Institute for Telecommunication Sciences

FY 2010 Technical Progress Report

U.S. Department of Commerce

Lawrence E. Strickling, Assistant Secretary
for Communications and Information

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Cover art by A.D. Romero. Photograph of sunset over the Flatiron Mountains viewed from the front of the Department of Commerce Boulder Laboratories building by A.A. Catellier.

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In 1927, less than 20 years after the first radio propagation measurements were taken from fixed monitoring stations by the Radio Section of the Department of Commerce (DOC), the first Radio Test Car was commissioned to allow measurements to be taken anywhere. RSMS I, its 1973 successor, was entirely designed by ITS and greatly expanded the DOC's ability to measure and analyze use of the radio spectrum. The technical sophistication and capabilities of the mobile measurement system were expanded again in 1985, 1992 and 2003, and the 5th Generation system is now under development.

Federal Aviation Administration (FAA) engineers atop the 4th Generation Radio Spectrum Measurement Science truck (RSMS4) at an airport site during an interagency measurement effort (photograph by F.H. Sanders).

ITS Overview

The Institute for Telecommunication Sciences (ITS) is the research and engineering laboratory of the National Telecommunications and Information Administration (NTIA) of the U.S. Department of Commerce (DOC). ITS provides technical support to NTIA in advancing telecommunications and networking infrastructure development, improving U.S. telecommunications trade opportunities, advancing information technology, and promoting more efficient and effective use of the radio spectrum. We use our research and expertise to analyze new and emerging technologies, and to contribute to standards creation. ITS provides important ongoing technical support to U.S. participation in many telecommunication standards organizations through the assumption of leadership roles in various working groups and the preparation of technical contributions and recommendations.

A National Research Resource

ITS serves as a principal Federal resource for the conduct of basic research on the nature of radio waves, addressing the telecommunications, emerging IT, and security challenges of other Federal agencies; state, local and tribal governments; private corporations and associations; and international organizations. We work with Government agencies and private organizations to explore, understand, and improve the use of telecommunications technologies and principles; investigate and invent new technologies; and overcome telecommunications challenges. Sponsored research contributes to NTIA's overall program and supports the goals of the DOC.

Government agency sponsors that provide significant support include the National Institute of Standards and Technology's Office of Law Enforcement Standards, the Department of Homeland Security, the Department of Transportation, the Department of Defense, the National Archives and Records Administration, and the National Weather Service.

Industry Sponsored Research

ITS supports private sector telecommunications research 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 (FLC), formally chartered by the Federal Technology Transfer Act in 1986.

CRADAs with other research organizations, telecommunications service providers, and equipment manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the DOC. ITS has had CRADAs with large companies as well as with small start-ups. Partnerships such as these enhance synergies between entrepreneurial ventures and broad national objectives.

Organization

The Institute's technical activities are organized into four divisions, which characterize ITS's centers of excellence:

- **Spectrum and Propagation Measurements:** designs, develops and operates state-of-the-art spectrum measurement systems; measures spectrum occupancy trends and emission characteristics of Federal transmitter systems; identifies and resolves radio frequency interference involving Federal systems.
- **Telecommunications and Information Technology Planning:** plans and analyzes telecommunications and information technology systems and services, improving their efficiency and enhancing their performance and reliability; e.g., Project 25 radios and their interoperability in public safety environments.
- **Telecommunications Engineering, Analysis and Modeling:** 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:** develops innovative telecommunication technologies and engineering tools through the use of electromagnetic theory, digital signal processing, broadband wireless systems performance, audio and video quality assessment, spectrum sharing concepts, and noise analysis.

The Director's Office supports these areas in budget and administrative functions.

Facilities

The Institute's world-class facilities and capabilities include:

- Audio-Visual Laboratories
- Public Safety RF Laboratory
- Public Safety Audio and Video Laboratories
- Radio Spectrum Measurement Science (RSMS) Program
- Secure Internet (SIPRNet)
- Table Mountain Field Site/Radio Quiet Zone
- Telecommunications Analysis Services

For more information about these and other resources at ITS, see *Tools and Facilities*, page 75.

Capabilities and Expertise

ITS is one of the world's leading laboratories for telecommunications research. Staff have strong engineering and scientific skills and experience. The majority of employees are electronics engineers; the rest are mathematicians, physicists, computer scientists, and administrative staff. ITS's areas of expertise include:

- **Radio Research and Spectrum Measurement:** ITS designs, develops and operates state-of-the-art spectrum measurement systems, Using those systems, ITS measures spectrum occupancy trends and emission characteristics of Federal transmitter systems, and identifies and resolves radio frequency interference involving Federal systems.
- **Communication Systems and Networks:** ITS plans, implements, and evaluates telecommunication systems and networks.
- **Public Safety Interoperability:** ITS facilitates inter-connectivity and interoperability between services and technologies used by public safety organizations.
- **Standards Development:** As it has for many years, ITS continues to provide leadership and technical contributions in national and international telecommunication standards committees. OMB Circular A-119 provides the ground rules and encouragement for Federal agency involvement in voluntary consensus standards development.
- **Wireless Voice/Data Systems and Emerging Technologies:** ITS assesses telecommunications system components, evaluates network survivability, and assesses system effectiveness in national security/emergency preparedness, military, and commercial environments. We test emerging technologies such as Voice over IP (VoIP), ultra-wideband, and Dynamic Spectrum Access.
- **Audio and Video Quality Research:** For over 25 years, ITS has conducted research on digital audio and video quality, grounded in signal processing theory and models of perception.

The 4th generation RSMS spectrum measurement vehicle parked in front of the U.S. Department of Commerce Boulder Labs building in Boulder, Colorado, July 2010. (photograph by J.R. Hoffman).

- **Electromagnetic Modeling and Analysis:** ITS maintains ongoing investigations in broadband wireless systems performance, propagation model development incorporating field measurement data, advanced antenna designs, and noise as a limiting factor for advanced communication systems.
- **IT Prototyping and Security Analysis:** ITS advances information technology through the design and implementation of prototype information systems, including large scale records management infrastructure. In addition to the analysis of radio communication systems, ITS applies its security expertise to current and emerging Internet technologies.

Benefits

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

- **Spectrum Utilization:** ITS research supports optimization of Federal spectrum allocation methods by identifying unused frequencies and potential interference through field measurements, and by promoting technology advances to aid in efficient use of the spectrum.
- **Telecommunications Negotiations:** Through expert technical leadership at international conferences and development of engineering tools to support negotiations, ITS provides support for tools such as interference prediction programs.
- **Public Safety:** Systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) for the use of "first responders" at the Federal, State, local, and tribal levels.
- **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.
- **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.
- **International Trade:** Promulgation of international telecommunications standards, facilitated by ITS participation, removes technical barriers to U.S. export of telecommunications equipment and services.
- **Technology Transfer:** Direct transfer of research results and measurements from ITS to U.S. industry and Government supports national and international competitiveness, brings new technology to users, and expands the capabilities of national and global telecommunications infrastructures.

Over A Century of Research

The first measurements of radio propagation by a U.S. agency were made in 1909 by the National Bureau of Standards, which in 1913 established the Radio Section of the Electricity Division to pursue radio work. In 1942, the Radio Section was incorporated into the Interservice Radio Propagation Laboratory, whose initial research focus was in support of the Armed Services during World War II. Re-named after the war as the Central Radio Propagation Laboratory (CRPL), the radio research group moved into a new facility built for them in Boulder, Colorado, and dedicated by President Eisenhower in September 1954. ITS is still housed in that building, now known as the Department of Commerce Boulder Labs.

In 1965, CRPL joined the Environmental Science Services Administration and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, ITSA in turn was split into four laboratories, Aeronomy, Space Research, Wave Propagation and the Institute for Telecommunication Sciences (ITS). ITS was transferred to the newly established Office of Telecommunications (OT) within the Department of Commerce in 1970. In 1977, OT was merged with the Office of Telecommunications Policy (previously in the Executive Office of the President) to form the National Telecommunications and Information Administration (NTIA), an agency of the Department of Commerce with ITS as its telecommunications research and engineering laboratory.

* * *

This Progress Report summarizes technical contributions made by ITS during Fiscal Year 2010 to both the public and private sectors. ❖

ITS Awards and Symposia in FY 2010

A team of three engineers from ITS and one from the NTIA Office of Spectrum Management (OSM) was nominated for a Department of Commerce Silver medal award in FY 2010. Adjudicated in FY 2010, the award was presented in the first few days of FY 2011. Also in FY 2010, ITS hosted the 11th Annual International Symposium On Advanced Radio Technologies (ISART) July 27–30, 2010. Sponsored by NTIA, the topic of ISART 2010 was "Spectrum Sharing Technologies."

Silver Medal Award

In 2010, a cross-divisional team of ITS and NTIA staff was selected to receive a Department of Commerce Silver Medal, the second highest honor given by the Department, in the category of Scientific/Engineering Achievement. Frank H. Sanders, Chief of the ITS Telecommunications Theory Division; John E. Carroll and Geoffrey A. Sanders, Electronics Engineers in the ITS Spectrum and Propagation Measurement Division; and Robert L. Sole, Electronics Engineer in NTIA's Office of Spectrum Management received their awards in October of 2010.

The group was recognized for swift and accurate measurements, tests, analysis, and documentation enabling them to identify the cause of radio interference to safety-of-life air traffic control radars at nearly half of the radar sites nationwide. The ITS engineers provided diagnostics to the agency operating the radars to identify the problem, and then provided a technical resolution for the problem. The affected radars give microburst warnings to air traffic control. The solutions developed by the group involve changes in the design, testing, and deployment of interfering transmitters. The group's accomplishment will ensure that radar microburst warnings at airports across the country continue to function without interference.

This accomplishment supports the Commerce Department's goal to promote U.S. innovation and industrial competitiveness by advancing measurement science and standards that drive technological change. ❖

Figure 1. Flanked by Department of Commerce Secretary Gary Locke (far left) and Assistant Secretary for Communications and Information Lawrence E. Strickling (far right), from left to right, G.A. Sanders, F.H. Sanders and J.E. Carroll of ITS and R.L. Sole of NTIA/OSM receive their Silver Medal Award at a Washington, DC, ceremony in October 2010.

ISART 2010

The 11th annual International Symposium on Advanced Radio Technologies (ISART) was held at the Department of Commerce Boulder Laboratories July 27–30, 2010. ISART is sponsored by the NTIA and hosted by ITS. The focus of ISART 2010 was "Spectrum Sharing Technologies," and organizers welcomed over 200 attendees from Federal, State and local governments, academia, and the private sector—the largest attendance in the history of the conference. Attendees were exposed to state-of-the-art emerging technologies, a behind-the-scenes look at government agency considerations and analyses, and dialogue and debate on the policy implications of spectrum sharing, including panel discussions on measuring spectrum occupancy, interference protection criteria, federal government spectrum, sharing land mobile radio (LMR) bands, sharing radar bands, context awareness, and current research in spectrum sharing. For the first time in 2010, the conference was videocast live and a number of people attended by videocast only.

Keynote speakers were Larry Strickling and Julius Knapp. Larry Strickling is the Department of Commerce (DOC) Assistant Secretary for Communications and Information and Administrator of NTIA. Through the Secretary of Commerce, Strickling is President Obama's principal advisor on telecommunications policy. Julius Knapp is Chief of the Office of Engineering and Technology (OET) of the Federal Communications Commission (FCC). OET is the FCC's primary resource for engineering expertise, provides technical support to the Chairman, Commissioners and FCC Bureaus and Offices, and serves as the FCC's lead office for coordinating FCC spectrum management matters with the federal government and the Interdepartment Radio Advisory Committee (IRAC). IRAC assigns frequencies to U.S. Government radio stations and develops and executes policies, programs, procedures, and technical criteria pertaining to the allocation, management, and use of the spectrum. ❖

Left: Figure 2. DOC Assistant Secretary Larry Strickling delivers the Day 2 Keynote Presentation.

Right: Figure 3. OET Chief Julius Knapp delivers the Day 3 Keynote Presentation.

Figure 4. Participants in the ISART 2010 Government Panel listen to Chair Preston Marshall (USC, out of picture). From left: Tom Kidd (USN, IRAC), Christopher Lewis (DOI, IRAC), Mike Williams (DOD), Victor Sparrow (NASA), Tomas Gergely (NSF, IRAC), and Ed Davidson (NTIA, IRAC) (photographs by F.H. Sanders).

The RSMS vehicle deployed to a field site to measure out of band emissions of a WiMAX base station (photograph by J.E. Carroll).

A screen shot from the division's RSMS 4G software suite showing the results of a spectrum survey conducted in the UHF LMR band.

An automated spectrum measurement is in progress inside the RSMS truck (photograph by J.R. Hoffman).

The RSMS 4G truck deployed at the Dept. of Commerce campus for a spectrum survey (photograph by R.J. Hoffman).

Spectrum and Propagation Measurements

In 2010 the FCC released its long awaited National Broadband Plan. The plan set an ambitious goal of 500 MHz of radio spectrum to be made newly available for use by mobile services within 10 years to meet ever increasing demand. A variety of approaches are available to secure the required spectrum. Historically, spectrum aggregation and reallocation have been used with great success, but it is becoming increasingly difficult to condense various services within existing bands or reallocate them to new bands while preserving the unique propagation characteristics required. Recently, in instances where incumbent systems could not be relocated, spectrum sharing via dynamic frequency access has been adopted. Now, as more computational power and intelligence is available to radio systems, opportunities for dynamic spectrum access to multiple radio bands are being explored.

Each approach involves a multitude of complex technical and economic trade-offs necessary to maintain the integrity of the legacy radio systems or services while providing useful spectrum for the new systems. The Spectrum and Propagation Measurements Division conducts a variety of electromagnetic compatibility measurements and analyses to evaluate the impact of these proposed new uses on incumbent Federal systems. The division's engineers conduct measurements of spectrum usage or occupancy, assess the compatibility of disparate radio systems through ad hoc and formal conformity assessment tests, and make both quantitative and qualitative assessments of receiver susceptibility to interference and noise. Their work serves as the technical basis for new spectrum policies and rulemakings. The following areas of emphasis are indicative of the work done recently in this division to support NTIA, other Federal agencies, academia, and private industry.

Radio Spectrum Measurement Science (RSMS) Program

The RSMS program encompasses the equipment and operational expertise required to perform sophisticated radio frequency measurements such as measuring spectrum occupancy or usage, conducting electromagnetic compatibility assessments, and resolving interference problems. The program provides for continuous improvements in measurement system capabilities and measurement techniques supporting both near and long term requirements. This ongoing development work readies the division's diverse team of measurement experts to respond on demand to address contemporary spectrum management challenges. RSMS projects funded by NTIA include RSMS Operations and RSMS 4th Generation System Development.

Table Mountain Research Program

The Table Mountain Field Site is the principal experimental field site for the Department of Commerce Boulder Laboratories. Designated by Congress as a protected radio quiet zone where the magnitude of external signals is restricted, the site facilitates various advanced research and measurement programs. Research at this site includes development and evaluation of measurement methods for spectrum occupancy, radio noise, antenna design, laser testing, and radar emissions. Work is conducted through NTIA funding as well as cooperative research and development agreements with non-Federal entities.

Spectrum Sharing Innovation Test Bed Pilot Program

Dynamic Spectrum Access (DSA) describes the second generation of cognitive radios, which contain greater processing power, allowing greater frequency agility and better adaptation to the radio environment so as to minimize interference to incumbent radio systems. The division is presently spearheading Test Bed measurements to assess the capabilities of the latest state-of-the-art DSA devices. The project is funded by NTIA/OSM.

Radio Noise and Spectrum Occupancy Measurement Research

ITS engineers are developing a next generation noise measurement system based on Vector Signal Analyzer (VSA) technology. VSA technology captures magnitude and phase information and allows for wider bandwidth noise measurements than those historically conducted at ITS. The project is funded by NTIA. ❖

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RSMS Operations

Outputs

- *Continued technical assistance to the Federal Aviation Administration (FAA) and Federal Communications Commission (FCC) to resolve interference into 5-GHz Terminal Doppler Weather Radar (TDWR) systems from Unlicensed National Information Infrastructure (U-NII) wireless devices*
- *Measurements of adjacent channel emissions in the Global Positioning System (GPS) bands from FAA Air Route Surveillance Radar (ARSR) systems*

Overview

The Radio Spectrum Measurement Science (RSMS) program has the task of performing critically needed and time-sensitive radio signal measurements that facilitate Federal Government spectrum allocation decisions and policy making. National Telecommunications and Information Administration (NTIA) Departmental Organization Order 25-7 assigns ITS responsibility for measurements that will guide the effective and efficient use of the spectrum. RSMS program managers coordinate with the NTIA Office of Spectrum Management (OSM) to ensure that identified spectrum research needs are addressed. ITS, through the RSMS Operations Project, provides NTIA and the executive branch with radio spectrum data, data analysis, reports, and summaries. RSMS encompasses the following types of measurements:

- Spectrum surveys and channel usage
- Equipment characteristics and compliance
- Interference resolution and electromagnetic compatibility
- Signal coverage and quality

In FY 2010, several different measurements were performed in support of the RSMS mission.

Terminal Doppler Weather Radar Interference

In early 2009, the Federal Aviation Administration (FAA) became aware of interference to their 5-GHz Terminal Doppler Weather Radars (TDWR) systems from Unlicensed National Information Infrastructure (U-NII) wireless devices operating in the same frequency band. TDWRs provide quantitative measurements of gust fronts, windshear, microbursts, and other weather hazards for improved safety of operations in and around major airports. In FY 2009, the RSMS Operations program assisted the FAA and the Federal Communications Commission (FCC) by undertaking a significant research effort to determine the cause of the interference, understand why some 5-GHz U-NII devices fail to detect TDWR signals, and engineer technical solutions. The RSMS program's unique measurement capabilities, techniques, and analyses (such as the one being performed in Figure 1) were fundamental to identifying the interference mechanisms into these radar systems with high levels of confidence.

Figure 1. An ITS engineer examining the output of a radar plan position indicator (photograph by G.A. Sanders).

In FY 2010, the RSMS Operations program continued to support the FAA and the FCC through consultation as technical subject matter experts as a solution was sought to prevent interference to these critical radar systems. ITS engineers participated in frequent meetings with the FAA, FCC, OSM, and private industry representatives. Participants jointly decided that to better protect TDWR systems, the current FCC 5-GHz U-NII device certification process should be altered. The current process exposes U-NII devices to simulated radar waveforms in a laboratory setting to characterize the device's response. The waveforms for testing are realized using a vector signal generator. ITS was tasked to develop and verify (Figure 2) a new subset of simulated radar waveforms that specifically mimics the TDWR for use in future certification testing.

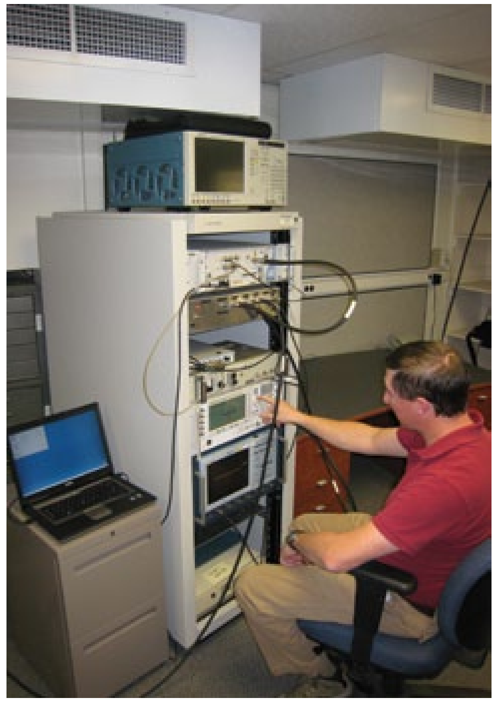

Figure 2. An ITS engineer verifying simulated TDWR radar signals (photograph by J.E. Carroll).

Radar System Unwanted Emission Measurements

In 2004, the White House released a new national policy on space-based positioning, navigation, and timing (PNT) services. The PNT policy is designed to ensure uninterrupted availability of these services; to meet the growing needs of the national security, economic and civil sectors; and to maintain the United States' pre-eminence in this area. In response to the national PNT Policy, NTIA developed a plan to address the Department of Commerce (DOC) responsibilities for management and protection of the frequency bands used for current and evolving PNT services.

To characterize the emission levels of Federal systems in the Global Positioning System (GPS) frequency bands, OSM and ITS jointly defined a measurement effort comprised of three subtasks. The first subtask, completed in FY 2009, consisted of identifying all the Federal systems that could possibly generate emissions (adjacent and harmonic) in the GPS bands and assisting Federal agency representatives to coordinate their use through the Interdepartment Radio Advisory Committee (IRAC). The second subtask, now nearing completion, was for RSMS to perform emission measurements to characterize the emission levels in the GPS bands from these selected Federal systems. In the third subtask, OSM will use the results of these emission measurements and previously developed interference scenarios to assess how closely the actual emission levels compare to existing standards.

In FY 2009, the RSMS program measured twelve 400 MHz LMR systems from various manufacturers and examined their harmonic emission levels in the GPS bands. Continuing with this work in FY 2010, the RSMS program measured the adjacent channel emissions from three FAA Air Route Surveillance Radar (ARSR) systems at the Mike Monroney Aeronautical Center in Oklahoma City, OK, to determine the out-of-band emissions in the GPS bands. Subsequent analysis was performed on this data and the results presented to OSM. ❖

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RSMS 4th Generation System Development

Outputs

- *Completed development of a low frequency preselector and new software modules for instrument control and measurement*
- *Made improvements to existing software and system capabilities and developed formal training on the use of the system*
- *Completed in-field testing and exploration of current generation software and system capabilities and initial exploration of platforms for developing next generation system and software*

Overview

The 4th generation system for Radio Spectrum Measurement Science (RSMS) consists of state-of-the-art tools (vehicle, software and hardware) for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The 4th generation system was developed to meet the recognized need to upgrade to the latest technology used in RSMS operations. RSMS measurement operations provide the National Telecommunications and Information Administration (NTIA) critical measurement support for determining policies affecting both the public and private sectors. To sustain this function, several new capabilities and improvements were added to the RSMS system in FY 2010.

Preselector Development

Integral to the RSMS measurement system has been the development of customized preselector units that filter out unwanted signals and amplify the input to increase system sensitivity, such as the one shown in Figure 1. Over the last year, ITS engineers completed development of a low-frequency preselector and the software to control the device and integrate it into the larger software package. This preselector provides amplification and dynamic attenuation for frequencies below 1 GHz, as well as additional gain and attenuation to optimize sensitivity and dynamic range when used in conjunction with the higher frequency preselectors.

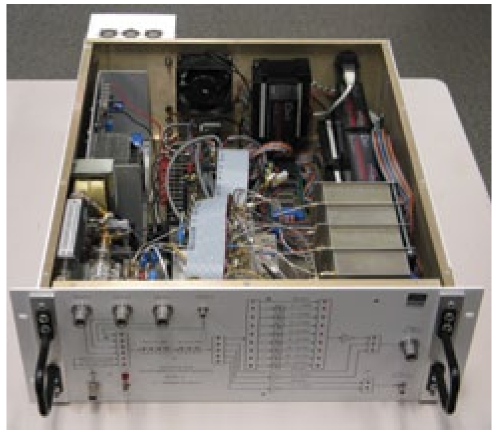

Figure 1. 4th generation low-frequency preselector (photograph by J.R. Hoffman).

Software Model Development

Over the 2010 fiscal year, several new additions and improvements were also made to software measurement routines. Modifications were made to the stepped amplitude probability distribution (APD) measurement, the manual spectrum-analyzer trace acquisition program, the swept measurement program, and several calibration routines. Most of the improvements included the addition of event tables and data viewers that reference the data to various points along the RF chain. The viewers also display data as individual (or multiple) plots on graphs that can further be saved as MATLAB™ .fig files. The measured data can also be processed into max, mean, median, and minimum values for each frequency step, as well as a contour plot of multiple amplitude probability distributions and a time-varying plot to show changes in signal use over time.

Two new software routines were developed: a swept-survey measurement, and a bandwidth-progression measurement. The swept-survey measurement is a specially customized routine tailored for performing swept spectrum surveys using a spectrum analyzer. The bandwidth-progression measurement is a specialized routine for analyzing signals by noting the change in power as the receiver bandwidth is varied. Several new data processing routines were also developed, primarily for analyzing spectrum-survey data.

Figure 2. The RSMS 4G truck deployed to a nearby high site for a spectrum survey. An ITS staff member is preparing a dish antenna on a rotatable mount (photograph by H. Ottke).

The Next Generation

The primary goal for FY 2010, which will carry over to FY 2011, has been to finalize the 4th generation software and initiate development of the next generation (the 5th). In the past, the typical system has had an approximately 10-year life cycle; however, the RSMS team has been working to extend the life of the 4th generation software to 20 years, so as to allow overlap between its use in the field and the development of the next generation. This is intended to prevent the awkward condition of having to use software in the field that is still under development. In the past year, various software development platforms were explored and tested, a preliminary selection was made, and a few trial modules were developed to further test the capabilities of the selected platform. In FY 2011, the next steps will be to train team members on use of the development software, to establish the functional measurement requirements, and to recommend the software architecture.

Spectrum Survey Development

To meet the need for accurate identification of spectrum usage, the goal of RSMS 4th generation system and software improvement plans is to ensure full capabilities for the conduct of future comprehensive spectrum surveys. Multiple exploratory spectrum survey measurements were conducted in the Denver area to examine the system capabilities, make improvements, and explore the nature of spectrum in the range between 100 MHz and 10 GHz. Figure 2 shows the RSMS 4G truck being set up to conduct one of these exploratory measurements. Several meetings and discussions regarding spectrum surveys were held to receive input from multiple sources, both technical and policy oriented. This input will serve to guide future development in ways that can best help answer questions about spectrum efficiency and utilization. An existing but unpublished ITS report on spectrum-survey techniques will be modified to include this recent work and published as a formal NTIA report in calendar year 2011. ❖

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Table Mountain Research Program

Outputs

- *Ground constant measurements and modeling*
- *NOAA Weather Radio Receiver performance testing and validation*
- *Antenna characterization and radio propagation studies*
- *Radar and LADAR research*

Overview

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. In addition to the ITS Science and Engineering projects described below, other telecommunications research is performed at Table Mountain through cooperative research and development agreements (CRADAs) with private industry.

Free Field Measurements of the Electrical Properties of Soil

During the summer of 2009 a series of measurements were undertaken at the Table Mountain field site to study near-earth radio wave propagation. These measurements raised a number of questions about the effect of dielectric permittivity and conductivity and their impact on near-earth radio propagation. To answer these questions, ITS engineers began a program in 2010 to investigate different methods for directly measuring the electrical properties of soils. Figures 1 and 2 show an experimental test fixture used in the development of a ground constant measurement system. The goal of this program is to identify a measurement technique that may be used to map the electrical properties of surface soils at the Table Mountain site. These data can then be used to help improve propagation modeling and prediction tools for near-earth radio-wave propagation.

Figure 1. An experiment to determine soil electrical properties (photograph by R.T. Johnk).

Radar and LADAR Research

The Table Mountain field site provides a large, open, unobstructed area that is ideal for the study of traditional Radar as well as laser-based LADAR systems. Researchers use the Table Mountain facility to validate new measurement methods, and to test the operation and performance of new Radar and LADAR systems. The work performed this year in this area included Bio-Aerosol detection, Synthetic Aperture LADAR, and long-range three dimensional holographic imaging.

NOAA Weather Radio (NWR) Testing

NWR provides continuous information on the latest weather conditions directly to the public from the National Weather Service (NWS) offices. A 1975 White House Policy statement also designated NWR as the sole Government-operated radio system to provide warnings of natural disasters and nuclear attack directly into private homes. As an extension to this policy, NWS in cooperation with the Federal Emergency Management Agency (FEMA) and the Federal Communications Commission (FCC), expanded the role of NWR to include "all hazards."

ITS has developed simulated broadcasts and a series of repeatable measurement methods to test the performance of NWR receivers. These test results are used by NOAA to determine whether a manufacturer may use the NWR logo on their products. The compiled results of numerous tests also help NOAA determine the possible cause of receiver malfunctions reported by the public when units do not respond during a weather event or other broadcast emergency. Individual NWR receiver manufacturers can enter into cooperative research and development agreements (CRADAs) with ITS in order to have units tested, problems uncovered and improvements made to new receiver models before applying to NOAA to use the NWR logo.

Figure 2. Calibrating the experimental ground constant measurement system (photograph by R.T. Johnk).

FY 2010 CRADA Partners

- Areté Associates
- Lockheed Martin/Coherent Technologies
- First RF Corporation
- University of Colorado, AUGNet
- Deep Space Exploration Society
- RF Metrics
- Symmetricom

Recent Publications

- Maciej Stachura and Eric W. Frew, "Cooperative Target localization with a communication aware active sensor network," in *Proc. AIAA Guidance, Navigation, and Control Conference*, Toronto, Canada, Aug. 2010
- Neeti Wagle and Eric W. Frew, "A particle filter approach to WiFi Target Localization," in *Proc. AIAA Guidance, Navigation, and Control Conference*, Toronto, Canada, Aug. 2010.
- Anthony Carfang, Eric W. Frew, and Timothy X. Brown, "Improved delay-tolerant communication by considering radio propagation in planning data ferry navigation," in *Proc. AIAA Guidance, Navigation, and Control Conference*, Toronto, Canada, Aug. 2010
- Jack Elston, Brian Argrow, Eric W. Frew, and Adam Houston. "Evaluation of UAS concepts of operation for severe storm penetration using hardware-in-the-loop simulations," in *Proc. AIAA Guidance, Navigation, and Control Conference*, Toronto, Canada, Aug. 2010
- R. Howe, "Imaging dense globular clusters like M3 and M15," in *Proc. 2010 Symposium on Telescope Science*, Society for Astronomical Sciences, Inc., Rancho Cucamonga, CA, May 2010
- Eric W. Frew and Brian Argrow, "embedded reasoning for atmospheric science using unmanned aircraft systems," in *Proc. AAAI 2010 Spring Symposium on Embedded Reasoning: Intelligence in Embedded Systems*, Palo Alto, CA, Mar. 2010
- Riggs, J., "Atmospheric image distortion correction with paired antennas," Research Day, University of Northern Colorado, Greeley, CO, Apr. 2010.

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Spectrum Sharing Innovation Test Bed Pilot Program

Outputs

- *Developed, assembled, and validated measurement systems for all Phase I test cases*
- *Performed measurements for all possible Phase I test cases*
- *Produced summary test reports for each Phase I test case*

Overview

The National Telecommunications and Information Administration (NTIA), in coordination with the Federal Communications Commission (FCC) and other Federal agencies, established a Spectrum Sharing Innovation Test Bed pilot program to examine the feasibility of increased spectrum sharing between Federal and non-Federal users as a means of improving spectrum efficiency. The program is evaluating the ability of Dynamic Spectrum Access (DSA) devices employing spectrum sensing and/or geo-location techniques to share spectrum with land mobile radio (LMR) systems operating in the 410–420 MHz Federal band and in the 470–512 MHz non-Federal band. DSA technology allows a radio device to evaluate its radio frequency environment using spectrum sensing and/or geo-location, to determine which frequencies are available for use on a non-interference basis, and to reconfigure itself to operate on the identified frequencies.

ITS involvement with the program began in the summer of 2008 with a series of meetings among six interested parties. Those meetings identified a variety of DSA devices to be tested which use diverse approaches to spectrum sharing. ITS and NTIA's Office of Spectrum Management subsequently drafted the Phase I test plan and completed the public review and comment process on that document in December 2008. The plan contains five categories of tests. Three types of tests focus on the characteristics of the DSA devices: emissions characterization, sensor characterization, and spectrum access behavior. The other two test categories address LMR emissions characteristics and LMR performance in the presence of DSA emissions.

Phase I Testing

ITS received the first pair of DSA devices for testing in late March 2009 and has subsequently completed Phase I testing on them. This required the team to interpret the generic test descriptions contained in the test plan, configure the test stations, implement each test, interpret anomalous or unexpected behaviors, and re-scope or modify procedures as necessary to complete testing. The team has completed at least one run-through for all of the test cases and has prepared summary reports for each. LMR emissions measurements have also been completed, as have a first round of LMR susceptibility tests against emissions captured from a DSA device. An example of the results of the latter is shown in Figure 1.

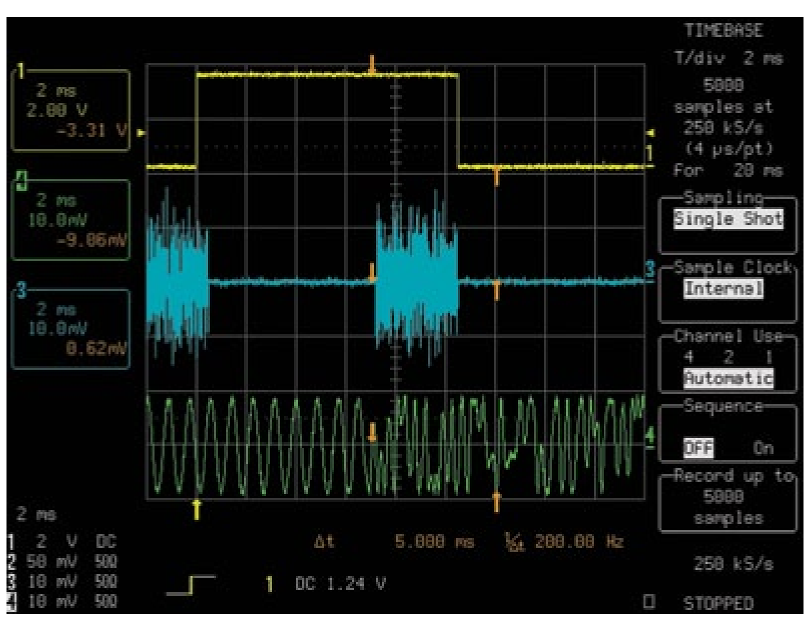

Figure 1. An oscilloscope trace shows the careful timing (indicated by the trigger signal, top) required to force a data collision between a DSA device transmission (middle) and an LMR packet (bottom). This test assessed an LMR's susceptibility to DSA interference.

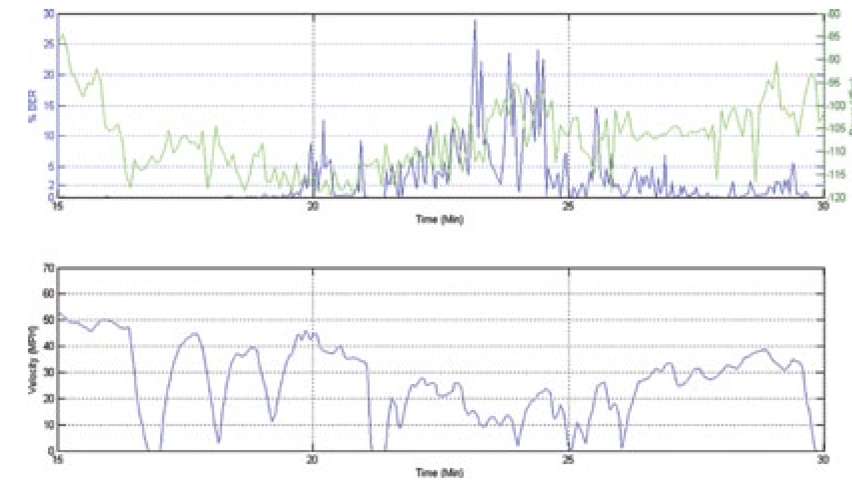

Figure 2. A plot of LMR bit error rate as a function of channel power and vehicle velocity from exploratory testing identified challenges with mobile measurements. Bit error rate (BER) unexpectedly increased with increased channel power at moderate speeds.

A second pair of devices was received in August 2009 and is presently mid-way through the testing regimen. The first devices are slated for Phase II and III testing in the first half of calendar year 2011. Meanwhile, ITS received a third set of devices in late October 2010 and has begun testing on them.

The first device ITS tested supported a variety of physical layer configurations, so it required an additional number of test cases. Also, the Phase I test plan included a comprehensive array of test procedures, each with its own set of test conditions, yielding a broad matrix of test cases. As testing progresses, engineers continue to assess the characteristics of the devices and to perform "matrix reduction" to eliminate redundant or less informative test cases. For example, testing has shown insignificant differences in the response of DSA sensors to LMR signals representing simulated 30 mph and 60 mph test cases, so the 30 mph test case for subsequent DSA devices will be omitted.

Preparation for Phases II and III

In preparation for crafting a field test plan, ITS engineers executed a number of exploratory measurements to examine a variety of LMR channel conditions that will affect a coexistence analysis with DSA devices. Of particular interest was a statistical baseline of channel conditions for mobile LMRs in an interference-free environment. Testing showed a considerable degree of variability in the LMR bit error rate which did not correlate to any first order statistics. This testing, some of the results of which are shown in Figure 2, greatly influenced the test scenarios selected for the Phase II and III field tests.

ITS is presently drafting the test plan for the Phase II and III field tests. Once the draft plan is complete, it will be presented to the Federal agencies for review and comment, followed by a public review process. Concurrently, the team is researching a suitable location for the field tests and is developing and validating a number of test fixtures that will be required to monitor the tests.

Phase II testing will examine the DSA devices' spectrum sensing capabilities in a live LMR environment with the transmitters attenuated to mitigate the potential for interference. After successful completion of Phase II, the devices will be allowed to transmit freely in the test bed environment. Phase III will expose the DSA devices to a variety of controlled and uncontrolled conditions and examine their behavior, and document any instances of harmful interference to incumbent LMR systems. ❖

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Radio Noise and Spectrum Occupancy Measurement Research

Outputs

- *Data processing and analysis of wideband noise measurement data taken at 112.5, 221.5, and 401 MHz in residential and urban environments in the Boulder/Denver area*
- *Draft NTIA report describing the Boulder/Denver area noise measurements and subsequent data processing and analysis*
- *Dynamic range characterization of the wideband noise measurement system and investigation of potential dynamic range improvement*

Overview

Proper radio communication system design requires, among other considerations, knowledge of the noise and interference environment at the receiving location. While distinguishing between noise and interference is subject to different interpretations, one interpretation is that interference arises from intentionally radiated signals, whereas noise arises either from natural sources or from unintentionally radiated signals generated by man-made sources. Noise can be further categorized as being either internal or external to the receiving system.

External, man-made noise was studied extensively in the 1960s and 1970s, culminating in the development of a man-made noise model that is still in use today (see Recommendation ITU-R P.372-10). However, there are many reasons to suspect that the man-made radio noise environment may have changed since the 1970s. The introduction of new technologies such as computers, cellular telephones, and other electronic devices; increases in spectrum crowding; the use of RF overlay technologies; the aging power distribution infrastructure; and improvements in auto ignition systems represent some of the changes that are likely to have had an impact. Because of all these factors, there has been a renewed, worldwide interest in measuring, quantifying, and modeling man-made radio noise.

Noise Measurement Data Analysis

Man-made radio noise research at ITS in FY 2010 was primarily focused on processing and analyzing the noise measurement data collected during the summer of 2009 at two business locations and two residential locations in the Boulder/Denver Area. The noise measurements were taken at 112.5, 221.5, and 401 MHz at each location. For each frequency and location, the data were collected every 10 minutes as a wideband complex baseband data record consisting of six million in-phase (I) and quadrature phase (Q) data samples in a 1.16 MHz vector signal analyzer (VSA) span and a narrowband complex baseband data record consisting of six million I and Q data samples in a 36-kHz VSA span. The wideband complex baseband data were analyzed to show the characteristics of individual noise data records and to provide various statistical descriptions of the noise. Characteristics of the individual complex baseband noise data records are presented as either time domain plots or amplitude probability distributions (APDs). Frequency domain characteristics of the complex baseband noise data records can also be examined to provide further insight into the attributes of the noise.

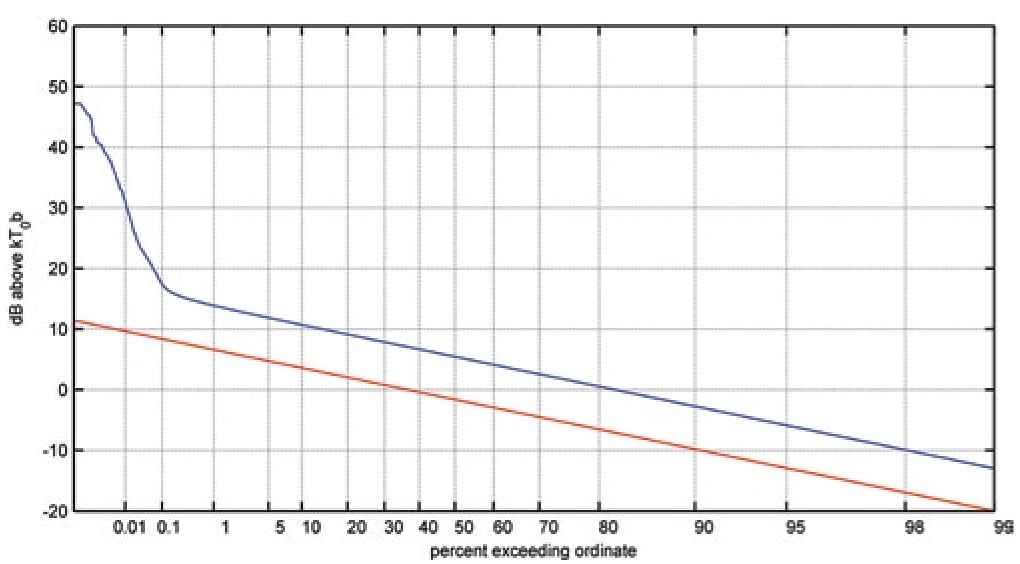

Figure 1. Example APD from a noise data record filtered to a 1-MHz bandwidth at a center frequency of 401 MHz at the Boulder business location (upper curve) along with the APD of the normalized measured receiver noise (lower curve).

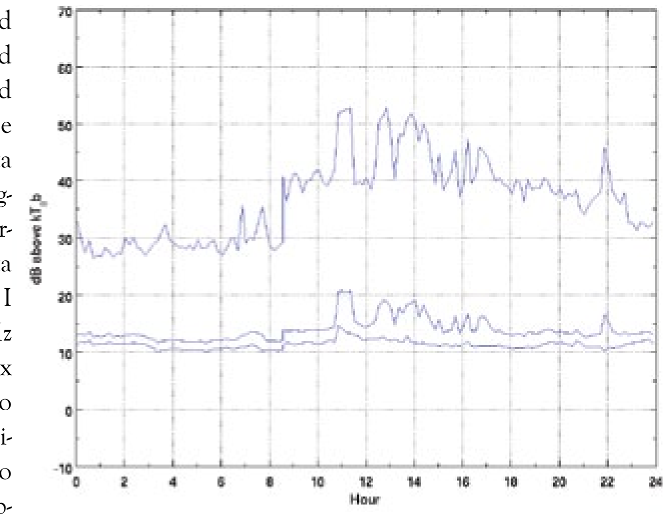

Figure 2. Example plot of the median, mean, and peak measured noise power from noise data records filtered to a 1-MHz bandwidth at a center frequency of 221.5 MHz at the Boulder business location.

The APD is an extremely useful mechanism for displaying the amplitude statistics of signals and noise and has been used for many years in radio engineering. Figure 1 shows an example APD of a noise data record filtered to a 1-MHz bandwidth at a center frequency of 401 MHz at the Boulder business location along with the APD of the normalized measured receiver noise as a reference. The elevated portion of the noise data record APD (at low percentages exceeding the ordinate) indicates the presence of impulsive noise.

The statistical data analysis included the median, mean, and peak noise power levels over a 24-hour period at each measurement location and frequency. An example plot of the median, mean, and peak measured noise power from noise data records filtered to a 1-MHz bandwidth at a center frequency of 221.5 MHz at the Boulder business location is shown in Figure 2. (Peak noise power is defined as the power exceeded 0.01% of the time here.) Note that, as would be expected, the mean and peak noise power is generally higher during the day than during the night. The noise is clearly non-Gaussian as the peak noise power is significantly more than 10 dB greater than the mean noise power.

Complementary cumulative distributions of the hourly median values of the median, mean, and peak power were also determined for each frequency and environment type (business or residential). Finally, values of median antenna noise figure F_{am} were determined for each measurement frequency and environment type. Values of F_{am} are a traditional way of describing man-made noise statistics and provide a convenient means to compare results from different studies. A draft NTIA report describing the noise measurements and the results of the data analysis is undergoing editorial review.

Other Work

Additional work in FY 2010 included characterization of the dynamic range of the current VSA-based noise measurement system. Potential improvement in dynamic range was investigated by replacing the VSA in the noise measurement system with a new, commercial-off-the-shelf spectrum analyzer with VSA capabilities. Greater dynamic range is beneficial in reducing the potential for system overload during measurements. Improvements in dynamic range of almost 10 dB were observed along with nearly a 1.5 dB improvement in noise figure.

Plans in FY 2011 include publication of the NTIA report on noise measurements as well as investigating potential modifications and improvements to the wideband noise measurement system in preparation for a more extensive outdoor noise measurement campaign and/or indoor noise measurements. ❖

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Oregon Congressman David Wu (left) visited the PSCR audio quality labs. Jeff Bratcher (center) demonstrated to Congressman Wu how ITS studies the affects of background noise on voice intelligibility. Dereck Orr (right) and Bratcher explained our goal to learn what technology and operational improvements may help overcome background noise issues (photograph by J. Burrus).

At the 2010 International Wireless Communications Exposition, ITS engineers demonstrated Voice over IP work, the effects of compression on video quality, the affects of background noise on audio quality, and a test tool for the Project 25 Inter-RF Subsystem Interface (photograph by K.R. Tilley).

An ITS engineer (right) experiences self-contained breathing apparatus (SCBA) with communications training to help understand SCBA user requirements for audio quality (photograph courtesy of Boise Fire Department).

As part of the joint research effort between ITS and NIST/OLES, the PSCR program hosted its inaugural stakeholders' meeting for the 700-MHz Public Safety Broadband Demonstration Network. Participants in breakout sessions voiced their expectations for a nationwide public safety broadband network and for the PSCR-managed demonstration network (photograph by K.R. Tilley).

Telecommunications and Information Technology Planning

The Telecommunications and Information Technology Planning Division is focused on research and development efforts from the perspective of the system or network level. Projects include development, testing, and evaluation of existing, new, and proposed telecommunications and information technology systems with a focus on improving efficiency, interoperability, performance, and reliability. This work, commonly referred to as systems engineering, is performed for both wireline and wireless applications.

The division also conducts all phases of strategic and tactical planning, as well as problem solving and actual engineering implementation. ITS engineers identify users' functional requirements and translate them into technical specifications. In the process, telecommunication system designs, network services, access technologies, and information technologies are all analyzed. The work within the Public Safety Communications Research (PSCR) program, a joint effort between ITS and the NIST Office of Law Enforcement Standards (NIST/OLES), continues to focus on public safety interoperable communications. The program performs research, development, testing, and evaluation to foster nationwide public safety communications interoperability.

Following is a summary of significant activities that occurred in the Telecommunications and IT Planning Division during FY 2010.

Public Safety Communications Research

The PSCR program (www.pscr.gov) is one of the largest programs at the Institute. The program conducts broad-based technical efforts aimed at facilitating communications interoperability and information sharing among wireless and IT systems within the public safety community. The sponsors of the program's research include the Department of Homeland Security and the Department of Justice. PSCR projects are planned and performed with coordination among local, State, tribal, and Federal practitioners. Technical thrusts within the program, described in separate sections on the following pages, include:

- Project 25 Standards Development
- Project 25 Compliance Assessment Program
- Public Safety Audio Quality
- Public Safety Interoperability Test Tools
- Public Safety Broadband Demonstration Network

Multimedia Quality Research

The Institute characterizes and analyzes the fundamental aspects of multimedia quality assessment. A primary goal of this research is to develop an algorithmic system to objectively assess multimedia quality by combining audio quality, video quality, and audiovisual synchronization information.

Wireless Network Measurement Methods

The Institute studies the performance characteristics of wireless networks and attempts to standardize measurement methods in order to better understand the applicability of different types of wireless networks to specific user requirements.

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Project 25 Standards Development

Outputs

- *Leadership roles and formal participation to promote public safety interests in achieving P25 goals*
- *Technical proposals to accelerate the development of P25 standards satisfying public safety requirements*
- *User outreach to increase practitioner involvement in the P25 process and the adoption of P25 standards*

Overview

The overall goal of Project 25 (P25) is to enable and promote the development and use of interoperable land mobile radio (LMR) equipment and systems that cost-effectively meet the complex and evolving mission-critical radio communication needs of the public safety community. Project 25 was established in 1989 by governmental entities and the Association of Public-Safety Communications Officials – International (APCO) for the primary purpose of realizing the benefits of digital narrowband LMR technologies for public safety practitioners and other users. To accomplish this vital goal, public safety, government, and manufacturer representatives participating in the P25 process develop, as a public-private partnership, voluntary consensus standards with the support of the American National Standards Institute (ANSI)-accredited Telecommunications Industry Association (TIA).

APCO Project 25 is unique in that it is an open, user-driven standardization process, with technical and operational requirements established through stakeholder participation. TIA published standards set the basis by which:

- Manufacturers develop, implement, and offer P25 equipment and systems.
- Recognized laboratories conduct P25 compliance testing.
- Users specify, procure, and operate P25 radios and communications infrastructure.

The deployment of P25 equipment and systems continues to grow, with broad adoption by the more than 50,000 public safety organizations in the U.S. and by public safety organizations in over 54 countries.

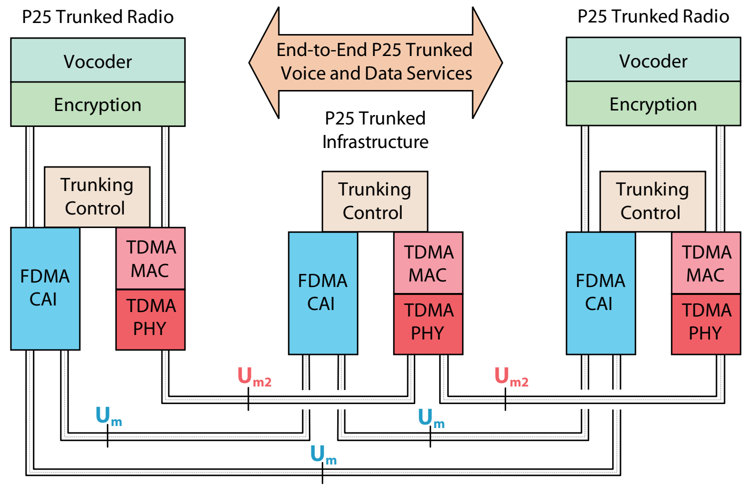
Recent Congressional legislative and related actions have recognized P25 standardization as the preferred solution for narrowband LMR public safety users. Congress has identified several key P25-defined open interfaces as critical for near-term completion, including two of particular importance: the P25 Inter-RF Subsystem Interface (ISSI) and the P25 Common Air Interface (CAI). The ISSI and the CAI are the most important P25 interfaces because they enable multi-agency interoperability using multi-manufacturer P25 radios and P25 infrastructures, even across large geographic areas including different public safety jurisdictions.

ITS Involvement

ITS began to advance the development of Project 25 requirements and standards shortly after P25 was established. ITS continues, under the sponsorship of NIST/OLES, to support the accelerated development of P25 standards to meet increasing needs for functionally enhanced, compliant equipment and systems, and to satisfy Congressional mandates. Additionally, ITS's P25 standards development support efforts are an integral part of the Public Safety Communications Research (PSCR) program, a joint effort of NIST/OLES and ITS. During FY 2010, ITS involvement, which provided technical and organizational representation for the sponsor, directly assisted the approval of new and revised P25 requirements and standards in several critical areas, including the ISSI and CAI, and in related areas of emphasis, including public safety audio quality research and the P25 Compliance Assessment Program.

Next Generation P25 CAI Standards

ITS technical efforts during this and prior fiscal years strongly supported the accelerated development and approval of new P25 standards for the next generation ("Phase 2") P25 CAI—the Two-Slot Time Division Multiple Access (TDMA) Standard. The P25 Two-Slot TDMA Standard is urgently needed to satisfy regulatory and user requirements for more efficient use of limited radio spectrum. ITS contributions during FY 2010 directly supported completion of the P25 Phase 2 Two-Slot TDMA Media Access Control Layer Description standard, expected to be approved in October 2010 for publication as TIA-102.BBAC. The new P25 CAI, located at the U_{m2} reference point, provides 6.25 kHz channel-equivalent voice and data operation. Largely because of regulatory and system efficiency considerations, both manufacturers and users plan on rapid near-term adoption of P25 two-slot TDMA equipment and systems. This suite of standards is being developed consistent with user needs specified in the P25 Statement of Requirements (P25 SoR).



Representative protocol model for P25 two-slot TDMA trunked voice and data service.

P25 User Requirements

ITS technical efforts strongly contributed to accelerated development and approval of the new and revised P25 user requirements by the P25 User Needs Subcommittee (P25 UNS). In this regard, the specific technical contributions originated by ITS enabled the following new and revised P25 user requirements to be approved since the publication of the previous P25 SoR in August 2009:

- Clarification of the applicability of the P25 user requirements as Mandatory or Optional
- Addition of requirements for ISSI equipment and functionality upgrade capabilities
- Clarification of overall requirements for the wireline P25 interfaces, including the ISSI
- Removal of user requirements for 6.25 kHz FDMA and 25 kHz TDMA
- Addition of requirements for the new P25 Wireless/Mobile Console Interface

ITS continued in FY 2010 to increase its technical support of P25 UNS activities to enable the timely realization of P25 user requirements that best serve the overall interests of the public safety LMR community—an effort that remains extremely challenging because of diverse and evolving user communication needs, funding and budgetary constraints, extended equipment lifecycles, regulatory changes, and rapid technological innovation.

Leadership and Participation

ITS leadership in the P25 UNS drove the development and approval of an updated P25 SoR in March 2010 to satisfy current user requirements on a timely basis. Throughout FY 2010, an ITS staff member acted as Editor of the P25 SoR, a role ITS staff has performed since 2005 at the request of the P25 Steering Committee.

Formal participation in the P25 process continued throughout FY 2010, with the submission of numerous letter ballot comments enabling standards to be approved consistent with ITS and sponsor objectives. Accelerated completion of key P25 standards continued in 2010, including the publication of over 20 standards associated with the CAI, ISSI, and other P25 interfaces. ITS staff continues to conduct important outreach activities; for example, enhancing the P25 Document & Standards Reference (P25 DSR) as part of the PSCR program (http://www.pscr.gov/outreach/p25dsr/p25dsr.php).

In FY 2011, ITS will continue to support accelerated development of key Project 25 requirements and standards to further realize interoperable narrowband LMR equipment and systems that satisfy the mission-critical communication needs of the public safety community.

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Project 25 Compliance Assessment Program

Outputs

- *Development of technical materials for DHS P25 CAP Governing Board*
- *Grant guidance language for Federal P25 equipment grant programs*
- *Laboratory assessment program management and subject matter expertise*
- *Compliance assessment related P25 standards*
- *First posting of P25 CAP documents to the Responder Knowledge Base*

Overview

Historically, public safety agencies have purchased and used equipment made by different manufacturers with inconsistent manufacturing practices and using different spectra. As a result of these inconsistencies, the equipment could not interoperate, preventing many public safety agencies from communicating when lives were in danger. Public safety organizations and the communications industry partnered through Project 25 (P25) to eliminate these issues by developing standards for easy interoperability of radios and other components regardless of manufacturer. The goal of P25 is to specify formal standards for interfaces between the various components of a land mobile radio (LMR) system, commonly used by emergency responders.

After years of effort, industry was successfully incorporating standards into much of the radio and communications equipment used by public safety. However, preliminary test data indicated that some radios sold under the P25 label did not meet all of the standards' requirements. The problem was the lack of a reliable method to verify equipment compliance with P25 standards. "Testing was something that, for a long time, public safety assumed occurred, but then they realized that their toasters were tested to a higher degree than their radio systems," says Dereck Orr, National Institute of Standards and Technology/Office of Law Enforcement Standards (NIST/OLES) Communications Program Manager.

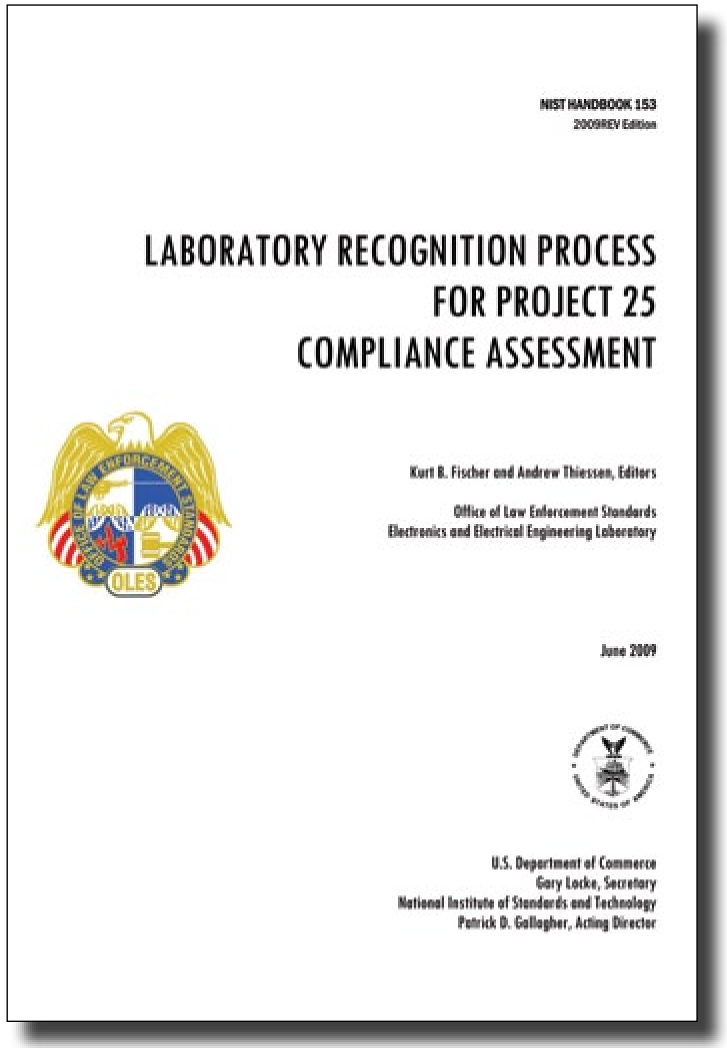
In 2008, ITS, NIST/OLES and the Department of Homeland Security's Office of Interoperability and Compatibility (DHS OIC) worked together to build an independent coalition of public safety users and communications equipment manufacturers to address this issue. This led to the creation of the congressionally-mandated P25 Compliance Assessment Program (CAP) to test equipment for standards compliance.

Program Structure

The P25 CAP is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the P25 suite of standards. The purpose of the program is to provide emergency response agencies with evidence that their communications equipment meets P25 standards for performance, conformance, and interoperability. Rather than relying on a large centralized test facility, the program recognizes independent laboratories authorized to conduct testing. It is an outstanding example of government making a minimal investment that catalyzes industry and the community it serves to develop a solution that will affect billions of dollars in purchases.

ITS supports NIST/OLES and DHS OIC in carrying out the rigorous and objective assessment process through which test laboratories demonstrate their competence, promoting the user community's confidence in, and acceptance of, test results from these recognized laboratories. Eight laboratories were recognized under this program as of May 2009, and all equipment suppliers that participate in the P25 CAP must use these recognized laboratories to conduct performance, conformance, and interoperability tests. The P25 equipment suppliers then release summary test reports from these recognized labs along with declarations of compliance. This documentation increases the public's confidence in the performance, conformance, and interoperability of P25 equipment. Further, the declaration of compliance related documents developed by program participants provide useful technical information about the equipment.

The P25 CAP is a partnership among ITS, DHS OIC, NIST/OLES, industry, and the public safety community. It provides a forum where performance, conformance, and interoperability issues that emerge as the technology and the user needs evolve can be recognized and resolved before product launch and deployment. ITS supports this process by leading the development of Compliance Assessment Bulletins and updating them as program needs continuously adapt to changing user requirements.


NIST HANDBOOK 153
2009REV Edition

LABORATORY RECOGNITION PROCESS FOR PROJECT 25 COMPLIANCE ASSESSMENT

Kurt B. Fischer and Andrew Thiessen, Editors

Office of Law Enforcement Standards
Electronics and Electrical Engineering Laboratory

June 2009

U.S. Department of Commerce
Gary Locke, Secretary
National Institute of Standards and Technology
Patrick D. Gallagher, Acting Director

NIST Handbook 153, "Laboratory Recognition Process for Project 25 Compliance Assessment," sets out the procedures and general requirements under which the P25 CAP recognizes P25 equipment testing laboratories. The handbook is co-edited by engineers from NIST/OLES and ITS.

Results

The P25 CAP is providing more than 60,000 emergency response agencies nationwide with a consistent and reliable indicator of P25 product compliance. It also provides a means of verifying that billions of Federal grant dollars and Federal procurements of LMR systems are being invested in standardized solutions and equipment that promotes interoperability.

The P25 CAP Governing Board met many times in FY 2010 and achieved a number of important milestones, including the release of many critical requirements documents, all drafted by ITS.

- The Inter RF SubSystem (ISSI) was added to the program. Additionally, updated Testing Requirements, Supplier's Declaration of Compliance Requirements, and Summary Test Report Requirements were released.
- Supplier's Declarations of Compliance and Summary Test Reports were first posted to the Responder Knowledge Base (www.rkb.us) Web site in January 2010. Currently P25 equipment from nine manufacturers is represented.
- ITS continues to work within the standards development process of TIA to ensure timely release of standards that directly impact the P25 CAP, particularly test standards for the Common Air Interface and the Inter-RF Sub-System Interface.
- ITS assisted in developing Federal grant guidance language for DHS that affects how Federal grant money is used by state and local public safety in the purchase of communications equipment. ❖

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Public Safety Audio Quality

Outputs

- *Technical reports describing experimental conduct and results*
- *Contributions to standards bodies regarding measurement methods for public safety audio quality*

Overview

Public safety workers operate in some of the harshest environments around. When they are in those environments, their life depends on their ability to communicate with their coworkers and commanders. It is essential that the ability to call for help, to warn others, and to communicate be available whenever a public safety practitioner's life is in danger. However, some background noises encountered in the public safety environment—such as sirens, chain saws and personal alert safety systems (PASS)—can interfere with those essential communications. Sometimes this interference is so severe that practitioners are prevented from understanding each other at the most critical moments. To understand how background noise affects voice communications and to determine what technology improvements are needed to overcome any background noise issues, ITS and its program sponsors (National Institute of Standards and Technology/Office of Law Enforcement Standards and the Department of Homeland Security/Office of Interoperability and Compatibility) have worked with practitioners to develop and implement tests that measure how digital radios operate in the presence of loud background noise.

The Public Safety Audio Quality project takes an innovative approach to addressing the needs of the public safety community. Working directly with practitioner agencies, the project conducts both field and laboratory studies to increase the awareness of public safety requirements, conduct experiments that reflect the real environment in which public safety must operate, and quantify potential communications technology issues and identify solutions for those issues.

Figure 1. An ITS engineer participates in firefighter training exercises to better understand firefighter communication challenges and enable development of realistic experiments that can quantify firefighters' ability to communicate (photograph courtesy of Boise Fire Department).

Field Studies

The field studies conducted by the project are essential to understand the environments in which public safety practitioners must operate (Figure 1). To date, field measurements and recordings have been made in a variety of public safety vehicles, and at several fire scenes to provide information specific to noises encountered by the fire service. These field studies provide information on radio usage, operational environment, and common practices of public safety personnel. Typically, these field studies involve two types of recordings. The first is recordings of overall operation that help increase understanding and comprehension of public safety operational requirements. The second is high-quality digital recordings of specific environmental noises that can be shared with the community and also used in laboratory experiments.

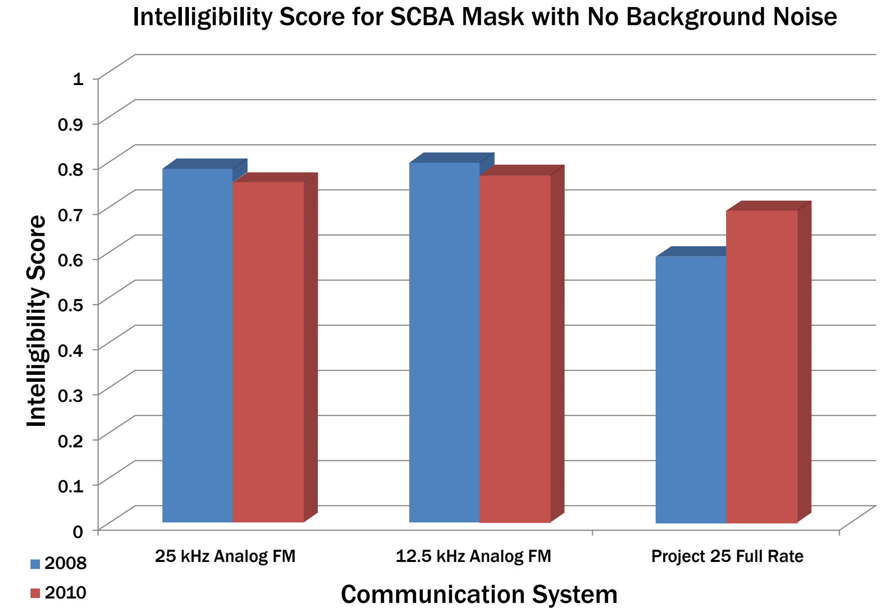

Figure 2. This chart shows a comparison of similar systems' intelligibility scores in the 2008 test and the 2010 test. The analog FM systems showed consistent results and the Project 25 (Digital) system showed a noticeable improvement in intelligibility.

Laboratory Research

The high-quality digital recordings are used to reproduce real-life sound levels inside a sound attenuated chamber which contains an ITU-Standard Head and Torso Simulator (HATS). The HATS has a calibrated speaker representing the mouth and a calibrated microphone representing each ear. With these, the HATS can be used to simulate a conversation in any noise environment for which a recording exists. Using a pair of these chambers containing HATS enables both halves of a conversation to be simulated and recorded for later analysis or playback to a subjective listener panel.

In a previous subjective experiment, a variety of fire-specific noises were mixed with audio to perform an intelligibility test. The noises included sounds such as a chainsaw, a fire-hose fog nozzle, a low air alarm from breathing apparatus, and a personal alert safety system (PASS) alarm. The experiment compared the intelligibility of digital and analog radio communication systems in the presence of such noises. Results were published in an NTIA Technical Report[1] and companion recommendations published by the International Association of Fire Chiefs (IAFC).[2]

Audio Performance Working Group

Based on that test, the Project 25 standards committee created the Audio Performance Working Group (APWG) to further quantify these issues. The APWG is looking at the issue as a systems issue where making many small improvements throughout the system can improve the quality at the output. To further this work, the APWG initiated a series of tests in FY 2010 with the following goals in mind:

- Test the impact of the IAFC recommendations to see how they improve the audio performance.
- Evaluate software updates to the vocoder.
- Incorporate radio channel impairments to help understand the compounding effect that multiple impairments will have on communications.
- Use reference implementations of the radio systems to provide a baseline performance that can be applied across manufacturers.

This testing brings together support from industry, state and local public safety agencies, and the federal government to help address these challenges. Initial results show that there has been progress in addressing the challenges of communicating in high levels of background noise (Figure 2), but that there is still work to do.

Future Work

In FY 2011 the project will conclude this series of tests and publish results that will enable the identification of strategies and technologies to improve the intelligibility of digital radio systems in the presence of loud background noises. The work will continue to involve the IAFC and the Project 25 communities.

1. *D. Atkinson and A. Catellier, "Intelligibility of selected radio systems in the presence of fireground noise: test plan and results," NTIA Technical Report TR-08-453, June 2008. http://www.its.bldrdoc.gov/pub/ntia-rpt/08-453/*
2. *IAFC Digital Problem Working Group, "Interim report and recommendations: Fireground noise and digital radio transmissions," International Association of Fire Chiefs, June, 2008. http://www.iafc.org/digitalproject/*

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Public Safety Interoperability Test Tools

Outputs

- *An ISSI reference implementation*
- *Software capable of conformance and performance testing the ISSI protocol*
- *Software capable of performance testing the CSSI protocol*
- *Testing the ISSI*

Overview

The Project 25 (P25) suite of standards was developed to promote interoperability of land mobile radio (LMR) equipment and systems among different levels of government and different vendors. Of the eight P25 interfaces, Congress considers completing the Inter-RF Sub-System Interface (ISSI) standard to be a top priority.

Essentially, ISSI is a network protocol that operates over standard network interface cards (NIC). This interface is intended to be included in future deployments of P25 Radio Frequency Sub-Systems (RFSS) so that the ISSIs of different RFSSs can be inter-connected using various media (e.g., Ethernet).When the ISSIs of various RFSSs are interconnected, IP packets containing IMBE™ encoded voice can be transmitted and received.

Completing the ISSI is considered important to public safety agencies because it promotes interoperability between equipment from different RFSS manufacturers, allowing consumers to implement P25 communications networks even if purchasing from multiple vendors. This will foster competition among RFSS manufacturers and lower P25 infrastructure costs.

The ISSI conformance test document (TIA-102.CACC) was published in January 2009. These conformance tests help to verify that vendor implementations conform to what has been specified in the P25 ISSI Messages and Procedures for Voice Services (TIA-102.BACA) standard.

In order to objectively verify that a vendor's equipment conforms to TIA-102.BACA, ITS, in conjunction with NIST, has developed ISSI Test Tools (ITT) as a reference implementation of the ISSI protocol stack. Since ITT is implemented in Java, the software can be loaded on a regular desktop PC that has a Linux or Windows operating system on it. A single instance of ITT is capable of emulating one of four different roles in a P25 ISSI-based network:

- Calling serving RFSS
- Calling home RFSS
- Called home RFSS
- Called serving RFSS

Ideally, ITT will be placed in a test configuration, as defined in the conformance test document, which will fulfill one of the four roles, depending on the test case under consideration. The number of vendor RFSSs and roles may vary depending on the test case requirements. It is also possible, and more common, to test in isolation the ISSI of a single vendor RFSS. This is the preferred configuration when attempting to determine a particular vendor's conformance. This scenario implies that there is only one vendor RFSS with a real ISSI and the rest of the ISSI interfaces are emulated by ITT (Figure 1). The number of emulated ISSIs and the role of the emulated interfaces will vary depending on the conformance test case. Since ITT does not currently have the capability to emulate the P25 Common Air Interface (CAI), the behaviors of (or events generated by) CAI subscriber units are emulated in the ITT software.

From the ITT user interface, the user can select a conformance test case to execute. After the test case has completed execution, the user can then view the Session Initiation Protocol (SIP) and Real-time Transport Protocol (RTP) push-to-talk (PTT) messages that were exchanged between ISSIs in a graphical message sequence chart (MSC) (Figures 2 and 3). When the test case has finished executing, ITT will automatically declare either pass or fail.

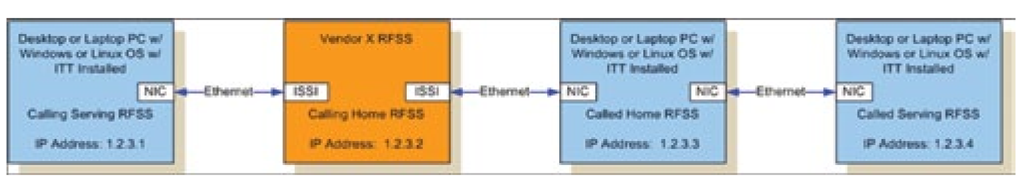

Figure 1: An example test architecture with three instances of ITT. IP addresses are for example purposes only.

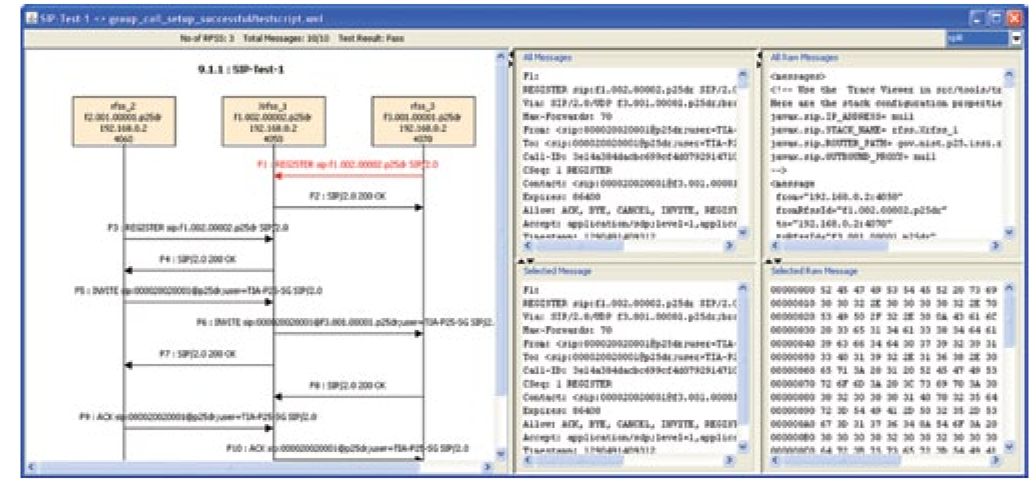

Figure 2: SIP MSC for Test Case 9.1.1 – Unconfirmed Group Call Successful

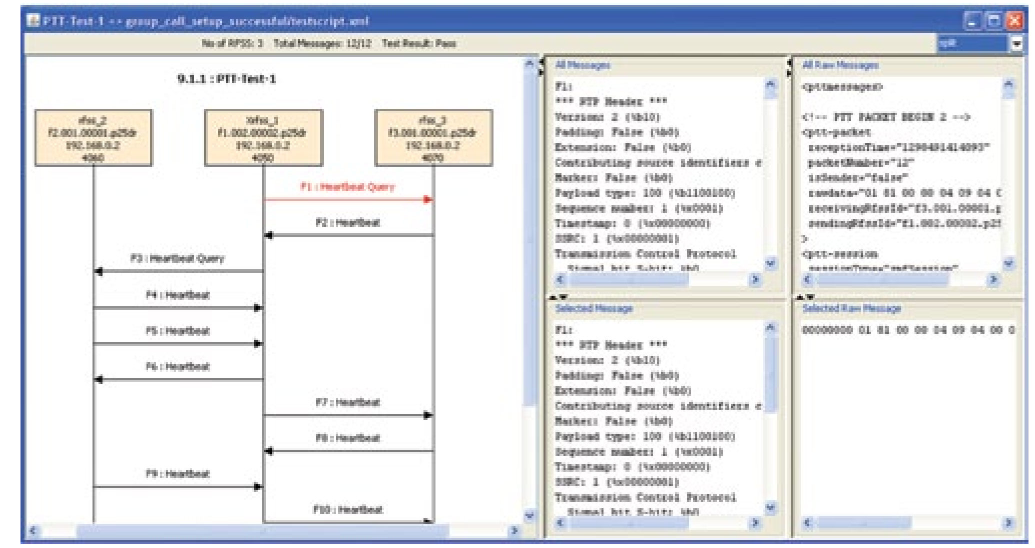

Figure 3: RTP PTT MSC for Test Case 9.1.1 – Unconfirmed Group Call Successful

Raw IP packet data can be rendered by clicking on the message of interest in the MSC. The ITT has a packet processing capability that will generate an MSC based on the packet capture (PCAP) data file that is fed in for processing. Wireshark is used in conjunction with ITT's packet processing capability to capture the messaging that occurs between all ISSIs (emulated or real) involved in a test and render the results in an easy-to-read MSC.

In 2010, the primary task for the ITT project was to complete conformance test case validation. The hardware configuration for this validation process required four PCs. The ITT software was installed on each PC. The validation process involved execution of the ITT test cases (close to 100 tests) to determine if the SIP and RTP messaging and message contents were implemented according to the ISSI specification. When errors in the software were found, bug reports were generated in the Issue Tracker database which is a component of the P25-wireline project on java.net. Software fixes for these reported bugs were implemented and included in Release 10 of the ITT software, released in mid-December 2010. To obtain the ITT software and to view the Issue Tracker database visit https://p25-wireline.dev.java.net/.

In 2011, this project will focus on the validation of ITT conformance test cases against commercial ISSI implementations. ✣

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Public Safety Broadband Demonstration Network

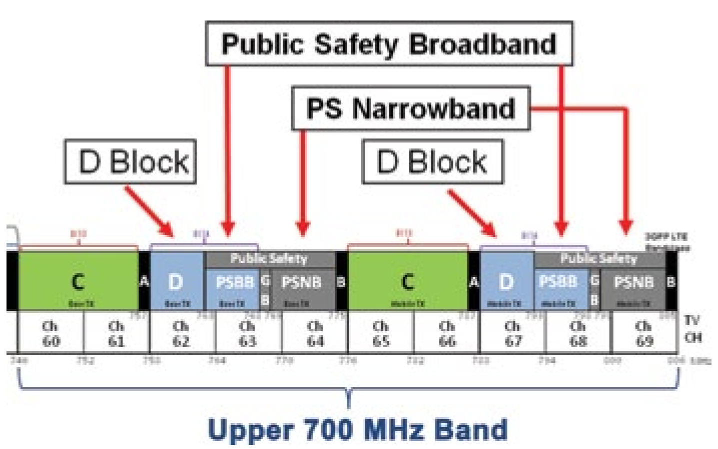
Outputs

- *Standards development contributions to 3rd Generation Partnership Project (3GPP)*
- *Technical contributions to public safety community regarding lessons learned*
- *Technical contributions to the FCC Emergency Response Interoperability Center (ERIC) and policy makers within the Executive Branch*

Overview

Stove-piped proprietary systems and non-contiguous spectrum assignments have long impeded effective cross agency/jurisdiction public safety land mobile radio (LMR) communications. To not have the same issues with new broadband technology for public safety, Congress made spectrum in the newly cleared 700 MHz frequency band available to public safety for a unified nationwide public safety broadband system. The Federal Communications Commission (FCC) and public safety leadership are working to develop baseline requirements for interoperability on this system. The Public Safety Communications Research (PSCR) program, a joint effort of the National Institute of Standards and Technology Office of Law Enforcement Standards and ITS, leads this effort, tailoring it to the unique operational and technical requirements specific to broadband communications for public safety.

The PSCR Broadband Demonstration Network, established in FY 2010, facilitates accelerated development of standards for emerging fourth-generation (4G) equipment. The Demonstration Network activities will support technical contributions to the 3rd Generation Partnership Project (3GPP, a collaboration among groups of telecommunications associations to make globally applicable cellular system specifications), the FCC Emergency Response Interoperability Center (ERIC, a center formed to specifically to address the needs of the 700 MHz public safety broadband wireless network), and other applicable standards organizations.



Public Safety 700 MHz spectrum allocation.

Public Safety Broadband Network Standard

Public safety and the FCC realized the need to identify a 4G wireless network operating standard to facilitate roaming and nationwide interoperability. Long Term Evolution (LTE) and Worldwide Interoperability for Microwave Access (WiMAX) broadband technologies are the two competing 4G standards deployed globally by the major cellular broadband vendors and carriers. LTE is part of the Global System for Mobile Communications (GSM) standards family and is supported by U.S. cellular telecommunications companies including AT&T and Verizon Wireless. WiMAX is supported by Clearwire in the U.S. Although the two standards are often considered comparable, some very unique differences do set them apart, including:

- LTE has greater technical flexibility. Public safety currently has a nationwide license in the 763 to 768 MHz and 793 to 798 MHz bands. This matched pair of spectrum is designed for Frequency Division Duplex (FDD) operations. Like traditional cellular systems, FDD has a separate bands for transmit and receive signals, which is supported by LTE. Most current WiMAX implementations use Time Division Duplex mode (TDD), which is not optimally suited for the current public safety spectrum allocation because the transmit and receive signals operate in the same contiguous block of spectrum.
- LTE specifically supports public safety's band class. The LTE standard has a defined band class (BC14) specifically for the U.S. public safety broadband spectrum allocation. WiMAX also has profiles by which frequency allocations are defined, but it does not currently have a profile for the U.S. public safety broadband spectrum allocation.
- LTE has broad market dominance. Globally, LTE is the overwhelming choice for mobile operators;[1] this offers public safety the opportunity to leverage the commercial innovation and cost efficiencies of adhering to the dominant worldwide commercial standard.

Public safety, through nearly all of its representative organizations, collectively made the choice for LTE as the public-safety favored technology standard. On June 9, 2009, both the Association of Public-Safety Communications Officials – International (APCO) and the National Emergency Number Association (NENA) endorsed LTE and urged all their organizations to join in the endorsement.[2] The National Public-Safety Telecommunications Council (NPSTC) officially endorsed LTE on July 1, 2009.[3] The FCC, in its Waiver Order,[4] also mandated LTE as the technology to be used in the public safety broadband spectrum assignments.

Goals of the Demonstration Network

Traditionally, LMR networks have been built by individual localities or on a statewide basis. Deploying new cellular technologies nationwide will be more complex and require an unprecedented level of coordination. National telecommunications companies maintain sophisticated test networks and dedicated laboratories to ensure that their selected vendor equipment meets their specifications and to identify interoperability issues prior to building their networks or adding new features, hardware, or software. Because there are currently no equivalent government or independent lab facilities in the U.S. to test and demonstrate public safety 700 MHz broadband networks and applications, the Public Safety Broadband Demonstration Network was established at the U.S. Department of Commerce (DOC) Boulder, Colorado, Laboratories to fulfill this function for the fragmented, resource-constrained community of public safety agencies. This over-the-air broadband demonstration network and laboratory, operating in the public safety broadband spectrum, leverages the expertise of the PSCR staff and the unique assets of the DOC Boulder Laboratories—specifically, the Table Mountain Radio Test Site and the Green Mountain Mesa site.

The Demonstration Network is made available through cooperative research and development agreements (CRADAs) for manufacturers and carriers to test the deployment of 700 MHz systems in a multi-vendor environment. It serves as an educational site for public safety by allowing interested agencies to observe these systems and execute public-safety specific test cases that are unique to their operational environment. The Demonstration Network's goals are to:

- Assess the defined open interfaces associated with LTE that will ensure interoperability for the public safety broadband system.
- Demonstrate broadband air-interface and core network capabilities to provide proof of concepts, improve quality of future systems, and create new technology and requirement benchmarks.
- Evaluate broadcast capabilities for wide-area simultaneous data delivery.
- Assess interoperability concepts with existing LMR, cellular, and broadband technology, leveraging several past PSCR projects.
- Explore roaming functionality with LTE and non-LTE systems, including how quality of service, billing, priority, pre-emption, and applications work when roaming.
- Validate key public safety functionalities and requirements, and gather public-safety specific information to influence the LTE standards process.

In FY 2011, the Public Safety Broadband Demonstration Network project will continue to conduct studies of LTE technology to drive the development of the nationwide, interoperable Public Safety Broadband Network. ❖

1. *http://www.networkworld.com/news/2010/060710-tech-argument-lte-wimax.html*
2. *APCO NENA press release, http://www.apco911.org/new/news/nena_endorse_lte.php*
3. *NPSTC June Meeting Minutes, page 16 with Doug Aiken motion to adopt LTE, http://www.npstc.org/meetings/009A-20100615 NPSTC June Meeting Minutes wAttendees.pdf*
4. *Federal Communications Commission, Requests for Waiver of Various Petitioners to Allow the Establishment of 700 MHz Interoperable Public Safety Wireless Broadband Networks, PS Docket No. 06-229, Order, 25 FCC Record 5145 (2010), pp. 5157 ff*

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Multimedia Quality Research

Outputs

- *Technical contributions to VQEG*
- *Technical contributions to ITU-T Study Group 9*
- *NTIA Technical Memorandum*

Overview

Distribution of audiovisual (multimedia) signals over wireless and wireline channels has increased exponentially in the last several years. Laptops, personal digital assistants (PDAs), and cell phones increasingly convey data using multimedia presentations. The digital technologies that transmit these audio and video signals occupy limited bandwidths, so the audiovisual compression often pushes the lower bounds of acceptable quality. To maintain their competitive edge, businesses in this rapidly growing market want objective quality measurements that are based on human perception.

ITS has a long history of successful research in the areas of speech quality and video quality assessment. The ITS Multimedia Quality Research project combines and extends these separate lines of research to characterize and analyze the fundamental aspects of multimedia quality assessment. This involves two simultaneous efforts: The first is to develop robust subjective methodology to measure audiovisual quality. This critical research need addresses the preliminary nature of existing ITU standards for measuring audiovisual quality. The second effort combines previously unrelated results of audio and video research into a single, cohesive audiovisual model. The vision is to develop a dependable algorithm that objectively predicts multimedia quality through a combination of audio quality, video quality, and audiovisual synchronization information.

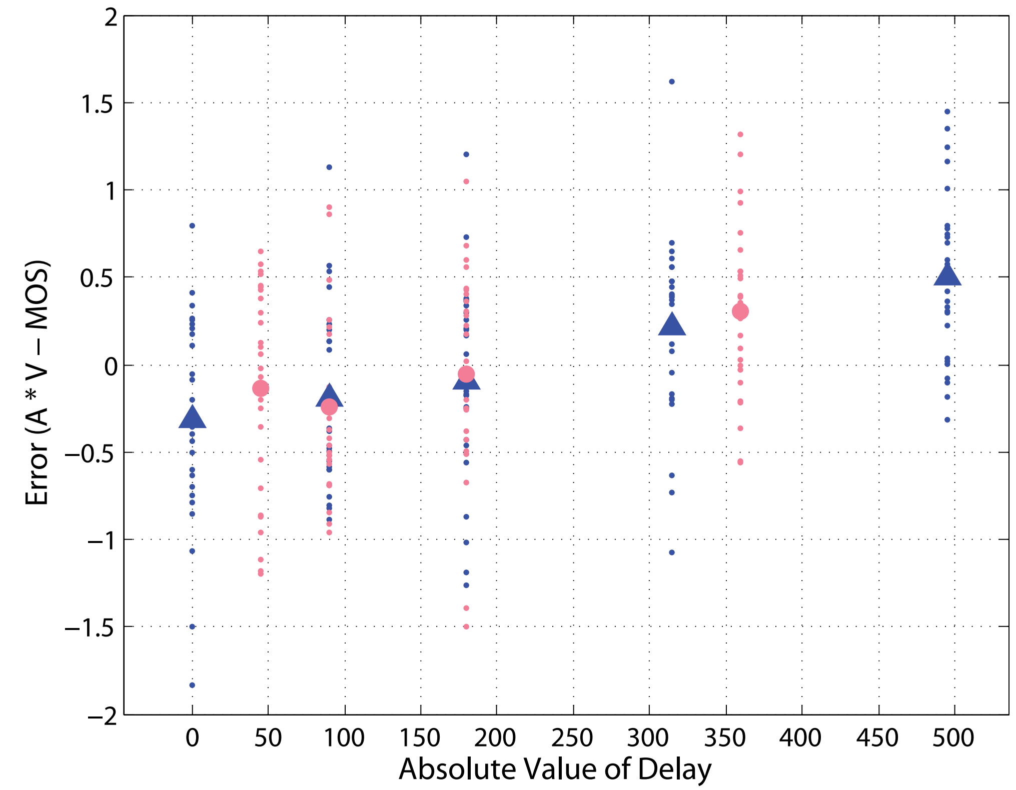
Research Experiments

In FY 2010, to advance these goals ITS produced an NTIA Technical Memorandum documenting a pair of related subjective experiments completed in FY 2009, completed two new subjective experiments, and began a third.

The NTIA Technical Memorandum studied the audiovisual quality of Internet video as a function of audio quality and video quality, measured both together and separately. The subjective data could be predicted rather well from the video Mean Opinion Scores (MOS) alone; however, this appeared to be a consequence of the wide quality range spanned by the video impairments in combination with the narrow quality range spanned by the audio impairments of the samples in the reviewed experiments.

Consequently, ITS conducted a further experiment, begun in FY 2009, to explore audiovisual quality of HDTV as a function of audio quality and video quality. This experiment included a carefully balanced range of audio and video impairments, with samples played on high quality speakers and televisions in a sound isolation booth. Results indicated that a generalized model consisting of a simple cross term (audio times video) can be justified. A journal article documenting this experiment and results from related studies by other laboratories will be published in FY 2011.

The second experiment built upon the first. Where previous experiments either examined audio quality and video quality (but not a-v sync), or studied a-v sync errors using broadcast quality audiovisual sequences, this experiment investigates a variety of audio-video synchronization impairments (a-v sync), as well as separate audio quality impairments and video quality impairments. Subjects observed multimedia samples containing combinations of these three separate impairments. Independent subjective measures of audio quality, video quality and a-v sync were combined in linear and non-linear models to predict multimedia quality. The accompanying figure shows the absolute value of delay plotted against the portion of the subjective data (MOS) that is not explained by a model containing audio (a) and video (v) terms. The important observation is that the quality drop is linear and symmetrical (i.e., audio leading video and audio lagging video were equally objectionable). This is in contrast to previous a-v sync experiments conducted on broadcast quality sequences, which showed asynchronous, non-linear drops in quality. This experiment is an initial foray into the complex quality interactions between source video sequence, coding quality, and a-v sync.



Absolute value of delay shifts plotted against the error remaining after predicted MOS using the multiplicative model $\hat{y} = 1.622 + 0.115\,(\boldsymbol{a} \times \boldsymbol{v})$. Positive delays are plotted in blue, with the mean plotted as a large blue triangle; and negative delays are plotted in pink, with the mean plotted as a pink circle.

The third experiment, in progress, investigates the effects of screen size on audiovisual quality from subjective measurements of audio quality, video quality, and audiovisual quality as delivered to various devices including a smartphone, netbook, laptop, and desktop computer. This experiment explores the implications of size and form factor to IPTV and video streaming over the Internet on audiovisual quality, while simultaneously investigating new techniques for multimedia subjective testing methodology.

This work is conducted in conjunction with projects underway in the Video Quality Experts Group (VQEG) and the ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). The JRG-MMQA is an official body of the ITU and is formed from members of ITU-T Study Groups 9 and 12. The Multimedia Quality Research Project presented experimental results to VQEG, and compared audiovisual experimentation techniques with other researchers to better advance state-of-the-art techniques in subjective testing.

In FY 2011, the Multimedia Quality Research project will continue conducting subjective experiments to advance audiovisual subjective test methodology and develop multimedia quality assessment models. New work will begin by exploring 3DTV subjective testing methodologies.

Recent Publications

Mark A. McFarland, Margaret Pinson, Carolyn Ford, Arthur Webster, William Ingram, Scott Haines, Kelsey Anderson, "Relating audio and video quality using CIF video," NTIA Technical Memorandum TM-10-472, Sept. 2010. ❖

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Wireless Network Measurement Methods

Outputs

- *Investigations into MIMO mechanisms*
- *Software-defined radio test instrument technologies*

Overview

In the cellular technology industry, Cooper's Law states that total wireless capacity within a given geographical area doubles every 30 months. This has held true since the earliest radio broadcasts by Marconi at the turn of the twentieth century. Continuously increasing capacity has been enabled by increasing perfection of Digital radio techniques used in broadband high-speed radio data systems. However, current systems are approaching the theoretical Shannon limit for information capacity within a given spectral bandwidth. The use of multiple input, multiple output (MIMO) techniques to carry more than one information stream over the same spectral allocation is a new tool in the telecommunications arsenal for continuing to expand capacity.

The underlying concept is that both the transmitter and receiver use multiple antennas. Each transmitting antenna sends out a radio signal at the same frequency and modulation type, but each carries a unique portion of the data to be transmitted. The receiving system senses the differences in the radio path taken by each signal and extracts the individual information streams from the slightly different aggregate signals intercepted by each receiving antenna. The signal is resolved into its component parts through post-processing techniques.

Investigations of MIMO Mechanisms

Modern radio network technologies like Wi-Fi, WiMAX, and LTE (Long Term Evolution) all embody a notion of spatial multiplexing—MIMO—in their highest speed incarnations. MIMO exploits the gain and phase differences between radio channels that are spatially separated by either polarization or location. Separate information streams are sent by spatially-separated transmitting antennas using the same spectral band. Each receiving antenna receives a weighted-vector sum comprising all of the encoded streams, and is able to resolve a single stream through knowledge of the properties of the radio channel that carried it. In the perfect case of uncorrelated radio channels, significant gains in the information carrying capacity of the wireless system can be achieved.

To achieve the potential spectral efficiency gains of MIMO, the presence of multiple uncorrelated radio channels is required. However, this requirement implies different conditions for optimal usage, depending on whether the differences in the radio channels are caused by different transmitting antenna polarizations or by location separation of similarly polarized antennas. In the former case, the signals are decorrelated through the initial launch conditions at the transmitting antenna, so minimal environmental effects are optimum to maintain the initial channel decorrelation.

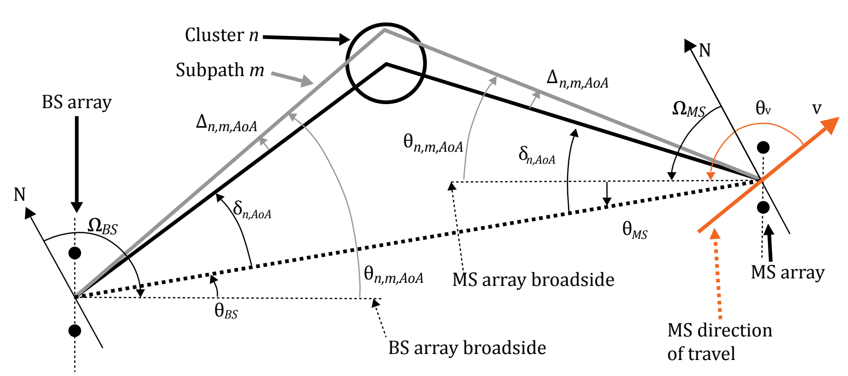

Figure 1. Multipath environments give rise to different angles of arrival.

In the case of physically separated transmitting antennas, variations in the physical path between each transmitting and receiving antenna allow the properties of those pathways to be individually resolved so that each individual information stream can be extracted from the aggregate sum intercepted by each receiving antenna. Some idea of the complexity of the transmission path of the radio signal can be seen in Figure 1, where the multiple contributions resulting from signals at different angles of arrival are graphically identified.

In the case of LTE, another effect is also used to enhance signal reception. The decorrelation of spatially separated channels requires more stringent propagation conditions than those found over the entire cellular transmission area. When the conditions for spatial multiplexing are not met, the LTE base station can fall back into a spatial diversity mode. The data is no longer separated into unique streams, but the same signal is transmitted from all of the transmitting antennas. The receiving system decides at each instant which polarization represents the best signal (in the case of polarization diversity), or which weighted combination from multiply located receiving antennas leads to the best reception (in the case of location diversity). Although the multiplicative factors of spatial multiplexing are not realized, diversity mode does increase throughput in poor signal-to-noise conditions by allowing the use of higher complexity modulations and reduced error correction mechanisms.

Application of both techniques requires knowledge of the antenna properties as well as the radio channel characteristics within the operational area. The Wireless Network Measurements Project has measured prototypical MIMO antennas inside an anechoic chamber using standard vector network analyzer techniques and is also investigating the use of high-speed time domain methods to resolve the impulse response of the antenna systems under test. Figure 2 is a photograph of one such measurement being performed. Another area of research involves finding ways to resolve the transfer matrix of the radio channel from radiated testing. This requires the use of specialized MIMO drive test tools capable of resolving the individual signals received by at least two antennas at the same instant. Signal processing algorithms are being tested to develop methods of determining the channel transfer matrix from measured radiated signals.

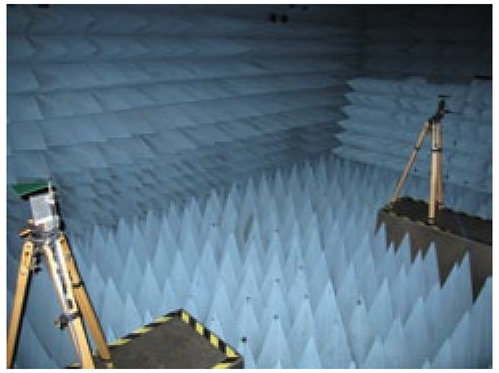

Figure 2. Polarization testing in an anechoic chamber (photograph courtesy of Jordan Riggs).

SDR Test Instrument Technologies

Through paper studies and simulations, as well as the creation of a software-defined radio (SDR) channel sounder, this project is investigating the properties of MIMO in multiple propagation environments. The primary metric of interest is radio channel correlation, and it is difficult to measure this parameter. Using relatively inexpensive SDR-based tools, a radio-channel sounder with a bandwidth of 25 MHz was created to determine the characteristics of radio channels in multiple propagation environments. The current design operates in the 2.4 GHz spectral region, and produces a pseudorandom number (PN) sequence encoded binary phase shift keyed (BPSK) signal that can be used to probe the radio channel. The special correlation properties of the PN sequence allow this signal to represent a synthetic impulse, yielding information about the transfer function, or impulse response, of the radio channel.

Currently, ITS is testing this SDR system in outdoor environments to determine its ability to resolve various types of scatterers. It will later be transitioned to a 700 MHz channel sounder as experimental spectrum becomes available. This device and another measurement system, based on the properties of real-time spectrum analyzers (RTSA), will be used to investigate the channel correlation characteristics of various propagation environments, including radio channels that are decorrelated through cross polarization. In this way, the strengths and weaknesses of MIMO processing can be evaluated to allow informed decisions about its use in Federal high-speed wireless data systems. ❖

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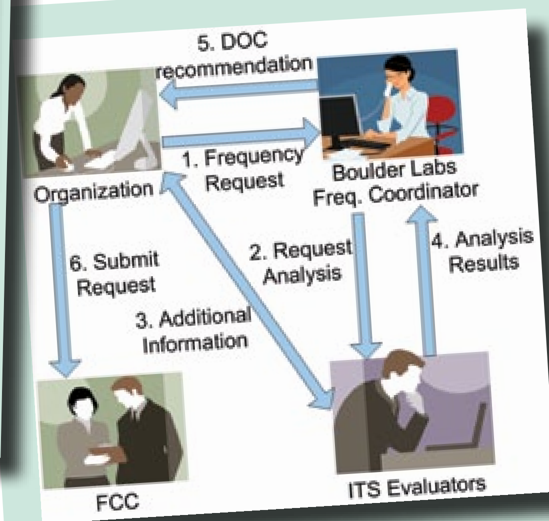
Domestic and International Standards Support



Area Federal Frequency Management

Distributed Computing Center

Equal Employment Opportunity Counselor

Activities within the Telecommunications Engineering, Analysis, and Modeling Division extend beyond the usual lab- and field-based measurement, modeling and research activities. These include support for U.S. involvement in domestic and international standards development organizations, regional frequency coordination of federal telecommunications users, management and support of institute-shared high-end computing systems, and involvement with human resource services, including the Equal Employment Opportunity (EEO) panel and the Editorial Review Board (ERB), among others.

Telecommunications Engineering, Analysis, and Modeling

The Telecommunications Engineering, Analysis, and Modeling Division conducts studies in these three areas for wireless and wireless-wireline hybrid applications. Engineering encompasses technical assessment of telecommunications systems, their components, and their performance, including the impact of access; interoperability; timing and synchronization; and susceptibility to noise, jamming, and interfering signals on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial operational environments. Analysis is often performed in association with the TA Services project, which offers custom analytical tools via an online cooperative research and development agreement (CRADA). Propagation prediction models are being incorporated into GIS formats and Web-based access. Modeling is one of ITS's core strengths enabling contributions to international and national standards bodies. Propagation models are used in conjunction with terrain databases and other data, like population. Adaptations of historic models, and application-specific models, have been developed, enhanced, and compared. Unique propagation models are developed for specific applications to meet sponsor requirements.

Engineering

Interference Issues Affecting Land-Mobile Systems: ITS participates in ATIS subcommittee WTSC-RAN (Wireless Technologies and Systems Committee—Radio Access Networks) and in ITU-R WP 5D. ITS developed PCS interference models for CDMA and W-CDMA. The project is funded by NTIA.

Public Safety Video Quality (PSVQ): The PSVQ project conducts subjective tests on video compression and artifacts that are shown to expert viewers. From these data, NTIA/ITS has made recommendations for video standard Rec. ITU-T P.912. Also, ITS leads yearly VQiPS workshops. This project is funded by NIST/OLES.

Fading Characteristics Verification: ITS participates in many aspects of public safety communications. This project is investigating whether the fading experienced with public safety communications can be modeled using Rayleigh fading. This project is funded by NIST/OLES.

Analysis

Telecommunications Analysis Services: ITS provides network-based access to research results, models, and databases supporting wireless system design and evaluation. These services are available to government and non-government customers and are funded through an online CRADA.

Propagation Modeling Website: The Institute continues to develop a suite of GIS-based applications for propagation modeling and performance prediction. This powerful GIS format complements ITS's propagation prediction capabilities. The work is funded by the U.S. Department of Defense.

HF Antenna Collocation Study: In work funded by the U.S. Army, ITS performed complex, iterative communication systems analyses using propagation and antenna models to demonstrate performance of a unique proposed layout of two collocated antennae that would allow two simultaneous HF links without interference.

Modeling

Broadband Wireless Standards: ITS develops radio propagation algorithms and methods to improve wireless system spectrum usage. ITS prepares technical contributions supporting U.S. interests in 3G broadband wireless systems for ITU-R Study Group 3, WPs 3J, 3K, 3L, 3M. ITS is active in path-specific model development for WP 3K and its development of ITU-R Recommendation P.1812. Work is funded by NTIA.

Short-Range Mobile-to-Mobile Propagation Model Development and Measurements: ITS is developing a model for short-range (1 m to 2 km) propagation between mobile radios. The propagation work consists of propagation model development and field measurements. This project is funded by NTIA/OSM.

Ultra-low Antenna Height Modeling and Close-in Distance and Measurements: ITS is developing a model for ultra-low antenna heights and close-in distances. This work consists of extensive field measurements in a project funded by the U.S. Naval Research Lab. ❖

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Interference Issues Affecting Land Mobile Systems

Outputs

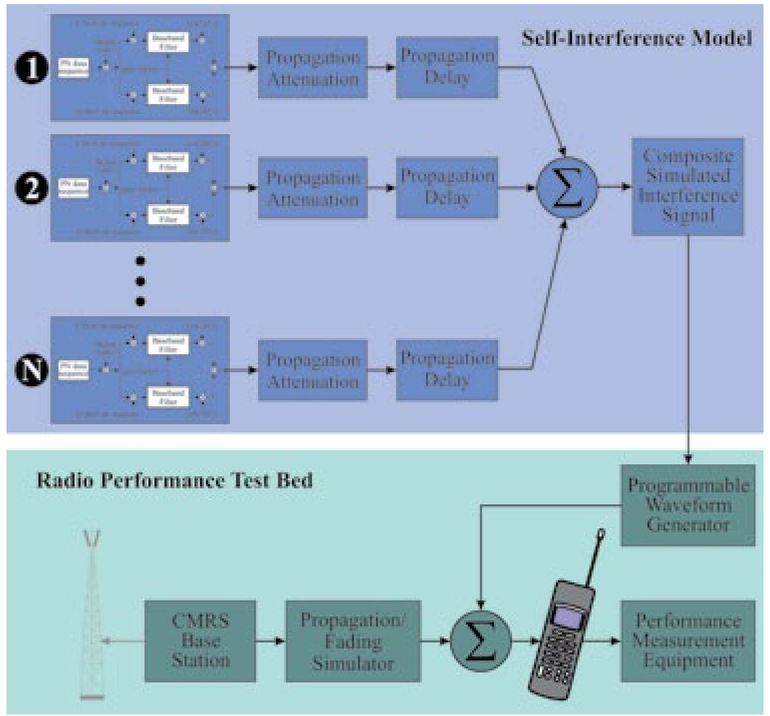
- *Self-interference model for evaluating CMRS technologies and deployment of adjacent-channel systems*
- *NTIA Report describing ITS's self-interference model and its development*
- *Technical contributions to industry-supported efforts for predicting, identifying, and mitigating interference-related problems*
- *Technical support for international and national standards development organizations*

Overview

While the U. S. Government is committed to identifying and freeing up large amounts of additional spectrum to support the development and deployment of next-generation commercial communication systems, throughput demands from commercial and government users will always outpace availability as newer technologies are developed. In addition, the increasing telecommunication needs of civil and Federal users (such as emergency responders) impose their own unique spectrum requirements. Globally, attempts to implement true universal coverage (worldwide roaming) place different demands on spectrum allocations depending on the locations of users and providers.

Interference Issues

Until advanced dedicated communication systems for emergency services are deployed, Commercial Mobile Radio Services (CMRS) will continue to be used for back-up emergency communications. As a result, wired and wireless communication services will experience elevated usage rates during emergency situations. This sudden influx of traffic by private, commercial, civil, and Federal users will result in system overloads, a decrease in signal quality, and further disruption of service in affected areas. Beyond the physical damage caused by destructive events, additional factors such as co-channel and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area will further reduce wireless network channel capacity. One way of coping with degraded infrastructure is to deploy temporary equipment to supplement surviving systems. National security/emergency preparedness (NS/EP) planners and network operators need to have knowledge of interference issues, system dynamics, and load patterns to efficiently and effectively deploy supplemental equipment in an overloaded environment.



Example of how the output of the self-interference model can be used in the evaluation of radio receiver performance in a simulated propagation environment.

Spread-spectrum technologies, which make efficient use of allocated spectrum and are relatively unaffected by noise, are used in current and next-generation cellular systems, but suffer from limitations due to issues such as co-channel interference. Work in detecting, identifying, and mitigating co-channel interference in congested environments requires tools that can characterize the interference experienced by these systems.

Interference Model for Spread Spectrum Technologies

To support this work, ITS developed an interference model for two code division multiple access (CDMA) based systems: the TIA/EIA95B standard and W-CDMA (wideband CDMA). This interference model is described in NTIA Report 10-467, "A co-channel interference model for spread spectrum technologies," published in FY 2010. The model produces representations of instantaneous air-interface signals containing outputs of multiple base stations with variable numbers of mobile users for each base station and includes both forward- and reverse-link processes.

The model calculates each channel's sampled quadrature phase shift keying (QPSK) or offset quadrature phase shift keying (OQPSK) signal contribution separately, including the power level as a gain factor of the baseband filter, then sums all signals identified in a specified scenario together to form a composite output signal. Software- and hardware-based simulations can use the sampled signal produced by the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference modes and can help solve existing congestion problems and anticipate potential problems.

In addition to interference issues, manufacturers and service providers need a better understanding of air-interface propagation characteristics in complex, congested urban environments. In environments with many obstructions, such as buildings or terrain, wireless systems often encounter diffraction effects, where wireless signals experience signal loss even when the signal is not completely blocked. Several diffraction models exist that calculate the power loss in such situations, each model having strengths and limitations. To help improve the accuracy of propagation calculations, ITS is making a comparative analysis of individual diffraction models to determine the best model for a given situation.

Standards Development

ITS provides propagation and interference expertise to the commercial sector through its participation in national and international standards development organizations. ITS contributed to the understanding of inter-system interference in personal communications services (PCS) by participating in the development of the Telecommunication Industry Association's (TIA) Technical Service Bulletin "Licensed Band PCS Interference" (TSB-84A). This handbook was a first step in addressing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of this work, coverage of interference issues concerning all mobile communication systems has been adopted by the Alliance for Telecommunications Industry Solutions (ATIS) sub-committee WTSC-RAN (Wireless Technologies and Systems Committee – Radio Access Networks). Work on the successor to TSB-84A is currently underway as Issue P0017, "Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems." ITS continues its involvement in this activity as issue champion and editor.

The International Telecommunication Union – Radiocommunication Sector (ITU-R) is the lead organization in the effort to coordinate worldwide development of future telecommunication systems and spectrum allocations. ITU-R Working Party 5D (WP5D) is developing standards for the group of future technologies referred to as IMT-2000 and IMT-Advanced. Coordinating world-wide frequency allocations is a near-impossible task, given the disparity in the historical evolution of frequency use and requirements in each country. Interference and coexistence issues are a primary concern as more systems try to use the same limited quantity of spectrum on a worldwide basis. To advance this work, ITS supplies technical support as a member of the U.S. delegation to WP5D. ❖

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Public Safety Video Quality (PSVQ)

Outputs:

- *A User's Guide to help public safety agencies specify video equipment*
- *Technical contributions to standard bodies to establish video quality measurements and standards for the public safety community*
- *Technical contributions on video quality standards to the sponsor*

Overview

Police and fire agencies often purchase radios, cameras and other communications equipment based on just their local needs. Unfortunately, this equipment may not always be of sufficiently high quality for use in certain applications, nor standardized enough to enable agencies to communicate with other agencies. This is because, until recently, there were no technical standards for emergency communications equipment. To improve communications for public safety agencies, ITS is conducting audio- and video-quality research to determine standard parameters for levels of quality of communication systems based on the specific needs of public safety practitioners and their applications. The PSVQ project is working on behalf of the Department of Homeland Security (DHS) and the Department of Commerce's Public Safety Communications Research (PSCR) program to ensure that first-responder video systems communicate clearly and accurately with each other.

VQiPS Working Group

To address this need, the PSVQ project formed the Video Quality in Public Safety (VQiPS) Working Group (WG) under DHS in 2009. The purpose of the WG is to provide the public safety community with the knowledge they need to purchase and employ the most appropriate video systems for their requirements, and to collectively communicate public safety practitioners' needs to industry and standards-making bodies.

The WG's main initiatives are:

- Development of a set of application-independent usage scenarios, or generalized use classes (GUC)
- Development of a User's Guide to help public safety agencies perform the following:
  - Assess their video needs
  - Match their needs to technical performance specifications and standards to support procurement
- Development of glossary of common terms
- Compilation of an inventory of existing standards and specifications that address various components of the video system for specific GUCs
- Development of a common library of test clips that represent GUCs

The User Guide is the central framework for containing and disseminating the work of the other three initiatives, and for any performance specifications developed by PSVQ in the future. Its purpose is to assemble in a single repository, as they are developed, all technical guidelines for use in video system design and specification that achieve the desired system usage across multiple disciplines. The User Guide will inform policy makers and procurement officials who are engaged in the selection of video systems. The desired usage across disciplines will drive applicable technical requirements. These requirements will facilitate the preparation of video system specifications for the public safety end user.

VQiPS Workshop

In February 2010, PSVQ hosted the third VQiPS workshop. The workshop's goal was to bring all users of video in the public safety community together to continue progress on the VQiPS WG initiatives. A wide range of participants attended, including local, state, and Federal representatives from a variety of disciplines such as law enforcement, fire services, and Emergency Medical Services (EMS); representatives from non-profit research organizations and academic institutions; and industry leaders. Ultimately, the VQiPS series of workshops will help to coordinate efforts in establishing quality requirements for video used in public safety applications.

Phase 1 of the VQiPS User's Guide was published in July 2010, and VQiPS will continue as an annual workshop to address the WG initiatives on an ongoing basis.

A still image from footage used to study the effects of compression on the ability to read license plates

Network Performance Specification Testing

In support of the VQiPS User's Guide, PSVQ performed a study to determine network performance specifications that apply to a subset of the VQiPS GUCs. The study investigated how the interaction of several aspects of a video scene (object size, scene motion, and scene lighting) and network conditions (resolution and bitrate) affects the ability of a practitioner to recognize an object within a scene. The test report contains a set of recommendations for H.264 compression and video resolution specifications, for several VQiPS GUCs. These recommendations will be incorporated into subsequent versions of the VQiPS User's Guide.

Websites for Additional Information

- PSVQ Web site: http://www.pscr.gov/projects/video_quality/video_about.php
- PSCR VQiPS Web site: http://www.pscr.gov/projects/video_quality/vqips/vqips.php
- SAFECOM VQiPS Web site, with publications: http://www.safecomprogram.gov/SAFECOM/currentprojects/videoquality/videoquality.htm ❖

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Fading Characteristics Verification

Outputs

- *Fading characteristics of the land mobile radio channel at 162 and 793 MHz*
- *Technical contributions to public safety standards bodies*

Overview

Land mobile radio (LMR) systems are used primarily by public safety organizations in mobile environments where dynamic path loss, multipath fading, noise, and interference can greatly affect communications. As public safety communications systems obtain higher spectral efficiency and more high-speed data applications, the properties of the communications medium become more significant, requiring a better understanding of the channel fading characteristics. The fading characteristics verification project helps ensure that services, such as public safety video, are able to maintain operational continuity in mobile environments.

Project Challenges

At any given instant in time, the radio channel can be characterized by a complex number, consisting of a magnitude and a phase. The magnitude indicates the instantaneous radio-channel attenuation or gain, and the phase indicates the instantaneous channel-transfer function phase. Generally, the magnitude value, or the fading loss, has been of primary interest because it decreases the signal-to-noise ratio (SNR) at the radio receiver. Since this is typically represented as a slow-varying function (over time regimes of tens or hundreds of milliseconds for land mobile radio), relatively simple measures like automatic gain control (AGC) can be used to mitigate such impairments. The probability distribution of signal attenuation, or fast fading, is typically modeled as a Rayleigh or Rician distribution dependent on the presence of a direct ray. The Rayleigh fading model has been the most widely used model for testing Project 25 radios. The Rayleigh model is considered to represent the worst-case condition because it does not contain a line-of-sight component.

With the advent of higher speed systems with short symbol times relative to the carrier, the channel phase is becoming more important. The phase variation of the channel is not well-studied, since empirical data about channel phase is not widely available. Analytical results about channel phase correlation based on Rayleigh's assumptions are available, but these results need to be compared to real environments. The significance of the radio channel's phase distribution is an important area of research made more significant by the widespread use of high-speed digital modulations. If the radio channel is imparting rapid-phase variations, in time regimes similar to a symbol period, these will manifest as bit errors in the decoded signal.

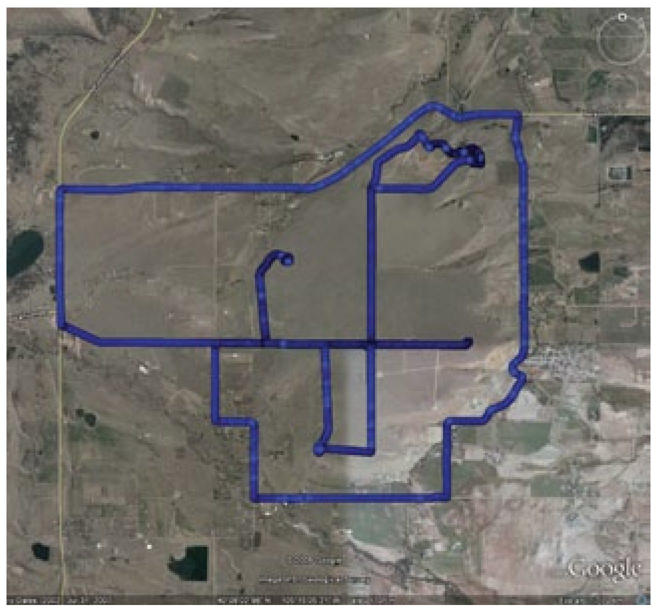

Figure 1. Satellite image showing the route taken during fading measurements in a rural environment (map data © 2009 Google, imagery U.S. Geological Survey).

Measurements

To provide different fading conditions that are relevant to public safety, measurements were conducted in rural, residential and low-rise urban environments at both 162 and 793 MHz frequencies. The rural environment was at Table Mountain (see Figure 1), the residential environment was located in south Boulder and the low rise urban in downtown Boulder. In addition, a fading channel simulator was used to gather simulated data for comparison purposes.

The measurement system, diagrammed in Figure 2, consisted of a transmitter placed at a static location and a mobile receiver, which simulated a LMR base station and mobile subscriber scenario. The transmitter was configured to transmit a 400 ms continuous-wave (CW) signal once per second on one-second boundaries. The receiver was synchronized with the transmitter via the Global Positioning System (GPS) unit to allow the 400 ms transmitted signal to be acquired once per second on the same one-second boundaries. Latitude and longitude data was logged separately via a laptop computer from the GPS receiver.

Measurements were performed at speeds between 8 and 100 km/h (i.e., walking and vehicular speeds). The resultant data will be analyzed to determine how closely the measurements align with multiple fading distribution models such as Rayleigh, Rician and Nakagami-m distributions as shown in Figure 3. The results of this effort will be presented to the Project 25 standards bodies as well as other appropriate venues. ❖

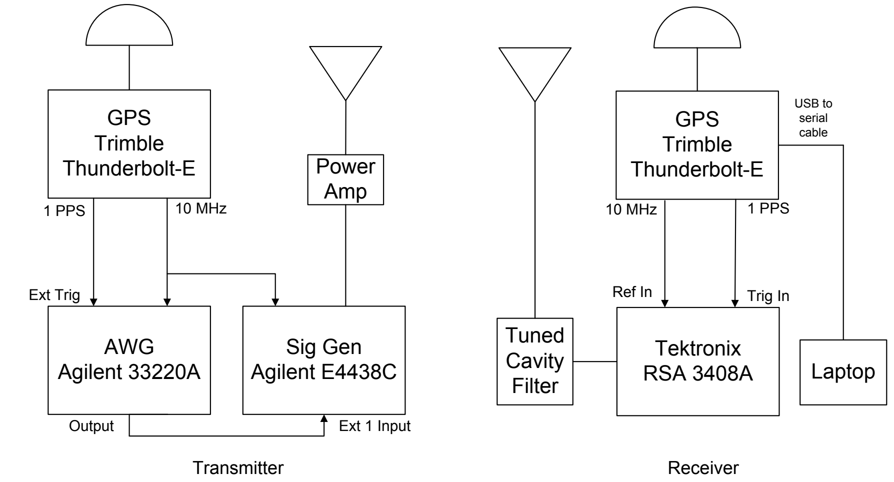

Figure 2. A diagram of the mobile measurement system used to gather fading measurement data.

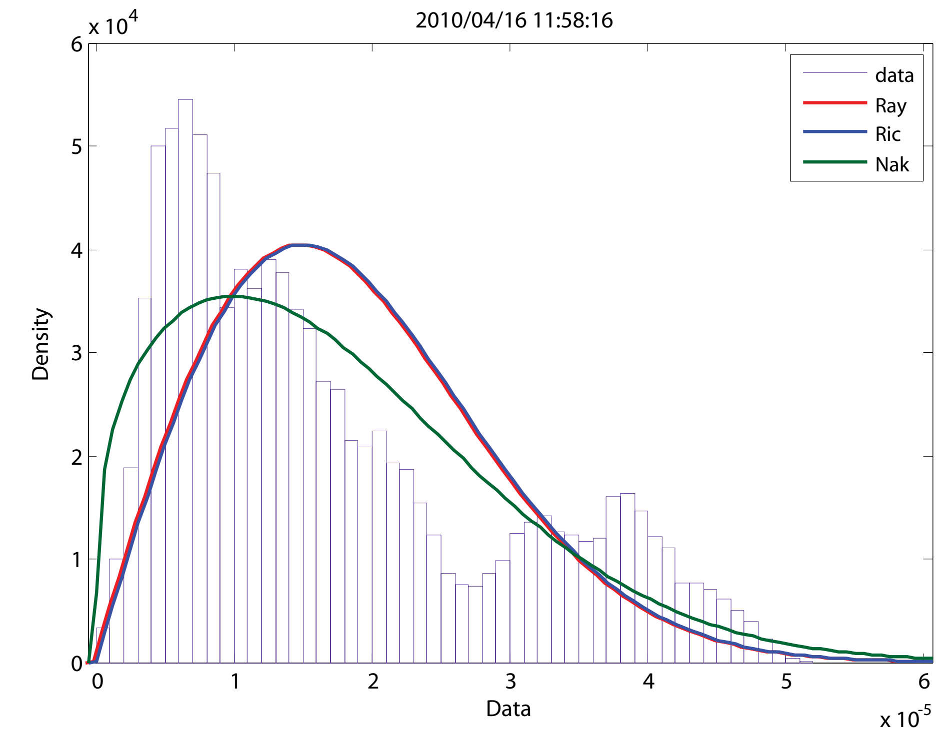

Figure 3. This graph is an example of the analysis of one set of measurements to show alignment of actual data with different fading distribution models.

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Telecommunications Analysis Services

Outputs

- *Internet access on a cost-reimbursable basis linking U.S. industry and Government agencies to the latest ITS engineering models and databases*
- *Contributions to the design and evaluation of broadcast, mobile, and 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*
- *Online cooperative research and development agreements (CRADAs) that allow users to task ITS to develop special models or perform special analysis tasks*

Overview

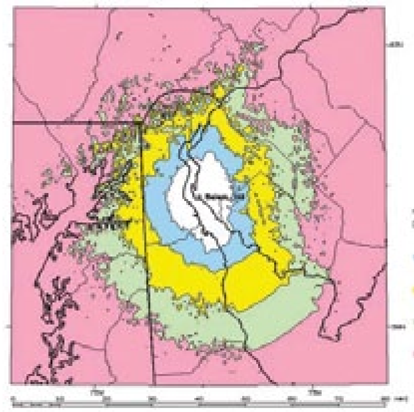
The Telecommunications Analysis Services (TA Services) program provides industry and Government agencies with access to the latest ITS research and engineering outputs on a cost-reimbursable basis. Services are provided through a series of computer programs designed for non-technical users with minimal 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.

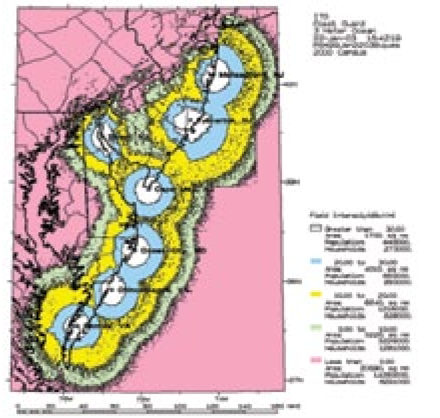
TA Services also allows users to work closely with ITS engineering staff to customize research and development models and their respective programs via the online cooperative research and development agreement (CRADA). Users can create tasks for a cost of up to $25,000 per CRADA. Through the TA Services Web site, new CRADAs can be quickly created as needed.

Available Models and Databases

Currently, TA Services provides access to many databases and services including 1-arc-second (30m) and 3-arc-second (90m) terrain data for the U.S. and world-wide GLOBE (Global Land One-km Base Elevation) terrain data, the U.S. Census data for 2000 and 1990, Federal Communications Commission (FCC) databases, and geographic information systems (GIS) databases from the Environmental Systems Research Institute (ESRI). Over the past 20 years, TA Services has developed both general-use propagation models for broad application across various frequency bands and application-specific models used for a particular type of analysis such as high definition television (HDTV). Customers with active accounts can use these models are placed through the TA Services Web-access system. Users can select models, enter information about their broadcast equipment, and produce transmitter coverage diagrams for an application.

These coverage maps follow FCC guidelines and requirements for Grade A and Grade B coverage showing both the signal coverage and the population that resides within the various analysis contours as specified by the user.





Left: Figure 1. Sample output of the CSPM model of a broadcast transmitter in New Jersey.

Right: Figure 2. Composite coverage of several Coast Guard stations located along the East Coast.

Specifically, TA Services offers raster-based population maps that support more accurate population calculations than vector-based maps. TA Services also maintains a catalog of FCC recorded television stations and advanced television stations from which data for these analyses can be drawn. Users can also combine individual transmitter coverage data into a composite coverage map. This allows the user to determine both single transmitter performance and integrated system performance with accurate population calculations.

Notable Projects

Public Broadcasting Service (PBS)

TA Services has assisted the U.S. Public Broadcasting Service (PBS) with the transition to digital television (DTV) by providing an application-specific model for use in advanced television analysis. This model allows users to create scenarios of desired and undesired station mixes. For example, a DTV broadcast station can run an interference application with other nearby DTV stations, as shown in Figure 1.

The results of these studies show those areas with new interference, and the population and number of households within those areas, so that designers can mitigate possible situations before they become a problem. The model can also determine how much a selected station's interference is affecting other stations. This allows engineers to make modifications and then determine the effect those modifications have on the interference emissions that affect other surrounding stations. In addition to creating graphical plots of signal levels, the program creates tabular output that shows the distance and bearing from the selected station to each potential interfering station as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

National Weather Service (NWS)

TA Services has also assisted the National Weather Service (NWS) in determining their system coverage and public outreach. The NWS is a major public service provider required to ensure that more than 95% of all Americans have access to potentially life-saving information in the event of a national emergency. Figure 2 shows an example of an NWS system coverage map. With the use of the TA Services system and databases, this national alert system was able to improve and verify the coverage of their large, diverse system, using the most recent Census information. Plans include the addition of the Census 2010 information as soon as it becomes available. TA Services' work with the U.S. Public Broadcasting System (PBS) serves to verify that agency is also meeting a similar population coverage requirement.

National Public Radio (NPR)

The National Public Radio (NPR) Laboratories used the CRADA capabilities to develop an in-band, on-channel (IBOC) interference model and plans to do similar development for HDTV. An example of this type of analysis is shown in Figure 3.

In FY 2009, ITS began the effort to upgrade the TA Services System to a new Geographic Information System (GIS) Web-based interface that will place the power of advanced GIS functions and features in the hands of TA Services customers. This work continues as funding is available. For more information on available programs, see the TA Services entry in the *Tools and Facilities* section (page 75) or call one of the contacts listed here. ❖

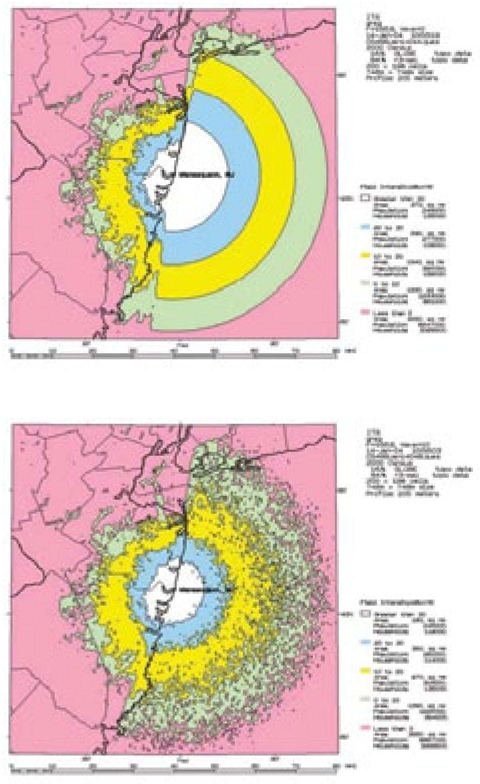


Figure 3. Coverage studies without (top) and with (bottom an ocean clutter loss addition to CSPM.

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Propagation Modeling Website

Outputs

- *A custom-tailored and installed Propagation Modeling Website (PMW) Geographic Information System (GIS) software suite for DOD customers*
- *Ability to simultaneously run a batch of transmitters, as specified in an Excel transmitter file*
- *Ability to mosaic DTED1, DTED2, SRTM1, SRTM2 or custom terrain files for use in a propagation analysis*
- *Use of parallel threading to decrease propagation analysis time proportional to the number of computer cores*

Overview

Advanced Geographic Information System (GIS) models have become an important tool in recent years for predicting the performance of communication systems. Government operations, including those for public safety and national security, depend critically on our ability to successfully predict propagation in a variety of environments and conditions. Over the past three years, ITS has developed the Propagation Modeling Website (PMW), a Web-based GIS propagation modeling tool, customized to meet the propagation prediction needs of the Department of Defense (DOD) sponsor.

The PMW project builds on 30-40 years of ITS expertise evaluating and analyzing propagation models. ITS developed TA (Telecommunications Analysis) Services, a propagation modeling tool based entirely on FORTRAN software, more than thirty years ago, before commercial GIS components, database systems, or sophisticated Web development tools were available. In response to the increasing use of commercial GIS tools, over ten years ago ITS created a desktop tool called the Communication System Planning Tool (CSPT) based on ESRI ArcGIS® ArcObject software and customized VB6.0 software.

From CSPT to PMW

CSPT currently contains propagation models for the following frequency ranges: LFMF (low/medium frequency) from 150 kHz to 2 MHz, HF (high frequency) from 2 MHz to 30 MHz, and VHF (very high frequency) 20 MHz to 20 GHz. Applications can range from worldwide outdoor coverage studies to indoor propagation studies of one building in an urban environment. The CSPT tools can download FCC FM and TV databases, perform overlap, composite, and interference studies and can report demographic information from the 1990, 2000 and 2007 (estimated) Census Population databases. CSPT leverages the existing stand-alone GIS product suite; however, the CSPT and GIS ArcInfo software must be installed on each desktop machine with a license for each machine. Also, each set of terrain data files, imagery data files, antenna pattern files, and transmitter files needed to be copied onto each CSPT machine or made available via a shared network system.

Figure 1. An example of the PMW GIS Web map page showing an analysis of four transmitter coverage plots.

Three years ago, ITS began migrating the VHF portion of the CSPT software from a stand-alone desktop solution into a Web-based solution called the PMW, accessed through a browser interface as shown in Figure 1. The PMW provides intranet users with Web-accessible propagation models, a central imagery/data storage facility, and a central database location to store all propagation analyses, using just one set of licensed software, as diagrammed in Figure 2. Maintaining, operating and upgrading the system are streamlined.

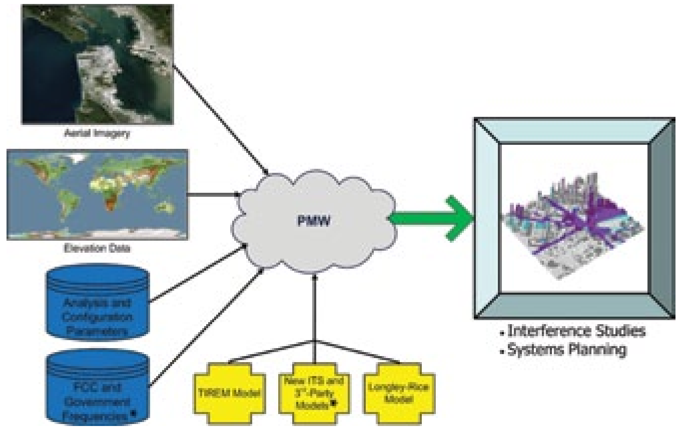
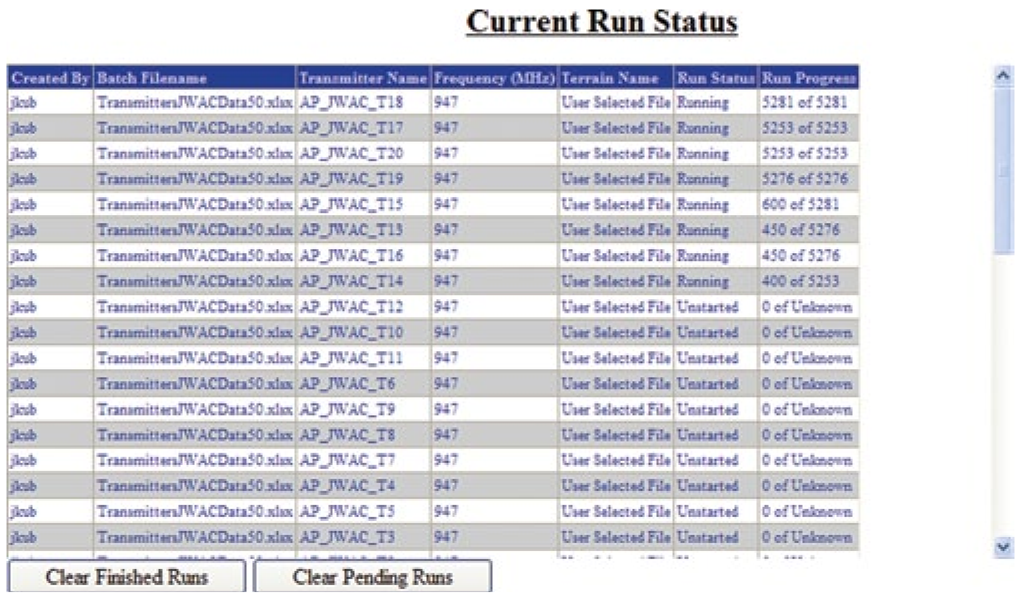


Figure 2. A block diagram of the PMW architecture; asterisks indicate planned future functionality.

The software currently includes the capacity to perform: TIREM 3.15 and Longley-Rice propagation analysis, database propagation parameter and measurement storage, transmitter spreadsheet server uploads, bulk transmitter analyses, antenna pattern file server uploads, terrain file server uploads, data input validation, 2D GIS transmitter and data displays, data analysis export to CSPT for creating CSPT analysis reports, and login access control. The PMW also incorporates a parallel threaded design that offers speed improvements over the CSPT single threaded model, proportional to the number of computer cores available to PMW (e.g. for an 8-core processor, PMW can process up to 8 analyses at a time, as shown in the batch record in Figure 3).

Over the next several years, as the PMW continues to mature, the DOD and other sponsors may choose several software enhancements. For faster propagation analysis, GPUs (Graphical Programming Units) and cloud computing may be implemented. Also, other models could be added, such as the ITS undisturbed field model, HF models and indoor-outdoor models.

The PMW is currently customized to fit the needs of our DOD sponsor and operate on their internal, secure network, running ITS-developed and third-party propagation coverage models for one or more VHF transmitters. However, other implementations of the PMW can be tailored to meet individual customer needs. Due to the large selection of GIS databases, customers can chose to include terrain, satellite and aircraft imagery, ground transportation infrastructure, building data, and population distribution. By developing TA Services, CSPT, and PMW, ITS has aided Government agencies, private cellular companies, public and private radio and television stations, transportation companies, and consultants to efficiently manage their telecommunications infrastructure. ❖



Current Run Status

Created By	Batch Filename	Transmitter Name	Frequency (MHz)	Terrain Name	Run Status	Run Progress
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T18	947	User Selected File	Running	5281 of 5281
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T17	947	User Selected File	Running	5253 of 5253
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T20	947	User Selected File	Running	5253 of 5253
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T19	947	User Selected File	Running	5276 of 5276
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T15	947	User Selected File	Running	600 of 5281
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T13	947	User Selected File	Running	450 of 5276
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T16	947	User Selected File	Running	450 of 5276
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T14	947	User Selected File	Running	400 of 5253
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T12	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T10	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T11	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T6	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T9	947	User Selected File	Unstarted	0 of Unknown
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jkub	TransmittersJWACData50.xlsx	AP_JWAC_T7	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T4	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T5	947	User Selected File	Unstarted	0 of Unknown
jkub	TransmittersJWACData50.xlsx	AP_JWAC_T3	947	User Selected File	Unstarted	0 of Unknown

Clear Finished Runs | Clear Pending Runs

Figure 3. A screen shot of the PMW batch Web page showing the first eight analyses in a batch running simultaneously.

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HF Emergency Communication Consolidation Study

Outputs

- *A communication systems analysis performed using unique Radio-Wave Propagation Models and antenna models*
- *A mutual coupling analysis between antennas in a proposed collocation layout*
- *Coverage maps that demonstrate communication systems performance of the proposed antenna layout and communications equipment*

Overview

As part of the United States Army (USA) Forces Command (FORSCOM) Base Realignment and Closure (BRAC) Program, Fort Bragg, North Carolina has been chosen as the new high frequency (HF) Disaster Recovery Center (DRC). The U.S. Army Information Systems Engineering Command (USAISEC) is consolidating three HF radio communication stations to one station. This station at Fort Bragg will be used as a national center to coordinate Army disaster relief operations. This communications center will be able to centrally manage Army operations throughout the Continental United States (CONUS), and allow two simultaneous HF links without interference. This station's primary mission is to enable communications for emergency and disaster relief, and its second ary mission is to enable administrative communications. ITS was tasked by the USAISEC to provide an analysis and recommendations for the antennas and their layout at the new HF radio station. The analysis included antenna design and performance, radio-wave propagation, and other communications issues that are of paramount importance to determining if, why, and how HF communications can be conducted at the Fort Bragg site. Coverage maps were generated to demonstrate HF communication systems performance for the new layout at the new HF radio station. An interference analysis was performed that involved mutual coupling computations between antennas.

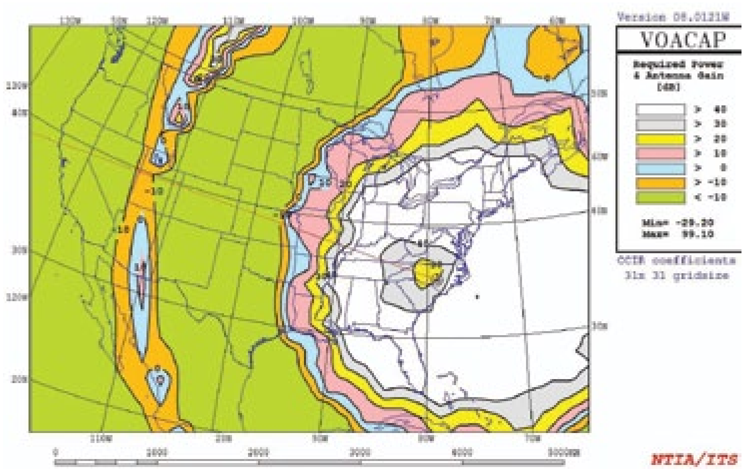
Antenna and Radio-Wave Propagation Analysis

The overall analysis effort is primarily based on antenna analysis and HF propagation model predictions. Using information gathered from both antenna analysis and HF propagation predictions, an iterative approach was used to determine the optimal antenna type and placement at the site. The consolidation of HF equipment for CONUS coverage at Fort Bragg presents many technical issues that must be addressed to maintain effective and efficient emergency communications. Communications at HF frequencies are predominantly by means of a sky wave that propagates via the ionosphere, and, to a lesser extent, by means of the ground wave. The distances between transmitter and receiver sites in the desired scenarios preclude communication via a ground wave due to ground-wave losses.

An ionospheric propagation model developed for the Voice of America by ITS, the Voice of America Coverage Analysis Program (VOACAP) was used to perform the HF propagation predictions in this analysis effort. VOACAP was first used in the iterative analysis procedure to make preliminary propagation predictions to provide information as to the antenna type and parameters that would be required to provide connectivity between the desired HF communication sites. The antennas had to be modeled to determine their far-field radiation pattern performance as a function of frequency and azimuth and elevation angles, since propagation in the ionosphere is dependent on the take-off angles of the radiation pattern.

The performance of propagation through the ionosphere is very dependent on these angles of radiation as well as the frequency, time of day, season, and sun spot number (SSN). Antenna specifications were then derived from these predictions and the antenna analysis to provide further refinement and more exacting HF propagation predictions with the propagation model.

Mutual coupling predictions between various antenna configurations were performed to determine the required locations and orientations to minimize coupling between antennas. Antenna analysis to determine the near-field response was required to perform the mutual coupling analysis.



HF Coverage Plot from Fort Bragg for a Coordinated Universal Time (UTC) of 1:00 PM During the month of December at 15 MHz and an SSN of 110.

Mutual Coupling Considerations

Antenna selection and antenna configuration on site are important for providing adequate gain in the right directions and at the same time providing isolation between antennas to mitigate interference when it is necessary to communicate simultaneously through the two links at the site. Wavelengths in the HF band range from 10 to 150 meters and, as a result, the antennas are very large and must be mounted at a fixed location. Limited real estate at the site also requires that the antennas be situated in close proximity to each other, with the result that they are in the near field of each other. This required that a mutual coupling analysis be performed to evaluate the interaction of the signal level produced from one antenna to the other at the site. Near-field analysis of the antennas was necessary to compute the mutual coupling.

Performance Prediction Coverage Maps

After the iterative approach described above was used to perform link computations between the desired sites with which Fort Bragg was to establish communications, the final antenna performance characteristics were integrated into the VOACAP to plot the coverage maps. These coverage maps are a function of antenna characteristics, time of day, season, frequency, and the prevailing state of the ionosphere. Log periodic dipole array antennas and broadband dipoles were selected as the best antennas to provide the required performance. The state of the ionosphere is described statistically through a stochastic process.

The engineering of an HF communication system is really defined by the constraints in design and the available equipment. In addition to coverage maps, it is also necessary to run point-to-point predictions with the VOACAP model to determine the best frequencies to use for different times of day, seasons, and SSN due to the stochastic nature of the ionosphere. The best procedure to determine communication capability between two sites would be to run the point-to-point analysis first to determine the best frequencies for a desired time of day, season and SSN, and then run the area coverage for those frequencies.

The coverage plot in the figure was run for a frequency of 15 MHz using the antenna patterns for the rotatable log periodic dipole antenna array for the month of December at a coordinated universal time (UTC) of 1:00 p.m. with an SSN of 110. The numerical values on the contour levels are the product of antenna gain in decibels (dB) and the transmitter power in decibels relative to a watt (dBw). The green, orange, and blue areas indicate what portions of CONUS will receive the signal from Fort Bragg at 90% reliability. The hopping nature of the HF sky wave is clearly evident from the figure. The loss in signal strength in Arizona, Utah, eastern Idaho, and western Montana indicate the boundaries between hops. Also the skip zone around Fort Bragg—where the power level and antenna gain product level drop below the required 40 dB—can be seen.

This project was completed in FY 2010 and future work would involve similar analyses of other U.S. Army HF site locations. ❖

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Broadband Wireless Standards

Outputs

- *Preparation for and support of the 2010 block meetings of ITU-R Working Parties 3J, 3K, 3L and 3M*
- *Development of sections of the handbook on the use of ITU-R propagation recommendations for interference and sharing studies*

Overview

Over the last decade, the radio frequency region of the electromagnetic spectrum has become increasingly important for enabling communications in general, and in particular for enabling communications networks' support of the tasks of ubiquitous wireless dissemination, collection, manipulation and analysis of digital information. It is no longer necessary to have a seamless and continuous wireline connection to one's computing device to access the Internet with very acceptable latencies. As a result, it is projected that the portions of the spectrum currently allocated for these uses will soon be insufficient to satisfy future demand, requiring more bands of spectrum to be made available either by reallocation and/or sharing.

In either case, prudent spectrum management practice dictates that harmful interference to and from existing and new services be minimized. General purpose radio propagation prediction models provide powerful tools for the evaluation of proposed spectrum reallocation and/or sharing scenarios' potential for interference. When these radio propagation prediction models are recommended international standards (i.e., Recommendations), they provide the technical basis for conducting multilateral coordination and regulation of spectrum and they also further international harmonization of spectrum allocations, which provides the additional benefits of economies of scale to equipment vendors and network/system providers, and global compatibility to users.

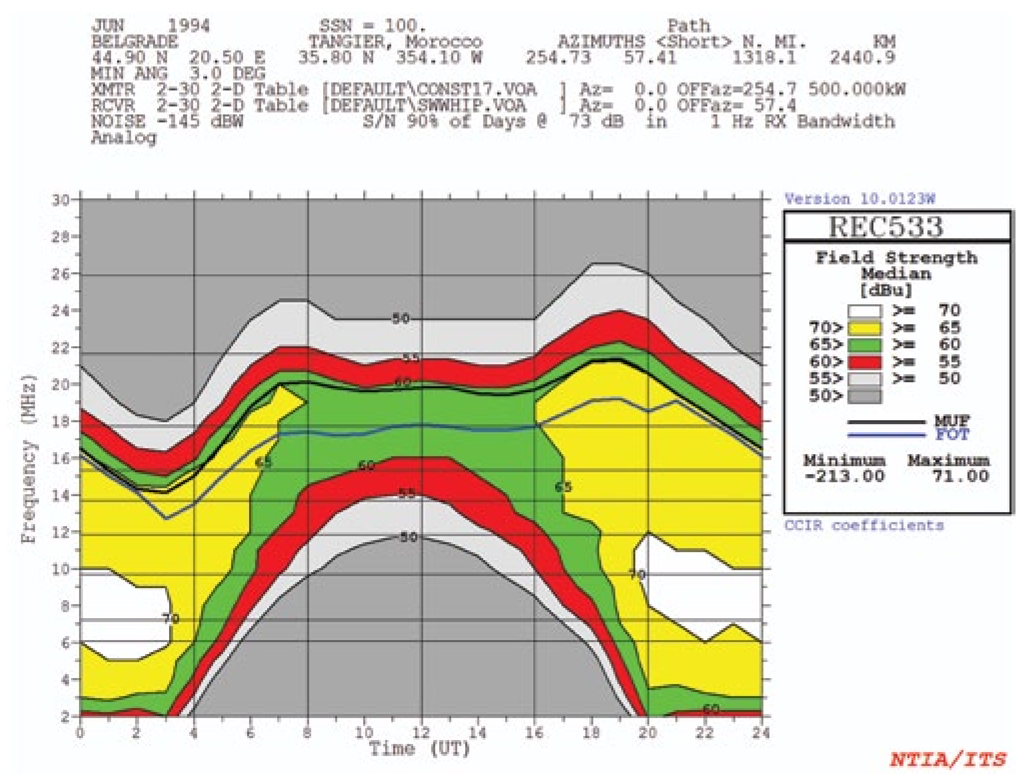
U.S. Representation to the ITU

The International Telecommunication Union (ITU) is the specialized United Nations agency that brings together governments and the private sector to coordinate the operation of telecommunication networks and services worldwide. It is an intergovernmental organization whose organizing documents have treaty status for the 192 Member States. In addition to the Member States, over 700 carriers, equipment manufacturers, funding bodies, research and development organizations and international and regional telecommunication organizations participate as Sector Members. ITS engineers participate in the ITU as authorized NTIA representatives on behalf of the U.S. Administration.

The ITU Radiocommunication Sector (ITU-R) is the authoritative international organization for the standardization, coordination and regulation of the radio frequency spectrum. Within the ITU-R, Study Group 3 is responsible for the development and maintenance of the Questions, Recommendations, Reports and Handbooks relevant to radio propagation, as well as for undertaking studies assigned to it as a result of decisions by World Radiocommunication Conferences. There are four Working Parties organized by ITU-R Study Group 3 to carry out its responsibilities: Working Party 3J (Propagation Fundamentals), Working Party 3K (Point-to-Area Propagation), Working Party 3L (Ionospheric Propagation) and Working Party 3M (Earth-Space and Point-to-Point Propagation). As part of this effort, four ITS engineers participate in one or more of these Working Parties. An ITS engineer also serves as Head of Delegation (official spokesperson) for the U.S. Administration at the meetings of ITU-R Study Group 3.

Standards Body Participation

The international block meetings of ITU-R Working Parties 3J, 3K, 3L and 3M took place in November 2010. U.S. Study Group 3 held monthly preparatory meetings from late May 2010 to review proposed U.S. Administration contributions to the block meetings. Four ITS engineers participated in these meetings. One of these was also selected to serve as acting international chairman of Working Party 3L at the 2010 block meetings.



Median field strength predictions using Rec. ITU-R P.533 as described in the handbook.

Technical Contributions

Among the U.S. contributions mentioned above, one concerned a handbook on the use of Study Group 3 Recommendations for interference and sharing studies. In support of the correspondence group tasked with development of the handbook, four ITS engineers were assigned authorship for one or more sections of this handbook, typically sections related to a Recommendation for which that engineer had specific expertise and experience. Certain of these sections involved detailed descriptions of how to use the model or models in that Recommendation to provide sample predictions for an example sharing or interference scenario, including Recommendations ITU-R P.533, P.1546 and P.1812. The figure shows an example of the use of Rec. ITU-R P.533 to predict the median field strength at Tangier, Morocco for a 24 hour period (UT) in June 1994 from a 500 kilowatt transmission originating in Belgrade, Serbia, for frequencies between 2 MHz and 30 MHz. Other sections with ITS authors involved those covering the application of the time and location variabilities of these models to interference and sharing studies and definitions for technical terms used in the recommendations and the handbook.

Another type of technical contribution involved intersessional replies to Liaison Statements from other ITU-R Working Parties. Owing to the fact that some Liaison Statements require a response before the next meeting of the Working Party being addressed, the Chairman of that Working Party may provide an intersessional reply. During FY 2010, an ITS engineer assisted the Chairman of Working Party 3M in drafting a reply Liaison Statement to Joint Task Group 5-6 on methods for computing aggregate interference from mobile service stations into a victim system onboard an aircraft. ❖

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Short Range Mobile-to-Mobile Radio Propagation Measurements and Models

Outputs

- *Analysis effort to develop propagation models for short-range mobile-to-mobile applications*
- *Measurement program to support analysis effort and refine propagation models*

Overview

Demand for scarce spectrum suitable for broadband wireless network services is increasing relentlessly. One strategy for accommodating this demand is to increase frequency reuse by using low power and low antenna height transceivers to limit the range of potentially interfering signals from devices using this spectrum. A natural extension of this strategy would suggest that these broadband wireless networking devices might share spectrum with pre-existing spectral allocations on a co-primary or secondary basis, as long as the potential for harmful interference into existing services can be minimized. Accurate radio propagation models can provide a powerful tool for spectrum managers who need to predict the potential interference that might arise from various spectrum sharing scenarios between broadband wireless network services and existing services.

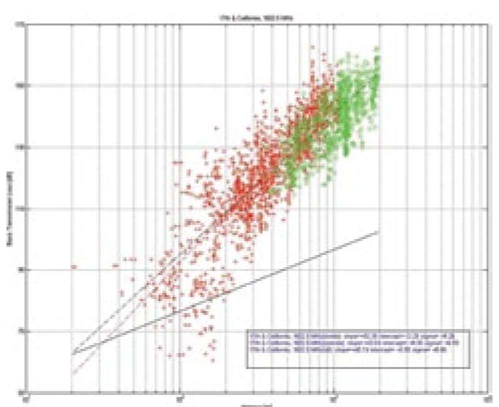
An important feature of many of these sharing scenarios is the fact that both terminals of the broadband wireless networking service devices are to be deployed at heights so low as to be immersed in surrounding environmental clutter. In this circumstance, the presence of clutter causes both enhancements and fading of the radio signal that are not accounted for in conventional models where it is assumed that one terminal is elevated to a height above the clutter. In order to remedy this deficiency, ITS has embarked on a combined program of measurements and model development to more accurately predict radio signal propagation for these very low terminal height and short range scenarios.

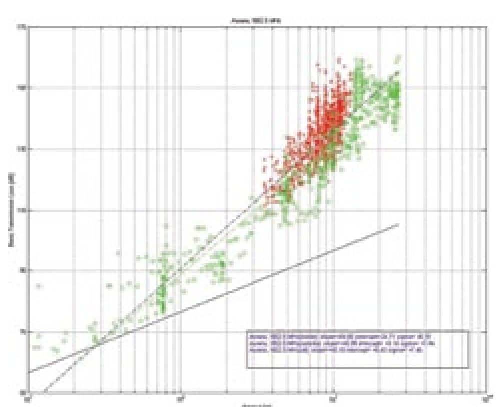
Model Development

In FYs 2007-2008, ITS engineers collected very low terminal height radio propagation measurements at seven different frequencies from 180 – 5,750 MHz in selected areas in the greater Denver, Colorado, metroplex. These measurement campaigns and model developments based on them have been described in previous ITS Technical Progress Reports. During FY 2010, NTIA's Office of Spectrum Management (OSM) tasked ITS to investigate modifications of the least squares fit empirical models (i.e., basic transmission loss versus the logarithm of distance) for measurements collected in downtown Denver. Two transmitter locations, which were sited in very close proximity to the high-rise urban canyon section of downtown Denver, were selected for study: the parking lots at 17th and California Streets and the Auraria Campus.

Each of these transmitter sites was quite different from the other in terms of the surrounding environmental clutter: the 17th and California site had almost no open foregrounds near the transmitters, while the Auraria Campus site had very open foregrounds. In each case (i.e., for each transmitter location), a subset of the receiver locations sampled approximately the same dense urban core section of the city, with the caveat that any given receiver location was almost never repeated exactly nor was it receiving simultaneously from the two different transmitter locations. The measurements for these two datasets falling within the same dense urban core, defined geographically, were combined and organized according to their respective distances from the corresponding transmitter site. Figures 1 and 2 show the results of the data segregation exercise. In each figure, red +'s show the receiver locations inside the dense urban core, while green o's show the receiver locations outside the dense urban core.

Figure 3 shows the combined results, where the magenta x's correspond to receiver locations inside the dense urban core and cyan diamonds correspond to receiver locations outside the dense urban core. An interesting and unexpected feature of this exercise was that the net deviation (as measured from the least squares fit lines of basic transmission loss versus distance) of the combined dataset did not increase significantly. This result suggests that, in terms of first order statistics, we can obtain useful measurements with a limited number of transmitter sites for a representative environment. It is, however, still to be determined just how many environmental classifications are required. ❖





Left: Figure 1. Measured basic transmission losses plotted vs. log (distance) for 1602.5 MHz for the 17th and California transmitter location.

Right: Figure 2. Measured basic transmission losses plotted vs. log (distance) for 1602.5 MHz for the Auraria Campus transmitter location. In both figures, the lines show the least squares fits to the measurements.

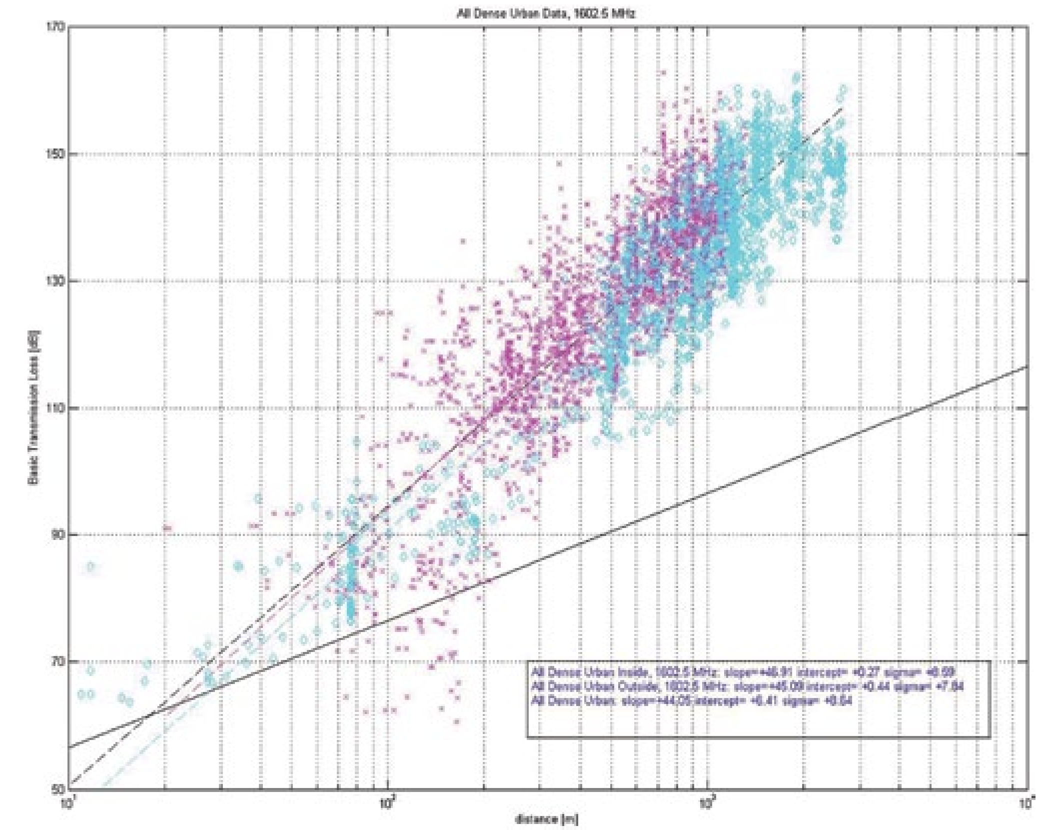


Figure 3. Measured basic transmission losses plotted vs. log (distance) for 1602.5 MHz for the combined sites. The lines show the least squares fits to the measurements.

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Ultra-low Antenna Height and Close-in Distance Propagation Modeling and Measurements

Outputs

- *Unique Radio-Wave Propagation Models developed for use with ultra-low antenna heights and close-in distances*
- *Undisturbed-Field Model that can be used for antenna heights as low as zero meters (on the ground) and distances as close as 2 meters*
- *Measurement program specifically tailored to collect data to verify the models developed for ultra-low antenna heights and close-in distances*

Overview

ITS was tasked by the U.S. Naval Research Laboratory to develop a radio-wave propagation model that could meet a unique set of requirements for use in scenarios with ultra-low antenna heights in the 0- to 3-meter range, at frequencies of 150 to 6000 MHz, and distances as close-in as 2 meters and extending out to 2 kilometers. Radio-wave propagation models that could meet these stringent requirements did not exist. ITS developed the Undisturbed-Field Model to meet these requirements.

Undisturbed-Field Model

The Undisturbed-Field Method involves the calculation of the radio-wave propagation loss based on the undisturbed electric field as a function of antenna heights, distance, frequency, and the ground constants. The antenna gains are factored out to result in a basic transmission loss for use in the undisturbed-field propagation model. The undisturbed field is the electric field produced by a transmitter antenna at different distances and heights above ground without any field-disturbing factors in or around the receiver antenna location. In contrast, a disturbed field is where an antenna located at the receiver site would disturb the electric field.

A detailed investigation of the differences between the undisturbed-field and disturbed-field methods of field computation was performed. The investigation determined that the difference between the propagation loss computed by undisturbed-field method and the disturbed-field method is minimal. The disturbed-field method is more exact, but it is more computationally intensive and difficult to calculate when compared to the relatively simple and fast computations used in the undisturbed-field method. The undisturbed-field model includes near-field effects, the complex two-ray model, antenna near-field and far-field response, and the surface wave. It can be used for antenna height ranges from 0 to 3 meters and frequencies from 150 MHz to 6000 MHz. Since this is a line-of-sight model, the ground is assumed to be flat with no irregular terrain over distances up to 30 meters. The undisturbed-field model can be used for distances up to 2 kilometers, but it is particularly applicable for near distances less than 30 meters. The disturbed-field method adds the effects of mutual coupling to the factors included above for the undisturbed-field method. Work continues on refining the undisturbed-field model.

Additional Propagation Models

Two other propagation models are still under development: an empirical model based on measured data and an analytical model that computes propagation loss over a concave path. An initial empirical model was developed based on the least squares fit to measured data using a single slope and intercept. The empirical model has been modified to accept additional measured data from the static vector network analyzer and dynamic spectrum analyzer measurements. Work continues on this model; current efforts are directed at fitting dual-slopes and breakpoints to the measured data.

A concave path model for low antenna heights was also developed from a theoretical approach using Fresnel reflection coefficients for multiple reflections from a continuous fit using linear segments to the curve that describes the terrain along the path. This model has demonstrated good agreement with measured data. Work continues on this model to generalize it to other path configurations.

The two monopole-on-a-ground plane antennas are positioned at a height of zero meters for a close-in distance and ultra-low antenna height measurement (photograph by S.Carroll).

Measurement Program

The measurement campaign focused on measurement configurations designed to use collected data to verify the analytical models developed for ultra-low antenna heights and close-in distances. Measurements were performed using many antenna heights from zero to 3 meters with distances of 2 meters to 2 kilometers. Two measurement systems were used: a static vector network analyzer using swept frequencies of 300 kHz to 6000 MHz, and a dynamic spectrum analyzer using discrete frequencies from 150 MHz to 6000 MHz. The photo shows one of the test configurations used to measure propagation loss at ultra-low antenna heights. The measurement van containing equipment for the two measurement systems is in the background.

The static vector network analyzer measurement system has certain advantages over other measurement techniques and provides data at frequencies within the operating bandwidth of the various antennas. The original raw data is recorded over a broad bandwidth, so that it can accurately be transformed into the time domain and time gated to remove interference, noise, unwanted reflections, and multipath. After time gating and further processing, the data is transformed back into the frequency domain. Cable losses, antenna gains, calibration factors, transmitter power, and received power are taken into account to derive the basic transmission loss. The disadvantages of using this system include a maximum distance limitation of approximately 250 meters, and that the data collection and measurement process is very time-consuming.

The dynamic spectrum analyzer measurement system can take measurements over much longer distances (up to 2 kilometers and further), and is significantly faster at collecting data than the vector network analyzer system, but it also has its limitations when dealing with noise and multipath interference. ITS collected data over four different paths to compare against the model predictions: a flat path, a diffraction path, and two concave paths. Measurements were performed over seven frequencies from 150 MHz to 6000 MHz, many combinations of antenna heights from zero to 3 meters, and distances from about 2 meters to 2 kilometers.

Work on this project in FY 2011 will focus on data reduction and analysis for the measurements performed with both systems, and further development of the analytical and empirical models for prediction of radio-wave propagation loss. ❖

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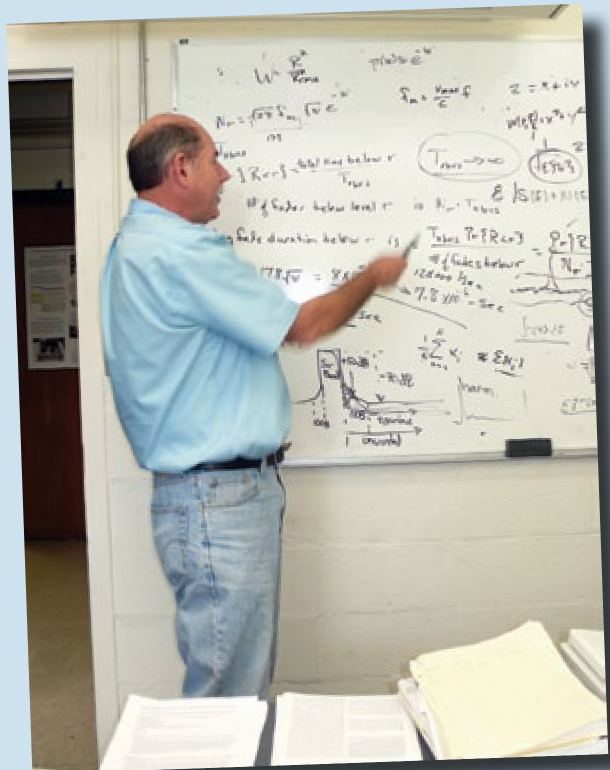
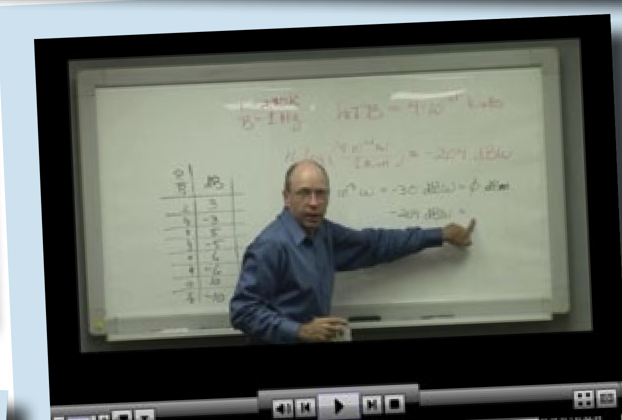


A Theory Division engineer during a technical discussion (photograph by F.H. Sanders).

Ongoing Theory Division projects include audio and video quality assessment and improvement. This is a view of video equipment in the ITS Audio Visual Laboratories that supports this research project (photograph by F.H. Sanders).



In August 2010, ITS launched its first telecommunications science video series for the public. The videos cover telecommunications topics ranging from an easily understandable review of fundamentals—such as defining decibels using base-10 logarithms—to in-depth explanations of complex engineering issues like resolving signal interference problems. In the first portion of each segment, a senior ITS engineer explores a particular aspect of radio spectrum measurement technique or theory with a whiteboard lecture; in the second portion, the lessons of the whiteboard discussion are implemented with actual measurement hardware and radio signals. The videos are posted at http://www.its.bldrdoc.gov/talks/rf/notes/.

Two ITS engineers measuring radar emissions from an air search radar (TPS-79) on a rooftop during a CRADA project to verify compliance with the Radar Spectrum Engineering Criteria (RSEC) (photograph courtesy of Lockheed Martin).

Telecommunications Theory

Demand for telecommunications is growing explosively, creating a need for more infrastructure and, ultimately, more bandwidth. Wireline networks can meet much of this demand, but some can only be met by wireless systems using radio spectrum. While wireline capacity can be expanded almost indefinitely by laying down more fiber, the radio spectrum is a limited resource and new radio technologies that use spectrum more efficiently and effectively must be developed to meet increasing demand. Radio spectrum management is moving away from traditional, top-down frequency-assignment methods and migrating toward self-controlled, interference-limited technologies.

Historically rigid service-by-service spectrum band allocation is being supplanted by sharing among different services within individual bands. Successful implementation of new sharing schemes depends on development of new capabilities in radio systems to autonomously recognize and avoid interference with each other. A new knowledge base is needed to understand the maximum levels of interference that radio systems can withstand and to guide performance improvements in new and existing networks, as well as new tools to monitor the quality of audio and video information on communication channels so that quality levels can be accurately adjusted in real-time to achieve maximal quality with minimal bandwidth use. To meet these needs, ITS performs research in both wireless and wireline telecommunications at fundamental levels of physics and engineering. Major areas of investigation include broadband wireless systems performance in the presence of interference; development of new, short-range radio propagation models; the effects of noise and interference as critical limiting factors for advanced communication systems; automated tools for assessing audio and video quality; and further development of advanced spectrum sharing concepts such as dynamic frequency selection (DFS). Through technical publications, cooperative research and development agreements (CRADAs), and interagency agreements, ITS transfers the results of this work to both the public and private sectors, where it is transformed into better telecommunications for the U.S., new and better products, and new opportunities for economic growth and development.

Areas of Emphasis

Audio Quality Research

ITS conducts research and development leading to standardization and industry implementation of perception-based, technology-independent quality measures for audio communication systems. The project is funded by NTIA.

Channel Effects on Radio System Performance

ITS, a recognized leader in radio channel measurement and modeling, is researching the effects of interference and noise on the performance of radio receivers and networks. Current work, funded by NTIA, is focused on the effects of noise and interference as limiting factors in the performance of radar and communication systems.

Video Quality Research

ITS develops perception-based, technology-independent video quality measures and promotes their adoption in national/international standards. The project is funded by NTIA.

Electromagnetic Compatibility Assessments for Radars and Communication Systems

In response to interference to radar receivers from non-radar systems operations in and adjacent to radar bands, ITS has performed extensive analyses and measurements jointly with NTIA's Office of Spectrum Management (OSM), including on-site measurements at locations across the country. One problem was traced to deployment of DFS wireless communication systems that are supposed to—but did not—detect and avoid the frequencies used by the radars; in FY 2010 technical solutions were developed and initial tests performed that demonstrated that this problem can be solved. Another issue is the prevention of interference from proposed new 1300 MHz (L band) orbital radar systems to terrestrial long-range air traffic control radars. The DFS work is funded by OSM; the orbital-to-terrestrial L-band radar work is funded under an Interagency Agreement with NASA's Jet Propulsion Laboratory (JPL).

RSEC-Compliance Measurements

ITS performed measurements at Lockheed Martin Company (LMC) facilities at Syracuse, NY, and near Yuma, AZ, on the emissions of new high-power radars to determine whether they meet the requirements of the NTIA Radar Spectrum Engineering Criteria (RSEC). This ongoing work is funded under a CRADA with LMC. ❖

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Audio Quality Research

Outputs

- *Technical publications and presentations on new research results*
- *Measurements and estimates of speech and audio quality and algorithm performance*
- *Algorithms and data supporting speech and audio coding and quality assessment*

Overview

Telecommunications services such as voice over Internet Protocol (VoIP), cellular telephones, automatic voice recognition, Internet digital audio streaming, audio broadcasting, and a host of other products are made possible through digital encoding and transmission of speech and audio signals. Despite the continuing maturation of enabling technologies, achieving efficient, robust, and flexible speech and audio signal encoding at reduced bitrates while maintaining good fidelity remains an elusive goal encumbered by a complex set of trade-offs. The trade-off between signal quality and encoded bitrate is the most apparent, but robustness (to transmission errors and losses) and adaptability (to different signal classes, bandwidths, quality levels, coding rates, or robustness levels) also come into play, and all of these can influence coding and transmission delay as well as algorithm complexity.

The ITS Audio Quality Research Program engages in ongoing research efforts that lead to new understandings of the complex relationships between these factors. The program identifies, develops, and characterizes innovations for speech and audio coding and transmission that may increase quality, robustness, or flexibility, or that may decrease bit-rate, delay, or complexity. In addition, the program seeks to advance tools and techniques for optimizing the trade-offs between these factors. Optimization requires measurement of speech and audio quality, another area of program focus. Measurement is challenging because it involves the interplay between numerous technology factors, human perception, and human judgment.

Speech Coding

The robustness of digital coding and transmission algorithms is critical in applications that use lossy channels, such as wireless links and VoIP systems. In FY 2010, program staff continued to work towards more robust speech coding through multi-descriptive coding (MDC). In MDC an encoder forms multiple partial descriptions of a speech signal. The descriptions are sent on different physical or virtual channels or on sequential uses of a single channel. If all descriptions arrive at the decoder intact, a high-quality reconstruction of the speech is possible; if any of the descriptions are lost, then a lower-quality reconstruction of the speech signal is still possible—a vast improvement over the complete outage in speech signal that would be the case without MDC.

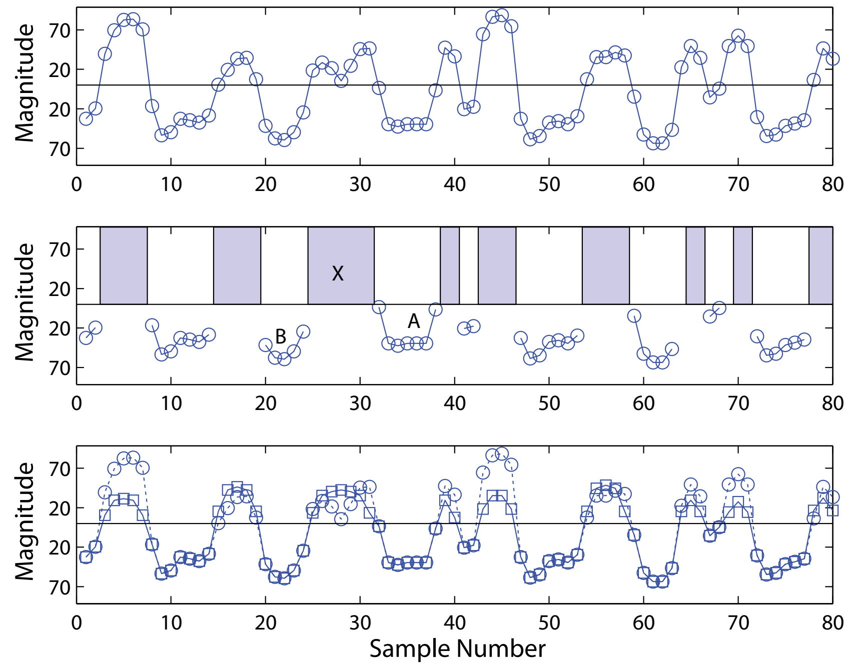
Program staff developed and tested a two-channel MDC system that separates a speech signal into two streams according to the polarity of the speech samples (speech polarity decomposition MDC or SPD-MDC). This scheme is implemented by separately coding sample signs and magnitudes. All signs are transmitted on both channels, providing a low level of redundancy, but magnitudes of positive and negative samples are sent on separate channels. Thanks to entropy coding the total rate of this two-channel multiple description system is less than that of a comparable single-description system.

If only one stream is received, the missing strings of samples are individually approximated at the decoder by means of a lookup table indexed by the length of the missing string. The lookup table provides the shape of the missing string, and this shape is then scaled in amplitude using information from the neighboring segments of the signal. The figure shows the approximation of missing string "X" using a lookup table supplemented by amplitude information from neighboring strings "A" and "B."

Subjective Measurement Of Speech Quality

Subjective testing is the most direct means for assessing speech or audio quality. This involves listeners who evaluate recordings in a controlled laboratory setting. For consistent and meaningful results the listening environment and sound recordings must be prepared with great care. Then a number of listeners are recruited to participate in the testing. Most tests use between 16 and 32 listeners, and each typically spends 30 to 60 minutes on the test. Overall, the entire process can be quite time-consuming and costly and methods for combating this are desirable. When many combinations of parameter values must be tested to identify combinations that give the highest quality, time and costs escalate accordingly.

Building on initial work performed in the previous year, program staff continued to developed, evaluate, and refine a much more efficient way to use subjective testing to identify optimizing parameter values. Gradient Ascent Subjective Testing combines classical gradient ascent search methods with paired-comparison subjective testing. Rather than exposing each listener to all possible parameter values, each listener's response to a given recording determines which recording is played next. This technique allows each listener to quickly focus in on the parameter values that give the best audio quality. The process is general in nature and thus can be used for testing audio, video, image, or multimedia quality.



Example SPD-MDC decoder operation when negative samples are received but positive samples are not received. Top: original signal samples. Middle: received samples and regions where missing samples must reside (shaded). Bottom: decoder output with original samples shown with circles and approximated samples shown with squares.

Additional Work

Throughout FY 2010, program staff performed additional speech and audio quality testing using both objective and subjective techniques, supporting this and other ITS programs. Laboratory facilities were upgraded and staff continued to transfer program results to industry, Government, and academia by means of technical publications, lectures, laboratory demonstrations, and poster presentations. Staff also completed peer review and associate editor functions for technical papers in support of the international speech and audio research community. Program publications, technical information, and other program results are available at http://www.its.bldrdoc.gov/audio.

Recent Publications

A. Catellier and S. Voran, "Low rate speech coding and random bit errors: a subjective speech quality matching experiment," NTIA Technical Report 10-462, October 2009.

S. Voran, "Subjective ratings of instantaneous and gradual transitions from narrowband to wideband active speech," in *Proc. of the IEEE International Conference on Acoustics, Speech and Signal Processing*, Dallas, TX, Mar. 2010.

S. Voran and A. Catellier, "Multiple-description speech coding using speech-polarity decomposition," in *Proc. of the IEEE Global Communications Conference*, Miami, FL, Dec. 2010. ❖

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Effects of the Channel on Radio System Performance

Outputs

- *Error statistics for degraded radio channels*
- *Relationships between channel characteristics and error statistics*
- *Radio system design parameters*
- *Interference protection criteria*

Overview

Telecommunications play a vital role in providing services deemed essential for modern life. Many of these services use radio links composed of a transmitter and receiver, i.e., the radio system and the channel over which its radio waves are propagated. Common examples are television and radio broadcasts, cellular phones, wireless local area networks, and radar. The channel, which can vary widely—as, for example, an urban area or an office environment—is often the primary impediment to reliable radio system performance. Potential degradation due to channel characteristics has wide ramifications for designing radio systems and regulating their operation. The fundamental purpose of this project is to understand the effects of the channel on radio system performance and apply this knowledge towards improving the design of radio systems and the regulation of their operation.

The channel degrades radio system performance by introducing undesired signals, attenuation, and multipath. Undesired signals include natural noise created by phenomena such as lightning, man-made noise generated by electrical devices, and signals from other radio systems. Attenuation is the loss of average signal power by obstructions in the radio environment such as hills, buildings, or walls within a building. Multipath is due to reflections, diffractions, and scattering off these same objects.

Undesired signals and attenuation reduce signal power margins. Multipath causes signal fading, inter-symbol interference in digital communications systems, and clutter in radar systems. All of these lead to an increase in the number of errors, and error statistics provide the performance metrics by which the effect of the channel on radio system performance is quantified. These statistics can be as simple as the rate at which errors occur or as complex as the mean time between errors.

Bit error statistic measurement system. The transmitter and receiver are software-defined radios enclosed in the white boxes with the attached whip antennas. The laptop computer displays received bits and the desktop display shows the directory of codes written for this application (photograph by M.A. McFarland).

The fundamental task of this project is to collect error statistics while the radio link is being degraded. These statistics can be obtained through mathematical analysis, simulation, or hardware measurements. Ideally, they are collected by two or more methods to improve their reliability. Another important task for this project is to make the most of channel measurements by establishing relationships between channel characteristics such as multipath delay spread and the error statistics.

These statistics are used in a variety of ways to improve the design of radio systems and the regulation of their operation. Designers use them to help determine radio system design parameters such as transmitted power, error correction gain, and channel equalization gain. For regulators, these statistics are useful in determining the interference protection ratios (IPC), which designate the maximum amount of interfering signal power a receiver can tolerate without compromising its own performance. As pressure increases for government services to share radio spectrum with private services in accordance with the recently introduced National Broadband Plan, reliable IPC become more important as they are needed to make this vision a reality.

Current Work

Work this year consisted of designing and building a bit error measurement system, developing an analytic radar interference model, and planning and hosting spectrum sharing forums during ISART 2010, the 11th annual International Symposium on Advanced Radio Technologies sponsored by the NTIA and hosted by ITS.

Engineers often use channel models derived from measurements to estimate radio performance. In FY 2010, we developed a bit error measurement system to collect radio performance data at the same time channel measurements are made. This measurement system will allow engineers to verify their channel models by comparing bit error statistics generated by the channel models to those actually measured in the channel. The bit error measurement system is composed of a transmitter, receiver, antennas, and computers to store and process the bits, as shown in the photograph. It uses binary phase shift keying with either coherent or non-coherent detection.

We also began the development of a radar interference model which will be used to provide quantitative interference information for establishing IPC. A radar interference model is essential, since radars use a large portion of the federal radio spectrum and industry has advanced a number of proposals for sharing it. The radar interference model will quantify performance in terms of detection statistics. At this point in development, the model is entirely analytic. Future work is likely to lead to simulations so that more realistic interference signals, not amenable to mathematical solutions, can be investigated. In FY 2011 we will be using the radar interference model to assist the U.S. Coast Guard in analyzing the effect of signals from 4^{th} generation broadband personal communication service devices on the performance of marine radar systems in nearby radio bands.

In FY 2010, we worked toward developing meaningful IPC by planning and moderating a variety of spectrum sharing forums for ISART 2010. Through these forums, leaders from government, industry, and universities were brought together to present and discuss their views on various spectrum sharing issues.

Knowledge gained through our research is often applied towards other projects at ITS. For example, in FY 2010, we applied our knowledge towards evaluating the effectiveness of public safety in-building radio enhancement systems (IBRES). The results of this evaluation are important to municipal public safety communications professionals tasked with assisting building owners to install reliable IBRES. We also completed an analysis of the error inherent to measuring power spectral densities with modern digital spectrum analyzers. These results, published in an NTIA Technical Report, are valuable to spectrum managers tasked with limiting interference between radio systems.

Recent Publications

R.A. Dalke, "Radio spectrum estimates using windowed data and the discrete fourier transform," NTIA Report TR-10-470, Sep. 2010. ❖

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Time Domain Pulsed Measurements of the NASA Space Power Facility

Outputs

- *A direct-pulse measurement system based on simple instrumentation: UWB pulse generator and 12 GHz bandwidth real-time oscilloscope*
- *A system ideal for propagation and reverberation measurement in highly-reverberant environments*
- *Measurements of insertion loss and chamber energy decay times*
- *2D and 3D finite-difference time-domain numerical models of the NASA SPF*

Overview

The National Aeronautics and Sapace Administration (NASA) is currently in the process of converting its Space Power Facility (SPF) at the Plum Brook Station near Sandusky, Ohio into a large environmental effects (E3) test chamber. E3 testing on the next-generation, manned Orion space vehicles will be performed in the SPF vacuum chamber, an all-aluminum hemisphere-on-cylinder vessel 100 feet in diameter and 122 feet high shown in Figure 1. Radiofrequency test equipment will be used around the periphery of the assembled Orion vehicle to conduct system-level radiated susceptibility testing. The unique shape, large volume, and high inner-surface reflectivity of the SPF vacuum chamber will create a distinctive electromagnetic environment within the chamber.

It is necessary to thoroughly understand the electromagnetic propagation and reverberation characteristics in the chamber to minimize risk to the vehicle under test. NASA wants to understand and control the electric field strength throughout the vacuum chamber, and minimize regions of localized high radio frequency (RF) intensity that could cause overexposure of a spacecraft under test to electromagnetic fields.

Figure 1. The SPF vacuum chamber with typical test article. Note the large access door and buttresses in front of and behind the rocket.

Direct-Pulse System

Researchers at ITS developed a system to perform ultra-wideband (UWB) propagation and loss measurements using a direct pulse measurement system. The system consists of an impulse generator, 12 GHz bandwidth high-speed oscilloscope, trigger generator, and precision microwave cables. It transmits ultra-wideband impulses (20 MHz – 1.5 GHz) which undergo multiple reflections from the chamber boundaries and are received remotely by a high-speed oscilloscope that is connected to a receiving antenna (Figure 2). The chamber was scanned over two planes, parallel to the chamber floor, with the transmitting antenna fixed at two locations; and along a vertical line extending from 50 to 110 feet above the center of the chamber floor. In all, 138 transmission measurements were performed using three different sets of antennas.

Measurement Data

The received waveform data are processed to yield two highly useful quantities: insertion gain and power-decay times. These parameters yield important information about the average and peak electric field levels that occur in the chamber volume and the electromagnetic loss mechanisms in the chamber itself. Figures 3 and 4 show insertion loss and energy-decay time characteristics obtained over two horizontal scan planes. The results are plotted for three pairs

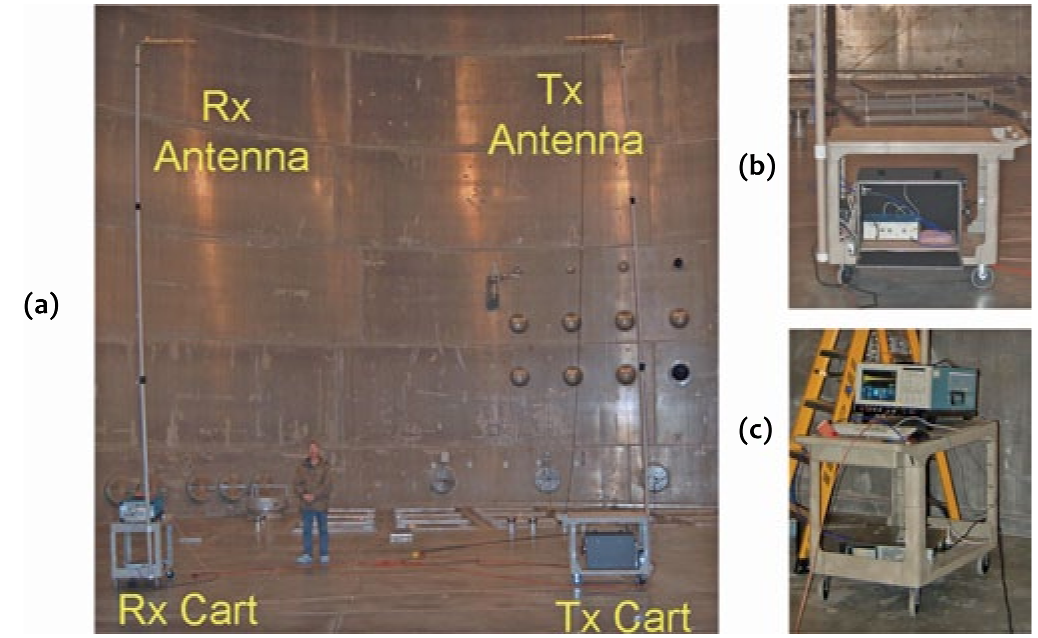

Figure 2. Setup for chamber measurements. (b) Pulse generator inside a shielded box. (c) Oscilloscope mounted on cart. Figure 3. Frequency-averaged (BW=10 MHz insertion loss results for 3 antenna types: Green (biconical), red (discone), and blue (log-periodic) (photographs by J.D. Ewan).

of antennas: biconicals (green), discones (red), and log-periodics (blue). The results highlight several interesting chamber characteristics. First, the clustering of the curves indicates that the chamber has uniform and diffuse electromagnetic fields—a characteristic necessary for effective E3 testing in this chamber. The tight clustering of the decay curves also indicates good electric field uniformity. The power-decay curves also tell us much about the chamber loss mechanisms. At low frequencies, the antenna loading dominates chamber losses, whereas at high frequencies, wall losses and surface/volumetric losses are significantly more common.

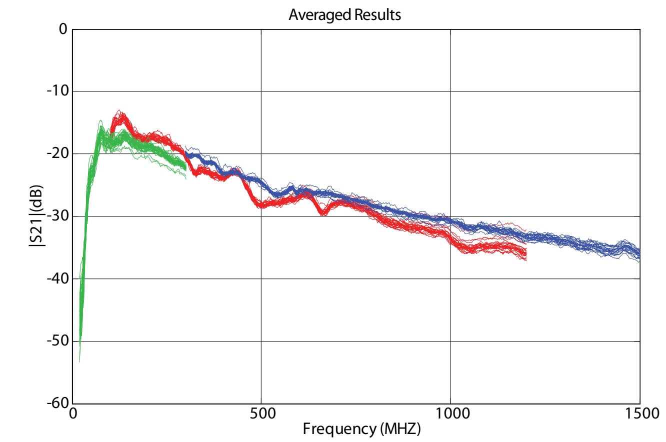

Figure 3. Frequency-averaged (BW=10 MHz insertion loss results for 3 antenna types: Green (biconical), red (discone), and blue (log-periodic).

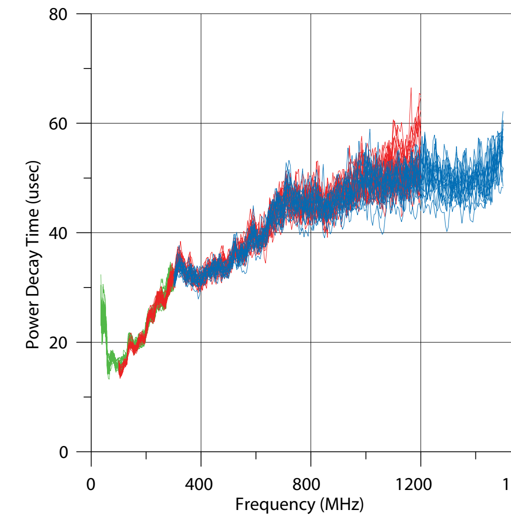

Figure 4. Power-decay time results obtained over all of the horizontal scans for three antenna types (20 positions). Green (biconical), red (discone), and blue (log-periodic).

Recent Publications

R.T. Johnk, J.D. Ewan, P.M. McKenna, R.L. Carey, N. DeMinco, "Time-domain propagation measurements of the NASA space-power facility," NTIA Technical Report TR-10-471, Sep. 2010.

R.T. Johnk, J.D. Ewan, P. M. McKenna, R. L. Carey, N. DeMinco, and K.A. Shalkhauser, "Time-domain pulsed measurements of the NASA space power facility," in *Proc. IEEE International Symposium on EMC*, Aug. 2009, pp. 187- 192. ❖

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Interference Effect Tests and Measurements on Weather Radars

Outputs

- *Predictions of the effects of interference from non-radar systems with weather radars*
- *Measurements of interference characteristics at weather radar sites and identification of interference sources and mechanisms across the U.S.*
- *Development of new dynamic frequency selection (DFS) test-and-certification protocols to prevent future interference to weather radars from DFS wireless transmitters*

Overview

In FY 2010, NTIA continued to investigate and provide solutions for ongoing 5 GHz radio interference to weather radars at sites across the United States. The work, which began in 2009, changed its focus from identification of interference sources to identifying solutions for the interference. The first NTIA Technical Report in a three-part series was also prepared, describing in detail the origins of the problem, the methodology that was used to analyze it, and the ultimate identification of the interference sources.

DFS Performance Issues

The interference, which originates from unlicensed national information infrastructure (U-NII) wireless communication devices that are supposed to share the band with the radars on a not-to-interfere basis, is occurring despite a dynamic frequency selection (DFS) technology feature that should preclude the problem. DFS is supposed to provide a detect-and-avoid capability for the frequencies used by the band-sharing 5 GHz U-NII transmitters.

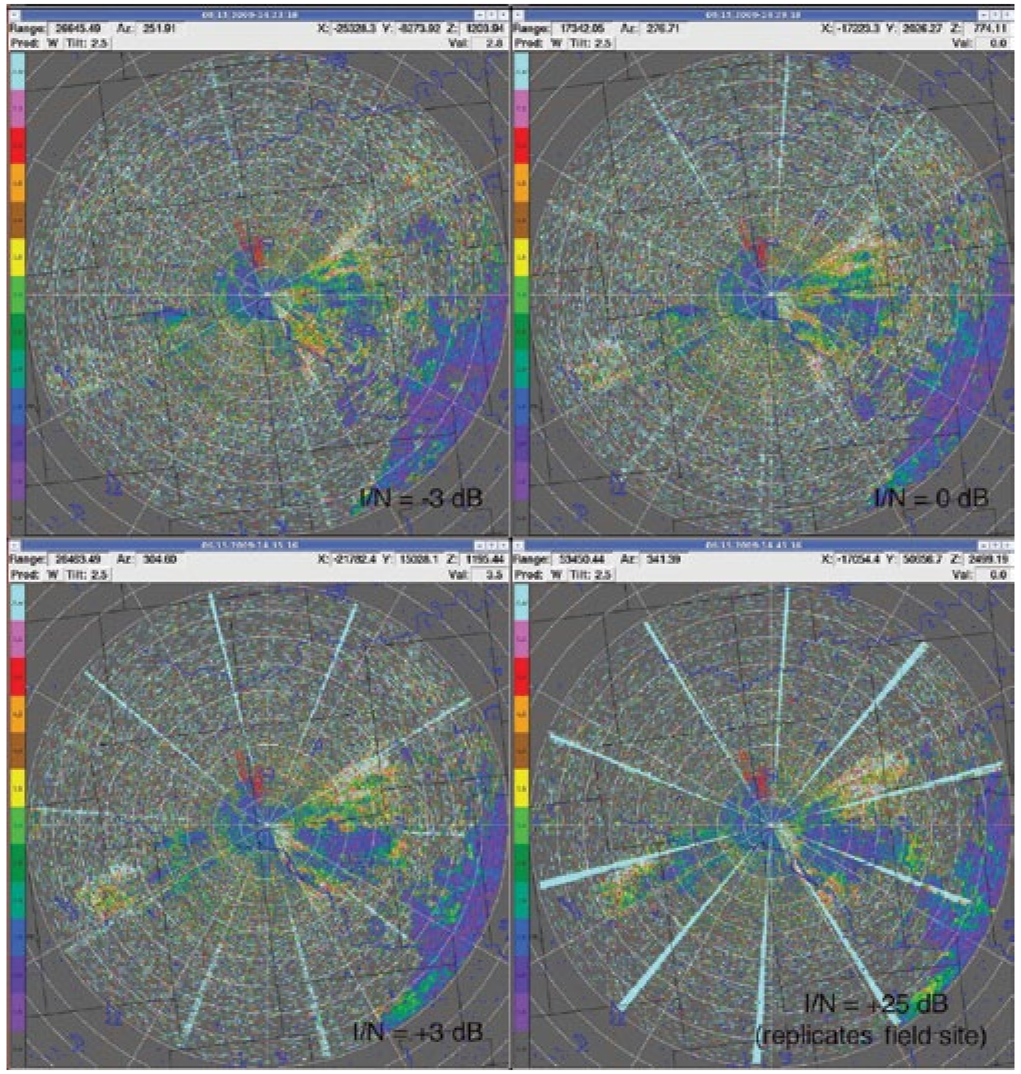
In 2010 it was determined that most models of DFS-equipped 5 GHz U-NII devices are operating properly; a small sub-set of models, however, were found to not detect in situ radar signals. Detailed tests and measurements on a variety of 5 GHz DFS U-NII devices at the ITS lab in Boulder demonstrated that the device models that were not detecting weather radars were nevertheless detecting DFS test-and-certification radar waveforms.

Resolving the Problem

Working together, NTIA (OSM and ITS), the Federal Communications Commission, the Federal Aviation Administration (FAA), and industry representatives of U-NII manufacturers developed a new set of radar waveforms to be used for certification purposes at the FCC laboratory. ITS engineers programmed the new waveforms in a vector signal generator, while U-NII manufacturers developed improved DFS radar-detection algorithms. The new certification waveforms were tested with new versions of 5 GHz DFS-capable U-NII devices at the ITS laboratory in Boulder. The results were successful; the data from the tests have been shared with the affected Federal agencies and industry, and follow-on field tests of the new versions of the DFS algorithms in new models of 5 GHz U-NII devices were planned for the early part of FY 2011 at an FAA radar facility in Oklahoma City.

Related Publication

J. E. Carroll, F. H. Sanders, R. L. Sole and G. A. Sanders, "Case study: Investigation of interference into 5 GHz weather radars from unlicensed national information infrastructure devices, Part I," NTIA Technical Report TR-11-473, Nov. 2010. ❖



Interference effects on a weather radar display. The bright lines, called strobes, are caused by test signals that replicate emissions from unlicensed devices. Interference effects occur when the emissions are 3 dB below the radar receiver noise floor. Actual interference at field locations has been documented by NTIA at 25 dB above the radar noise floor (lower right).

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Video Quality Research

Outputs

- *Digital video quality measurement technology*
- *Journal papers and national/international video quality measurement standards*
- *Technical input to development of U.S. policies on advanced video technologies*
- *Development, advancement, and maintenance of a national objective and subjective digital video quality measurement laboratory*

Overview

Service providers and end-users need objective video quality metrics for specifying system performance, comparing service offerings, performing network maintenance, and optimizing limited network resources (such as bandwidth). The goal of the ITS Video Quality Research project is to develop the required technology for assessing the performance of new digital video systems and to actively transfer this technology to other government agencies, end users, standards bodies, and the telecommunications industry, thereby producing increased quality of service, which benefits all end users and service providers.

Technical Solutions

ITS has developed new powerful measurement methods to assess the performance of digital video systems. These techniques have received four U.S. patents, been adopted as the North American Standard for measuring digital video quality (ANSI T1.801.03-2003), and have been included in five International Telecommunication Union (ITU) Recommendations (ITU-T Recommendation J.144, J.244, J.249, J.340, and ITU-R Recommendation BT.1683).

To facilitate the transfer of ITS-developed video quality metrics (VQMs) into the private sector, ITS has developed and maintains multiple software tools for 32-bit and 64-bit operating systems. The Command VQM (CVQM) tool provides a simple command line interface for processing (i.e., performing calibration and video quality measurements on) a pair of video files that have been captured from the video source and destination. The Batch VQM (BVQM) tool allows the user to perform Graphical User Interface (GUI) based batch mode processing of many captured video streams. The In-Service VQM (IVQM) tool performs in-service video measurements using PCs located at the source and destination ends. Three other software tools measure Peak Signal-to-Noise Ratio (PSNR), Fraction of Dropped Frames (FDF), and Variable Frame Delays (VFD). Source code and executable binaries of these tools are available on the ITS Web site and may be used royalty-free by all interested parties.

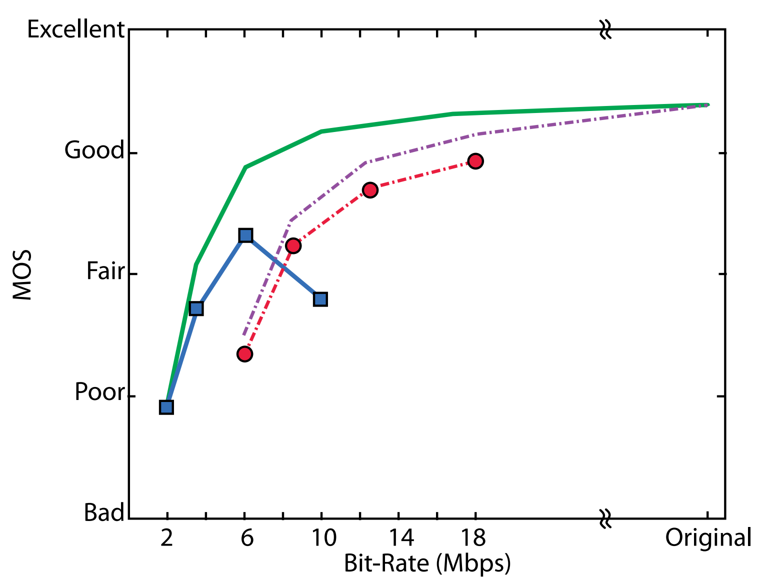

Figure 1. Mean Opinion Score (MOS) vs. Bit-Rate.

Figure 2. Stills from sample CDVL videos.

Industry Leadership

ITS enables standardization of video quality objective models by providing leadership and technical resources to the Video Quality Experts Group (VQEG). ITS provides the resources needed for models to be independently validated, which is a requirement for standardization. During FY 2010, this support was focused on the HDTV validation test and culminated in the publication of the HDTV Final Report on June 30, 2010. ITS staff chaired the HDTV committee, coordinated the validation effort, filmed many of the broadcast quality videos, and created video impairments for the validation effort. Algorithms developed by ITS enabled validation data from six subjective video quality experiments to be mapped into a single super-set of validation data, greatly increasing its usefulness. Five of the six HDTV experiments will be made available royalty free for research and development purposes in FY 2011.

ITS frequently collaborates with U.S. industry partners. In FY 2010, ITS and Verizon published the results of a joint effort that analyzed the comparative benefits of the MPEG-2 and H.264 video coding algorithms, both coding only and in the presence of transmission errors such as dropped packets. Partial comparison results from this study are shown in Figure 1, where H.264 coding-only is solid green, H.264 with 0.02% packet loss is solid blue/squares, MPEG-2 coding-only is dotted purple, and MPEG-2 with 0.02% packet loss is dotted red/circles. Subjective testing results partially uphold the commonly held belief that H.264 provides quality similar to MPEG-2 at no more than half the bit rate for the coding-only case. However, the advantage of H.264 diminishes with increasing bit rate and for the packet loss case, H.264 suffers a large decrease in quality whereas MPEG-2 undergoes a much smaller decrease.

ITS spearheaded the development of the Consumer Digital Video Library (CDVL) Web site (www.cdvl.org), which provides high quality uncompressed video scenes that may be freely used for research purposes. The new Web site assists industry and standardization efforts for improving video coding algorithms, video quality metrics, and video enhancement algorithms. Registered users may download videos, upload and share their test scenes, and participate in forum discussions. In FY 2010, ITS made over 1,000 source video scenes available for a wide variety of formats and applications. Stills from several of these sample CDVL videos are shown in Figure 2.

Further information can be found on the Video Quality Research home page at http://www.its.bldrdoc.gov/n3/video/index.php. ❖

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Broadband Wireless Research

Outputs

- *High-resolution propagation measurements performed using COTS EMC antennas*
- *Practical two-step measurement procedure demonstrated to be viable in Table Mountain test*
- *Useful propagation measurements and EMC test site validations tool for wireless and EMC engineers*
- *Method presented to IEC CISPR/A Working Group 1 as potential EMC test site validation tool*

Overview

The proliferation of short-range wireless devices highlights the need for practical methods of high-resolution channel sounding. This program has been developing a new technique to provide high-resolution short-range propagation measurements using ordinary commercial, off-the-shelf (COTS) electromagnetic compatibility (EMC) antennas such as biconical dipoles, log-periodic dipole arrays (LPDA), dipoles, and dual-ridge horns to perform high-resolution, time-domain channel sounding measurements. This is not a simple task, for two important reasons: these antenna types are not optimized for time-domain measurements, and they have temporally-extended impulse responses that prevent the separation and identification of reflections from nearby objects. ITS engineers have circumvented this problem by developing a two-step measurement procedure that removes the antenna impulse response and greatly enhances the range resolution in the acquired waveforms. This makes it possible to isolate and quantify scattering and propagation events.

Measurements

The measurement system consists of a vector network analyzer (VNA), a pair of COTS EMC antennas, an analog optical link, and interconnecting RF cables. The VNA performs stepped-frequency transmission measurements between the antennas, and the resulting S-parameter data are stored for subsequent post processing. Two sets of measurements are required: 1) the in situ test setup from which propagation parameters of interest are to be extracted, and 2) a free-space reference. The free-space reference is a transmission measurement between a pair of antennas without reflections from nearby reflectors such as ground, buildings, or trees.

Figure 1. Free-Space reference obtained with biconical antennas at the Table Mountain Field Site.

Figure 1 shows a free-space reference setup at the Table Mountain Field site for horizontally-polarized biconical antennas. Figure 2 shows an in situ measurement in an anechoic chamber using biconical antennas. Figure 3a shows the frequency-domain transmission data for both the free-space reference and the anechoic chamber of Figure 2. Figure 3b shows the dB difference between the chamber and free space reference, and it highlights degrading chamber performance with decreasing frequency. Figure 4a shows the corresponding time-domain transmission data waveform obtained in situ. This waveform can be enhanced using the free-space reference in conjunction with signal processing, improving both resolution and measurement fidelity. Figure 4b shows the enhanced waveform, with clearly defined scattering events followed by a large low-frequency resonance.

The results obtained to date show promise, and further tests are planned for FY 2011.

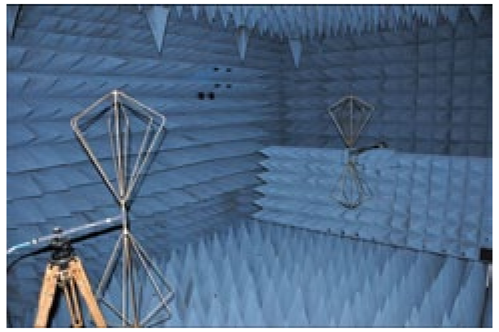
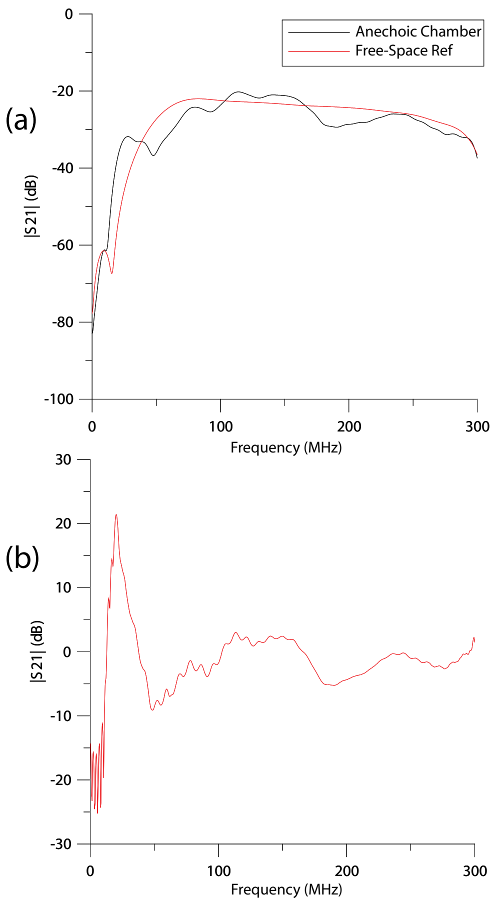


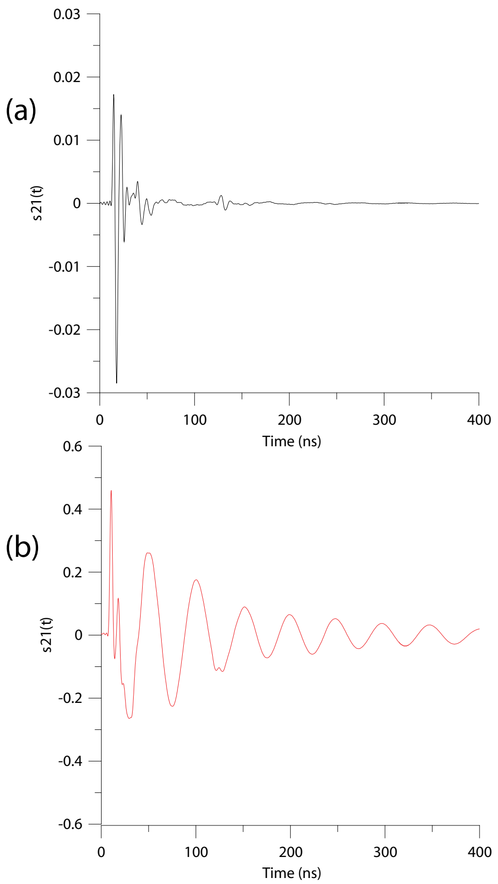
Figure 2. In situ test setup inside the NIST (Boulder) anechoic chamber.

Recent Publications

R.T. Johnk, J. D. Ewan, N. DeMinco, R. L. Carey, P. McKenna, C. J. Behm, T. J. Riley, S. Carroll, M. A. McFarland, J. W. Leslie, "High-resolution propagation measurements using biconical antennas and signal processing." in *Proc. of the IEEE International Symposium on EMC*, Jul. 2010, pp. 85 to 90. ❖



Left: Figure 3. (a) Transmission amplitude spectrum with vertically-polarized biconicals at a separation of d = 3 m inside an anechoic chamber and a gated free-space reference. (b) Normalized amplitude spectrum. Note the strong cavity resonance at 18 MHz.



Right: Figure 4. (a) In situ anechoic chamber waveform obtained with biconicals at a separation of d = 3 m. (b) Enhanced waveform. The decaying sinusoidal waveform is due to the 18 MHz chamber resonance.

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Lockheed Martin mobile lab and equipment trailers at the Table Mountain Field Site preparing to field test optical radar (LIDAR) instruments under a CRADA (photograph courtesy of Lockheed Martin Coherent Technologies).

The PROWLR system is able to detect chemical and biological hazards using LIDAR techniques. Here, the Lockheed Martin system is shown being tested against benign targets at the Table Mountain Field Site (photograph courtesy of Lockheed Martin Coherent Technologies).

Testing LADAR equipment in a mobile facility at the Table Mountain Field Site (photograph courtesy of Lockheed Martin Coherent Technologies).

Technology Transfer to Industry and Academia

Outputs

- *Cooperative research and development agreements with private companies and universities to perform telecommunications research and/or to use the Table Mountain Field Site for telecommunications-related research.*

"Technology transfer is the process by which existing knowledge, facilities, or capabilities developed under Federal research and development (R&D) funding are utilized to fulfill public and private needs."

Technology Transfer Desk Reference, Federal Laboratory Consortium for Technology Transfer (FLC)

Overview

The Federal Laboratory Consortium for Technology Transfer (FLC), formally chartered by Congress in 1974 to facilitate technology transfer in the U.S., is a network of over 250 Federal laboratories including ITS, and the only government-wide forum for technology transfer. The FLC promotes and facilitates technical cooperation among Federal laboratories, industry, academia, and State and local governments. The federal technology transfer program is designed to increase the return on investment of the federal R&D budget in ways that help federal agencies meet mission requirements while enhancing U.S. competitiveness in the world economy.

CRADAs

ITS participates in technology transfer and commercialization efforts through fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities, through making the Table Mountain Field Site available for research by industry and academia, and through other collaborative efforts.

ITS has participated for many years in cooperative research and development agreements (CRADAs) with non-Federal organizations to design, develop, test, and evaluate advanced telecommunication concepts, allowing Government expertise and facilities to be applied to interests in the private sector. CRADAs were authorized under the Federal Technology Transfer Act of 1986 (FTTA), as amended, to allow Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties that protect proprietary information, grant patent rights, and provide for user licenses to corporations. Not only does the private sector partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do. 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.

Table Mountain Field Site

While ITS often participates in CRADAs that involve performing measurements for an organization (thus transferring the Institute's knowledge and expertise), another common form of technology transfer utilized by ITS is to make the Table Mountain Field Site available for telecommunications research. Federal facilities such as Table Mountain often contain resources (or, as in this case, are resources) otherwise unavailable to small business and industry. The figures on the facing page show examples of work performed through CRADAs at this site. Active Table Mountain CRADAs in FY 2010 and publications resulting from them are described on page 12 and 13 in the Spectrum and Propagation Measurements section.

ITS is interested in assisting private industry in all areas of telecommunications. This Technical Progress Report reveals many technological capabilities that may be of value to private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology useful to them. Because of the great commercial importance of many new and emerging telecommunication technologies, ITS will continue to contribute to the rapid commercialization of these new technologies by pursuing technology transfer to the private sector through CRADAs. ❖

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ITU-R Standards Activities

Outputs

- *Technical support for U.S. Administration activities in ITU-R Study Group 3 and Working Parties 3J, 3K, 3L, 3M, 5B, 5D, and 6C*
- *Ongoing measurements of interference from/to radar systems and communications systems*
- *Development of a new version of ITU-R Recommendation M.1177, Procedures for the Measurement of Radar Emission Spectra*

International Telecommunication Union complex in Geneva, Switzerland (photograph by Tim Riley).

Overview

Success in worldwide telecommunications markets, as well as effective and compatible use of telecommunications technologies both domestically and abroad, is vital to the long-term economic health of the United States. To achieve these goals the U.S. Administration participates in the single most important worldwide telecommunications regulatory and standardization body, the International Telecommunication Union – Radiocommunication Sector (ITU-R), to further its objectives with regard to all forms of wireless communication on a global basis. ITS provides ongoing technical support to the U.S. Administration in ITU-R Study Groups 3 and 5 and their Working Parties; in particular, Working Parties 3J, 3K, 3L, 3M, 5B, 5D, and 6C.

Study Group 3

In the context of Study Group 3, ITS personnel serve as Chairmen of U.S. Study Group 3 and U.S. Working Party 3K, and Co-Chair of U.S. Working Party 3J. ITS personnel are also participants in the international meetings of Study Group 3 (Head of the U.S. Delegation) and Working Parties 3J, 3K, 3L, and 3M, where ITS personnel serve as Subgroup and Drafting Group Chairmen and Rapporteurs for Vocabulary. ITS personnel have contributed substantially to the Handbook on Propagation Information for Prediction of Interference and Coordination Distance, and have continued to work closely with the United Kingdom and German Administrations on further developments of Recommendation ITU-R P.533. ITS personnel continue to support the work of Rapporteur Group "Obstacle Diffraction" of Subgroup 3J-4 (formerly Correspondence Group 3K-1).

Working Parties 5B and 5D

In the context of Working Party 5D, an ITS engineer has provided technical support and participated as a member of the U.S. Delegation in national and international meetings of this Working Party during the current Study Period, 2008-2012 (see Interference Issues Affecting Land-Mobile Systems, page 36). As part of this work, this ITS engineer also communicated with other U.S. national standards bodies (e.g., ATIS).

In Working Party 5B, ITS engineers provide ongoing technical support to the U.S. Administration in areas including reallocation of radar spectrum, communications systems interference effects on radars, dynamic frequency selection technology for spectrum sharing between communications systems and radars, the development of radar emission spectra measurement techniques and the development of more efficient radar emission spectra criteria. In addition to activities in Working Party 5B, ITS engineers also participate in the Radar Correspondence Group and the Radar Unwanted Emissions Group. This year ITS engineers proposed a new version of Recommendation M.1177, "Techniques for measurement of unwanted emissions of radar systems;" the new version of the Recommendation was approved by Study Group 5.

Working Party 6C

ITS personnel presented two USA Contributions containing technical content to be used for the creation of two Preliminary Draft New Recommendations concerned with the measurement of video quality. The Contributions were accepted for further work in WP6C. An ITS staff member serves as the ITU-R WP6C Rapporteur for global video evaluation methodology landscape. The purpose of this position is to harmonize video quality activities among the ITU-T and ITU-R Study Groups working in the area of video/multimedia quality assessment. ❖

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ITU-T and Related U.S. Standards Development

Outputs

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

Margaret H. Pinson Co-Chairs the VQEG's HDTV Group at the Boulder meeting in January 2010.

Overview

The Institute has a long history of leadership, technical contributions, and advocacy of U.S. Government and industry proposals in the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) and related U.S. standards organizations. ITU-T is a specialized agency of the United Nations, responsible for developing the international standards (Recommendations) that providers use to plan, interconnect, and operate public telecommunication networks and services worldwide. ITU-T Recommendations strongly impact both the evolution of U.S. telecommunication infrastructures and the competitiveness of U.S. telecommunication products in international trade.

The Institute's long-term goal in ITU-T (and related national standards work) is to motivate the standardization of user-oriented, technology-independent measures of telecommunication service quality, and to relate those measures to the technology-specific performance metrics and mechanisms providers use to provision and operate networks. This work promotes fair competition and technology innovation in the telecommunications industry, facilitates inter-working among independently-operated networks and dissimilar technologies, and helps users define their telecommunication needs and select products and services that best meet them.

One way ITS promotes telecommunications standardization efforts is by accepting leadership roles in key standards development organizations (SDOs). In FY 2010, Institute staff members held several prestigious leadership roles including Chair of ITU-T Study Group (SG) 9 (Television and sound transmission and integrated broadband cable networks), Co-Chair of the ITU Video Quality Experts Group (VQEG), and Co-Chair of the Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). An ITS staff member served as Co-Chair of VQEG's HDTV Group and led the group's technical work to completion.

ITU-T Study Group 9

ITU-T Study Group 9 carries out studies on the use of telecommunication systems for broadcasting of television and sound programs and the use of cable television networks to provide interactive video services, telephone, and data services, including Internet access. Among the Recommendations standardized by ITU-T SG9 are those defining video and multimedia quality assessment and those supporting Emergency Telecommunications over broadband cable networks.

While this project provides input to the Alliance for Telecommunications Industry Solutions (ATIS), the Society of Cable Telecommunications Engineers (SCTE), the Internet Engineering Task Force (IETF), and the ITU-R, the majority of work is directed to ITU-T Study Group 9 and VQEG. In FY 2010, Arthur Webster served as international Chair of ITU-T SG9, which is responsible for broadband cable networks and television and sound transmission. Margaret Pinson co-chaired Question 12/9 (Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services) and served as Head of the U.S. Delegation to ITU-T SG9.

VQEG

An ITS staff member founded the Video Quality Experts Group and has co-chaired it since 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics (VQMs). The group's reports strongly impact the standardization of VQMs in both ITU-T and ITU-R. VQEG works largely via several e-mail reflectors, publicly accessible at http://www.VQEG.org. During FY 2010, the number of participants subscribed to the main reflector grew to over 650. VQEG produces independent validation data, which the U.S. considers to be a key prerequisite for standardizing a VQM. Thus, VQEG acts as a cooperative technical advisory committee that facilitates standardization efforts in ITU-T SG9, SG12 (Performance and Quality of Service (QoS)), and ITU-R WP 6C (Broadcasting Services—Programme Production and Quality Assessment) to develop objective, computer implementable, perception-based video and multimedia quality metrics that emulate the human visual system.

ITS staff members provide key leadership and technical contributions to VQEG. Arthur Webster co-chaired VQEG and chaired the two meetings that occurred in FY 2010—one of which was hosted by ITS at the Boulder Labs facility. Margaret Pinson co-chaired the HDTV effort (see the accompanying photograph), which finished the validation test for HDTV models in response to urgent industry requests. The completion of this test led to two Draft New Recommendations in ITU-T SG9. ITS also assisted in developing the Hybrid Perceptual Bit-Stream video test plan. Through the combined efforts of this and other ITS projects, the Institute provided key video source material that comprises most of the validation sequences used in the HDTV effort. ITS is spearheading new ITU-T work on audiovisual quality assessment through its leadership in VQEG.

JRG-MMQA

In related work, ITS leads the ITU-T's Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). This is a cross-cutting ITU-T standards body that unites the video quality expertise of SG 9 with the audio and network quality expertise of SG 12 in an effort to develop objective, perception-based metrics for combined audio and video signals in mobile and PC environments. The JRG-MMQA typically meets concurrently with VQEG. The JRG-MMQA provides an official mechanism for coordination of VQEG activities with ITU-T SG9 and ITU-T SG12.

Draft Recommendations

As mentioned above, FY 2010 saw the completion of VQEG's HDTV Project. The results of this validation test were reported to the ITU, and ITU-T Study Group 9 prepared two Draft New Recommendations based on VQEG's test results:

- J.vqhdtv-fr, "Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a full reference."
- J.vqhdtv-rr, "Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a reduced reference." ❖

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First leased for the purpose of performing radio experiments in 1954 and purchased by the government seven years later, the Table Mountain Field Site and Radio Quiet Zone now supports the fundamental research activities of ITS (which manages the site), NTIA, the National Oceanic and Atmospheric Administration (NOAA), the National Institute of Standards and Technologies (NIST), and the U.S. Geological Survey (USGS).

A view of the Public Safety Audio Laboratory (PSAL) showing some of the digital audio mixing, distribution, storage, and filtering equipment used in the investigation of the voice and video quality of public safety communication systems in harsh environments (photograph by D.J. Atkinson).

ITS Tools and Facilities

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. In turn, these capabilities support the development and verification of new quality estimation techniques for compressed digital audio and video, as well as the development of novel subjective testing techniques for audio and video signals, and efficient and robust coding algorithms.

Laboratory equipment supports standard-definition (SD) and high-definition (HD) video signals, as well as monophonic, stereophonic, and 5.1-channel audio streams. Signals are acquired with the highest quality microphones and cameras. Recording and playback devices include studio-quality analog and digital video tape recorders with two to eight audio channels, digital audio recorders, digital audio tape machines, and CD players. These systems are augmented with several digital audio and video workstations and numerous top-quality Analog-to-Digital and Digital-to-Analog converters.

Analog audio mixing, filtering, and equalizing equipment is available. An array of digital audio and video encoders and decoders are available as well as an HDTV modulator and demodulators. Analog and digital audio and video routing switchers and patch panels allow for nearly arbitrary interconnections between the various pieces of equipment. Reproduced signals are presented through studio quality video monitors, monitor loudspeakers, headphones, or handsets.

Three separate rooms with controlled visual and/or acoustic environments are available for the subjective testing of audio and video signals. The controlled environments are specified in ITU-T Recommendation P.800 and ITU-R Recommendation BT.500, respectively. These specifications address background noise levels, wall colors, light levels, room dimensions, and other properties. The labs feature an array of audio and video signal generators and analyzers to support laboratory measurement and calibration activities. Computers play a key role in laboratory operations. Four systems offer the ability to record and play uncompressed digital audio bit-streams together with synchronized uncompressed SD and HD video bit-streams that conform to ITU-R and SMPTE Recommendations (e.g., SMPTE 259M/272M, 292M). Audio and video processing is performed on high-performance workstations, supported by high-capacity RAID arrays for storage of the uncompressed audio and video streams.

Lab activities include objective estimation of audio and video quality and subjective testing of audio and video quality. Random access digital audio-video playback systems coupled with discrete-time and continuous-time wired and wireless electronic data entry systems greatly facilitate many of the subjective testing activities. Because multiple 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++ and MATLAB®, processes video signals in accordance with ANSI T1.801.032003, ITU-T Recommendation J.144, and ITU-R Recommendation BT.1683, resulting in estimates of video quality that show good correlation with subjective test results. Several different objective speech and audio quality estimation algorithms are available, including those defined in ANSI T1.518, ITU-T Recommendation P.862, and ITU-R Recommendation BS.1387. The labs support both batch-mode and real-time objective quality estimation.

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Automated Wideband Noise Measurement System

To address a renewed interest in measuring, quantifying, and modeling man-made radio noise, ITS developed an automated wideband noise measurement system. The measurement system consists of an antenna, ITS custom-built preselector, vector signal analyzer (VSA), and personal computer. The cornerstone of the system is the VSA that permits wideband noise measurements in up to 36 MHz of bandwidth and the recording of digitized in-phase/quadrature (I/Q) samples of the entire noise signal.

The capability of this system to record actual I and Q signal data in a wide bandwidth provides many options as to how the data can be processed and further utilized. The preselector contains a fixed bandpass filter tuned to the measurement frequency, a low pass filter, and a low noise amplifier (LNA). The filters can be easily exchanged (or replaced by a tunable bandpass filter) to conduct noise measurements at different frequencies. This configuration provides for a very sensitive measurement system with a noise figure (NF) of approximately 3dB. The system uses a quarter-wave monopole antenna, tuned to the desired measurement frequency and mounted on a ground plane.

The personal computer is used to run software developed by ITS to control the noise measurement. This software allows the user to set the measurement frequency, bandwidth (span), number of data points, and other parameters. Once the measurement is started, it will automatically collect data at user-defined time intervals for a user-specified duration. The software can also perform and display results of noise diode calibrations, spectrum captures, and single, manual noise measurement data captures. To provide a high degree of RF shielding between the measurement equipment and the antenna, as well as AC power, temperature control, and shelter, the noise measurement system is currently housed in the RSMS-4G measurement vehicle.

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Boulder Labs Frequency Manager

An ITS staff person acts as the Boulder Labs Frequency Manager, chairing the Boulder Labs Interference Committee. This committee protects the Department of Commerce Boulder Laboratories campus and the Table Mountain Radio Quiet Zone facilities from harmful radio frequency interference by evaluating new transmitters before they begin operating. Propagation analyses using various propagation prediction models or field measurements may be required in order to resolve potential electromagnetic interference problems.

The Committee has jurisdiction over all government and private industry users seeking permission for frequency usage at the Table Mountain Radio Quiet Zone, and over stations in the area that meet the following conditions of effective radiated power (ERP) and radial distance:

- All stations within 2.4 km.
- Stations with 50 W or more ERP within 4.8 km.
- Stations with 1 kW or more ERP within 16 km.
- Stations with 25 kW or more ERP within 80 km.

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Digital Sampling Channel Probe

The digital sampling channel probe (DCP), designed and patented by ITS, is used to characterize wideband propagation characteristics of the radio channel. Consisting of a transmitter, receiver, and data acquisition system, the DCP is used to make impulse response measurements. The DCP can be configured to transmit orthogonal pseudo noise codes at the same RF frequency for MIMO studies or variable rate codes at multiple RF frequencies.

The DCP receiver down-converts and digitizes the pseudo-noise signal at an intermediate frequency (IF) and then post-processes the data to calculate the channel impulse response. The system can collect data on 1-8 channels every 600-800 µs, allowing characterization of the Doppler spectrum and time variability of the mobile channel for systems up to 5.8 GHz.

Historically, the DCP was employed for channel characterization of cellular and personal communications services. ITS has expanded the probe to eight channels for mobile phased array or MIMO measurements. The mobile probe's measurement range has also been extended down to the UHF TV bands, where it has been used for short-range mobile to mobile channel characterization. In this mode of operation a variable bit rate code generator is used to allow simultaneous recordings at different bandwidths and frequencies. Also available is a high-frequency probe, particularly suited for high resolution requirements such as wireless local area network (LAN) applications at carrier frequencies up to 30 GHz and bandwidths up to 500 MHz. For more information, see http://flattop.its.bldrdoc.gov/rcirms/

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Green Mountain Mesa Field Site

The Green Mountain Mesa Field Site is located on the main Department of Commerce Boulder Laboratories campus. The site is used year round for outdoor wireless network research and was extensively refurbished in FY 2010. Improvements included installation of a portable building situated on a concrete pad to securely house the fiber and power distribution. A new 55' tower was also constructed and raised to support research and evaluation of LTE (Long Term Evolution), a 4th generation wireless technology.

The site is connected to the ITS laboratories via both fiber optic and 802.11 links. The new tower also supports a microwave link to the Table Mountain Field Site. The fiber optic link provides access to the ITS local area network (LAN) while the 802.11 link connects this field site to the ITS Wireless Networks Research Center. The site can provide six independent duplex fiber channels to the ITS lab. This allows research to be conducted over an isolated one-mile outdoor Wi-Fi link. The fiber connectivity provides a LAN connection to the outdoor wireless router and the capability to operate remote data collection equipment. The outdoor router, located on an 80-foot tower, provides long-range 802.11 links to other sites. These links provide 802.11b services and are also used for network performance testing. The site's unique location, several hundred feet above the main Department of Commerce campus, allows for the provisioning of wireless test links over a large portion of eastern Boulder County.

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High Performance Computing Cluster

The HP BLADE computing cluster is an extensible platform with many CPU cores and a lot of memory. It is primarily used for running signal propagation prediction models with large amounts of terrain data in parallel. The cluster allows researchers to make significant progress towards achieving real-time results that are highly desirable for many consumers of propagation modeling data. Customized software developed at ITS allows this capability to be leveraged for ITS and joint research projects in many ways. The cluster runs both GNU/Linux and Windows Server and also has the capability for virtualization of many client operating systems. The BLADE is housed inside a climate controlled server room with high available power and battery power backup. There is sufficient capacity to enable rapid response to new computing challenges with new hardware or techniques. The servers all include redundant disk arrays, and backup to a large disk store. The room itself is physically secured through an access control and security system that logs entry by authorized personnel.

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ITS Internet Services

ITS provides public Internet access to NTIA/ITS publications, program information, meeting information, and online resources, for use 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 standards committees. Highlights of ITS Internet Services include:

- Information about ITS programs and projects at http://www.its.bldrdoc.gov/programs/
- An ITS organization chart and listing of ITS staff with contact information at http://www. its.bldrdoc.gov/organization.php.
- Recent ITS publications including NTIA Reports, special publications, and journal articles at http://www.its.bldrdoc.gov/pub/pubs.php
- Radio propagation data at http://www.its.bldrdoc.gov/data/radio_propagation_data/
- Radio propagation software at http:// www.its.bldrdoc.gov/software/.
- Information about the Table Mountain Field Site at http://www.its.bldrdoc.gov/table_mountain/
- Audio Quality Research at http://www.its.bldrdoc.gov/audio/
- Video Quality Metric software at http:// www.its.bldrdoc.gov/n3/video/vqmsoftware.htm
- Information about ITS-sponsored events such as ISART and ITS-led Study Groups at http://www.its.bldrdoc.gov/meetings/.

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Public Safety Audio and Video Laboratories

One of the most challenging aspects of public safety communication is the harsh noise environment in which public safety practitioners must effectively establish and conduct voice communications. The Public Safety Audio Laboratory (PSAL) and Public Safety Video Laboratory (PSVL) are facilities for investigating the voice and video quality of public safety communication systems in harsh environments. The PSAL consists of digital systems for mixing, storage, and distribution of audio; sound attenuated chambers for effective isolation; and International Telecommunication Union (ITU)-compliant head and torso simulators (HATS) for acoustic coupling to radio interfaces. The PSVL consists of cameras, video capture systems, video coding and decoding systems, network simulators, video editing stations, and props.

The PSAL is built on a foundation of digital audio mixing and distribution. All audio mixing, distribution, storage, and filtering are conducted in the digital realm with 48 kHz-sampled audio. This provides a high-quality, distortion-free distribution system that is not impacted by other equipment in the laboratory. The digital capabilities include: digital mixing, 24-track digital recording, 8-channel digital input and output to Windows-based computers, digital audio tape (DAT), and 1/3 octave digital filters. Usage of analog audio signals is kept to a minimum by 1) digitizing analog inputs at the input and keeping them digital throughout any processing, and 2) only performing digital-to-analog conversion on signals that are to be converted to acoustic signals.

The more specialized equipment in the PSAL includes the two HATS systems. The HATS systems are defined by the ITU in Recommendations P.58 (Head and torso simulator for telephonometry), P.57 (Artificial ears), and P.51 (Artificial mouth). These recommendations specify the physical characteristics and acoustical/electrical interface characteristics that enable a consistent simulation of the speaking and hearing frequency responses of the “average” human. The HATS enable consistent acoustic input to communications equipment under test and provide a “willing subject” that will not be subject to hearing loss when exposed to harsh noise environments for extended periods.

The PSAL system provides a reproducible acoustic path that enables emulation of the harsh noise environments encountered by public safety practitioners. The recorded output from the system can be used in a number of ways. For example, the recordings might be analyzed by an objective measurement technique such as that defined in ITU Recommendation P.862 (Perceptual evaluation of speech quality (PESQ): an objective method for end-to-end speech quality assessment for narrow-band telephone networks and speech codecs). Alternatively, the recordings might be incorporated into a subjective test experiment where listeners will rate the quality of the audio.

The primary role of the PSVL is to support the PSVQ project. In accomplishing this mission, scenes that contain selected vital elements of public safety responder uses are created and filmed on high-definition cameras. These scenes include simulations of surveillance cameras (indoor and outdoor), in-car police cameras, and search and rescue robot cameras, among others. The video is then captured and edited on the PSVL workstations. Selected scenes are processed through controlled versions of the communication systems that might be typical of what a jurisdiction might consider purchasing. The communication systems processing includes compression schemes and simulated wired and wireless networks.

To determine if a system is adequate for use in specified applications, first responders view the video and attempt to perform certain tasks such as identifying an object or reading a license plate. The results of these tests provide data for developing recommendations. Together, the PSAL and PSVL provide valuable insight into the requirements for public safety audio and video communications.

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Public Safety RF Laboratory

ITS’s management of the Public Safety RF Laboratory (PSRF Lab) encompasses several different but related technical efforts. One effort involves land mobile radio (LMR) systems and components testing in accordance with the Telecommunications Industry Association (TIA) Project 25 (P25) testing standards (TIA 102) for common air interface (CAI) performance, conformance, and interoperability. ITS’s PSRF Lab contributes to those three facets of the P25 CAI testing standards in order to further the goals of the Project 25 Compliance Assessment Program (P25 CAP).

The PSRF Lab is also involved in the development of interface testing regimens for the P25 inter-subsystem interface (ISSI). To facilitate this technical effort, several multi-site, multi-channel demonstration trunking systems have been installed, using commercial-off-the-shelf (COTS) components from different manufacturers. This research and development trunking system installation was recently expanded through a contract award to an additional P25 trunked infrastructure manufacturer and system integrator.

The LTE Test Bed is another active effort to support the development of new public safety mobile communications technologies. The PSRF Lab hosts this test bed so that manufacturers may use it to hone public safety mobile communications products incorporating LTE, a new generation of mobile broadband access technology, before they are brought to market.

While the PSRF Lab’s test and measurement capability is primarily intended to support development and maturation of public safety mobile communications technology, the underlying infrastructure and analysis facilities can support a much broader range of tests and radio equipment. This excess capability is available to other federal agencies on a first-come, first-served basis.

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Pulsed Radar Target Generator

The Pulsed Radar Target Generator is an electronic tool used to produce targets on a radar screen. The generator produces signals that simulate the returns that would normally be seen by a radar from targets in the environment. The signals are injected into the radar’s receiver at the normal frequency of operation. Some radar models transmit modulated pulses. The generator can produce modulated pulses such as chirped and phase coded modulations (including the popular Barker code set). Several parameters of the signals can be adjusted over a wide range to be compatible with several different radar models. For the same model radar, the number of targets and the range to the targets can be adjusted. Other adjustments include the displayed bearing of the targets and whether the targets are stationary or moving along concentric circular paths. Compensation adjustments can be made for radars that have large tolerances in their operating specifications. The targets can be set to occur at a fixed time interval after a timing pulse (for example, beginning of scan) supplied by the radar. The generator can be used to verify operation or troubleshoot the radar under test. ITS has used the generator to provide simulated desired signals in interference studies where interference is injected into the radar and the effect on the targets is recorded.

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RSMS System Tools

The Radio Spectrum Measurement Science (RSMS) system is a unique, state-of-the-art measurement system designed for gathering information about spectrum occupancy, equipment compliance, electromagnetic compatibility, and interference resolution. The system allows ITS to provide the National Telecommunications and Information Administration (NTIA) with critical measurement support for determining policies regarding government radio systems and spectrum utilization. The RSMS system is a dynamic and flexible system that incorporates automated, semi-automated, and manual techniques for the measurement and analysis of radio emissions. While not defined by any single hardware configuration, the system employs state-of-the-art spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal intercept and collection systems. The system is designed to be sufficiently flexible to accommodate the taking of mobile or stationary measurements, in a laboratory or in the field.

An integral part of the system is the measurement vehicle itself, now in its 4th generation. The vehicle has a highly shielded enclosure (60 dB isolation) with three full size equipment racks, three 10-meter telescoping masts, a 20-kW diesel generator, Internet connections, fiberoptic control lines, and a climate control system. The control and acquisition software is entirely developed by ITS so new and innovative measurement techniques can be easily introduced to meet immediate needs. A major objective in the development of the 4th generation software was to provide the ability to easily accommodate new equipment and different hardware configurations as needed to expand on existing measurement capabilities.

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Radio Propagation Measurement Capabilities

ITS maintains and develops both static and mobile propagation measurement systems that address a number of wireless propagation scenarios, covering a frequency range of 20 MHz to 30 GHz. The mobile propagation system is deployed on two vehicles: a transmitter truck and a receiver van. The transmitter truck has an on-board generator, a pair of telescoping masts, RF transmitters, associated modulators, and a precision rubidium clock. The receiver van contains seven antennas mounted on a large aluminum ground plane, receiver racks, a multi-channel digitizer, spectrum analyzers, and an on-board generator. The van has a GPS navigation system with a dead-reckoning backup. The system can be operated in two different modes: 1) spectrum analyzer 2) broadband channel probe. In mode 1, a continuous-wave (CW) signal is transmitted and commercial-off-the-shelf (COTS) spectrum analyzers are used to receive the transmitted signal and measure total channel power. The received power levels are post processed to yield accurate path loss and evaluate slow-fading effects. This mode has high dynamic range, sensitivity, and excellent immunity to interference. The system can also be operated as a broadband channel probe by applying binary phase shift keying (BPSK) modulation to the transmitted signal using a 511-bit pseudorandom number code. This signal is down-converted to a 10 MHz intermediate frequency and captured using a high-speed digitizer. The data are then post-processed to yield a channel impulse response from which useful channel parameters (e.g. delay spread, basic path loss) can be read. This system is currently configured to measure up to four channels simultaneously. It has the capability of measuring both fast- and slow-fading phenomena as well as path loss

A narrowband mobile propagation measurement system is currently under development based on a combination of a communications receiver and a computer sound card. The system transmits a CW signal into the environment that is received by a communications receiver. The audio output of the receiver is, in turn, fed into an external sound card which digitizes the signal. The digitized signal is sampled at a sufficiently high rate to capture the fast variations in the signal. The signal can be post-processed to study fast- and slow-fading phenomena (shadowing, diffraction, Doppler spreading). Path loss can also be calculated if a suitable calibration is performed.

Over the past two years, a new ultra-wideband propagation measurement system has come on line. It consists of a COTS vector network analyzer (VNA), transmit and receive antennas, and an analog optical link. The VNA is configured to perform 2-port S-parameter transmission measurements between fixed transmit and receive antennas. The system covers a frequency range of 20 MHz to 18 GHz and is used to measure time- and frequency-domain propagation phenomena at distances of 2-300 m. It is configured in a stepped-frequency mode, and S21 data are acquired and stored. The resulting frequency-domain data are post-processed, inverse Fourier transformed, and gated to yield propagation parameters such as delay spread and basic path loss. This system has high accuracy and is ideal for precision propagation measurements and model development/validation. The frequency- and time-domain signal processing yield high-dynamic range and excellent immunity to RF interference. The system transmits very low power levels (typically +5 dBm) and has low interference potential to existing wireless services. It has been used extensively for near-earth propagation measurements at Table Mountain with excellent path loss and channel impulse response data obtained. This system also has excellent range resolution capabilities that permit the isolation and evaluation of selected propagation events. Plans are currently being made to perform indoor and building penetration measurements using this system.

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SIPRNet Capability

ITS maintains a connection to the Secret Internet Protocol Routable Network (SIPRNet). This connection provides ITS sponsors and Department of Defense users direct access to ITS tools and facilities in a secure environment, improving the quality of support that the Institute can give organizations with classified needs.

The SIPRNet capability provides a secure environment within which project planning and associated support activities can be carried on without interruption for agencies that require related discussions and data transfer to take place over a classified channel. ITS maintains several computer systems with a variety of software capabilities to support propagation planning and modeling, as well as emerging technologies research. The secure facilities allow users to import data from many military facilities and support organizations into propagation models and other management software, delivering complete end-to-end propagation planning capability in a secure environment. Research studies conducted by ITS that have been rated as classified information can also reside on the SIPRNet, allowing access by other agencies on a need-to-know basis.

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Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older systems can result in electromagnetic compatibility (EMC) problems. Although theoretical models and simulations provide useful information in guiding design decisions, the complexity of modern systems and the existing spectral environment often require real-world measurements of a system's effects within its actual or proposed operating environment to determine its impact on other radio spectrum users. It may also be necessary to produce controlled interfering signals with known characteristics in environments where suspected interferers may be unavailable for tests and measurements. This includes situations such as laboratory investigations of possible interference from ship or aircraft-mounted radars or terrestrial or space-based communications systems. In these situations, a system is needed that simulates the spectral emissions of other devices with a wide range of latitude and fidelity.

ITS engineers have developed two approaches to generating interference signals. One is to build custom-hardware and software combinations of discrete-component equipment, including programmable arbitrary waveform generators, mixers, RF signal generators, and amplifiers. ITS has used a number of these configurations to simulate the spectral output of a wide variety of communication systems. These signals can be coupled directly into a system under test or they can be transmitted through space into a target system's receiver to more accurately gauge its response to a real interference situation. The second approach for generating interference is to use high-speed digitizers, called vector signal analyzers (VSAs), to record interference waveforms in bandwidths up to 36 MHz, and to then either radiate or hardline-couple those waveforms into victim receivers using vector signal generators (VSGs) that operate somewhat as inverses to VSAs. Alternatively, VSGs may be pre-programmed with the requisite mathematical information to create particular waveform modulations, such quadrature phase shift keyed (QPSK) signals.

ITS VSGs can be used in conjunction with high-power amplifiers to generate interference signals at high power at frequencies as high as 26 GHz. The advantages of using VSGs to generate interference include simplicity of operation and use, plus the ability to replicate very complex interference waveforms with complete confidence in the fidelity of the simulated signal to the characteristics of the original signal from which it was derived.

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Table Mountain Field Site and Radio Quiet Zone

Established in 1954, the Table Mountain Field Site and Radio Quiet Zone is a unique radio research facility. Located north of Boulder, the site extends about 2.5 miles north-south by 1.5 miles east-west, and has an area of approximately 1,800 acres. The site is designated as a Radio Quiet Zone where the magnitude of strong, external signals is restricted by State law and Federal Regulation to minimize radio-frequency interference to sensitive research projects. Facilities at the site include:

- Spectrum Research Laboratory—A state-of-the-art facility for research into radio spectrum usage and occupancy. Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other.
- Open Field Radio Test Site—Table Mountain, a flat-topped butte with uniform 2% slope, is uniquely suited for radio experiments. It has no perimeter obstructions and the ground is relatively homogeneous. This facilitates studying outdoor radiation patterns from bare antennas or antennas mounted on structures.
- Mobile Test Vehicles—There are several mobile test equipment platforms available at the site, ranging from four-wheel drive trucks to full-featured mobile laboratories.
- Large Turntable—A 10.4-meter (34-foot) diameter rotatable steel table mounted flush with the ground. Laboratory space underneath houses test instrumentation and control equipment, and motors to rotate the turntable. The facility can be operated remotely by computer.
- 18.3-Meter (60-Foot) Parabolic Dish Antennas—These two antennas are steerable in both azimuth and elevation and have been used at frequencies from 400 MHz to 6 GHz.
- Radar Test Range—A large space just south of the Spectrum Research Laboratory is available for testing radar systems.

The Table Mountain Research program supports a number of research activities, e.g., studying the effects of radio propagation on digital signal transmission, environmental and man-made noise, verification of antenna propagation models, and the development of measurement methods needed to assess efficient spectrum occupancy and usage. Partnerships and cooperative research activities with other agencies are encouraged at the site. Learn more online at: http://www.its.bldrdoc.gov/table_mountain.

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Telecommunications Analysis Services

The Telecommunications Analysis (TA) Services program provides the latest ITS-developed engineering models and research data to industry and other Government agencies via the Web at: http://tas.its.bldrdoc.gov. 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: online terrain data with 1-arc-second (30 m) resolution for CONUS and 3-arc-second (90 m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; U.S. Census data for 2000, 1997 update, and 1990; FCC databases; and GIS databases (ArcInfo). TA Services has developed models that predict communication system coverage and interference for many broadcast applications. New models in the GIS environment have been developed. Programs available through TA Services include:

- 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 (LOS) 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 U.S. using digitized topographic data. The program 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.
- TERRAIN—Plots terrain elevation contours from any of the terrain databases available (1-arc-second Spatial Data Transfer Standard for CONUS, 3-arc-second U.S. Geological Survey, and GLOBE for the whole world).
- COVERAGE—Calculates the received 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 (ITM) can be chosen for calculations.
- CSPM—Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity. 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 the ITS ITM in a point-to-point mode, or other user-chosen algorithms for path loss calculation.
- HDTV—Allows users to analyze interference scenarios for proposed digital television (DTV) stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all program users. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in his/her catalog.
- NWS—A specialized application that helps the National Weather Service maintain its catalog of weather radio stations (currently about 920).
- PBS—An analysis model similar to the HDTV model, but specialized for Public Broadcasting Services (PBS) stations. 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.
- ICEPAC/VOACAP/REC533—High frequency prediction models that can be downloaded free and executed on Windows based platforms.
- ITM—Source code available for the ITS Irregular Terrain Model (Longley/Rice).
- IF-77—Source code available for the IF-77 Air/Ground, Air/Air, Ground/Satellite prediction software (.1 to 20 GHz).

Learn more about Telecommunications Analysis Services online at: http://tas.its.bldrdoc.gov.

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Wireless Networks Research Center

The Wireless Networks Research Center (WNRC) provides a common laboratory area for research in wireless networks and wireless network access technologies. The WNRC allows ITS to consolidate efforts in several areas, such as the RF/network interface. This work uses RF link characterization correlated with low-level network management protocols to develop PCS-to-PCS interference models, wireless network propagation models, noncooperative wireless measurement, and wireless network discovery. RF/network interface measurement devices are used to make detailed measurements of PCS and cellular networks. One device uses a series of PCS/cellular phones to extract low-level protocol messages, network management information, and RF signal quality parameters. Another has the ability to perform provider-independent PN offset scans and CDMA2000 level 3 message logging.

The WNRC contains an experimental IEEE 802.11b wireless local area network (WLAN). ITS has conducted a series of wireless Voice over IP (VoIP) tests utilizing this infrastructure. The WLAN resources include IP packet logging equipment that can be used in network measurements. A code domain analyzer (CDA) measurement capability, used to collect both short and long term Walsh channel data for any target IS-95 base station, has been added to the WNRC. The CDA operates in both the cellular and PCS frequency bands and can be used in fixed or mobile environments. The WNRC is used to conduct ITS work in the area of inter-PCS interference, in support of the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSCRAN. ITS also has the capability to simulate PCS interference using a series of ITS implemented interference models.

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(303) 497-3640, cbehm@its.bldrdoc.gov
or: Timothy J. Riley
(303) 497-5735, triley@its.bldrdoc.gov ❖

Engineers from ITS and NIST set up equipment in the PSCR Broadband Demonstration Network, one of several component projects of the overall Public Safety Telecommunications Interoperability project being carried out in collaboration with NIST/OLES (photograph by K.R. Tilley).

The Consumer Digital Video Library (CDVL) Web site (www.cdvl.org) went live in November 2009. The site provides access to high quality uncompressed video scenes that may be freely used for research purposes and is maintained by the Video Quality Research Project.

An ITS engineer setting up a receive antenna inside a NASA facility in preparation for radio frequency testing during an interagency project (photograph by J.D. Ewan).

ITS Projects in FY 2010

NTIA Science and Engineering Projects

Audio Quality Research

Develop and evaluate new techniques for encoding, decoding, and analyzing speech signals. Provide algorithms, software, and technical expertise to other ITS programs. Provide technical presentations and laboratory demonstrations as requested.

Project Leader: Stephen D. Voran
(303) 497-3839, svoran@its.bldrdoc.gov

Broadband Wireless Research

Deploy state-of-the-art measurement systems for collecting broadband radio-wave propagation data, to promote spectrum extension, aid in the development of 3G and 4G cellular systems, and evaluate proposed short range unlicensed device interference.

Project Leader: Dr. Robert Johnk
(303) 497-3737, bjohnk@its.bldrdoc.gov

Broadband Wireless Standards

Provide leadership and technical support to committees (e.g., ITU-R SG 3/WP 3K, 3J, 3M, and 3L, TIA TR-8) developing broadband wireless communications standards that affect Federal agencies' use of the services. Building on previous ITS work, develop model comparisons for each propagation model.

Project Leader: Paul M. McKenna
(303) 497-3474, pmckenna@its.bldrdoc.gov

Effects of the Channel on Radio Systems

Identify, model, and characterize a small number of radio systems and use these to predict the effects of the channel on others. Use the results to predict how interference introduced by new spectrum engineering methods impacts legacy systems.

Project Leader: Robert J. Achatz
(303) 497-3498, rachatz@its.bldrdoc.gov

Multimedia Quality Research

Develop a subjective methodology to measure audiovisual quality. Create a single, cohesive audiovisual model, that objectively predicts multimedia quality through a combination of audio quality, video quality, and audiovisual synchronization information.

Project Leader: Arthur A. Webster
(303) 497-3567, awebster@its.bldrdoc.gov

Network Performance

Provide objective, expert leadership and key technical contributions in ITU-T and related U.S. industry committees responsible for developing broadband network performance, Quality of Service (QoS), and resource management standards.

Project Leader: Arthur A. Webster
(303) 497-3567, awebster@its.bldrdoc.gov

Networking Technology

Research, develop, and demonstrate state-of-the-art methods and tools related to the measurement of wireless data networks, such as wireless local area networks (WLANs) and the use of software-defined radios (SDR) as dynamically reconfigurable wireless network testing tools.

Project Leader: Dr. Robert Stafford
(303) 497-7835, stafford@its.bldrdoc.gov

Noise and Spectrum Occupancy Measurement Research

Characterize and track over time the levels of radio channel noise in various frequency bands and environments. Identify areas of greatest need, design and implement systems to perform measurements in those areas, and report on the results. Conduct spectrum usage surveys.

Project Leader: Jeffery A. Wepman
(303) 497-3165, jwepman@its.bldrdoc.gov

RSMS Enhancements

Support RSMS operations through the development and maintenance of software, hardware, systems, and equipment.

Project Leader: John E. Carroll
(303) 497 3367, jcarroll@its.bldrdoc.gov

RSMS 4th Generation Development

Provide new and innovative measurement hardware and software tools for current and future RSMS capabilities. Project future needs and develop long-term strategies for building the necessary tools.

Project Leader: J. Randy Hoffman
(303) 497-3582, rhoffman@its.bldrdoc.gov

RSMS Operations

Provide NTIA with critical measurement support to determine radio spectrum usage 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.

Project Leader: John E. Carroll
(303) 497-3367, jcarroll@its.bldrdoc.gov

Table Mountain Modernization

Maintain and upgrade the Table Mountain Field Site infrastructure, ensure a safe working environment there, and provide logistical support for research activities at the field site.

Project Leader: J. Wayde Allen

(303) 497-5871, wallen@its.bldrdoc.gov

Table Mountain Research

Utilize the Table Mountain Field Site and Radio Quiet Zone to support fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services in order to expand ITS's knowledge base, identify emerging technologies, and develop new measurement methods.

Project Leader: J. Wayde Allen

(303) 497-5871, wallen@its.bldrdoc.gov

3rd Generation Wireless Interference Modeling and Characterization

Present technical contributions on PCS interference effects to ATIS Technical Subcommittee WTSCRAN. Contribute to related fora (e.g., ITU-R Working Parties 5D, 3K, and 3M) as appropriate. Develop a technology-independent, multi-channel PCS interference model for use in the evaluation of CMRS and other potentially affected (e.g., public safety) systems.

Project Leader: Timothy J. Riley

(303) 497-5735, triley@its.bldrdoc.gov

Video Quality Research

Develop technology for assessing the performance of digital video transmission systems. Improve measurement technology for multimedia definition (MD) and high definition (HD) video systems. Facilitate the development of international video quality measurement standards by participating in both the Independent Lab Group (ILG) of the Video Quality Experts' Group (VQEG) and as a proponent for new reduced reference (RR) measurement technology for standard definition (SD) and HD TV systems.

Project Leader: Stephen Wolf

(303) 497-3771, swolf@its.bldrdoc.gov

NTIA/OSM Projects

2.7 GHz Out of Band Interference

Perform measurements and analysis of electromagnetic compatibility (EMC) issues between incumbent radar systems in the 2.7-2.9 GHz spectrum band and other, non-radar transmitter systems that are operating in adjacent spectrum.

Project Leader: Frank H. Sanders

(303) 497-7600, fsanders@its.bldrdoc.gov

Bin 1 Waveform

Develop new bin 1 waveforms for by the FCC in conducting compliance tests on Unlicensed National Information Infrastructure (U-NII) devices that use dynamic frequency selection (DFS).

Project Leader: Geoffrey A. Sanders

(303) 497-6736, gsanders@its.bldrdoc.gov

Radar Support Tasking

Support USWP8B, USJRG, and the U.S. Administration's positions in ITU-R WP8B and Joint Rapporteur Group (JRG) 1A-1C-8B by providing position papers, technical reports, and attendance in these forums. Also support the Radar Correspondence Group (RCG) and the JRG 1A-1C8B and RCG websites.

Project Leader: Frank H. Sanders

(303) 497-7600, fsanders@its.bldrdoc.gov

Short-Range Mobile-to-Mobile Propagation Prediction Model

As part of a multi-year effort to address the need for an under-1 km propagation prediction model, continue looking at this specific scenario and its unique environmental influences. Continue model development and a field measurement campaign to verify and validate those models. Bring the results of the project to the ITU-R and IEEE, as appropriate.

Project Leader: Paul M. McKenna

(303) 497-3474 pmckenna@its.bldrdoc.gov

Spectrum Sharing Innovation Test Bed Pilot Program

Develop and build measurement systems for each of the measurements. Perform measurements that examine the feasibility of increased frequency sharing.

Project Leader: Eric D. Nelson

(303) 497-7410, enelson@its.bldrdoc.gov

Other Agency Projects

Department of Commerce / NIST / Office of Law Enforcement Standards

Public Safety Telecommunications Interoperability

Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the identification, development, and validation of interoperability standards for the justice/public safety/homeland security community. Support the joint NTIA/ITS and NIST/OLES Public Safety Communications Research (PSCR) program projects listed below. Provide technical assessments and evaluations of commercial products and services that may provide interim solutions for various interoperability scenarios.

Project Leader: Jeffrey R. Bratcher

(303) 497-4610, jbratcher@its.bldrdoc.gov

Analysis, Demonstration, T&E

Project Leader: DJ Atkinson

(303) 497-5281, datkinson@its.bldrdoc.gov

Assessment of Integration Strategies

Project Leader: Kameron A. Behnam

(303) 497-3830, kbehnam@its.bldrdoc.gov

Development of Requirements, AF Interoperability Standards

Project Leader: Andrew P. Thiessen

(303) 497-4427, athiessen@its.bldrdoc.gov

P25 CAP and Public Safety Lab Equipment and Support

Project Leader: Jeffrey R. Bratcher

(303) 497-4610, jbratcher@its.bldrdoc.gov

Video Clip Preparation

Project Leader: Margaret H. Pinson

(303) 497-3579, mpinson@its.bldrdoc.gov

Fading Characteristics Validation

A measurement effort to characterize radio channel characteristics relevant to public safety.

Project Leader: Christopher Redding

(303) 497-3104, credding@its.bldrdoc.gov

Public Safety Video Quality Assessment

Develop and conduct video quality tests to assist public safety agencies with telecommunications systems and equipment selections. Analyze data and write a report on the results.

Project Leader: Dr. Carolyn Ford

(303) 497-3728, cford@its.bldrdoc.gov

Public Safety Communications Best Practices Development

Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the identification, development, and validation of interoperability standards for the J/PS/HS community, and other communication system products and services supporting wireless telecommunications and information technology (IT) needs. Provide technical assessments and evaluations of existing and emerging commercial products and services that may provide interim solutions for various interoperability scenarios.

Project Leader: Frank H. Sanders

(303) 497-7600, fsanders@its.bldrdoc.gov

Department of Commerce / NOAA / NOAA Weather Radio Program Office

NOAA Weather Radio Receiver Tests

Compile the characteristics and responses of NWR receivers to various simulated NWR transmissions.

Project Leader: Raian F. Kaiser

(303) 497-5491, rkaiser@its.bldrdoc.gov

Department of Defense (DOD)

Enhancements to Communication System Planning Tool (CSPT)

Enhance the ITS CSPT model through improvements in the incorporated models and addition of models, as well as user support.

Project Leader: Julie Kub

(303) 497-4607, jkub@its.bldrdoc.gov

Propagation Modeling Web site (PMW)

Create version 1.0 of the PMW to allow users to run single and batch TIREM and ITM propagation models, save them to a database, and display on a GIS Web site.

Project Leader: Julie Kub

(303) 497-4607, jkub@its.bldrdoc.gov

DOD / Military Health Service

TMA TRIP System Expansion

Project Leader: Michael Cotton

(303) 497 7346, mcotton@its.bldrdoc.gov

DOD / U.S. Air Force

RNSS Mitigation Techniques

Provide and operate a controlled set of Radio Navigation Satellite Service (RNSS) signals for an Air Force study to examine mitigation techniques between RNSS signals and radar receivers in the 1215 – 1400 MHz frequency band.

Project Leader: John E. Carroll

(303) 497-3367 jcarroll@its.bldrdoc.gov

DOD / U.S. Army

HF Emergency Communications Consolidation

Propagation coverage analysis, antenna interference studies, operation coordination recommendations, antenna site surveys and development of communication specification recommendations relative to collocation of three commercial ALE HF communication systems to be used for simultaneous voice communication.

Project Leader: Christopher Behm

(303) 497-3640, cbehm@its.bldrdoc.gov

Department of Homeland Security (DHS)/ National Communications System

ETS Standards Development

Facilitate the standardization of NS/EP specifications, protocols, and mechanisms. Develop and/or verify emergency telecommunications service (ETS) mechanisms. Assist NCS in support of Presidential Decision Directive 63 and associated critical infrastructure protection (CIP) initiatives.

Project Leader: Arthur A. Webster
*(303) 497-3567,*awebster@its.bldrdoc.gov

DHS / Office of Emergency Communications

Investigative Device Measurement Methods

Develop standardized measurement methods for body wire systems and other investigative devices. Support the Federal Partnership for Interoperable Communications (FPIC) standards committee. Support public safety practitioner involvement in the PSCR Broadband Demonstration Network

Project Leader: Jeffrey R. Bratcher
(303) 497-4610, jbratcher@its.bldrdoc.gov

DHS / Office of the CIO

Standardization of Measurement Methods for Investigative Devices

Provide engineering and technical support to the Office of the CIO Wireless Management Office for development of standardized measurement methods of investigative devices. Conduct measurements on new and/or proposed investigative devices defined by DHS.

Project Leader: DJ Atkinson
(303) 497-5281, datkinson@its.bldrdoc.gov

DHS / U.S. Coast Guard

Radar EMC Study

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

Department of Interior / National Park Service

Acadia National Park Communications Alternatives Study

Provide coverage plots of the present communications capabilities at Acadia National Park. Perform single, double, and triple alternative base station location evaluations. Provide analysis tools to assess the viability of each alternative.

Project Leader: Christopher Behm
(303) 497-3640, cbehm@its.bldrdoc.gov

SERC Communications Specification

Project Leader: Christopher Behm
(303) 497-3640, cbehm@its.bldrdoc.gov

Department of Transportation / Federal Railroad Administration

Railroad Telecommunications Study

Continue technical support to the Federal Railroad Administration as it pertains to railroad telecommunications and the activities of the Association of American Railroads' (AAR) Wireless Communications Committee (WCC).

Project Leader: John M. Vanderau (303) 497-3506, jvanderau@its.bldrdoc.gov

National Aeronautics and Space Administration

EM Characterization at a NASA SPF

Provide a direct-pulse measurement system for the NASA Space Power Facility. Perform measurements of insertion loss and chamber energy decay times.

Project Leader: Dr. Robert Johnk
(303) 497-3737, bjohnk@its.bldrdoc.gov

L-Band Interference Thresholds

Obtain, for the receivers of the FAA long-range radars ARSR-3, ARSR-4, and CARSR, the interference duty cycle thre-shold below which emissions from the planned NASA JPL Soil Moisture Active/Passive (SMAP) orbital radar will not cause loss of desired targets by the terrestrial radars.

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

National Archives and Records Administration

NARA e-Government Study

Demonstrate and evaluate the "Information Portal" concept to allow the National Archives and Records Administration (NARA) to offer a system that will improve knowledge sharing across the organization and complement their physical records storage practice with an electronic version of the same.

Project Leader: Alan W. Vincent
(303) 497-3500, avincent@its.bldrdoc.gov

Various Federal & Non-Federal Agencies

Telecommunications Analysis Services

Develop and maintain TA Services analysis tools (propagation models) and their corresponding interfaces to users and databases, including maintenance and development of GUIs and various databases.

Project Leader: Julie Kub
(303) 497-4607, jkub@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAS)

Lockheed Martin

Laser Testing at Table Mountain

Support LMCT's field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar at Table Mountain Field Site.

Project Leader: J. Wayde Allen
(303) 497-5871, wallen@its.bldrdoc.gov

EQ-36 RSEC Measurements

Measure the emission spectrum and related emission characteristics of the EQ-36 radar to ascertain compliance with the NTIA RSEC emission mask limits.

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

RSEC Measurements

Measure the emission spectrum and related emission characteristics of a radar to ascertain compliance with the NTIA RSEC emission mask limits.

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

Various

Alert Works: NOAA Weather Radio Receiver Tests

Compile the characteristics and responses of NWR receivers to various simulated NWR transmissions.

Project Leader: Raian F. Kaiser
(303) 497 5491, rkaiser@its.bldrdoc.gov

Areté Associates: Coded Aperture LADAR for Long Range Applications

Support Areté Associates in testing and demonstrating laser radar technologies at the Table Mountain Field Site.

Project Leader: J. Wayde Allen
(303) 497-5871, wallen@its.bldrdoc.gov

Boombang: NOAA Weather Radio Measurements

Compile the characteristics and responses of NWR receivers to various simulated NWR transmissions.

Project Leader: Raian F. Kaiser
(303) 497 5491, rkaiser@its.bldrdoc.gov

Deep Space Exploration Society: Weak Signal Extraction from Noise

Collect GNSS and deep space probe data to further signal analysis techniques in radio science.

Project Leader: J. Wayde Allen
(303) 497 5871, wallen@its.bldrdoc.gov

First RF Corporation: Installed Performance of Antennas

Support First RF in testing antenna system performance on a number of vehicles including UAVs, using the turntable facility at the Table Mountain Field Site.

Project Leader: J. Wayde Allen
(303) 497-5871, wallen@its.bldrdoc.gov

RF Metrics: X-Band Radar RSEC Measurement

Measure the emission spectrum and related emission characteristics of an X-Band radar to ascertain compliance with the NTIA RSEC emission mask limits.

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

PM Radars: RSEC Measurements on a TPQ-48 Radar

Measure the emission spectrum and related emission characteristics of a-portable radar to ascertain compliance with the NTIA RSEC emission mask limits.

Project Leader: Frank H. Sanders
(303) 497-7600, fsanders@its.bldrdoc.gov

Symmetricom: Inmarsat Timing Performance

Characterize the timing performance and group delay stability of the Inmarsat data service. Characterization includes a direct measurement of the Inmarsat waveform as it is received by a ground station using a time-disciplined collection system.

Project Leader: J. Wayde Allen
(303) 497 5871, wallen@its.bldrdoc.gov

University of Colorado: Ad Hoc UAV Ground Network (AUGNet) Test Bed

Support the University of Colorado's experiments with communication networks between low-cost small unmanned aerial vehicles (UAVs) similar to model radio-controlled (RC) airplanes, and ground-based radios.

Project Leader: J. Wayde Allen
*(303) 497-5871,*wallen@its.bldrdoc.gov ❖

ITS Publications and Presentations in FY 2010

NTIA Publications

M.A. McFarland, M.H. Pinson, C.G. Ford, A.A. Webster, W.J. Ingram, S. Haines, K. Anderson, "Relating audio and video quality using CIF video," NTIA Technical Memorandum, TM-10-472, Sep. 2010.

NTIA/ITS has conducted a series of studies to quantify the effects that individual audio and video qualities have on the overall Mean Opinion Score (MOS) for a given set of audio-visual clips. The experiment described in this report studies the effects that the synthesis of audio and video quality has on a subject's overall MOS. The overall MOS for this set of audiovisual clips can be predicted rather well from the video MOS alone. This appears to be a consequence of the wide quality range spanned by the video impairments, in combination with the narrow quality range spanned by the audio impairments. This result will not necessarily be valid for other choices of audio-visual material.

R.T. Johnk, J.D. Ewan, P.M. McKenna, R.L. Carey, N. DeMinco, "Time–domain propagation measurements of the NASA Space-Power Facility," NTIA Technical Report TR-10-471, Sept. 2010.

This report describes a recent measurement effort conducted by the Institute for Telecommunication Sciences at a chamber located at the NASA Space Power Facility (SPF) in Sandusky, Ohio. The report describes the chamber and the measurement system, and provides some selected time- and frequency-domain results. A detailed description of the measurement procedures and post-processing is provided. The results obtained indicate that the SPF chamber exhibits robust reverberant behavior. The flexibility and efficiency of time-domain measurements is also demonstrated.

R.A. Dalke, "Radio spectrum estimates using windowed data and the discrete Fourier transform," NTIA Technical Report TR-10-470, Sep. 2010.

Digital signal processing algorithms are commonly used to obtain radio spectrum estimates based on measurements. Such algorithms allow the user to apply a variety of time-domain windows and the discrete Fourier transform to RF signals and noise. The purpose of this report is to provide a description of how signal processing options such as window type, duration, and sampling rate affect power spectrum estimates. Power spectrum estimates for periodic RF signals and random processes (stationary and cyclostationary) are analyzed. The results presented can be used to select signal processing parameters and window types that minimize errors and uncertainties.

F.H. Sanders, "Derivations of relationships among field strength, power in transmitter-receiver circuits and radiation hazard limits," NTIA Technical Memorandum TM-10-469, Jun. 2010.

This NTIA Technical Memorandum provides a single, comprehensive set of derivations of the mathematical relationships among power in a radio transmitter or measurement circuit, the associated incident field strength in space, transmitter–receiver antenna characteristics, free space propagation equation variables and radiation hazard limits.

T.L. Rusyn, T.J. Riley, "A co-channel interference model for spread spectrum technologies," NTIA Technical Report TR-10-467, Jun. 2010.

Even under ideal circumstances, insufficient spectrum is available for assigning a unique band of frequencies to each communication system. In less ideal circumstances, when a communication system experiences outages due to equipment failure or natural or man-made disasters, the demands on the existing spectrum become even greater. More efficient use of the available spectrum requires sharing between multiple systems. To allow similar and dissimilar systems to co-inhabit a frequency band, the interactions between the systems need to be better understood. The Institute for Telecommunication Sciences (ITS) has developed the ITS CMRS Interference Model (ICIM) tool for generating and evaluating the interference between similar and dissimilar communication systems either co-located or located in adjacent areas. This tool generates system-specific interference signals to determine the level of co-channel interference from both immediate and adjacent cells. It produces a representation of an instantaneous air-interface signal, which can contain outputs of multiple base stations with variable numbers of logical channels for each base station and can assign relative power levels for each individual logical channel. Both forward and reverse link processes are included.

F. H. Sanders, R. T. Johnk, "Emission measurements of a cellular and PCS jammer at a prison facility," NTIA Technical Report TR-10-466, May 2010.

This report describes emission-spectrum measurements of a denial-of-service (jammer) transmitter that was operated temporarily in 800 MHz and 1900 MHz cellular and PCS bands at a prison location. The jammer targeted signals indoors within a minimum-security facility operated by the Federal Bureau of Prisons. Spectrum measurements of the jammer emissions were performed inside and outside the targeted jamming zone with multiple measurement bandwidths and detectors, both in-band and in selected Federal land mobile radio and Global Positioning System (GPS) spectrum bands. Measurements at each location were performed with the jammer on versus off so as to show the relative power levels of the jamming signal and the ambient cellular and PCS signals at each location. In-band jammer emissions were measured outside the targeted zone at distances of up to 127 m from the edge of the targeted zone.

F.H. Sanders, R.T. Johnk, M.A. McFarland, J.R. Hoffman, "Emission measurement results for a cellular and PCS signal–jamming transmitter," TR-10-465, Feb. 2010.

This report describes emission measurements on a denial-of-service (jammer) transmitter operating in the 800 MHz and 1900 MHz cellular and PCS bands. The jammer operates at a power level of up to 100 watts in each band, repetitively sweeping a carrier-wave signal across the range of frequencies in which service is to be denied. Frequency domain emissions were measured from 100 MHz to 6 GHz with 100 dB of dynamic range. With the installation of a diplexer that is used as an RF filter, some measurable out-of-band (OOB) emissions occur in spectrum adjacent to the fundamental-frequency bands. Across the rest of the 100 MHz to 6 GHz spectrum range, unwanted emission levels are suppressed by 100 dB or more when the diplexer is installed. OOB emissions in adjacent bands may be reduced by sweeping across less than the full width of the targeted bands, or by installing custom-designed RF output filtering.

C.G. Ford, "Multimedia synchronization study," NTIA Technical Memorandum TM-10-464, Oct. 2009.

ITS is conducting a series of studies to quantify the effects of the separate audio and video compression qualities, and the differential delay in their synchronization, to the perceived aesthetic quality of a multimedia signal. The experiment described in this report was specifically designed to study the effects of the differential delay.

S. Wolf, "A full reference (FR) method using causality processing for estimating variable video delays," NTIA Technical Memorandum TM-10-463, Oct. 2009.

Digital video transmission systems consisting of a video encoder, a digital transmission method (e.g., Internet Protocol – IP), and a video decoder can produce pauses in the video presentation, after which the video may continue with or without skipping video frames. This time varying delay of the output (or processed) video frames can present a challenge for some video quality measurement systems. The reason is that time alignment errors between the output video sequence and the input (or reference) video sequence may produce measurement errors for full reference measurements like Peak Signal-to-Noise Ratio (PSNR) that greatly exceed the perceptual impact of the time varying video delays. This document presents a Full Reference (FR) method for estimating variable video delays. The algorithm can optionally execute a sophisticated causality processing algorithm to improve the robustness of the delay estimates. The delay estimates produced by this algorithm can be utilized by an FR quality measurement system to remove variable video delay as a calibration step before computing the quality measurement.

A.A. Catellier and S.D. Voran, "Low rate speech coding and random bit errors: a subjective speech quality matching experiment," NTIA Technical Report TR-10-462, Oct. 2009.

When bit errors are introduced between a speech encoder and a speech decoder, the quality of the received speech is reduced. The specific relationship between speech quality and bit error rate (BER) can be different for each speech coding and channel coding scheme. This report describes a subjective experiment concerning the relationships between BER and perceived speech quality for the TIA Project 25 Full Rate (FR), Enhanced Full Rate (EFR), and Enhanced Half Rate (EHR) speech codecs. Using the FR codec with 2% random bit errors as a reference, we sought to characterize the BER values for which the EFR (or EHR) codec produces speech quality that is equivalent to the reference. We used an adaptive paired-comparison subjective testing algorithm to efficiently adapt BER values for the EFR and EHR codecs to quickly locate the BER values where listeners found the speech quality to be the same as the reference. The results from sixteen listeners reveal ranges of BER values that were judged to produce speech quality equivalent to the reference. When these ranges are reduced to central values, those values indicate that, on average, the EFR and EHR codecs are more robust to bit errors than the FR codec. We provide a set of additional results from a popular objective speech quality estimator for comparison purposes.

Conference Papers and Journal Articles

D.J. Atkinson, "Digital radios for firefighters: the impact of new technology," in *Proc. International Wireless Communications Expo (2010 IWCE)*, Las Vegas, NV, Mar. 2010

M.H. Pinson, S. Wolf, N. Tripathi, and C. Koh, "The Consumer Digital Video Library," in *Proc. Fifth International Workshop on Video Processing and Quality Metrics for Consumer Electronics - VPQM 2010*, Scottsdale, AZ, Jan. 2010

M.H. Pinson, S. Wolf, and G. Cermak, "HDTV subjective quality of H.264 vs. MPEG-2, with and without packet loss," *IEEE Transactions on Broadcasting*, vol.56, no.1, pp.86-91, Mar. 2010

K.A. Remley, G. Koepke, C.L. Holloway, C.A. Grosvenor, D. Camell, J. Ladbury, R.T. Johnk, and W.F. Young, "Radio-wave propagation into large building structures—Part 2: characterization of multipath," *IEEE Transactions on Antennas and Propagation*, vol.58, no.4, pp.1290-1301, Apr. 2010.

A.P. Thiessen, "Project 25 Compliance Assessment Program," in *Proc. International Wireless Communications Expo (2010 IWCE)*, Las Vegas, NV, Mar. 2010

S.D. Voran, "Subjective ratings of instantaneous and gradual transitions from narrowband to wideband active speech," in *Proc. 2010 IEEE International Conference on Acoustics Speech and Signal Processing (ICASSP)*, pp. 4674-4677, Mar. 2010

Unpublished Presentations

M. Barkowsky, M.H. Pinson, R. Pépion, and P. Le Calllet, "Analysis of freely available subjective dataset for HDTV including coding and transmission distortions," presented at the Fifth International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM–10), Scottsdale, AZ, Jan. 2010

N. DeMinco and P. McKenna, "A comparative analysis of fast multiple knife-edge diffraction methods with measured data," presented at the USNC/URSI National Radio Science Meeting, Boulder, CO, Jan. 2010.

C.G. Ford and I.W. Stange, "A framework for generalizing public safety video applications to determine quality requirements," presented at the 3rd INDECT/IEEE International Conference on Multimedia Communications, Services & Security, Krakow, Poland, May 2010.

J.E. Carroll, "Interference effects and interference limit criteria for radar receivers," presented at the 2010 meeting of the IEEE TC-6 Spectrum Committee, Fort Lauderdale, FL, Jul. 2010

J. Kub and R. DeBolt, "The challenge of converting from a desktop GIS propagation modeling tool to a Web site" presented at the MITRE Antennas and Propagation conference in McLean, VA, Jun. 2010.

J. Kub and R. DeBolt, "How to use PMW (Tools)," presented at the International SGA (Signal-Intelligence Geospatial Analysis) Conference, Baltimore, MD, Apr. 2010.

F.H. Sanders, "Interference effects and interference-limit criteria for radar receivers," presented at the USNC/URSI National Radio Science Meeting, Orlando, FL, Jul. 2010.

F.H. Sanders and R.L. Sole, "Interference effects and interference-limit criteria for radar receivers," presented at the USNC/URSI National Radio Science Meeting, Boulder, CO, Jan. 2010.

S.D. Voran, "Does ADPCM Speech Coding Work Better when Time Flows Backwards?" presented at the 2009 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics, New Paltz, NY, Oct. 2009.

S.D. Voran, "Gradient ascent paired-comparison subjective testing," presented at the International Committee for Information Technology Standards (an ANSI Technical Advisory Group), Louisville, CO, Feb. 2010.

R.T. Johnk, J.D. Ewan, N. DeMinco, R.L. Carey, P.M. McKenna, C.J. Behm, T.J. Riley, S. Carroll, M.A. McFarland, and J.W. Leslie, "High-resolution propagation measurements using biconical antennas and signal processing," presented at the IEEE International Symposium on Electromagnetic Compatibility (EMC 2010), Fort Lauderdale, FL, Jul. 2010.❖

ITS Standards Work in FY 2010

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Abbreviations/Acronyms

2D	two-dimensional
3D	three-dimensional
3G	third generation cellular wireless
4G	fourth generation cellular wireless
AAR	Association of American Railroads
AC	alternating current
AGC	automatic gain control
ANSI	American National Standards Institute
APIC	APCO Project 25 Interface Committee
APCO	Association of Public Safety Communications Officials International
APD	amplitude probability distribution
APWG	Audio Performance Working Group
ARSR	Air Route Surveillance Radar
ATIS	Alliance for Telecommunications Industry Solutions
AUGNet	Ad Hoc UAV Ground Network
BER	bit error rate
BPSK	binary phase shift keying
BVQM	Batch VQM
CAI	Common Air Interface
CAP	Compliance Assessment Program
CD	compact disk
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Acces
CDVL	Consumer Digital Video Library
CIF	common intermediate format
CIO	Chief Information Officer
CIP	critical infrastructure protection
CISPR	Special international committee on radio interference (IEC)
CMRS	Commercial Mobile Radio Services
CONUS	Continental U.S.
COTS	commercial-off-the-shelf
CPU	central processing unit
CRADA	cooperative research and development agreement
CRPL	Central Radio Propagation Laboratory
CSPM	Communication System Performance Model
CSPT	Communication System Planning Tool
CSSI	Console Subsystem Interface
CVQM	Command Line VQM
CW	continuous wave
DAT	digital audio tape
dB	decibel
DCP	digital sampling channel probe
DFS	Dynamic Frequency Selection
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of the Interior
DSA	Dynamic Spectrum Access
DSR	Document & Standards Reference
DTV	digital television
EMC	electromagnetic compatibility
EMS	Emergency Medical Services
ERIC	Emergency Response Interoperability Center
ERP	effective radiated power
ESRI	Environmental Systems Research Institute
ESSA	Environmental Science Services Administrtion
ETS	emergency telecommunications service
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FDF	Fraction of Dropped Frame
FDMA	Frequency Division Multiple Access
FEMA	Federal Emergency Management Agency
FLC	Federal Laboratory Consortium
FM	frequency modulation
FPIC	Federal Partnership for Interoperable Communications
FTTA	Federal Technology Transfer Act
FY	Fiscal Year
GHz	gigahertz
GIF	Graphics Interchange Format
GIS	Geographic Information System
GLOBE	Global Land One-km Base Elevation
GPS	Global Positioning System
GPU	Graphical Programming Unit
GSM	Global System for Mobile Communications
GUC	Generalized Use Class
GUI	graphical user interface
HAAT	height above average terrain
HATS	head and torso simulator
HD	high definition
HDTV	high definition television
HF	high frequency
HPGL	Hewlett-Packard graphics language
I/Q	in-phase/quadrature
IAFC	International Association of Fire Chiefs
IBOC	in-band on-channel
IBRES	in-building radio enhancement systems
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	intermediate frequency
ILG	Independent Lab Group
IMBE™	Improved Multi-Band Excitation
IP	Internet Protocol
IPC	interference protection criteria
IPTV	Internet protocol television
IRAC	Interdepartment Radio Advisory Committee
ISART	International Symposium on Advanced Radio Technologies
ISSI	Inter-RF Subsystem Interface
IT	Information Technology
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITT	ISSI Test Tools
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
IVQM	In-Service VQM
JPL	Jet Propulsion Laboratory
JRG	Joint Rapporteur Group
JRG-MMQA	Joint Rapporteur Group on Multimedia Quality Assessment
kHz	kilohertz
km	kilometer
kW	kilowatt
LADAR	laser detection and ranging
LAN	local area network
LFMF	low/medium frequency
LMDS	local multipoint distribution systems
LMR	land mobile radio
LNA	low noise amplifier
LOS	line of sight
LPDA	log periodic dipole antenna
LTE	long term evolution
m	meter
MD	multimedia definition
MDC	multi-descriptive coding
MHz	megahertz
MIMO	multiple input, multiple output
MOS	Mean Opinion Score
MSC	Message Sequence Chart
MSTV	Association for Maximum Service Television
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NCS	National Communications System
NENA	National Emergency Number Association
NF	noise figure
NIC	network interface card
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPR	National Public Radio
NPSTC	National Public-Safety Telecommunications Council
NS/EP	national security/emergency preparedness
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
OET	Office of Engineering and Technology
OIC	Office of Interoperability and Compatibility
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OQPSK	offset quadrature phase-shift keying
OSM	Office of Spectrum Management
OT	Office of Telecommunications
P25	Project 25
PASS	personal alert safety system
PBS	Public Broadcasting Service
PC	personal computer
PCAP	P25 Compliance Assessment Program
PCS	Personal Communications Services
PDA	Personal Digital Assistant
PESQ	Perceptual Evaluation of Speech Quality
PMW	Propagation Modeling Website
PN	pseudorandom number

PNT	positioning, navigation and timing
PRQC	Network Performance, Reliability and Quality of Service Committee
PSAL	Public Safety Audio Laboratory
PSCR	Public Safety Communications Research
PSNR	peak signal-to-noise ratio
PSRF	Public Safety RF Laboratory
PSVL	Public Safety Video Laboratory
PSVQ	Public Safety Video Quality
PTSC	Packet Technologies and Systems Committee
PTT	push-to-talk
QoS	quality of service
QPSK	quadrature phase shift keyed
R&D	research and development
RAID	redundant array of inexpensive disks
RC	radio-controlled
RF	radio frequency
RFSS	Radio Frequency Sub-System
RNSS	Radio Navigation Satellite Service
RR	reduced reference
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement Science
RTP	Real-Time Transport Protocol
RTSA	Real-Time Spectrum Analyzer
SCBA	self-contained breathing apparatus
SCTE	Society of Cable Telecommunications Engineers
SD	standard definition
SDR	software-defined radio
SG	Study Group
SIP	Session Initiation Protocol
SIPRNet	Secret Internet Protocol Routable Network
SMPTE	Society of Motion Picture and Television Engineers
SNR	signal-to-noise ratio
SoR	Statement of Requirements
SPD-MDC	speech polarity decomposition MDC
SPF	Space Power Facility
SSN	Sun Spot Number
TA	Telecommunications Analysis
TDD	Time Division Duplex mode
TDMA	Time Division Multiple Access
TDWR	Terminal Doppler Weather Radar
TIA	Telecommunication Industry Association
TIA TR-8	Personal and Private Land Mobile Radio standards development committee (TIA)
TIREM	Terrain Integrated Rough Earth Model
TSB	Technical Service Bulletin/ Telecommunications Systems Bulletin
TV	television
U.S.	United States
UAV	unmanned aerial vehicle
UHF	ultra-high frequency
U-NII	Unlicensed National Information Infrastructure
UNS	User Need Subcommittee
USA	U.S. Army
USAISEC	U.S. Army Information Systems Engineering Command
USC	University of Southern California
USGS	U.S. Geological Survey
USN	U.S. Navy
UTC	coordinated universal time
UWB	ultra-wideband
VFD	Variable Frame Delays
VHF	very high frequency
VNA	vector network analyzer
VOACAP	Voice of America Coverage Analysis Program
VoIP	voice over Internet protocol
VQEG	Video Quality Experts Group
VQiPS	Video Quality in Public Safety
VQM	Video Quality Measurement
VSA	vector signal analyzer
VSG	vector signal generator
W	watt
WCC	Wireless Communications Committee
W-CDMA	wideband CDMA
WG	Working Group
Wi-Fi	wireless fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	wireless local area network
WNRC	Wireless Networks Research Center
WP	Working Party
WTSC-RAN	Wireless Technologies and Systems Committee Radio Access Networks (ATIS)