliness by users. If trouble reports are received from the deployed RFIMS vehicles, the lab is used to recreate the situation, analyze the causes, and implement a viable solution. The lab is available to ITS engineers, all nine FAA regions, FAA headquarters and the FAA Technical Center to support the use and future development of the RFIMS.

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Spectrum Compatibility Test and Measurement Sets

The introduction of new systems in close frequency proximity to older ones can cause electromagnetic compatibility (EMC) problems. Real world measurements of a proposed system's effects within its proposed operating environment are often required to determine its impact on other users of the radio spectrum. In such cases, a system is needed which can simulate the spectral emissions of other devices with a wide range of latitude. Such a system is also needed in situations which require the production of a controlled interfering signal with known characteristics in environments where the suspected interferer may be unavailable for use. These situations include laboratory tests using interference from ship or aircraft mounted radars or communications systems. To meet these needs, ITS engineers have developed two different types of interference generators. The first system is the Broadband Arbitrary Waveform Transmitter (BAWT) that is used to simulate the spectral output of a wide variety of radar and communication systems. These signals can be coupled directly into the system under test or they can be transmitted into the target system's antenna to more accurately gauge its response to a real interference situation. In cases where the exact form and characteristics of the proposed interferer are poorly known, a second type of generator may be used. This device, the Broadband Noise Generator (BBNG) produces a noise-like signal at the frequency of interest with a bandwidth determined by the investigator. This signal is typically directly coupled into the target system for measurement purposes. The BBNG is especially useful for assessment of system performance in the presence of noise-like spurious emissions from adjacent-band systems.

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Table Mountain Radio Quiet Zone

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

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Telecom Glossary 2000 Web Page

Telecom Glossary 2000 (see pp. 30–31) is available on the web at the URL http://www.its.bldrdoc.gov/projects/telecomglossary2000
The glossary is an update-in-progress of FED-STD-1037C, *Glossary of Telecommunication Terms* (1996). The draft of *Telecom Glossary 2000* provides ~8000 definitions in the disciplines of fiber optics communications, telephony, NS/EP, NII, spectrum sharing, radar, radio communications, TV (UHF, VHF, cable, HDTV), HF ALE radio, facsimile, networks (intelligent networks, next-generation Internet, open network architecture, ISDN, B-ISDN, and network management), communications security, data processing, premises wiring, grounding and bonding, telegraphy, and video. Recently added disciplines include web terminology, T1 Standards, information assurance/security, and photonics. The glossary is presented in hypertext with clickable graphics and hyperlinks to defined terms. The web site contains an ITS-developed search engine with easy-to-follow, menu-driven instructions, to allow a more organized and more thorough review of the entire glossary. The advantages of the search engine include tailored access to the text of all definitions, ranking of results, hyperlinks to all search engine results, and speedy use of the entire glossary.

The glossary is accessible and free to anyone with web access. Typical users include Federal purchasing agents, NS/EP implementors, NII planners, Standards writers and users, R&D workers, O&M workers, technical writers, telecom instructors and telecom vendors. Future plans call for making the completed, up-to-date, hyperlinked, web-accessible telecommunications glossary an American National Standard, available free to the public on the ATIS/T1 web site.

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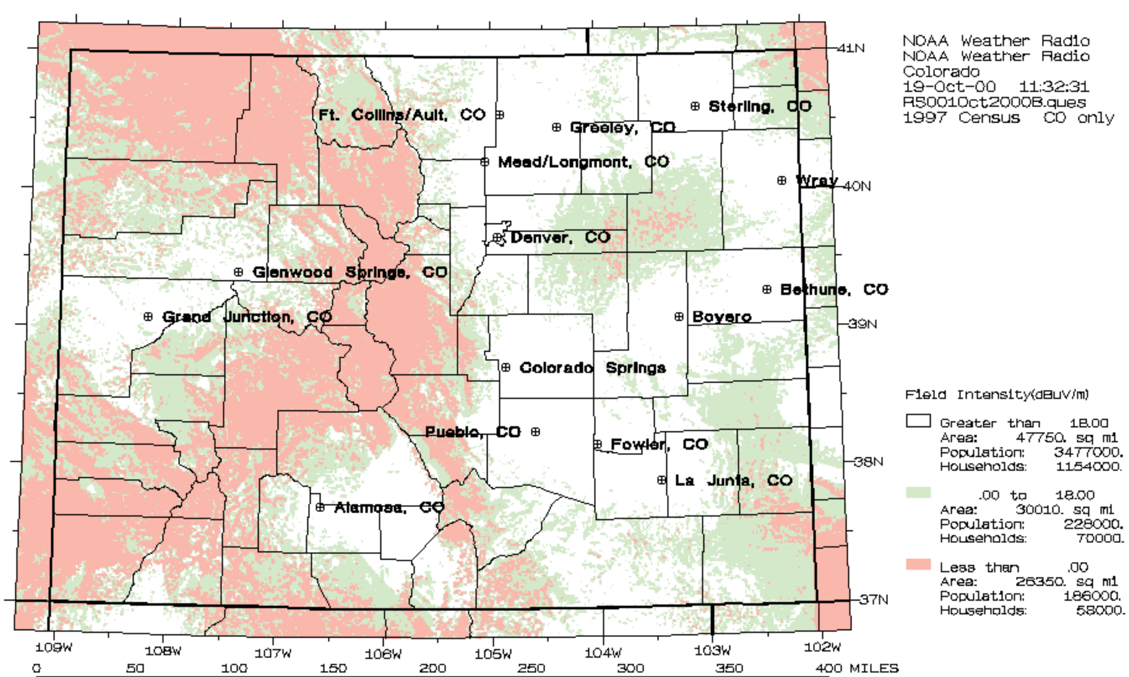
Telecommunications Analysis Services

Telecommunications Analysis Services (TA Services) provides the latest engineering models and research data developed by ITS to industry and other Government agencies via a web-based interface (http://flattop.its.bldrdoc.gov). It is designed to be both user-friendly and efficient. It offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with some 1 second and 3-arc-seconds (90 m) resolution for much of the world and GLOBE (Global Land One-km Base Elevation) data for the entire world; 1990 census data (also 1997 updated); Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ARCINFO). TA Services has developed models which predict communication system coverage and interference for many broadcast applications. New models in the GIS environment for personal communications services (PCS) and Local Multipoint Distribution Services (LMDS) have been developed (see Telecommunications Analysis Services, pp. 44-45). The following is a brief description of some programs available through TA Services.

HAAT – Calculates Height Above Average Terrain for an antenna at a specified location.
PCS/LMDS - Allows the user to create or import surfaces which may include terrain, buildings, vegetation and other obstructions in order to perform Line of Sight and diffraction studies.
FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND - Allows the user to search the FCC database for particular stations or by search radius around a point of interest.
PROFILE - Extracts path profiles according to user-specified input parameters. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also receive plots of the profiles adjusted for various K factors. For microwave links, Fresnel zone clearance can be determined so that poor paths can be eliminated from a planned circuit or network.
SHADOW - Plots the radio line-of-sight (LOS) regions around a specified location in the United States using digitized topographic data. It shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.
COVERAGE - Calculates the receive signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model can be chosen for calculations.
CSPM - Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity, as shown in the Figure. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical maps or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses ITS's Irregular Terrain Model in a point-to-point mode or other user chosen algorithms for path loss calculation.



Example of a composite coverage analysis using CSPM.

HDTV – Allows the user to analyze interference scenarios for proposed new DTV stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all users of the program. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using the existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in the user's catalog.
PBS – An analysis model similar to the HDTV model, but specialized for Public Broadcasting Stations (PBS). Typical outputs may consist of composite plots showing Grade A and B coverage of several stations or "overlap" plots which show areas covered by more than one station.

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Ultrawideband (UWB) Interference Testing Laboratory

The Ultrawideband (UWB) Interference Testing Laboratory has been developed to evaluate the performance of radio systems exposed to UWB signals. Currently, this fully-automated laboratory is configured for measuring the effects of UWB signals on Global Positioning System (GPS) receivers. Three signal sources — the desired GPS signal, the undesired UWB signal, and white noise — are combined and applied to GPS receivers while certain performance metrics for the receiver are measured. To ensure repeatable measurements, the GPS signals are generated using an elaborate GPS simulator that mimics precise patterns of signals from continuously moving GPS satellites. UWB signals are produced by impulse generators driven by an arbitrary waveform generator and/or by custom driver circuits. A wide variety of UWB signal structures can be generated by varying the average pulse repetition frequency (PRF), the pulse dithering process (pulse spacing modulation), and signal gating characteristics. An aggregate of up to six independent UWB signals can be generated and combined for investigating the effects of multiple UWB signals on radio systems.

While this UWB Interference Testing Laboratory is currently configured for investigating GPS receivers, the signal generation and data acquisition capabilities can be readily reconfigured to test any system or application potentially vulnerable to UWB signals.

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Wireless Link Simulation Laboratory

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

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

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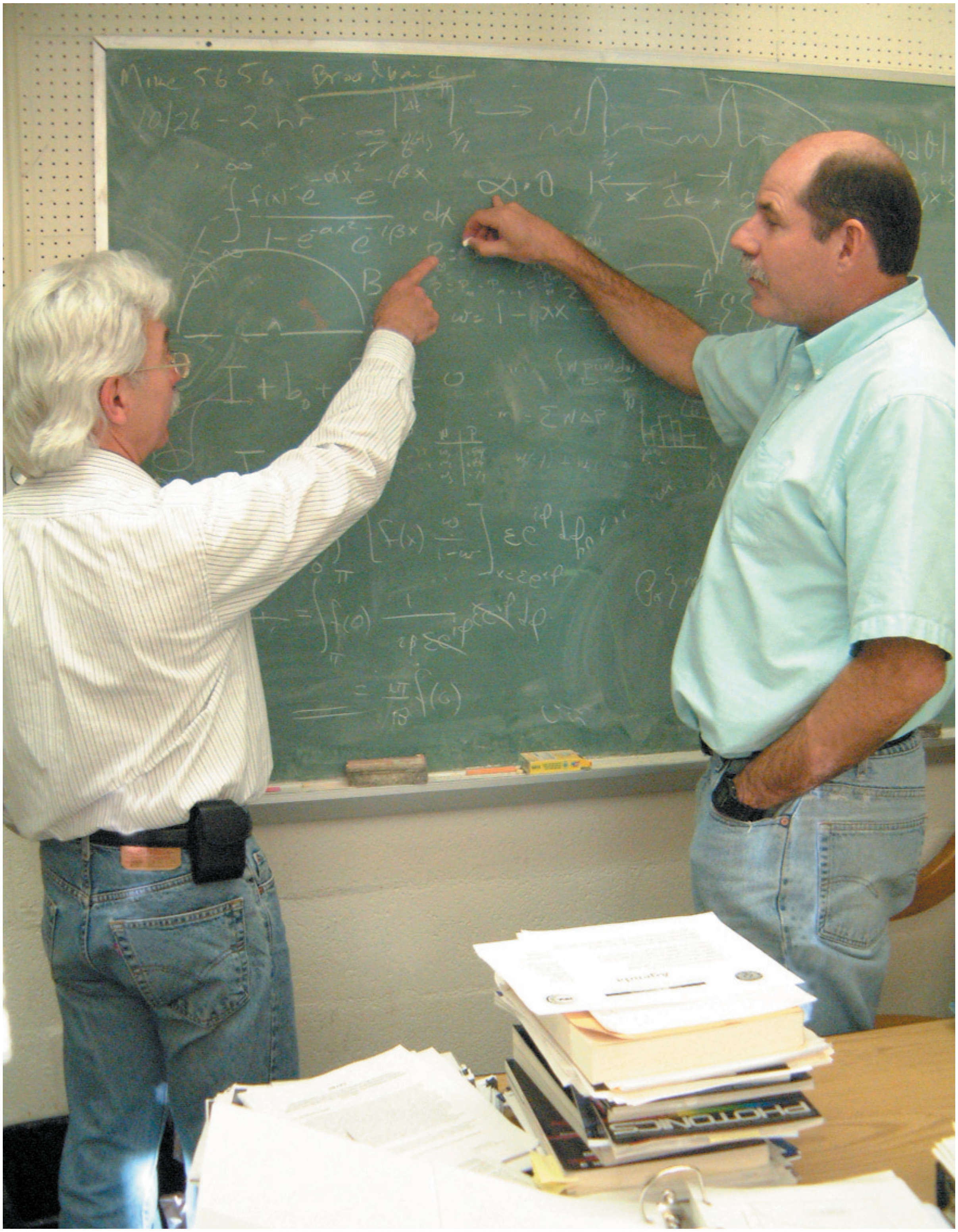

ITS engineers engaged in a theoretical problem (photograph by F.H. Sanders).

ITS Projects in FY 2000

NTIA Projects

Audio Quality Research Identify and respond to questions associated with quality issues in digital speech and audio compression and transmission, through literature study, digital signal processing (DSP) theory and derivations, DSP simulations, and subjective listening experiments. Deliverables include algorithms and software for speech and audio quality assessment and coding, oral presentations, technical papers and reports, and technical input to national and international standards bodies.
Project Leader: Stephen D. Voran (303) 497-3839
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Broadband Wireless Research Provide radio-wave propagation data between 100 MHz and 100 GHz, in order to promote the use of HF radio spectrum and new signal processing methods, as well as the development of new wideband wireless data services.
Project Leader: Peter B. Papazian (303) 497-5369
e-mail ppapazian@its.bldrdoc.gov

Broadband Wireless Standards Develop technical means to improve predictions of signal coverage and interference for third generation wireless services through support to ITU-R (e.g., SG 3/Working Party 3K) and to Public Safety community interests in TIA TR-8 (Project 25); develop enhancements or refinements to propagation-related models as needed; develop evaluations of and recommendations for spectrum optimization techniques.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Evaluation and Preparation of Propagation Models Provide propagation model support to NTIA/OSM: document the Fresnel Kirchhoff methodology propagation model subroutines; upgrade the model to account for both Sommerfeld and Fok propagators; develop methods for treating multipath rays and identify an implementation scheme.
Project Leader: Paul M. McKenna (303) 497-3474
e-mail pmckenna@its.bldrdoc.gov

Network Interoperability Conduct an unbiased assessment of interoperability techniques and develop a framework for analyzing and understanding interoperability issues; apply this framework to current and future interoperability issues in networks, public safety radio, and other technologies.
Project Leader: Randall S. Bloomfield (303) 497-5489
e-mail rbloomfield@its.bldrdoc.gov

Network Performance Provide leadership and technical contributions in ITU-T and related U.S. standards committees whose responsibilities support DOC and NTIA goals and public interest needs.
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Networking Technology Develop an ITS networking analysis capability to address Government needs for network performance, reliability, and cost effectiveness. Deliverables include a networking analysis tool set and an NTIA Report.
Project Leader: Raymond D. Jennings (303) 497-3233
e-mail rjennings@its.bldrdoc.gov

Policy Support Provide engineering and technical support to NTIA in telecommunications policy development. Provide support in various technical analyses including broadband deployment technologies, low power FM radio drop-ins, and broadband wireless forecasting and assessment.
Project Leader: Val M. O'Day (303) 497-3484
e-mail voday@its.bldrdoc.gov

Public Safety Research Provide engineering and technical support to the Public Safety Program of NTIA/OSM; coordinate with other complementary programs (and their associated agencies) devoted to public safety communications applications.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Rewrite of ITU Document 1177 Rewrite the ITU-R Draft Recommendation M.1177-1B, Working Party 8B, "Techniques for Measurement of Unwanted Emissions of Radar Systems" (Question ITU-R 202/8); demonstrate the use of ITS-developed techniques and algorithms to perform the measurements described in this document; represent the U.S. as a delegate at the ITU in Geneva to support this document.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

RSMS Operations Provide NTIA with critical measurement support to determine broadband spectrum occupancy across the U.S.; resolve interference problems involving Government radio systems; and determine the emission characteristics of radio transmitter systems that may affect Government operations or that may be acquired by Government agencies.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

RSMS Enhancements Develop new capabilities for the fourth generation of the Radio Spectrum Measurement System, including techniques, algorithms, and hardware.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

Software Defined Radio Support Provide technical support to NTIA/OSM in the area of software defined radio. Deliverables include a briefing presented to the IRAC
Project Leader: Jeffery A. Wepman (303) 497-3165
e-mail jwepman@its.bldrdoc.gov

Spectrum Analysis Research Provide continuing support to NTIA/OSM and the IRAC technical subcommittee in the areas of necessary bandwidth formulas and ultrawideband systems spectral analysis.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

Third Generation Wireless Contribute to the rapid development and deployment of third generation (3G) wireless services: develop an accurate indoor propagation model, provide leadership in propagation model development in the ITU-R, and analyze, model, and simulate noise, interference, and bit errors for 3G wireless proposed standards. Deliverables include articles, reports, and presentations.
Project Leader: Robert J. Achatz (303) 497-3498
e-mail rachatz@its.bldrdoc.gov

Third Generation Wireless Interference Modeling and Characterization Develop interference models for each PCS technology, and apply the models in characterizing one-on-one, one-on- many, and many-on-one PCS interference scenarios. Deliverables include a handbook to be used by network planners and field personnel.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

UWB Signal Measurements Provide NTIA/OSM with critical measurement support to determine spectrum and time domain characteristics of ultrawideband (UWB) transmitters. Deliverables include measurements, analyses, and published reports.
Project Leader: William A. Kissick (303) 497-7410
e-mail wkissick@its.bldrdoc.gov

Video Quality Research Develop the required technology for assessing the performance of advanced television and other digital video transmission systems (e.g., HDTV and video teleconferencing). Deliverables include a video quality toolkit for Internet 2 applications, conference and journal papers, and technical standards contributions.
Project Leader: Stephen Wolf (303) 497-3771
e-mail swolf@its.bldrdoc.gov

Wireless Testing, Facilities, and Standards
Conduct performance testing of a state-of-the-art HF e-mail system that implements protocols under consideration for MIL-STD0188-110B, Interoperability and Performance Standards for Data Modems. Deliverables include a test plan, measurements, a test report, and technical contributions to the HF Radio Subcommittee.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Other Agency Projects

Central Intelligence Agency

Analysis of RF Threat to Telecommunications Infrastructure Analyze the effects of high power RF fields on critical elements of the military and civilian telecommunications infrastructure.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Department of Commerce

Systems Engineering and Technical Assistance As a follow-on to the Telecommunications Assessment performed previously for the Department, provide engineering services and technical assistance consistent with the current priorities of the DOC.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Department of Defense

International Symposium on Advanced Radio Technologies Plan, organize, publicize, host, chair, and provide a report on the 2000 symposium.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

PCS/LMDS for DoD Enhance the ITS PCS/LMDS model (developed in the Geographic Information System (GIS) environment) by adding interference capability and converting the model to run on an NT-based system.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Software Radio Research Perform research in software radio technology.
Project Leader: Jeffery A. Wepman (303) 497-3165
e-mail jwepman@its.bldrdoc.gov

Department of Justice

Public Safety Wireless Network (PSWN) Support Provide support for the PSWN in public safety standards efforts with the Telecommunications Industry Association TR-8 process; develop and utilize an Interoperability Test Facility. Deliverables include letter reports to the sponsor.
Project Leader: Eldon J. Haakinson (303) 497-5304
e-mail ehaakinson@its.bldrdoc.gov

Federal Aviation Administration

Completion of Radio Frequency Interference Monitoring Systems (RFIMS) Perform final preparation and delivery to the FAA of RFIMS vans no. 10 and 11, and close down the delivery phase of the RFIMS project.
Project Leader: Brent L. Bedford (303) 497-5288
e-mail bbedford@its.bldrdoc.gov

Investigation of Potential Interference from UWB Signals to GPS Receivers - An Expansion Project Accelerate and expand the project to provide an initial assessment of ultrawideband (UWB) interference to GPS receivers.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

Federal Highway Administration

Technical Support for Implementation of a Nationwide DGPS Service Provide continuing support for the implementation of a nationwide differential Global Positioning System (DGPS) radio beacon service, which would provide a nationwide navigation and positioning signal.
Project Leader: John J. Lemmon (303) 497-3414
e-mail jlemmon@its.bldrdoc.gov

Federal Railroad Administration

Railroad Telecommunications Study Provide an independent assessment and technical support in the test and evaluation of a Project 25 railroad radio system demonstration.
Project Leader: John M. Vanderau (303) 497-3506
e-mail jvanderau@its.bldrdoc.gov

Miscellaneous Federal and Non-Federal Agencies

Telecommunications Analysis Services Make available to other Government agencies and to the public, through user-friendly computer programs, a large menu of engineering models, scientific and informative databases, and other useful communication tools.
Project Leader: Gregory R. Hand (303) 497-3375
e-mail ghand@its.bldrdoc.gov

National Communications System

Advanced HF Applications As the Federal representative to the MIL-STD-188-110B Working Group, review the standard and coordinate comments from the Federal users community. Write a final report on the low-cost ALE system developed by ITS in FY99, in order to provide documentation for users.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Digital Land Mobile Radio Standards Development Assist NCS in developing a comprehensive set of interoperability standards for digital land mobile radio, for public safety applications, by providing leadership and technical contributions in the Project 25 Encryption Task Group and associated APCO, TIA, and FTSC standards oversight committees.
Project Leader: William J. Pomper (303) 497-3730
e-mail wpomper@its.bldrdoc.gov

Mobile IP Network Access Technologies Enhance NS/EP responder access to network-based information by evaluating and demonstrating emerging technologies for mobile access to IP networks. Deliverables include a wireless network data collection system.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Network Survivability and Restoral Reduce vulnerabilities and enhance restoral capabilities in public telecommunication networks by spearheading the development of network reliability standards in T1A1 and related standards organizations; apply computer simulation and other reliability analysis and traffic engineering tools to assess and optimize network reliability.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

NS/EP Requirements for Wireless Networks Assist NCS in planning effective NS/EP strategies for wireless networks, and in implementing those strategies through technical contributions to industry standards, procurement specifications, and NS/EP operating procedures.
Project Leader: Paul M. McKenna (303) 497-3474
e-mail pmckenna@its.bldrdoc.gov

PCS/3G Wireless Interference Develop interference models for various PCS technologies and apply the models in characterizing PCS interference scenarios; determine operational guidelines and other practical means of mitigating observed interference effects. Deliverables include technical contributions to standards bodies.
Project Leader: Timothy J. Riley (303) 497-5735
e-mail triley@its.bldrdoc.gov

Priority Services in Converging Networks Assist NCS in extending GETS-like priority access capabilities to wireless and broadband infrastructures, selected international services, and IP-based networks through technical contributions and leadership in telecommunication standards committees, prototype testing and evaluation of advanced NS/EP technologies, and the development of a software-based system for displaying commercial wireless service coverage and associated NS/EP infrastructures.
Project Leader: Christopher J. Behm (303) 497-3640
e-mail cbehm@its.bldrdoc.gov

Standards Promulgation Support Update key standards and Recommendations to maintain their value; prepare WWW, CD-ROM, and search-engine equipped versions of selected documents to facilitate their distribution; help prepare open literature publications to expand public awareness and use of NCS standards products; and provide support for selected standards development activities.
Project Leader: Neal B. Seitz (303) 497-3106
e-mail nseitz@its.bldrdoc.gov

Tandem Vocoder Objectively evaluate tandem vocoding systems, by measuring the voice quality of various combinations, to establish the feasibility (from a voice quality perspective) of tandeming vocoders in order to relay voice communications between disparate systems.
Project Leader: Christopher Redding (303) 497-3104
e-mail credding@its.bldrdoc.gov

Telecom Glossary 2000 Provide proposed revisions to FED-STD-1037C, Glossary of Telecommunication Terms, to include new terminology relating to computer security, network security, information assurance, and the Internet; coordinate electronic "cyber meetings" to edit electronic submissions and comments; compile, edit, and circulate drafts.
Project Leader: Evelyn M. Gray (303) 497-3307
e-mail egray@its.bldrdoc.gov

Use of IP-Based Networks in Real-Time NS/EP Applications Examine the impact of emerging Internet Protocol (IP)-based networks on real-time NS/EP communications with an emphasis on voice and video applications; survey standardization and technology trends to identify actions that should be taken by Government to ensure that NS/EP requirements are considered in the development of future IP-based networks.
Project Leader: Arthur A. Webster (303) 497-3567
e-mail awebster@its.bldrdoc.gov

USSG B Standards Support Provide administrative focal point and support for ITAC-T U.S. Study Group B (USSG B) – Network Infrastructure Study Group. Deliverables include announcement, agenda, document log, and summary minutes for each meeting.
Project Leader: Marcia L. Geissinger (303) 497-5216
e-mail mgeissinger@its.bldrdoc.gov

National Institute of Standards and Technology

OLES Communication Standards Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow OLES and the National Institute of Justice to help develop and validate interoperability standards for the justice and public safety communities. Provide technical assessments and evaluations of products and services. Deliverables include standards, reports, guides, guidelines, handbooks, and white papers.
Project Leader: Val J. Pietrasiewicz (303) 497-5132
e-mail valp@its.bldrdoc.gov

Technical Support for Design of N-WEST Laboratory Develop plans for an indoor broadband wireless access system laboratory, which will be capable of characterizing the digital transmission of data at millimeter-wave frequencies.
Project Leader: Roger A. Dalke (303) 497-3109
e-mail rdalke@its.bldrdoc.gov

US Air Force

Initial Assessment of UWB and GPS Compatibility Provide an initial assessment of ultrawideband (UWB) interference to GPS receivers, through the measurement of specified GPS receiver parameters which are used to determine the performance of the receivers when exposed to various UWB signals.
Project Leader: J. Randy Hoffman (303) 497-3582
e-mail rhoffman@its.bldrdoc.gov

US Army

Jammer Effectiveness Model (JEM) Develop a new version of JEM, for performance prediction of radar and communication systems in an electronic warfare or interference environment.
Project Leader: Nicholas DeMinco (303) 497-3660
e-mail ndeminco@its.bldrdoc.gov

Signature Management and Deception Support Assist the Night Vision Electronic Sensors Directorate (NVESD) in defining an updated signature management laser communication system. Deliverables include three reports.
Project Leader: Edmund A. Quincy (303) 497-5472
e-mail equincy@its.bldrdoc.gov

US Coast Guard

US Coast Guard Measurements Perform electromagnetic compatibility measurements; conduct performance standards tests on handheld VHF receivers. Deliverables include an NTIA Report.
Project Leader: Brent L. Bedford (303) 497-5288
e-mail bbedford@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

American Automobile Manufacturers Association

Roadway RF Environment Measurements, Phase 2 Determine the maximum incident field strengths that occur in the vicinity of high-power radars in the roadway RF environment in the United States.
Project Leader: Frank H. Sanders (303) 497-5727
e-mail fsanders@its.bldrdoc.gov

ARINC

Spectrum Planning Tool Set Develop a Geographic Information Systems (GIS)-based spectrum planning tool set for railroad applications.
Project Leader: Robert O. DeBolt (303) 497-5324
e-mail rdebolt@its.bldrdoc.gov

Lucent Technologies

IBOC Evaluation Act as impartial third-party observer during test phase of an in-band on-channel (IBOC) FM digital audio broadcasting system.
Project Leader: Kenneth C. Allen (303) 497-5474
e-mail kallen@its.bldrdoc.gov

ITS Technical Publications Editor and an ITS engineer discussing plans for this year's Technical Progress Report (photograph by F.H. Sanders).

ITS Outputs in FY 2000

NTIA Publications

M.G. Cotton, R.J. Achatz, Y. Lo, and C.L. Holloway, "Indoor polarization and directivity measurements at 5.8 GHz," NTIA Report 00-372, Nov. 1999.

This report investigates how antenna polarization and directivity affect indoor radio channel bandwidth and signal coverage. Indoor impulse response measurements were taken at 5.8 GHz for four canonical propagation conditions: within a room, down a corridor, around a corridor corner, and from a corridor into a room. Directional linearly-polarized (LP), directional circularly-polarized (CP), and omnidirectional LP antennas were employed, and conclusions were drawn from basic transmission loss, rms delay spread, and cross-polarization discrimination results. Measurements indicated less LP basic transmission loss than CP basic transmission loss for both line-of-sight (LOS) and obstructed (OBS) channels. Also, LP rms delay spread was similar to CP rms delay spread in both LOS and OBS paths. The apparent advantage of using LP signals over CP signals indoors may be attributed to the relatively high degree of circular depolarization measured. Results also supported the use of omnidirectional antennas indoors to improve signal coverage. Omnidirectional measurements, however, demonstrated large delay spreads for some extraneous cases. These cases are emphasized to demonstrate the potential diversity holds for improving bandwidth capacity of indoor communication systems.

M.G. Cotton, E.F. Kuester, and C.L. Holloway, "A frequency- and time-domain investigation into the geometric optics approximation for wireless indoor applications," NTIA Report 00-379, Jun. 2000.

In this study we investigated the geometric optics (GO) approximation to the fields of an incremental electric dipole above a half plane for geometries typical of wireless indoor communications. This inspection was motivated by efforts to establish a ray-trace model to characterize indoor radio propagation channels. Eight canonical geometries were examined to isolate near-surface and near-field effects that are not accounted for in the GO approximation. Common building materials and physical dimensions (i.e., antenna separation and height) as small as 1 cm were investigated for frequencies up to 8 GHz. Theoretical fields were calculated via numerical evaluation of Sommerfeld integrals and compared to corresponding GO approximations. As expected, GO approximations agreed with theoretical results when the source and observation points were multiple wavelengths above the surface and relatively far apart. Close to the surface, an interesting interference pattern in the frequency domain was caused by adjacent fields in the two media propagating at different speeds. This so-called "pseudo-lateral wave" phenomenon is discussed and demonstrated in various examples. Next, we emulated system specifications (i.e., center frequency and bandwidth), computed time-domain impulse responses, and used delay spread as a metric to quantify GO error. Results show that mechanisms exist under certain circumstances which invalidate GO assumptions; conventional expressions to complement GO approximations are summarized.

R.A. Dalke, R.J. Achatz, and Y. Lo, "Nonlinear operation of a MMIC power amplifier and its effects on battery current, interface, and link margin," NTIA Report 00-375, Jan. 2000.

This report describes measurement, modeling, and simulation methods that are used to analyze the relationship between nonlinear operation of a typical PCS portable transceiver power amplifier and battery current, out-of-band power, and link margin. First the nonlinear characteristics of the PCS amplifier and associated battery current were obtained from amplifier measurements at various bias voltages and RF output signal levels. A mathematical model of the power amplifier based on these measurements was then used to simulate the communications link for purposes of determining the power spectral density and symbol-error ratio for a variable envelope digitally modulated signal using $\pi/4$ DQPSK with 35% root raised cosine filtering. The out-of-band power and symbol-error ratio were computed to determine the link margin for a maximum symbol-error ratio of

10-3.

S.K. Jones, R.L. Hinkle, F.H. Sanders, and B.J. Ramsey, “Technical characteristics of radiolocation systems operating in the 3.1-3.7 GHz band and procedures for assessing EMC with fixed earth station receivers,” NTIA Report 99-361, Dec. 1999.

No abstract available.

R.J. Matheson, “Spectrum usage for the fixed services,” NTIA Report 00-378, March 2000.

This study is an update to a 1993 ITS staff study entitled “A preliminary look at spectrum requirements for the Fixed Services.” That study included a description of the services provided in 30 of the Government and non-Government frequency bands between 406 MHz and 30 GHz known as point-to-point terrestrial microwave bands. Each of the 30 frequency bands were described in terms of the services provided, growth of licenses, and the geographical distribution of current licenses. The technical, regulatory, and economic factors affecting each band and the total microwave market were described, as well as a prediction of the rate of future growth (or decrease) for each band and market segment. This study adds 6 more years of license information and updates much data on recent regulatory and market trends. Some of the general technology and market descriptions have been left out of this update, but earlier predictions are compared to actual market performance and revised forecasts are made.

E.A. Quincy, R.J. Achatz, M.G. Cotton, M.P. Roadifer, and J.M. Ratzloff, “Radio link performance prediction via software simulation,” NTIA Report 00-371, Oct. 1999.

The subjective quality of speech and image information, transmitted over a high frequency radio link impaired with varying levels of interference, has been evaluated using software simulation. The high frequency radio link was also degraded by frequency-selective multipath and non-Gaussian noise. During radio link signal simulation an error sequence, determined from a comparison of transmitted and received bits, was collected. Next digitized speech and image information was distorted by the error sequence. Last, the quality of the distorted speech and image information was subjectively evaluated. This process was repeated for a large number of interference conditions. The same process can be used to show how multipath and non-Gaussian noise affects speech and image quality. Other wireless applications such as personal communications services and wireless local area networks can be analyzed in the same way using radio channel measurements and models made by the Institute for Telecommunication Sciences.

F.H. Sanders, “Measured occupancy of 5850-5925 MHz and adjacent 5-GHz spectrum in the United States,” NTIA Report 00-373, Dec. 1999.

Dedicated short-range communication (DSRC) systems have been proposed for operation at locations across the United States in the 5850- to 5925-MHz band. To establish electromagnetic compatibility between DSRC and other 5-GHz systems, it is necessary to understand current and future occupancy of this spectrum. This report summarizes results of measurements made in 5-GHz spectrum for the Federal Highway Administration (FHWA) of emissions from high-power radars and a fixed satellite service (FSS) earth station. Results of 5-GHz spectrum survey measurements in major metropolitan areas are also included. Measured spectrum occupancy in 5-GHz bands is typically dominated by radar systems. Radar spurious emissions are the major element of occupancy observed between 5850-5925 MHz, although future radar designs are expected to make more use of this band. Therefore, proposed 5-GHz DSRC systems will have to share spectrum with both spurious and on-tuned emissions from radars. DSRC frequency assignments will need to be coordinated with local radar assignments to avoid co-channel operations at short separation distances, and it is recommended that DSRC system designs be electromagnetically compatible with radar spurious emissions.

R.L. Sole, B. Bedford, and G. Patrick, “Lower Mississippi River ports and waterways safety system (PAWSS) RF coverage test results,” NTIA Report 00-374, Nov. 1999.

No abstract available.

Outside Publications

Articles in Conference Proceedings

P. Corriveau, A. Webster, A.M. Rohaly, and J. Libert, "Video quality experts group: The quest for valid objective methods," in *Proc. SPIE Conference - Photonics West*, San Jose, CA, Jan. 2000.

> Subjective assessment methods have been used reliably for many years to evaluate video quality. They continue to provide the most reliable assessments compared to objective methods. Some issues that arise with subjective assessment include the cost of conducting the evaluations and the fact that these methods cannot easily be used to monitor video quality in real time. Traditional analog objective measurements, while still necessary, are not sufficient to measure the quality of digitally compressed video systems. Thus there is a need to develop new objective methods utilizing the characteristics of the human visual system. While several new objective methods have been developed, there is yet no internationally standardized method.
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> In October 1997, VQEG was formed at a video quality experts meeting at Centro Studi e Laboratori Telecomunicazioni (CSELT) in Turin, Italy. The group is composed of experts from various backgrounds and affiliations, including participants from several internationally recognized laboratories working in the field of video quality assessment. The majority of participants are active in the International Telecommunications Union (ITU) and VQEG combines the expertise and resources found in several ITU Study Groups to work towards a common goal. The first task undertaken by VQEG was to provide a validation of objective video quality measurement methods leading to Recommendations in both the Telecommunications (ITU-T) and Radiocommunication (ITU-R) sectors of the ITU. To this end, VQEG designed and executed a test program to compare subjective video quality evaluations to the predictions of a number of proposed objective measurement methods for video quality in the bit range of 768 kb/s to 50 Mb/s. The results of this test show that there is no objective measurement system that is currently able to replace subjective testing. Depending on the metric used for evaluation, the performance of eight or nine models was found to be statistically equivalent, leading to the conclusion that no single model outperforms the others in all cases. The greatest achievement of this first validation effort is the unique data set assembled to help future development of objective models.

P. Corriveau, J. Lubin, J.C. Pearson, A. Webster, et al., "Video quality experts group: Current results and future directions," in *Proc. International Conference on Visual Communications and Image Processing 2000*, Perth, Australia, Jun. 2000.

> For abstract, see above.

C. L. Holloway and M.S. Sarto, "On the use of a hybrid IE/FDTD method for the analysis of electromagnetic scattering and coupling problems," in *Proc. IEEE International Symposium on Electromagnetic Compatibility 2000*, Washington, DC, Aug. 2000.

> We present a hybrid time-domain numerical technique for analyzing electromagnetic scattering and coupling problems. This hybrid technique consists of combining the time-domain integral equation (IE) and the finite difference time-domain (FDTD) methods. This approach eliminates some of the computational difficulties of using a standard FDTD methodology. One problem with such a hybrid technique is that unwanted reflections can occur at the IE/FDTD boundary. In this paper, we introduce a technique to reduce these unwanted reflections. We will present various examples illustrating how the IE/FDTD hybrid approach can be used to solve EMC problems.

P. Papazian, P. Wilson, and Y. Lo, "Phase calibration of a PCS wideband antenna array system," in *Proc. IEEE Conference on Vehicular Technology*, Boston, MA, Sep. 2000.

> This paper investigates parameters that determine the phase stability of a PCS antenna beam steering system and the effectiveness of a reference channel for correcting phase instability. It presents data collected using a multi-channel broadband receiver developed for advanced antenna algorithm testing. Phase data collected in the laboratory is contrasted with roof top data showing variability caused by environmental effects such as temperature changes. Data from a reference signal and data from a simulated mobile using a different reference oscillator are also contrasted. Measurement data collected using the reference channel indicates that the relative phase between channels varies by ±0.5

over one day. Data collected with a simulated mobile reference oscillator in a non-controlled environment indicates that the relative phase between channels varies by ±5 over one day.

T.G. Sparkman, "Lessons learned applying software engineering principles to visual programming language application development," in *Proc. COMPSAC 99*, Phoenix, AZ, Oct. 1999.

Visual programming languages make software design accessible even to untrained programmers, but basic software engineering practices must still be followed to create a usable product. This paper describes the process by which software was developed to control sophisticated laboratory equipment for a radio frequency interference monitoring system (RFIMS). Development of requirements and specifications is discussed. It is shown that the product was improved by the use of extensive planning and user testing. In addition, the steps required for designing a clear and intuitive graphical user interface (GUI) are discussed. The GUI interface specifications, user panel templates, menu system hierarchy, and programmatically guiding the user are some of the tools that were successfully employed in the project development.

S. Voran, "Results on reverse water-filling, SNR, and log-spectral error in codebook-based coding," in *Proc. 2000 IEEE Speech Coding Workshop*, Delavan, WI, Sep. 2000.

This paper identifies optimum levels of reverse water-filling for codebook-based coding of noise and speech signals. We find that there is little to be gained from optimizing an effective rate parameter. We identify trade-offs between SNR and log-spectral error. We show that the application of a gain factor compares favorably with reverse water-filling in some situations.

P. Wilson and P. Papazian, "PCS band direction-of-arrival measurements using a 4 element linear array," in *Proc. IEEE Conference on Vehicular Technology*, Boston, MA, Sep. 2000.

A four-element array system for continuously acquiring direction-of-arrival data is described. The system allows for the collection of much larger data sets than previously published. Large data sets give a more realistic statistical description of the propagation environment applicable to "smart" fourth-generation broadband mobile wireless communications systems. A mobile experiment (drive route) in the PCS band was conducted in a largely suburban neighborhood. The measured impulse responses were used to estimate the multipath pattern using two blind direction-of-arrival estimation methods, the parallelogram method and the normalized maximum likelihood method. The results show that the parallelogram method better estimates the line-of-sight direction and the direction-of-arrival of the main beam in the azimuth delay power spectrum. The normalized maximum likelihood method better identifies isolated, narrow spikes in the azimuth delay power spectrum.

P. Wilson, P. Papazian, M. Cotton, C. Holloway, and Y. Lo, "The Institute for Telecommunication Sciences Channel Sounding Program," in *Proc. IEEE International Conference on Third Generation Wireless Communications*, San Francisco, CA, Jun. 2000.

The Institute for Telecommunication Sciences, part of the National Telecommunications and Information Administration, has a long-standing program to develop radio channel measurement systems. This paper briefly reviews selected examples of recent measurements, outdoor and indoor, in order to give an overview of the ITS channel sounding program. The examples presented are: 1) diversity gain versus bandwidth experiments for a 1.92 GHz mobile PCS channel in a suburban neighborhood, 2) transmission loss versus frequency (440 MHz, 1.36 GHz, and 1.92 GHz) for a mobile outdoor channel, and 3) transmission loss and RMS delay spread versus antenna type (LP or CP) in an indoor environment at 5.8 GHz. These experiments demonstrate the flexibility of the system. The important system parameters are wide bandwidths and multiple channels, as required for 3G and 4G wireless systems.

Journal Articles

A.U. Bhobe, C.L. Holloway, M. Piket-May, and R. Hall, "Coplanar waveguide fed wideband slot antenna," *Electronics Letters*, vol. 36, no. 16, pp. 1340-1342, Aug. 2000.

A new design for a coplanar waveguide (CPW) fed slot antenna is presented. The impedance matching and the radiation characteristics of this structure were studied using the method of moment technique. This antenna has an impedance bandwidth (for a VSWR < 2) of 49% and a radiation bandwidth of 42% about its 4.8 GHz center frequency, compared to the 12-20% impedance bandwidth of the standard CPW fed slot antenna. The cross-polarization in both the principle planes is at least 20 dB below co-polarization across the entire bandwidth. Simulated and measured results of the antenna are presented. This wideband antenna has significant applications in wireless technologies.

N. DeMinco, "Propagation prediction techniques and antenna modeling (150 to 1705 kHz) for Intelligent Transportation Systems (ITS) broadcast applications," *IEEE Antennas and Propagation Magazine*, vol. 42, no. 4, pp. 9-34, Aug. 2000.

This paper discusses the basic aspects of radio-wave propagation and antenna modeling in the band of frequencies from 150 to 1705 kHz. The paper contains descriptions of both sky-wave and ground-wave propagation-prediction models, in addition to the methodology used to analyze antennas that operate in this band. A method of calculating and normalizing antenna gain for systems computations is also discussed. The sky-wave models described in this paper are valid from 150 to 1705 kHz. The ground-wave models described in this paper are valid from 10 kHz to 30 MHz. The propagation of radio waves in the band of frequencies from 150 to 1705 kHz includes both a ground wave and a sky wave, and is quite different from propagation at any other frequency. The methods used for antenna modeling and analysis in this band are also quite unlike those in other bands. The AM broadcast band of 535 to 1605 kHz is planned to be used in the Advanced Traveler Information Systems (ATIS) of Intelligent Transportation Systems (ITS), to provide information such as road conditions, road hazards, weather, and incident reporting for rural travelers. The band of frequencies from 285 to 325 kHz is presently being used in another application of ITS, called the Differential Global Positioning System (DGPS), which will be used for precision location systems and making performance predictions for both of these ITS applications, or for any other systems that operate in this band of frequencies from 150 to 1705 kHz. Some examples of comparisons of measured and predicted data are also contained in this paper. A computer program that includes all of these propagation-prediction models and antenna-modeling techniques was used to generate these examples.

C.L. Holloway, "Expressions for the conductor loss of strip-line and coplanar-strip (CPS) structures," *Microwave and Optical Technology Letters*, vol. 25, no. 3, pp. 162-168, May 2000.

In this paper, we present closed-form expressions for the attenuation constant due to conductor loss for strip-line and coplanar-strip (CPS) structures. These expressions are functions of a universal parameter referred to as the stopping distance, where it is shown that this stopping distance is a function only of the local edge geometry, i.e., the strip thickness, the shape of the edge, and the material of the strip conductor. We also present an expression for the current distribution of the ground planes of a strip-line structure, which is used to derive an expression for the conductor loss of the ground planes. Results obtained with these loss expressions are compared to, and closely agree with, both experimental results and full-numerical results found in the literature for these two structures.

C.L. Holloway and E.F. Kuester, "Equivalent boundary conditions for a perfectly conducting periodic surface with a cover layer," *Radio Science*, vol. 35, no. 3, pp. 661-681, May-June 2000.

Using the method of homogenization, effective electromagnetic properties for a two-dimensional, perfectly conducting, periodic rough surface with a thin periodic cover layer are derived. This allows for the development of an equivalent boundary condition for the "effective" fields at such a surface. It is shown that the coefficients in this equivalent boundary condition can be interpreted as electric and magnetic polarizability densities. We apply this boundary condition to calculate the reflection coefficient of H- and E-polarized plane waves incident at a rough, perfectly conducting surface. The reflection coefficients derived here are compared with previous results from the literature for surfaces with no cover layer, demonstrating the accuracy of the new equivalent boundary condition. We also obtain previously known equivalent boundary conditions for a flat perfectly conducting plane with a thin cover layer as a special case of our result. This work is a first step in the derivation of generalized impedance-type boundary conditions for conducting rough interfaces (to be published separately).

Other Publications

Atkinson, D.J., V.J. Pietrasiewicz and K.E. Junker, “Video surveillance equipment selection and application guide,” NIJ Guide 201-99, Oct. 1999.

Patents Issued

U.S. patent number 06092040, “Audio signal time offset estimation algorithm and measuring normalizing block algorithms for the perceptually-consistent comparison of speech signals,” July 18, 2000.

Unpublished Presentations

R.J. Achatz, “Broadband wireless LANs,” presented at the International Symposium on Advanced Radio Technologies (ISART), Boulder, CO, Sep. 2000.

R.J. Achatz and R.A. Dalke, “Digitally modulated radio link performance in UHF man-made noise,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

C. Behm and R.B. Stafford, “Design and application of a software HF modem,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

A. Bhobe, C. Holloway, and M.N. Piket-May, “CPW-FED novel wideband slot antenna structures,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

R.A. Dalke, “MMDS performance modeling,” presented at the International Symposium on Advanced Radio Technologies (ISART), Boulder, CO, Sep. 2000.

R. Dalke and R. Achatz, “VHF man-made radio noise,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

N. DeMinco, “Medium frequency propagation prediction techniques and antenna modeling for broadcast applications,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

C.L. Holloway and E.F. Kuester, “Impedance-type boundary conditions for a periodic interface between a dielectric and a highly conducting medium,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

J.J. Lemmon, “Wideband model of HF atmospheric radio noise,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

R.J. Matheson, “Spectrum management rules for a flexible-use environment,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

R.J. Matheson, “The history of radio noise studies at the DOC Boulder labs,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

P. Papazian, “An overview of propagation data near 30 GHz for LMDS,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

V.J. Pietrasiewicz, “The effect of evolving IT applications on broadband wireless requirements,” presented at the International Symposium on Advanced Radio Technologies (ISART), Boulder, CO, Sep. 2000.

E.A. Quincy, “Bandwidth requirements for orthogonal frequency division modulation,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

T. Riley, “Third-generation HF modem/protocol performance under degraded conditions,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

F.H. Sanders, “Measuring radar spurious emissions for compliance with the NTIA radar spectrum engineering criteria (RSEC),” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

F.H. Sanders, “Broadband communications: Overview and access,” presented at the International Symposium on Advanced Radio Technologies (ISART), Boulder, CO, Sep. 2000.

M.S. Sarto and C.L. Holloway, “On the use of a hybrid MFIE/FDTD method for the analysis of electromagnetic scattering coupling problems,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

R. Stafford, “Time-domain measurements of the electromagnetic properties of soils,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

S. Voran and S. Wolf, "Objective estimation of video and speech quality to support network QoS efforts," presented at the 2nd Department of Energy/Internet2 Quality of Service Workshop, Houston, TX, Feb. 2000.

P. Wilson and P. Papazian, “PCS band channel sounding measurements in a suburban area,” presented at National Radio Science Meeting (URSI), Boulder, CO, Jan. 2000.

Standards Leadership Roles

Evelyn M. Gray, Senior Editor of ANSI X3.172-1996, “American National Standard Dictionary of Information Technology” (4300 entries), and participant, with NCITS Technical Committee K5, in the revision to develop the Millennial Edition.

Eldon J. Haakinson, National Chair of the U.S. contingent of ITU-R Study Group 3 (Radiowave Propagation); International Chair of Working Party 3K (Point-to-Area Terrestrial Propagation Issues)

Paul M. McKenna, selected to be Chair of ITU-R Task Group 3/2 on Broadcast and Land Mobile Point-to-Area Propagation Predictions.

William J. Pomper, Chair of APCO/NASTD/FED Project 25 Encryption Task Group; Member of TIA/TR-8 - Mobile and Personal Private Radio Standards Committee; Technical Advisor to NCS Federal Telecommunications Standards Committee.

Neal B. Seitz, Chair of ITU-T Study Group 13 Working Party 4 (Network Performance and Resource Management); Chair of ANSI-accredited Technical Subcommittee T1A1 (Performance and Signal Processing)

Arthur Webster, Co-chair of Video Quality Experts Group (VQEG); Rapporteur for Question 11/12 (Objective Methods for Evaluating Audiovisual Quality in Multimedia Services) in ITU-T Study Group 12 (End-to-end Transmission Performance of Networks and Terminals). Note: this Question has been moved to ITU-T Study Group 9, which is responsible for Cable Television Recommendations. Arthur Webster will continue as Rapporteur.

Representative Standards Contributions

E. Gray, "Development of T1 Glossary 2000," T1A1/2000-017, Apr. 2000.

P. Raush, "Example Application of Network as a Measure of Survivability," T1A1.2/2000-007, Jan. 2000.

A. Rohaly, J. Libert, P. Corriveau, A. Webster, et al., "Final report from the Video Quality Experts Group on the Validation of Objective Models of Video Quality Assessment," ITU-T Standards Contribution COM 9-80-E, Jun. 2000.

A. Webster, "Final Report from the Video Quality Experts Group on the Validation of Objective Models of Video Quality Assessment," T1A1.1/2000-017, Apr. 2000.

A. Webster, "Proposed Definitions for T1A1.2/2000-002R2," T1A1.2/2000-034, Jun. 2000.

A. Webster and P. Raush, "Traffic Analysis Background," T1A1.2/2000-031, Apr. 2000.

A. Webster and P. Raush, "Traffic Analysis Aspects of IP and Other Packet-Based Networks," T1A1.2/2000-049, Aug. 2000.

S. Wolf, "Two Objective Video Quality Metrics," T1A1.1/2000-021, Apr. 2000.

Publications Cited*

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

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

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

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

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

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

T.R. Riley, et al., "A comparison of HF digital protocols," *QST*, Jul. 1996, pp. 35-39.

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

Telecommunications Industry Association, TIA/EIA Telecommunications Systems Bulletin, TSB-84A, "Licensed PCS to PCS Interference," Jul. 1999.

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

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 Trans. on Speech and Audio Processing*, vol. 7, no. 4, pp. 371-382 and pp. 383-390, Jul. 1999.

*Publications cited in the report that are not Fiscal Year 2000 reports

Abbreviations/Acronyms

2.5G	two and a half generation
3G	third generation

A

AAMA	American Automobile Manufacturers Association
A/D	analog to digital
AGILE	advanced generation of interoperability for law enforcement
AIS	automatic identification system
ALE	automatic link establishment
AM	amplitude modulation
AMPS	advanced mobile phone service
ANS	American National Standard
ANSI	American National Standards Institute
APCO	Association of Public Safety Communications Officials
APD	amplitude probability distribution
APRE	audio play, record, and estimate
ARQ	automatic repeat request
ARSR	air route surveillance radar
ASIC	application specific integrated circuit
ASR	airport surveillance radar
ATB	antenna testbed
ATBM	anti-tactical ballistic missile
ATCBI	air traffic control beacon interrogator
ATIS	advanced traveler information system
	Alliance for Telecommunications Industry Solutions
ATM	asynchronous transfer mode

B

BAWT	broadband arbitrary waveform transmitter
BBNG	broadband noise generator
BCSM	basic call state model
BIOT	British Indian Ocean Territory
B-ISDN	broadband ISDN
BPSK	binary phase shift keying
BW	bandwidth
BWCF	bandwidth correction factor

C

CCIR	International Radio Consultative Committee (now ITU-R)
CD	compact disk
CDMA	code division multiple access
CD-ROM	compact disk read-only memory
CELP	code excited linear predictor
CJ	criminal justice
CP	circularly polarized
CPS	coplanar strip
CPW	coplanar waveguide
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CRSMS	Compact Radio Spectrum Measurement System
CSELT	Centro Studi e Laboratori Telecomunicazioni
CSPT	Communication System Planning Tool

D

DAB	digital audio broadcasting
dB	decibel
DF	direction finding
DGPS	differential GPS
DOA	direction of arrival
DOC	Department of Commerce
DoD	Department of Defense
DQPSK	differential quadrature phase-shift key
DSCP	digital sampling channel probe
DSL	digital subscriber line
DSP	digital signal processing
DSRC	dedicated short-range communication
DTV	digital television
DUT	device under test

E

E911	enhanced 911
EDGE	enhanced data rates for global evolution
EHF	extremely high frequency
EMC	electromagnetic compatibility
ESSA	Environmental Science Services Administration

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDTD	finite-difference time domain
FED-STD	Federal Standard
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIT	flexible interoperable transceiver
FM	frequency modulation
FPGA	field programmable gate array
FTP	file transfer protocol
FTSC	Federal Telecommunications Standards Committee
FTTA	Federal Technology Transfer Act
FY	fiscal year

G

G3G	global third generation
GETS	Government Emergency Telecommunications Service
GHz	gigahertz
GIF	graphics interchange format
GIS	geographic information system
GLOBE	global land one-km base elevation
GO	geometric optics
GPRS	general packet radio service
GPS	Global Positioning System
GSM	Global System for Mobile
GTD-UTD	geometric theory of diffraction - uniform theory of diffraction
GUI	graphical user interface
GWEN	Ground Wave Emergency Network

H

HALO	high altitude long operation fixed-wing aircraft
HAPS	high altitude platform station
HDTV	high definition television
HELIOS	high altitude long endurance solar-powered aircraft
HF	high frequency
HP	Hewlett-Packard Company
HPC	high probability of connectivity
HPGL	HP graphics language

HTML hypertext markup language

HTTP hypertext transfer protocol

I

IBOC in-band on-channel

ICMP Internet control message protocol

IE integral equation

IEEE Institute of Electrical and Electronics Engineers

IF intermediate frequency

IMBE improved multi-band excitation

IMT 2000 International Mobile Telecommunications 2000

I/N interference to noise

INFOSEC information system security

IP Internet protocol

IPSEC IP security protocol

IRAC Interdepartment Radio Advisory Committee

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

J

JEM Jammer Effectiveness Model

K

kHz kilohertz

L

LAN local area network

LMDS local multipoint distribution service

LMR land mobile radio

LOS line-of-sight

LP linearly polarized

LULC land use/land cover

M

Mb megabyte

MHz megahertz

MIL-STD military standard

MMDS multichannel multipoint distribution service

MNB measuring normalizing block

MPEG Motion Picture Experts Group

MPLS multiprotocol label switching

MSC mobile switching center

MSTV Association for Maximum Service Television, Inc.

N	
NASTD	National Association of State Telecommunications Directors
NCITS	National Committee for Information Technology Standards
NCS	National Communications System
nDGPS	nationwide differential GPS
NGDC	National Geophysical Data Center
NII	national information infrastructure
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NMLM	normalized maximum likelihood method
NOAA	National Oceanic and Atmospheric Administration
NPRM	Notice of Proposed Rule Making
NSA	National Security Agency
NS/EP	National Security and Emergency Preparedness
NSTISSI	National Security Telecommunications and Information Systems Security Instruction
NTIA	National Telecommunications and Information Administration
NVESD	Night Vision Electronic Sensors Directorate
O	
O&M	operations and maintenance
OBS	obstructed
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
ORTA	Office of Research and Technology Applications
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTAR	over-the-air rekeying
OTP	Office of Telecommunications Policy
P	
PBS	Public Broadcasting System
PBX	private branch exchange
PC	personal computer
PCM	pulse code modulation
PCS	Personal Communications Services
PDO	Program Development Office
PIN	personal identification number
PLC	packet loss concealment
PM	parallelogram method
PN	pseudo-random
PPM	pulse position modulated
PRF	pulse repetition frequency
PRN	pseudo-random noise
PS	public safety
PSP	Public Safety Program
PSTN	public switched telephone network
PSWAC	Public Safety Wireless Advisory Committee
PSWN	public safety wireless network
Q	
QoS	quality of service
R	
R&D	research and development
RBOC	Regional Bell Operating Company
RDBMS	relational database management system
RF	radio frequency
RFIMS	Radio Frequency Interference Monitoring System

RMS	root mean square
RSEC	radar spectrum engineering criteria
RSMS	Radio Spectrum Measurement System
RUS	Rural Utilities Service

S

SCP	service (signal?) control point
SDH	synchronous digital hierarchy
SDL	specification and description language
SDMA	space division multiple access
SDR	software defined radio
SG	study group
SIP	session initiation protocol
SNR	signal-to-noise ratio
SOC	system on a chip
SONET	synchronous optical network
SPIE	International Society for Optical Engineering
SPS	standard positioning service
SRD	standard requirements document
SS7	signaling system no. 7
SV	space vehicle
S-VHS	super VHS (Video Home System)

T

TA Services	Telecommunications Analysis Services
TCP	transmission control protocol
TDMA	time division multiple access
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TSB	Telecommunications Systems Bulletin
TV	television

U

UAV	unmanned air vehicle
UHF	ultra high frequency
UMTS	universal mobile telecommunications system
URL	uniform resource locator
URSI	International Union of Radio Science
U.S.	United States
USCG	U.S. Coast Guard
USSG	U.S. study group
US WEST	US West Advanced Technologies, Inc.
UTRA	UMTS terrestrial radio access
UWB	ultrawideband

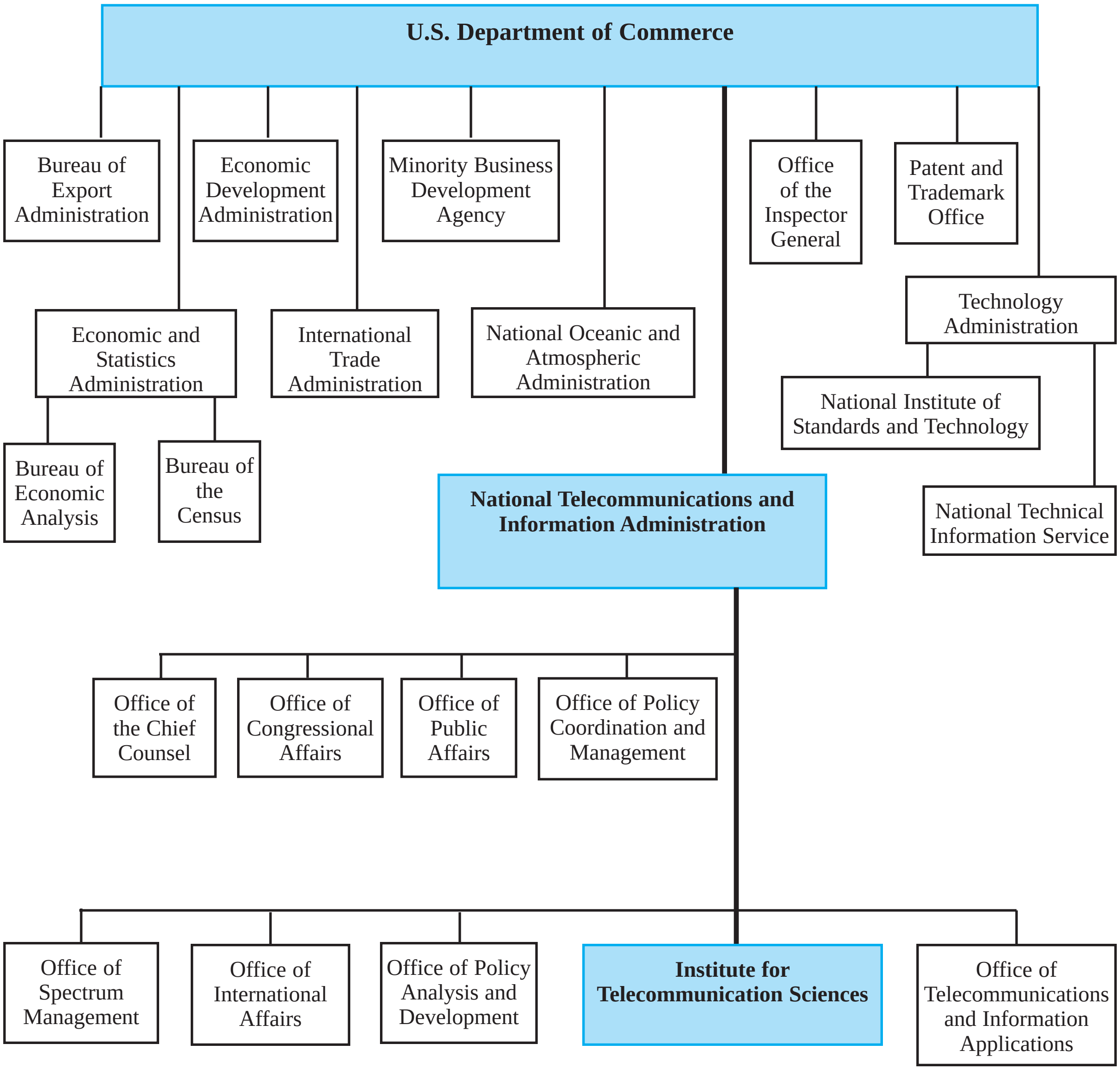
V

VHDL	VHSIC hardware description language
VHF	very high frequency
VHSIC	very high speed integrated circuit
VME	Versa Module Eurocard
VoIP	voice over Internet protocol
VQEG	Video Quality Experts Group
VSA	vector signal analyzer
VSWR	voltage standing wave ratio
VXI	VME bus extension for instrumentation

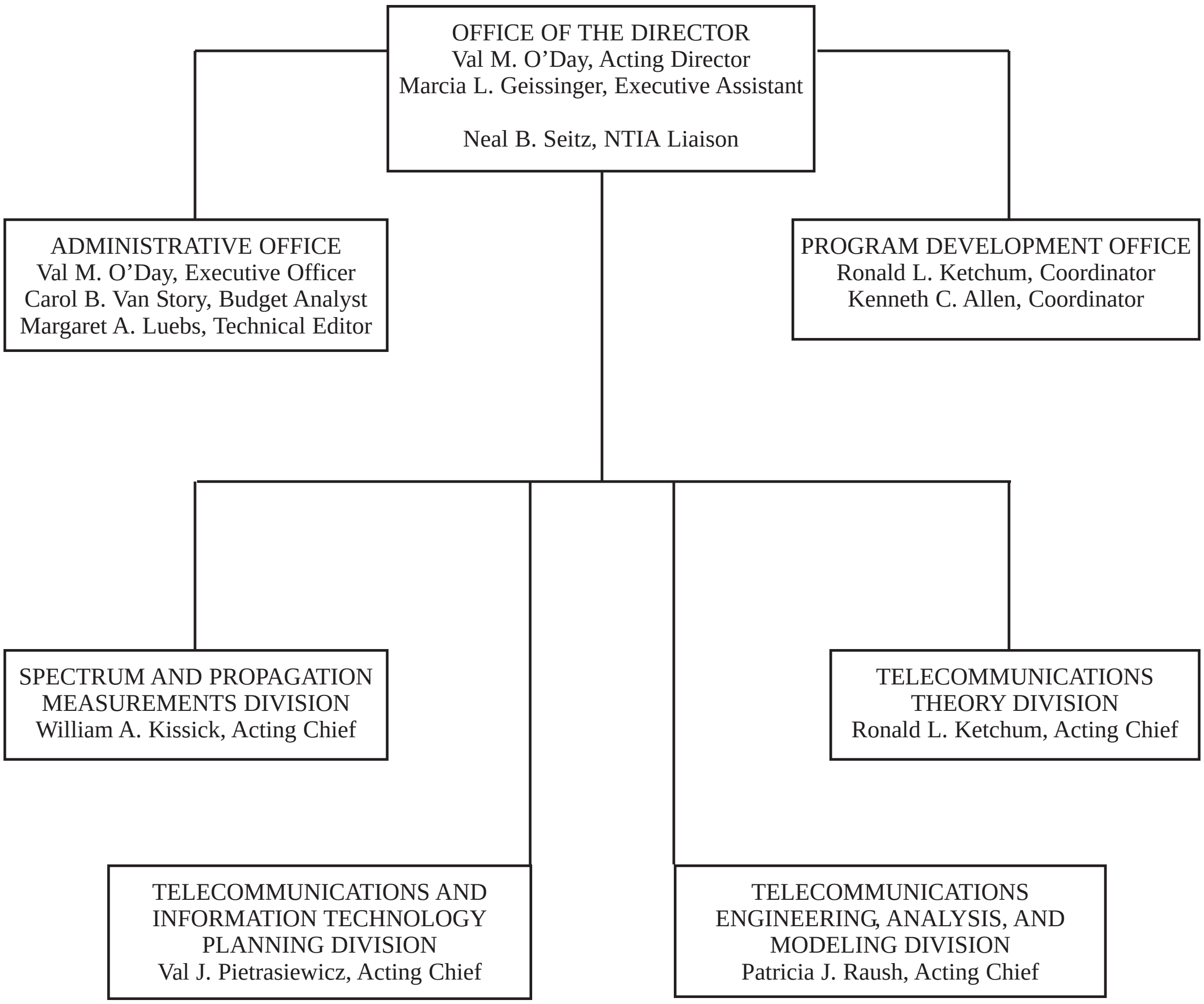
W

W3C	World Wide Web Consortium
W-CDMA	wideband CDMA
WCTF	Wireless Communication Task Force
WDM	wave division multiplexing
WIN	wireless intelligent nework
WWW	worldwide web

DOC/NTIA Organization Chart



ITS Organization Chart



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