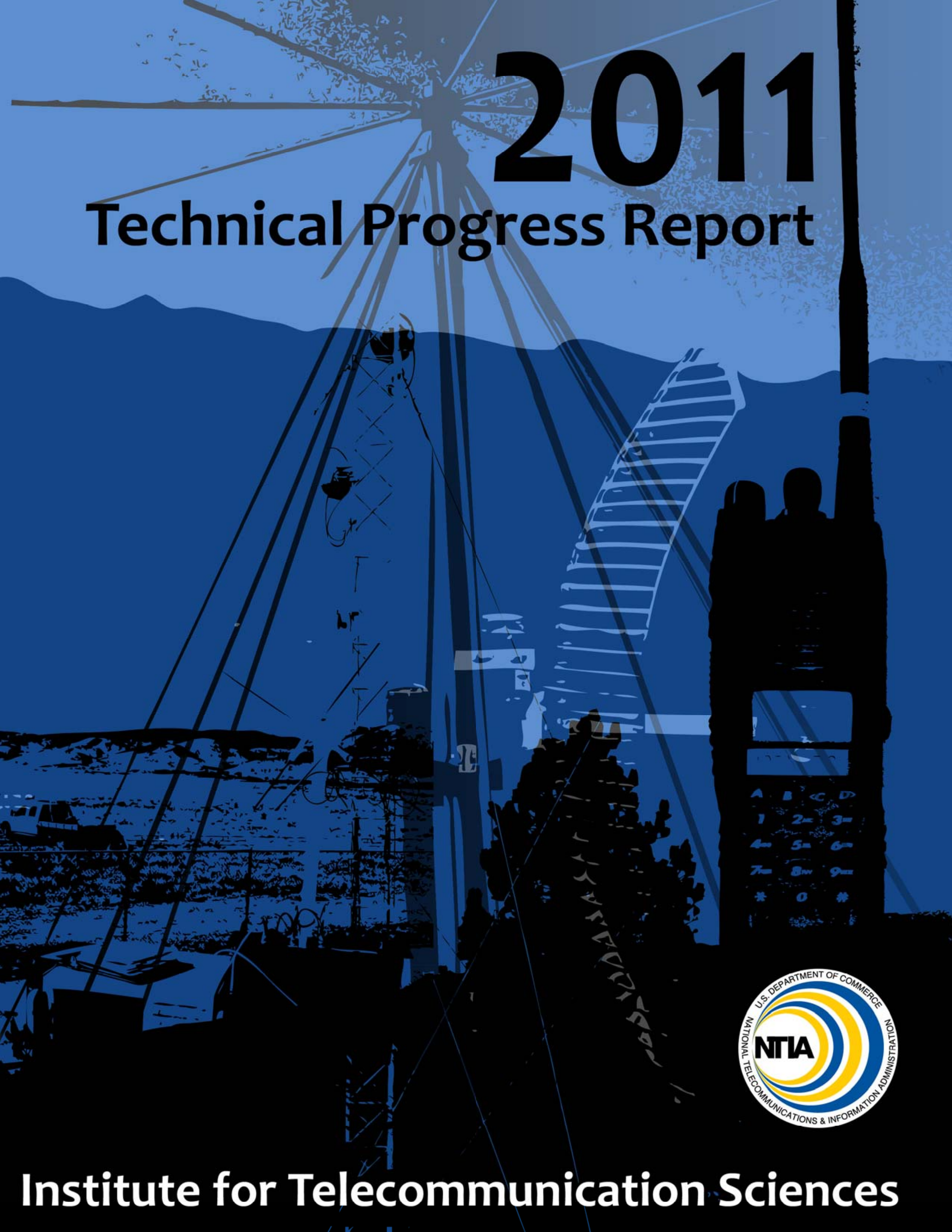
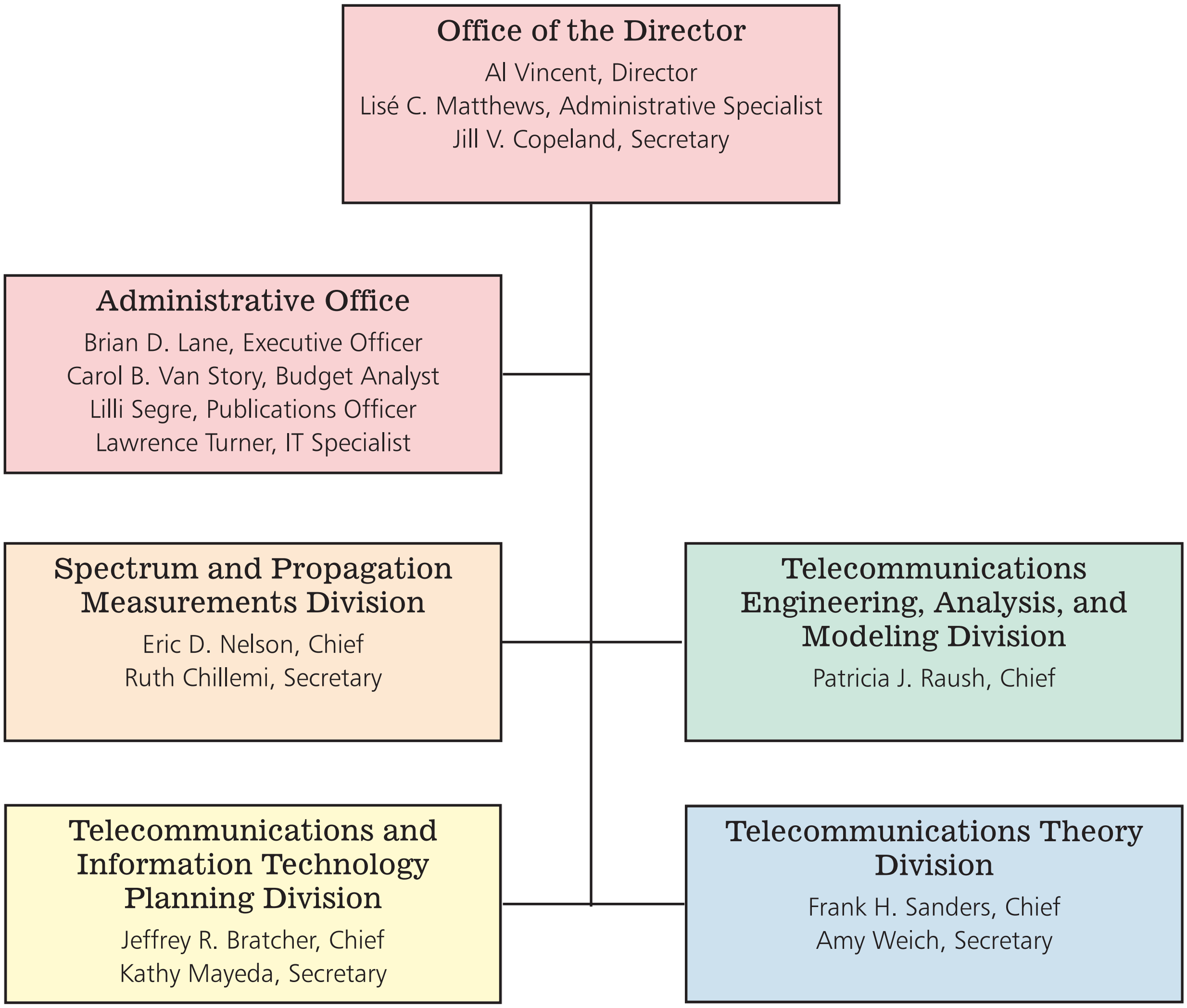
2011 Technical Progress Report



Institute for Telecommunication Sciences

ITS Organization Chart



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Institute for Telecommunication Sciences
FY 2011 Technical Progress Report

U.S. Department of Commerce

Lawrence E. Strickling, Assistant Secretary
for Communications and Information

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The Institute for Telecommunication Sciences

The Institute for Telecommunication Sciences (ITS) is the research and engineering laboratory of The National Telecommunications and Information Administration (NTIA), an agency of the Department of Commerce (DOC). ITS performs basic research in radio science that provides the technical foundation for NTIA's policy development and spectrum management activities.

ITS research enhances scientific knowledge and understanding in cutting-edge areas of telecommunications technology. The Institute's research capacity and expertise is used to analyze new and emerging technologies, and to contribute to standards creation. Research results are broadly disseminated through peer-reviewed publications as well as through technical contributions and recommendations to standards bodies. ITS staff represent U.S. interests in many national and international telecommunication conferences and standards organizations. Through leadership roles in various working groups, ITS helps to influence development of international standards and policies to support the full and fair competitiveness of the U.S. communications and information technology sectors. ITS research helps to drive innovation and contribute to the development of communications and broadband policies that enable a robust telecommunication infrastructure, ensure system integrity, support e-commerce, and protect an open global Internet.

Commerce Secretary John Bryson (second from left) visits the Public Safety Communications Research (PSCR) laboratory at ITS. Captain Paul Roberts of the Boise, Idaho, Fire Department (far right) and Lieutenant Ken Link of the Monroe Township, New Jersey, Fire Department (second from right) were in the lab to participate in ongoing subjective testing experiments conducted by the Public Safety Video Quality (PSVQ) project. PSCR is a multi-agency project that directly supports DOC Strategic Objective 13: "Enhance scientific knowledge and provide information to stakeholders to support economic growth and improve innovation, technology, and public safety." ITS Division Chief Jeff Bratcher (center left) co-directs the PSCR project with Dereck Orr (far left) of the National Institute of Standards and Technology Law Enforcement Standards Office (NIST/OLES). The work is sponsored by the Department of Homeland Security Office for Interoperability and Compatibility (DHS OIC) and the Department of Justice (DOJ) Community Oriented Policing Services (COPS) Office, Federal agencies to whom ITS provides technical engineering support as part of NTIA's mission objective to collaborate with them to begin developing a nationwide interoperable Public Safety Broadband Network. Photo by Will von Dauster, NOAA.

Mission Statements

The Department of Commerce creates the conditions for economic growth and opportunity by promoting innovation, entrepreneurship, competitiveness, and stewardship informed by world-class scientific research and information.

The National Telecommunications and Information Administration (NTIA) serves as the President's principal adviser on telecommunications and information policy matters, and develops forward looking spectrum policies that ensure efficient and effective spectrum access and use.

The Institute for Telecommunication Sciences (ITS) performs telecommunications research, conducts cooperative research and development with U.S. industry and academia, and provides technical engineering support to NTIA and other Federal agencies.

ITS serves as a principal Federal resource for the conduct of basic research on the nature of radio waves. Technology transfer helps private entities adapt and commercialize ITS research to enhance existing telecommunications products and services and develop new ones.

ITS Overview

Outputs

- *Explore, understand, and improve the use of telecommunication technologies and principles*
- *Solve telecommunications challenges for other Federal agencies, state and local Governments, private corporations and associations, and international organizations*
- *Develop and influence national and international standards and policies*
- *Investigate and invent new information and telecommunication technologies*
- *Address emerging telecommunications, information technology, and security challenges*
- *Promptly disseminate research results via the most effective media, while maintaining the highest standards of quality, accuracy, and technical soundness*

A National Research Resource

About half of our research programs are undertaken for and with other Federal agencies; state, local and tribal governments; private corporations and associations; or international organizations. 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 (CRADA). CRADAs were authorized by the Federal Technology Transfer Act of 1986 to encourage 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, the nationwide network chartered by the Act to promote and strengthen technology transfer.

ITS has entered into CRADAs with other research organizations as well as with telecommunications service providers and equipment manufacturers—companies ranging from multinationals to small start-ups. These partnerships 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:** performs technical assessments of existing, new, and proposed individual telecommunication systems; analyzes ways to improve the efficiency and enhance the technical performance of telecommunications systems; and develops propagation prediction models for use in multiple applications.
- **Telecommunications Theory:** develops innovative telecommunication technologies and engineering tools through the application 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.

Capabilities and Expertise

ITS is one of the world's leading laboratories for telecommunications research. Its staff of electronics engineers, mathematicians, physicists, computer scientists, and administrators have strong engineering and scientific skills and experience. ITS's areas of expertise include:

- **Radio Research and Spectrum Measurement:** ITS designs, develops and operates state-of-the-art spectrum measurement systems to measure spectrum occupancy trends and emission characteristics of Federal transmitter systems, and to identify and resolve radio frequency interference in 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.
- **Standards Development:** ITS contributes to voluntary consensus standards development by providing leadership and technical contributions in national and international telecommunication standards committees.
- **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. The Institute tests emerging technologies such as Voice over IP (VoIP), ultrawideband, and Dynamic Spectrum Access (DSA).
- **Audio and Video Quality Research:** ITS conducts research on digital audio and video quality, grounded in signal processing theory and models of perception.
- **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 applies its security expertise to current and emerging Internet technologies through the design and implementation of prototype information systems, including large scale records management infrastructure.

Benefits

The Institute's research significantly benefits both the public and private sectors.

- **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:** ITS provides expert technical leadership at international conferences and develops engineering tools such as interference prediction programs to support negotiations.
- **Public Safety:** ITS provides systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) for the use of "first responders" at Federal, State, local, and tribal levels.

- **National Defense:** ITS research contributes to the strength and cost-effectiveness of the U.S. Armed Forces through improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of emergency communications.
- **Domestic Competition:** ITS develops user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services.
- **International Trade:** ITS participation facilitates promulgation of international telecommunications standards, removing 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.

ITS world-class facilities and capabilities include:

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

Read more about these and other resources at ITS in the *ITS Tools and Facilities* section, page 84.

In FY 2011, research performed by ITS helped ensure that planes land safely, first responders can communicate with each other, and the U.S. Department of Defense can optimize deployment of communications systems—among many other things. ITS released 11 NTIA technical memoranda, reports, or handbooks and four articles by ITS researchers were accepted by refereed scientific publications.

Figure 1. Commerce Secretary John Bryson (far left) presented a Silver Medal Award to (left to right) Jeff Bratcher, Dereck Orr (NIST/OLES), Eric Nelson, John Vanderau, Robert Stafford, and Ron Carey. Acting Deputy Secretary of Commerce Rebecca Blank (third from right), Assistant Secretary for Communications and Information and NTIA Administrator Larry Strickling (second from right), and Under Secretary of Commerce for Standards and Technology and NIST Director Patrick Gallagher (far right) assisted in the presentation. Photo courtesy Department of Commerce.

Figure 2 (left). Jeff Bratcher and Andrew Thiessen receive a Bronze Medal award during a video-conference ceremony; the simultaneous presentation to their team members in Washington D.C. is being videocast behind them. Figure 3 (below). PMW team members (from left to right) Teresa L. Rusyn, Julie E. Kub, George Engelbrecht, and Kristen E. Davis, receiving the Bronze Medal award. Photos by Lilli Segre.

Awards and Honors

Ten ITS employees received Gold or Silver Medals and nine employees on two ITS teams and one NTIA inter-office team received Bronze Medals for work completed in FY 2011.

Since 1949, the Department of Commerce has granted honor awards in the form of Gold, Silver, and Bronze Medals. Gold and Silver Medals are granted by the Commerce Secretary; the Bronze Medal is granted by the head of an operating unit or Secretarial Officer.

Gold Medal Award

The U. S. Department of Commerce Gold Medal award is the highest honorary award given by the Department. The award is granted by the Secretary for distinguished performance characterized by extraordinary, notable, or prestigious contributions that impact the mission of the Department and/or one operating unit and that reflect favorably on the Department.

An interdepartmental, inter-agency team from NTIA and the National Institute of Standards and Technology (NIST), which included ITS Information Technology Specialist Michael Ossman, received Gold Medals in the category of Personal and Professional Excellence for their work as part of an international effort to deploy the Domain Name System Security Extensions (DNSSEC) at the Internet's authoritative root zone. The group performed exceptional service to the Department and the U.S. by enhancing the accuracy and integrity of information supplied by the DNS that is essential to the operation of systems and services using the Internet. The accomplishment assures continued stability and security of the Internet and continued private sector investment and innovation.

Silver Medal Award

The Silver Medal is the second highest honorary award given by the Department, and is granted by the Secretary for exceptional performance characterized by noteworthy or superlative contributions that have a direct and lasting impact within the Department.

An inter-divisional and inter-agency team led by Public Safety Communications Research (PSCR) program Co-Managers ITS Division Chief Jeff Bratcher and NIST Office of Law Enforcement Standards (NIST/OLES) Management and Program Analyst Dereck Orr (Figure 1) received Silver Medals in the Leadership category for leading the inter-agency effort to develop and implement the Project 25 (P25) Compliance Assessment Program (CAP) to meet public safety's need for objective evidence that specific land mobile radio (LMR) systems meet standards of performance and interoperability. The P25 CAP program, described on page 24, is one of five principal technical and research programs at ITS that are focused on fostering nationwide interoperability of public safety communications.

Bronze Medal Awards

The Bronze Medal is granted by the head of an operating unit or Secretarial Officer for superior performance. This year's recipients were:

- Jeff Bratcher, Andrew Thiessen and eight other team members from five different offices of NTIA received Bronze Medals for furthering President Obama's Wireless Innovation and Infrastructure Initiative goal of establishing a single, nationwide public safety wireless broadband network (Figure 2).
- The four members of a multidisciplinary team from the Telecommunications Engineering, Analysis, and Modeling Division (Figure 2) received Bronze Medals for development of the Propagation Modeling Website (PMW) through other agency work for the Department of Defense. The work is described on page 42.
- John Carroll, Steve Engelking, and Geoffrey Sanders received Bronze Medals for designing and deploying an advanced new Radio Spectrum Measurement Science (RSMS) system in support of critical radio spectrum measurement in less than two years. RSMS development efforts are described on page 10.

The White House, *Presidential Memorandum: Unleashing the Wireless Broadband Revolution,* June 28, 2010:[1]

❝Few technological developments hold as much potential as much potential to enhance America's economic competitiveness, create jobs, and improve the quality of our lives as wireless high-speed access to the Internet.❞

❝We can also unlock the value of otherwise underutilized spectrum and open new avenues for spectrum users to derive value through the development of advanced, situation-aware spectrum-sharing technologies.❞

Left: ITS measurement van undergoing emissions testing in an anechoic chamber. Photo courtesy of EMC Integrity.

Right: EQ-36 Counterfire Target Acquisition Radar undergoing emissions measurement. Photo by Frank Sanders.

Left: Engineers Bob Johnk and Paul McKenna and Intern Linh Vu (left to right) make adjustments to an antenna used to measure soil electrical properties. Photo by Wayde Allen.

Right: A dynamic frequency selection access point being field tested with radars at the FAA Aeronautical Center in Oklahoma City, OK. Photo by Frank Sanders.

1. http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution

Spectrum and Propagation Measurements

In June 2010, President Obama released a Memorandum entitled “Unleashing the Wireless Broadband Revolution.” The memo highlighted the need for innovative spectrum-sharing techniques to increase spectrum efficiency to sustain critical Government radio operations while permitting dramatic increases in commercial spectrum use. The Spectrum and Propagation Measurements Division directly supports this mandate through research and experimentation that provides insights into spectrum use and radio system compatibility, which informs the spectrum policy making process.

The division’s engineers conduct measurements of spectrum usage and occupancy, assess the compatibility of disparate radio systems, develop and conduct conformity assessment tests, characterize system noise, and measure receiver performance criteria. The following areas of emphasis are indicative of the work done recently in the division to support NTIA, other Federal agencies, academia, and private industry.

Radio Spectrum Measurement Science (RSMS) Program

The RSMS program develops and operates an automated testing capability that is adaptable to a wide variety of measurement scenarios. Composed of commercial and custom test equipment, the RSMS system supports ad hoc measurements to assess and resolve complaints of interference involving Government radio systems, conducts both comprehensive and band-specific spectrum surveys, measures existing and proposed radio system emissions for electromagnetic compatibility studies, and performs ongoing conformance tests on radio systems. RSMS projects funded by ITS cover incremental enhancements and maintenance of the system, the development of new capabilities, and operational deployments.

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 supported by ITS funding as well as cooperative research and development agreements with non-Federal entities.

Spectrum Sharing Innovation Test Bed Pilot Program

Dynamic Spectrum Access (DSA) technology promises greater frequency agility and improved radio adaptation to the environment for increased spectrum efficiency. The division is presently spearheading Test Bed measurements to assess the capabilities of 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 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 ITS.

“The Secretary of Commerce, working through NTIA … shall create and implement a plan to facilitate research, development, experimentation, and testing by researchers to explore innovative spectrum-sharing technologies, including those that are secure and resilient.”

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Radio noise can degrade the performance of wireless communication devices. To ensure reliable communications, radio systems must be designed to compensate for noise as well as to protect against interference. Accurate and reliable measurements of radio noise provide important information for effective design of wireless communication systems. The results of ITS noise measurements influence design decisions by private companies and public entities.

Radio Noise and Spectrum Occupancy Measurement Research

Outputs

- *Comparison of measured man-made radio noise levels with current models and results from other measurement studies*
- *Publication of NTIA report describing the Boulder/Denver area noise measurements, subsequent data processing and analysis, and comparison of the results with current models and other measurement studies*
- *Development of techniques for obtaining the time-domain characteristics and observing the maximum levels of impulsive noise events that cause noise measurement system overloads*

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 also be 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. Furthermore, there is concern that the growing popularity of hybrid electric and plug-in electric vehicles, with their potential for generating greater levels of electromagnetic interference, may increase levels of man-made radio noise in the future. Because of all these factors, there has been a renewed, worldwide interest in measuring, quantifying, and modeling man-made radio noise.

Noise Measurement Data Comparison

The first major goal of man-made radio noise research at ITS in FY 2011 was to compare the radio noise levels observed during the measurements taken by ITS in the summer of 2009 to levels predicted by the current International Telecommunication Union (ITU) man-made radio noise model. The noise measurements were taken at center frequencies of 112.5, 221.5, and 401 MHz at two business locations and two residential locations in the Boulder/Denver area. 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 bandwidth.

The measurements used to develop the ITU model, taken from the mid-1960s to the early 1970s, were taken with a measurement system having a 4 kHz equivalent noise bandwidth. Therefore, to accomplish an accurate comparison between the results of the current measurement study and the ITU model, the current measured data were filtered in software to a 4 kHz equivalent noise bandwidth before processing.

One of the key advantages of the ITS noise measurement system is its ability to record wideband I and Q data and thereby permit post processing filtering of the data to narrower bandwidths. After filtering, the data were then processed to obtain values of the median antenna noise figure F_{am}, a standard measure used to statistically describe noise power levels. Hence, values of F_{am} provide an excellent means of comparing results from different man-made radio noise studies. Figure 1 shows

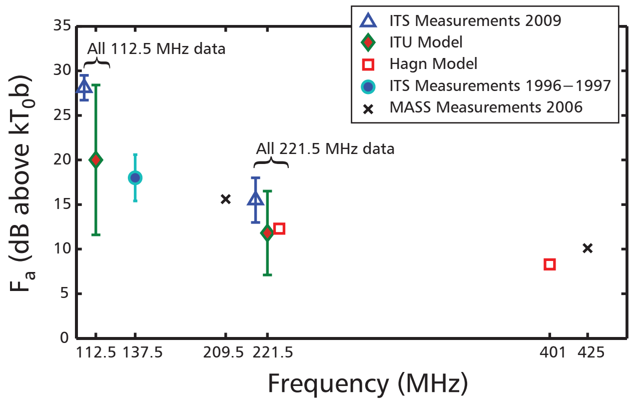
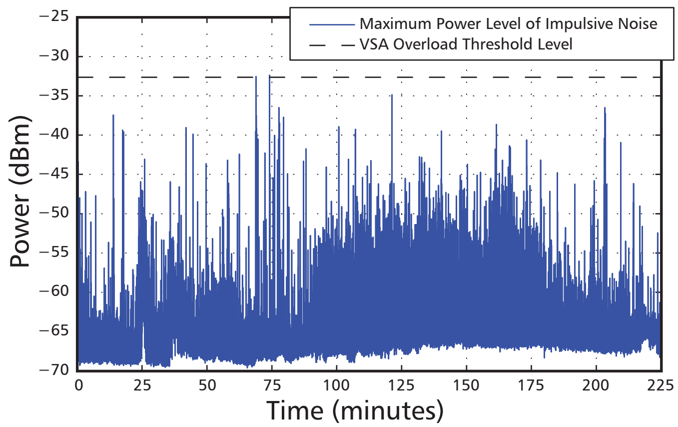


Figure 1 (left). Comparison of measured and predicted values of F_{am} and standard deviation of F_{am} for business locations.

Figure 2 (below). Maximum power levels of impulsive noise measured at a center frequency of 112 MHz on the U.S. Department of Commerce Boulder Laboratories Campus.

a comparison of values of F_{am} and standard deviation of F_{am} between those computed from the measurements in this study, previous measurements taken by ITS and MASS Consultants Limited in the United Kingdom, and those predicted by the ITU and Hagn (another well-known model) models for business locations. Note that values of F_{am} computed from the measurements in this study, while greater than those predicted by the ITU model, were still roughly within one standard deviation of those predicted by the ITU model.



Other Work

A pivotal accomplishment in FY 2011 was the completion and publication of a comprehensive NTIA report describing the ITS noise measurement system, the recent noise measurements taken by ITS, and the results of the subsequent data processing and analysis.

Additional work in FY 2011 included the development of measurement techniques to characterize the nature of, and to determine the maximum levels of high-level impulsive noise events that cause overloads to the vector signal analyzer (VSA) used in the noise measurement system. A better understanding of the nature and levels of high-level impulsive noise is needed to help achieve the goal of improving the dynamic range of the noise measurement system and preventing measurement system overloads. To provide a time-domain characterization of the impulsive noise, a modified version of the basic ITS noise measurement system is used with low-sensitivity and a VSA span wide enough to encompass the 60 dB bandwidth of the fixed RF bandpass filter (9.28 MHz). To best capture the maximum levels of impulsive noise, an automated, zero-span, swept measurement system using peak detection was developed. Use of this type of system allows determination of the maximum levels of impulsive noise that occur by being able to observe levels continuously over a much longer time period than with the VSA-based noise measurement system.

Measurements using both systems were completed on the U.S. Department of Commerce Boulder Laboratories Campus during FY 2011. Figure 2 shows an example of the maximum power levels of impulsive noise measured at a center frequency of 112 MHz at this location along with the threshold level that would cause a VSA overload to occur. Further measurements in the downtown Denver area (a higher noise level environment) are planned for next year.

Related Publication:

J.A. Wepman and G.A. Sanders, "Wideband man-made radio noise measurements in the VHF and low UHF bands," NTIA Technical Report TR-11-478, Jul. 2011.

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Accurate information about current spectrum occupancy is a prerequisite for spectrum management and optimization, but accurately characterizing spectrum occupancy is both time-consuming and complex. The RSMS measurement system was developed to enable accurate, repeatable, actionable surveys of radio wave activity of all types, in all bands.

RSMS Development

Outputs

- *Completed a scheduler for the RSMS-4G software, completing the suite*
- *Completed a four-week-long spectrum survey in Arvada, CO*
- *Completed a series of seminars demonstrating how to use the RSMS-4G software*
- *Completed measurements to determine the best measurement practices for inclusion in a spectrum measurement techniques report to be released early next fiscal year*
- *Completed the "RSMS-5G Programming Guide" outlining coding conventions and architecture for the next generation of RSMS software*

The Radio Spectrum Measurement Science (RSMS) 4th generation measurement system 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 RSMS Development Program ensures that the Institute for Telecommunication Sciences (ITS) has the most advanced software and hardware to perform accurate and complete measurements. ITS spectrum measurements provide NTIA with critical scientific data to support the development and determination of telecommunication policies affecting both the public and private sectors. To sustain this function, several new capabilities and improvements were added to RSMS in FY 2011. Looking to the future, the 5th generation of RSMS measurement software was defined in FY 2011 and development will begin in FY 2012.

Scheduler Development and Completion of the RSMS-4G Software

Over the past decade, many different measurement techniques have been developed within the RSMS-4G software suite. In FY 2011, the RSMS-4G scheduler was created, completing the RSMS-4G software package. The scheduler allows researchers to schedule many different types of measurements to run autonomously over a period of time. This makes it possible to apply the appropriate measurement techniques for each type of radio signal being measured during a spectrum survey. It also makes it possible to measure dynamic frequency bands and others that are of interest to policy makers with greater fidelity. Dynamic frequency bands need to be measured multiple times a day, so that statistics such as peak use times, channel occupancy and channel usage can be determined through post-processing. Using the scheduler, it is possible to schedule routine calibrations to ensure the system is running properly and that the data being collected can be processed correctly once the measurement completes. Several seminars were presented to train ITS engineers in the use of the new scheduler and the measurement capabilities of the RSMS-4G software.

Spectrum Measurement Best Practices Development and Spectrum Survey

Throughout FY 2011, measurements and research were conducted to determine the best measurement techniques to use when measuring different types of radio signals. These techniques were later used while performing a spectrum survey. Accurate identification of spectrum usage depends significantly on using the appropriate measurement techniques for the band being surveyed. An NTIA report detailing these techniques has been prepared and is now proceeding through peer review for release in FY 2012.

A comprehensive spectrum survey was conducted to explore the nature of spectrum usage in the frequency range between 108 MHz and 10 GHz in Arvada, CO during the summer of 2011. Figure 1 shows the RSMS-4G vehicle, which serves as a mobile lab, set up to conduct these measurements. Two separate systems were run simultaneously in the RSMS vehicle, with one system dedicated entirely to measuring land-mobile radio (LMR) bands to monitor spectrum usage. Some of these bands are currently being investigated as potential candidates for spectrum sharing by government and public sector communication devices. The use of advanced spectrum sharing technologies

Figure 1. RSMS-4 measurement vehicle in Arvada, CO, while performing a spectrum survey.

Figure 2. ITS engineers Chriss Hammerschmidt (left) and Heather Ottke monitoring the spectrum survey while in progress.

Photos by R.J. Hoffman.

to share LMR bands has been proposed as one way to more efficiently use the spectrum. The second system monitored the rest of the radio spectrum from 108 MHz to 10 GHz using many different measurement techniques. Figure 2 shows ITS engineers monitoring the spectrum survey measurement in Arvada, CO.

The Next Generation of RSMS Software

With the completion of the RSMS-4G software, it is time to start looking to the future. In the past, the typical RSMS software has had approximately a 10 year life cycle; however, the RSMS team has worked to extend the life of the 4^{th} generation software to 15 years, so as to allow overlap between its use in the field and the development of the next generation.

The next generation of RSMS software, RSMS-5G, has been designed as a collection of tools and measurements that make use of these tools rather than a large complex single software package. This will make it possible to rapidly develop measurements as they are needed once the core software package is complete. RSMS-5G will also be compatible with more modern computer systems and multiple operating systems. The need for third party software has been greatly reduced, so as to extend the life of the software and reduce cost. During FY 2011, the "RSMS-5G Programming Guide" was completed. This guide outlines the software architecture, coding conventions, and functional requirements of the RSMS-5G software. Development of this software will begin in FY 2012.

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ITS is the principal Federal resource for technical assistance in understanding and resolving telecommunication challenges. Other Federal agencies request the assistance of RSMS measurement expertise and capabilities to resolve existing interference problems, to plan appropriately to prevent interference, and to optimize signal coverage and quality.

RSMS Operations

Outputs

- *Emission measurements of four Navy radar systems to support the U.S. Administration's position in the International Telecommunication Union's Working Party 1A meeting*
- *Emission measurements of a sub-sampling of existing airborne radio altimeters to jointly develop a measurement approach with the FAA that can be used for future emission measurements of radio altimeters*
- *Follow-up field testing of Unlicensed National Information Infrastructure devices in the presence of a 5 GHz weather radar*
- *Technical assistance to the U.S. Department of Defense regarding electromagnetic compatibility between L-band radar systems and other services in the same frequency band*
- *Technical assistance to the Federal Aviation Administration and Federal Communications Commission regarding electromagnetic compatibility between Terminal Doppler Weather Radar systems and unlicensed wireless devices operating in the same frequency band*

Overview

The Radio Spectrum Measurement Science (RSMS) program performs critically needed and time-sensitive radio signal measurements that facilitate Federal Government spectrum allocation decisions and policy making. 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. Through the RSMS Operations program, ITS provides NTIA, other Federal agencies, 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

Navy Radar Emission Measurements

International Telecommunications Union (ITU) Recommendation SM.1541 Annex 8 specifies the out-of-band emission limits for radar systems internationally and is akin to the United States' Radar Spectrum Engineering Criteria (RSEC). Emission measurement data of four Navy radar systems, taken in FY 2011 under the RSMS Operation program (Figure 1), were submitted as U.S. contributions to the ITU Working Party 1A meeting in 2011 to support the U.S.

Figure 1. The RSMS truck collecting emission measurement data from Navy radar systems. Photo by John E. Carroll.

Figure 2. ITS engineers Frank Sanders (left) and Geoffrey Sanders (no relation) perform field tests to verify that 5 GHz U-NII devices with newly-developed firmware correctly detect TDWR signals. Photo by John E. Carroll.

Administration's position on changes to Recommendation SM.1541, which were ultimately adopted. The changes are intended to promote more efficient use of the radar spectrum by certain classes of radar systems, to which these Navy radar systems belong.

Radio Altimeter Emission Measurements

The RSMS Operations program measured emissions from 25 airborne radio altimeters and post-analyzed the measurement data to arrive at a preliminary determination of spectrum usage in the 4200 to 4400 MHz band. Using these preliminary results, ITS engineers created a draft measurement approach that can be used for future radio altimeter emission measurements. RSMS engineers will be working with the FAA in 2012 to perform a comprehensive study of radio altimeter emissions that will be used to determine the spectrum usage of a broad array of radio altimeters, as well as to further refine the measurement approach.

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 warnings of gust fronts, windshear, microbursts, and other weather hazards for improved safety of operations in and around major airports. In 2009–2010, ITS conducted field measurements to identify the cause of interference and laboratory tests to understand the interference mechanism and how to improve the FCC device certification process to prevent interference.

In FY 2011, the RSMS Operations program continued to support the FAA and the FCC to identify solutions to prevent interference to these critical radar systems. As technical subject matter experts ITS engineers participated in meetings with the FAA, FCC, OSM, and private industry representatives. ITS engineers worked with private industry representatives to field test (Figure 2) U-NII devices with newly-developed firmware upgrades that better detect TDWR signals. These tests were performed in the presence of an actual TDWR system in Oklahoma City, OK, to verify proper operation of the new detection algorithms. ITS engineers also developed a new set of simulated TDWR waveforms for use in the FCC 5 GHz U-NII device certification process. Both of these efforts will ultimately reduce occurrences of interference to TDWR systems from 5 GHz U-NII devices.

Finally, ITS publicly released the first two NTIA reports (of a three part series) detailing the 2009 to 2010 NTIA study of electromagnetic compatibility between TDWR systems and 5 GHz U-NII devices.

Related Publications

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 Report TR-11-473, Nov. 2010.

J.E. Carroll, G.A. Sanders, F.H. Sanders, and R.L. Sole, "Case Study: Investigation of interference into 5 GHz weather radars from unlicensed national information infrastructure devices, Part II," NTIA Report TR-11-479, Jul. 2011.

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The Spectrum Sharing Innovation Test Bed Pilot Program provides an opportunity for Federal agencies to work cooperatively with industry, researchers, and academia to objectively examine new technologies that can improve management of the nation's airwaves. Dynamic spectrum access holds out the promise to allow users of land mobile radio to share spectrum with each other and with other users in the same or adjacent bands. But is this technology ready to ensure the availability and lack of interference that is mission critical to public safety users?

Spectrum Sharing Innovation Test Bed Pilot Program

Outputs

- *Completed and documented Phase I lab measurements on a second and third set of DSA devices*
- *Drafted a Phase II/III field test plan which was reviewed by Federal agencies*
- *Assembled test equipment for field tests and validated proposed measurement methods*

Overview

NTIA, in coordination with the FCC and other Federal agencies, established a Spectrum Sharing Innovation Test Bed pilot program to examine the feasibility of dynamic 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 that use spectrum sensing and/or geolocation techniques to share spectrum with land mobile radio (LMR) systems operating in the 410–420 MHz Federal band. DSA technology allows a radio device to evaluate its radio frequency environment using spectrum sensing and/or geolocation, to determine which frequencies are available for use on a non-interference basis, and to reconfigure itself to operate on the identified frequencies.

In FY 2011, program participants were delayed in delivering their devices for lab testing, so the program's emphasis shifted to preparations for field-testing of the two devices that had completed the Phase I battery of tests. ITS engineers drafted a field test plan to satisfy the requirements laid out for Phases II and III of the program charter. The Interdepartment Radio Advisory Committee's Technical Subcommittee (IRAC/TSC) as well as the DSA equipment providers participating in the test bed vetted the test plan. The plan will be announced in a Federal Register Notice early in FY 2012, which will pave the way for field testing.

Program Design

The test bed program assesses the characteristics of several DSA devices under both lab and field conditions to determine the maturity of DSA technology and to inform the rulemaking process. The objective is to define the essential DSA qualities that must be regulated to permit spectrum sharing without harmful interference to incumbent systems.

The program is divided into two phases of testing. Phase I takes place under controlled conditions at ITS's lab in Boulder. Testing includes measurements of typical radio characteristics such as transmitter emissions, sensor performance, and policy-based radio etiquettes. Figure 1 shows an ITU standard Head and Torso Simulator (HATS) being used in the laboratory to create reference recordings for use in tests. Figure 2 shows the results of field measurements in a live LMR environment. NTIA's Office of Spectrum Management will use the lab measurement data to construct predictive models of the interference potential of DSA devices both individually and in the aggregate. In Phases II and III, a set of field tests will be used to validate DSA sensor and geolocation performance in live LMR environments.

Phase I Testing

At the end of FY 2010, ITS had completed Phase I lab testing on one device, was in the midst of testing a second device, and had just received a third device for evaluation. This year, engineers completed testing on the second device. An equipment failure hindered this effort and required that a replacement device be obtained, which in turn necessitated a series of regression tests. Testing on the third device covered a number of essential tests but could not be completed. This device required a number of software configuration changes to permit its operation in the controlled conditions stipulated in the test plan. During configuration of this device, engineers discovered deficiencies in its communications protocol that brought into question its suitability for further testing. The device was subsequently returned to the participant for further analysis.

Figure 1. Recordings of phonetically balanced English speech are captured using a reference LMR for later playback in field tests. Photo by Eric Nelson.

In July, ITS received a fourth DSA device for testing. After completing a preliminary evaluation of its functionality several software maintenance utilities were requested of the participant to permit engineers to configure the radios for testing. The test bed participant is developing a user interface which will support this requirement.

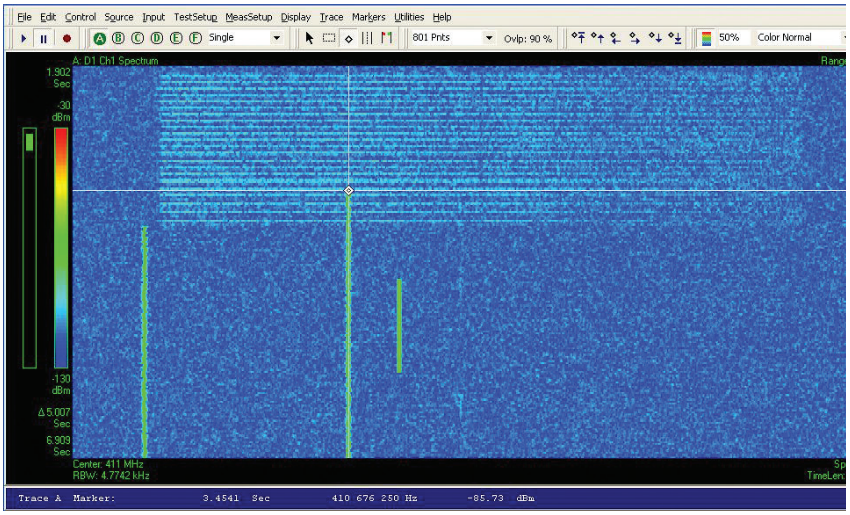
In addition, ITS completed a set of tests to determine the interference protection criteria for DSA sharing with typical incumbent land mobile radios (LMR). The tests quantified the effect of DSA emissions on the operation of LMRs at marginal power levels. Analysis of the results indicated that assumptions drawn from TSB-88.1-C, a handbook on LMR systems engineering, could be applied to predict the nature of DSA to LMR interference. Only a simple adjustment that accounts for the differences between DSA and LMR emissions is required. Another test showed how a DSA device loitering in the proximity of an LMR receiver could cause chronic interference with inbound transmissions.

Preparation for Phases II and III

In FY 2011 ITS engineers, drawing upon a number of exploratory measurements, completed a draft field test plan which covers Phase II and III of the program. The test plan was presented to Federal agencies for review and comment through the IRAC/TSC review process. This was followed by a test bed participant review.

Phase II of the test plan provides for the examination of 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 permitted 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.

Figure 2. A spectrogram obtained in a field test shows a collision between a DSA device and incumbent LMR transmissions.



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FCC regulations restrict wireless radio transmissions in two "radio quiet zones" in the U.S. Restrictions are designed to minimize harmful interference at the National Radio Astronomy Observatory and the neighboring Naval Radio Research Observatory, both in West Virginia, and at Table Mountain. ITS administers the Table Mountain site for the DOC Boulder Laboratories. In addition to coordinating use of the site by Federal laboratories, ITS makes it available for commercial and academic research and development through cooperative agreements.

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 ITS Science and Engineering projects designed to enhance scientific knowledge, other telecommunications research is performed at Table Mountain through cooperative research and development agreements (CRADA) with private industry. CRADAs allow private companies to benefit from the unique resources available at ITS to test and optimize new and improved products prior to bringing them to market.

Free Field Measurements of the Electrical Properties of Soil

ITS engineers have been experimenting with a number of different methods for measuring the dielectric properties of soil at the Table Mountain site. Numerical simulations for several different measurement approaches have been created, and prototypes of systems based on these simulations have been built and tested at the Table Mountain facility (Figure 1). The goal of this program is to identify the technical challenges for making these measurements, and to develop 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 calibrate other measurement systems, and will help improve propagation modeling and prediction tools for near-Earth radio-wave propagation.

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. Synthetic aperture LADAR is one of the emerging technologies tested by CRADA partners at Table Mountain. Applications include bio-aerosol detection 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 designated NWR as the sole Government-operated radio system to provide warnings regarding natural disasters and nuclear attack directly into private homes. As an extension to this policy, in cooperation with the Federal Emergency Management Agency (FEMA) and the Federal Communications Commission (FCC), NWS has expanded the role of NWR to include "all hazards"—natural disasters such as earthquakes or avalanches, environmental catastrophes such as chemical releases or oil spills, and public safety emergencies such as AMBER Alerts™ or 911 telephone outages.

Figure 1. ITS engineers set up equipment for measuring the dielectric properties of soil. Photo by Wayde Allen.

Figure 2 (left). View of the Table Mountain site showing the NOAA weather radio antenna tower.

Figure 3 (below) The RF shielded enclosure used for NWR testing at Table Mountain.

Photos by Raian Kaiser

ITS has developed simulated broadcasts and a series of repeatable measurement methods to test the performance of NWR receivers (Figures 2 and 3). NOAA allows receivers that demonstrate they meet the required performance standards to bear the NWR logo, certifying to the public that they are capable of receiving weather and/or warning information from NWS Forecast Offices, Department of Homeland Security offices, and Emergency Operation Centers. Individual NWR receiver manufacturers enter into CRADAs with ITS in order to have units tested, problems uncovered and improvements made to receiver models before applying to NOAA to use the NWR logo.

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.

FY 2011 CRADA Partners

- Areté Associates
- Lockheed Martin/Coherent Technologies
- First RF Corporation
- University of Colorado, AUGNet

CRADA Partner Publications

- B. Argrow, E. Frew, J. Elston, M. Stachura, J. Roadman, A. Houston, and J. Lahowetz, "The Tempest UAS: The VORTEX2 supercell thunderstorm penetrator," *Infotech@Aerospace 2011*, St. Louis, MO, Mar. 2011
- J. Elston, M. Stachura, B. Argrow, E. Frew, and C. Dixon, "Guidelines and best practices for FAA Certificate of Authorization applications for small unmanned aircraft," *Infotech@Aerospace 2011*, St. Louis, MO, Mar. 2011
- J. Elston, B. Argrow, A. Houston, and E. Frew, "Design and validation of a system for targeted observations of pre-tornadic supercells using unmanned aircraft," IEEE/RSJ International Conference on Intelligent Robots and Systems, Taipei, Taiwan, pp. 101-106, Oct. 2010
- B. Pearre and T.X. Brown, "Model-free trajectory optimization for wireless data ferries among multiple sources," *IEEE GLOBECOM 2010 Workshop on Wireless Networking for Unmanned Aerial Vehicles*, Miami, FL, Dec. 2010.

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In a joint research effort between ITS and NIST/OLES, the PSCR program is building and testing a 700 MHz Public Safety Broadband Demonstration Network to provide manufacturers and first responders a location for early deployment of their systems in a multi-vendor, neutral, host environment. The network comprises three stationary eNodeB base stations, and one mobile eNodeB station housed in a truck. This configuration allows stakeholders to perform comprehensive system and node-level tests, including in-depth and advanced performance testing and multi-user, loaded network stress testing.

Below: U.S. Commerce Secretary John Bryson (left) visited ITS' public safety labs. Jeff Bratcher (second left) demonstrated to Secretary Bryson how ITS studies the effects of background noise on voice intelligibility. Bryson met firefighters Ken Link (third left) and Paul Roberts (right) who were participating in video acuity experiments for public safety. Roberts and Link described how ITS research relates to their own real-world fire fighting experiences. Photo by Will von Dauster.

Left: ITS staff maintain Long-Term Evolution (LTE) antenna panel connections at the Table Mountain Field Site, which houses a stationary eNodeB near the tower. Photo by Ken Tilley.

Above right: The Green Mountain Mesa Field Site houses the network's second stationary eNodeB in the structure below the LTE tower. Right: Dr. Rob Stafford of ITS (center, facing) shows the Broadband Demonstration Network to participants during one of two stakeholder meetings hosted by PSCR in FY 2011. The third stationary eNodeB station (left of center, beige with three black bolts) is housed in this ITS lab. Photo by Ken Tilley.

Telecommunications and Information Technology Planning

The Telecommunications and Information Technology Planning Division is focused on research, development, and testing 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 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.

Below is a summary of the significant project areas that researchers in the Telecommunications and IT Planning Division worked on during FY 2011. Details pertaining to each project are described in separate sections on the following pages.

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.

Public Safety Communications Research

The PSCR program (www.pscr.gov) is one of the largest sponsored programs at the Institute. The program conducts broad-based technical efforts aimed at facilitating communications interoperability and information sharing 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 include:

- Project 25 Compliance Assessment Program
- Project 25 Standards Development
- Public Safety Audio Quality
- Public Safety Broadband Demonstration Network
- Public Safety Broadband Research

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The Multimedia Research Project explores audio quality and video quality interactions. Technical papers describe the techniques, experiments and underlying algorithms, transferring the technology and the tools to other researchers in government, academia and private industry. The objective quality measurements produced by ITS research help multimedia businesses make informed design decisions about trade-offs among quality, compression and bandwidth.

Multimedia Research

Outputs

- *Technical papers*
- *Subjective test best practices*
- *Technical content for standards*

Overview

The Audio Quality and Video Quality Projects at ITS study audio quality and video quality individually. This dichotomy is often advantageous for researching compression and delivery methods but does not represent how most people consume movies, television or Internet video. The Multimedia Project builds on the subjective and objective quality assessment methods developed by the Audio Quality and Video Quality projects.

Audio Quality × Video Quality = Audiovisual Quality

Multimedia subjective tests methodically ask many people their opinion of many multimedia clips. Between 2006 and 2010, the Multimedia Project conducted a series of subjective tests that looked at the impact of audio and video on people's opinion of audiovisual quality. Each test asked people their opinion of audio samples, of video samples, and of audiovisual samples. Labs around the world conducted similar tests.

A study documenting the development of an audiovisual model (an equation used to calculate audiovisual quality) appeared in the *IEEE Signal Processing Magazine* in November 2011. The equation uses individually measured audio and video quality to predict audiovisual quality and is surprisingly simple—a simple multiplication of audio quality times video quality provides a fair estimate of audiovisual quality.

This equation can help:

- Telecommunications service providers to apportion audio and video bandwidth intelligently.
- Equipment manufacturers build tools to predict audiovisual quality from separate measures of audio quality and video quality.

It can also inform the design of forthcoming audiovisual subjective tests and objective quality measurement tools.

An International Study: Improving Audiovisual Subjective Tests

Normally, subjective tests are conducted in a highly controlled lab environment (see Audio Visual Laboratories, page 84) according to International Standards (e.g., ITU-T P.910, ITU-R BT.500). The controlled environment resembles the places where most television and movies used to be watched—a living room or home theater.

Figure 1 (above). ITS test chamber set up to look like a living room. The curtains were opened to allow sunshine into the room. Figure 2 (right). This side of the room gave people the option of putting a mobile device on the table. People had the choice of standing, sitting or pacing, as they would in the real world. Photos by Andrew Catellier.

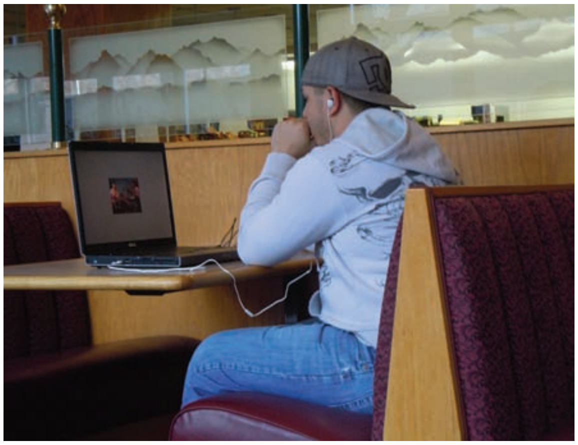

Figure 3. Taking a subjective test in the cafeteria. Background noise included conversations among patrons, music, and food preparation. Photo by William Ingram.

Now, thanks to ubiquitous Internet access, smartphones, tablets, and laptops, video is available nearly anywhere. These devices and services raise unique questions about delivered multimedia quality and Quality of Experience, questions that cannot be answered in traditional laboratory environments. New subjective testing methods that allow for flexible testing environments must be developed.

Six laboratories from four countries conducted a study of subjective test environments. Most experiment variables were constant at each lab, except for the experiment's environment. Some labs conducted the experiment in controlled, traditional lab environments; others conducted the experiment in a cafeteria (Figure 3), in a hallway, or on a patio.

The results delivered by each lab were statistically equal. As it turns out, the number of subjects that participated at each lab had the greatest effect on the experimental results. Other factors, such as the native language of the country in which the experiment took place, lighting in the experiment environment, and background noise, had minimal impacts.

Further analysis and a publication describing this experiment will occur next year. The results of this experiment will influence new ITU Recommendations for subjective testing and will be submitted to a journal for publication.

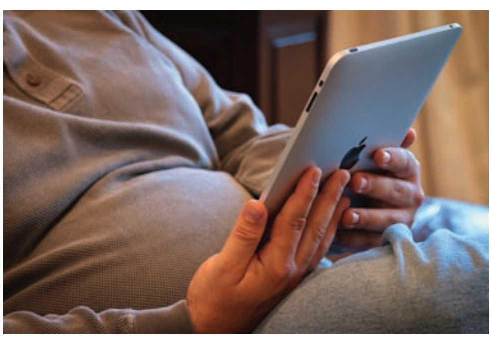

Figure 4. Taking a subjective test in the living room, while relaxing in a comfortable chair. Photo by Andrew Catellier.

Subjective Tests with Mobile Devices

Because the number and availability of Internet-connected mobile devices is swelling, it is becoming increasingly likely that any given person will view multimedia content on a mobile device. Additionally, in developing countries, Internet-connected mobile devices are the only way people can view multimedia. The existence of these devices makes the task of ensuring high-quality content delivery much more complicated.

For example, someone could use a set top box to watch a previously broadcast football game on a large TV in a living room. Another person could stream a live broadcast of the football game to a laptop while working in a coffee shop. A commuter using a video-on-demand service could use a tablet to watch the latest popular sitcom. Students abroad could download a weather forecast using a smartphone. How is delivered quality measured in these situations?

To answer this question, ITS conducted subjective tests using HDTV videos. The subjects were shown the same audio and video on six devices: two smartphones, a tablet (Figure 4), two laptops, and a broadcast-quality television and speakers.

Like the aforementioned international study, this experiment was conducted in two different environments. One was a traditional lab environment and the other was a simulated living room (Figures 1 and 2). The quality ratings obtained in the lab and in the living room were statistically identical.

Further analysis and a publication about this experiment will occur next year.

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The P25 Compliance Assessment Program impacts billions of dollars in purchases of public safety equipment by providing a mechanism to ensure that purchased equipment conforms to interoperability standards. By supporting the migration from proprietary and stove-piped communications systems to open, standards-based infrastructure, the P25 CAP ensures that emergency response technologies effectively meet the needs of practitioners in the field.

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*

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.

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 achieved a number of important milestones in FY 2011, including the release of a number of critical requirements documents, all drafted by ITS.

Supplier's Declarations of Compliance and Summary Test Reports, first posted to the Responder Knowledge Base (www.rkb.us) Web site in January 2010, continue to increase in number. Currently, P25 equipment from thirteen manufacturers is represented.

ITS continues to work within the standards development process of the Telecommunications Industry Association (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. Additionally, ITS is working independently of TIA to develop conformance tests appropriate for compliance assessment for inclusion in the P25 CAP.

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.

The P25 CAP was selected for a US Department of Commerce Silver Medal, the second highest achievement in the department, for its leadership in ensuring public safety communications interoperability.

Public safety and industry have partnered through P25 on developing standards that allow radio systems to interoperate regardless of manufacturer.

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ITS involvement in P25 standards development directly supports NTIA's objectives for developing and influencing national and international standards and policies to support the full and fair competitiveness of the U.S. information and technology sectors and for enhancing scientific knowledge and providing information to stakeholders to support economic growth and improve innovation, technology, and public safety.

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 public safety 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 within the more than 60,000 public safety organizations in the U.S. and by public safety organizations in over 54 countries.

Recent Congressional legislative and related actions recognized P25 standardization as the preferred solution for narrowband LMR public safety users. Congress 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 P25 requirements and standards shortly after P25 was established. Under the sponsorship of NIST/OLES, support continues for the accelerated development of P25 standards to meet increasing needs for functionally enhanced, compliant equipment and systems, and to satisfy Congressional mandates. ITS's P25 standards development support efforts are also an integral part of the Public Safety Communications Research (PSCR) program, a joint effort of ITS and NIST/OLES. During FY 2011, ITS provided technical and organizational representation for the sponsor, directly assisting the approval of new and revised P25 requirements and standards in several critical areas, including the ISSI and CAI. ITS also supported related areas of emphasis, such as public safety audio quality research and the P25 Compliance Assessment Program.

Next Generation P25 Wireline Interface Standards

ITS technical efforts during this and prior fiscal years strongly supported the accelerated development and approval of new and revised P25 standards for the next generation ("Phase 2") P25 wireline interface standards. In FY 2011, ITS focused on advancing the ISSI, the Data Network Host Interface, and the Telephone Interconnect Interface. As a result, TIA expects to publish significantly revised versions of documents describing and defining these

P25/TIA-102 LMR Service	P25/TIA-102 LMR System Configuration Involving the ISSI			
	Trunking	Conventional Complexity Level		
		1	2	3
Voice	TIA-102.BACA-A	TIA-102.BACE	TIA-102.BACE	(to be specified)
Mobility Management	TIA-102.BACA-A	(not applicable)	TIA-102.BACE	(to be specified)
RFSS Capability Polling	TIA-102.BACA-A-2	(not applicable)	TIA-102.BACA-A-2	(to be specified)
Supplementary Services	TIA-102.BACD	TIA-102.BACE	TIA-102.BACD	(to be specified)
Packet Data	TIA-102.BACF TIA-102.BACA-A-1	(to be specified)	(to be specified)	(to be specified)
Support for Half-Rate Vocoder	(to be specified)	(to be specified)	(to be specified)	(to be specified)

Project 25/TIA-102 Inter-RF Subsystem Interface (ISSI) protocol communications standards.

three P25 interfaces in the near future. ITS also originated numerous technical and editorial proposals to advance the development of a draft telecommunications systems bulletin (TSB). When completed TSB-102-B, will provide a critically needed overview of the LMR systems, services, and interfaces currently supported by the TIA-102 series of documents. The TIA-102 documentation suite is being developed taking into account user needs specified in the P25 Statement of Requirements (P25 SoR).

P25 User Requirements

ITS technical efforts strongly contributed to accelerated development and approval of new and revised P25 user requirements by the P25 User Needs Subcommittee (P25 UNS). Since the publication of the previous P25 SoR in March 2010, technical contributions originated by ITS enabled the following new and revised P25 user requirements to be approved:

- Addition of new requirements for the P25 Console Subsystem Interface (CSSI)
- Clarification of requirements for the P25 Fixed Station Subsystem Interface (FSSI)
- Clarification of requirements for P25 conventional and trunked systems
- Clarification and extension of voice encryption requirements

In FY 2011, ITS continued 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 April 2011 to satisfy current user requirements on a timely basis. Continuing into FY 2011, 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 2011, 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 2011, 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 2012, 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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Improving spectral efficiency within public safety spectrum depends largely on increased reliance on digital rather than analog radio technology. Digital radio systems offer a number of other advantages in addition to improved spectral efficiency. But for public safety practitioners, intelligibility—the degree to which speech can be understood—is the highest priority in communications. Public Safety Audio Quality research characterizes the factors that influence intelligibility of digital radio communications. This research provides digital equipment manufacturers and standards bodies important information about how to design increased intelligibility into digital radio systems.

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 practitioners work 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 their commanders. It is essential that public safety practitioners be able to call for help, to warn others, to communicate when their lives are in danger. However, some background noises encountered in the public safety environment, such as sirens, chainsaws and personal alert safety systems (PASS), can interfere with those essential communications. Sometimes this interference is so severe that it can prevent a practitioner and the person talking with him or her 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 (NIST/OLES and DHS OIC) 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.

Field Studies

The field studies conducted by the project are essential to understand the environments in which public safety practitioners must operate. 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 will 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 type of recording is a high-quality digital recording of a specific environmental noise that can be shared with the community and also used in laboratory experiments.

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) (Figure 1). The HATS has a calibrated speaker representing the mouth and a calibrated microphone representing each ear. It can be used to simulate a conversation in any noise

Figure 1. An ITU standard Head and Torso Simulator (HATS) outfitted with a firefighter's mask and set up to talk into a radio. Photo by Ken Tilley.

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 such sounds as a chainsaw, a fire-hose fog nozzle, a low air alarm from breathing apparatus, and a 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 Report[1] and companion recommendations published by the International Association of Fire Chiefs.[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. Working with APWG, industry and state and local public safety agencies, ITS completed another round of testing in FY 2011. Some of the observations made based on the test results are listed below:

- Changes to best practices and technical changes to the vocoder both improved the intelligibility of speech. This was especially notable in the improvement to intelligibility in the presence of PASS alarm noise for the P25 system (Figure 2).
- There are some conditions where analog radios still have higher intelligibility than P25 systems.
- For all conditions the P25 Full Rate and P25 Half Rate showed no significant differences in performance.
- The test revealed that for some radio channel degradations, P25 systems have a higher intelligibility level than analog systems.
- The use of different PASS alarms had no observable impact on intelligibility.
- Using a mask with an internal microphone improved intelligibility over using a mask with a voice port.

Overall, in the past three years, excellent progress has been made to improve intelligibility in high-background noise environments. With continued effort on the part of industry and public safety, there are promises of even more improvements. This will result in better communication for public safety practitioners, improving their safety and making them more effective.

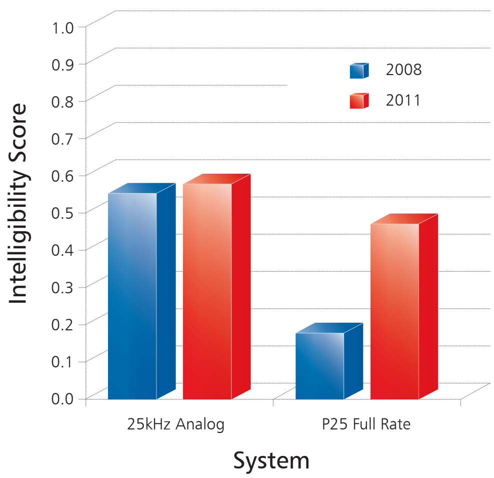

Figure 2. This chart shows a comparison of similar systems' intelligibility scores in the 2008 and 2011 tests for the PASS alarm background noise. The analog FM system showed slightly improved results and the Project 25 (Digital) system showed a marked improvement in intelligibility.

Future Work

In FY 2012 the project will finish publishing results of recent testing through the TIA standards committees and begin to study the impact that emerging broadband wireless network technologies will have on public safety voice communication.

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.
2. IAFC Digital Problem working Group, Interim Report and Recommendations: Fireground noise and Digital Radio Transmissions, International Association of Fire Chiefs, May, 2008.

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The public safety community, along with the U.S. Administration,* has come together to support the creation of a single nationwide broadband network for public safety, eschewing the fractured approach found in today's land mobile radio systems. 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. The Public Safety Broadband Demonstration Network is an independent, vendor-neutral venue where public safety agencies can test equipment and identify interoperability issues prior to building or altering their networks.

* http://ntia.doc.gov/files/ntia/publications/ntia_public_safety_network_comments_06102011.pdf

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 noncontiguous spectrum assignments have long impeded effective cross agency/jurisdiction public safety land mobile radio (LMR) communications. To avoid similar issues with new broadband technology, 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 (NIST/OLES) 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 six telecommunications standards bodies to produce globally applicable cellular system specifications), the FCC Emergency Response Interoperability Center (ERIC, formed to specifically to address the needs of the 700 MHz public safety broadband wireless network), and other applicable standards organizations.

Public Safety Broadband Standards and Requirements

Public safety and the FCC realized the need to identify a 4G wireless network standard to facilitate roaming and nationwide interoperability. In 2009, public safety, through nearly all of its representative organizations, collectively made the choice for 3GPP's Long Term Evolution (LTE) as the favored technology standard. The FCC in its Waiver Order[1] also mandated LTE as the technology to be used in the public safety broadband spectrum assignment.

Since that time, public safety has worked to develop requirements to help inform its efforts to build a nationwide network. PSCR staff chair the National Public Safety Telecommunication Council's (NPSTC) Broadband Working Group that developed the NPSTC Public Safety Broadband Statement of Requirements in 2007. Task Groups under the Broadband Working Group that are currently working to update the 2007 requirements in a piece-meal fashion include:

- Local Control Task Group—working to define what local and state agencies will need to control in a nationwide broadband network in order to meet their needs
- Priority/Quality of Service Task Group—working to define public safety's default and dynamic priority and quality of service requirements for LTE to ensure a consistent user expectation nationwide
- Multimedia Emergency Services (MMES)—capitalizing on work in the E-911 arena to develop requirements to extend E-911 capabilities to support public safety's needs
- Voice Task Group—working to define public safety's mission-critical voice requirements, both within the nationwide broadband network as well as between the broadband network and existing land mobile radio systems
- Security Task Group—working to define public safety's security requirements in the context of a broadband network

PSCR staff leverage the public safety community's requirements work to advance 3GPP LTE standards to meet public safety's needs. Current efforts include working to extend the 3GPP Multimedia Emergency Services efforts based

1. http://fjallfoss.fcc.gov/ecfs/document/view.action?id=7020505752

on the NPSTC MMES Task Group deliverables as well as working to create a direct mode capability based on NPSTC Voice Task Group deliverables.

In addition to participating in 3GPP and other standards development bodies as public safety requirements dictate, PSCR staff are members of the Alliance for Telecommunications Industry Solutions (ATIS) International Mobile Subscriber Identity (IMSI) Oversight Council (IOC), which is responsible for allocation of the U.S. Public Land Mobile Network Identifiers (PLMN ID) to qualified applicants. PSCR staff successfully modified the ATIS IOC Guidelines to allow a Public Safety broadband licensee to apply for a single PLMN ID for use in the nationwide network.

Goals of the Demonstration Network

National telecommunications companies maintain sophisticated test networks and dedicated laboratories to ensure that selected equipment meets their specifications and to identify interoperability issues prior to building their networks or adding new features, hardware, or software. The Public Safety Broadband Demonstration Network was established at the U.S. Department of Commerce Boulder Laboratories to provide an equivalent Government lab facility in the U.S. where the fragmented, resource-constrained community of public safety agencies could test and demonstrate public safety 700 MHz broadband networks and applications. 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 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 (CRADA) 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:

Public Safety Broadband Demonstration Network base station at the Green Mountain Mesa site. Photo by Ken Tilley.

- 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, preemption, 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 2012, 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.

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Public Safety Broadband Research

Outputs

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

Public safety broadband users have unique needs compared to users of civilian cellular networks. Signal degradation that is a nuisance to a civilian user may be life-threatening in a public safety emergency. The most promising technology to assure public safety broadband transmissions are both robust and efficient is Long Term Evolution (LTE) using multiple input, multiple output (MIMO) techniques. The Public Safety Broadband Research program at ITS explores ways to optimize these technologies. In the process, the program is developing new tools for active network testing. While the needs of the public safety community are most urgent, the results of this research will be applicable to inform design decisions for any high-speed wireless data system.

Overview

Although spectral efficiency (i.e., the number of bits per second per hertz) is important to any high-speed wireless data system, public safety broadband users face some unique problems compared to those encountered in similar civilian cellular networks. Since the business world optimizes its networks to cover the maximum number of paying customers, capacity constraints tend to naturally assure a fairly strong signal for the majority of users.

The public safety network, by contrast, must often emphasize coverage instead of capacity, since there are no billable customers but incidents may happen in areas where population density is low (e.g., forest fires). This means that the public safety broadband user may frequently encounter conditions of low signal to noise ratio (SNR), but his need for maximum data throughput on the network has not diminished even though signal conditions are suboptimal.

The Public Safety Broadband Research project seeks ways to assure highly efficient data transfer to public safety broadband users in suboptimal radio conditions. Currently, the broadband technology of greatest interest to public safety is Long Term Evolution (LTE) and, arguably, one of the strongest determinants of spectral efficiency in LTE is the use of multiple input, multiple output (MIMO) techniques to carry more than one information stream over the same spectral allocation. In the current LTE implementation of MIMO, the receiver receives two different signals that are transmitted at the same frequency but from different antennas. Under good SNR conditions, the receiver can take advantage of knowledge of the two slightly different radio paths to separate the two signal components from the aggregate signal received.

Investigations of MIMO Mechanisms

Almost all LTE systems in the U.S. operate in the 700 MHz band and use cross polarized antennas to achieve the radio path differences required for MIMO. Propagation effects on these signals due to ground based objects has not been extensively studied and consequently network designers must use very conservative assumptions in current LTE networks. The Public Safety Broadband Research project is working to fill this knowledge gap using current propagation models combined with a measurement campaign conducted in the laboratory as well as in the field. For the laboratory work, a MIMO-capable signal generator is available, but field studies require a test signal of significant strength. All current LTE networks provide a test signal embedded in their LTE transmissions, and this is being used for the current measurement.

The LTE signal is very complicated, as the schematic in Figure 1 shows. For public safety use, the signal encompasses 300 subcarriers of 15 KHz bandwidth that change 14,000 times per second to carry traffic and control signals. Every sixth subcarrier (i.e., every 90 KHz) carries

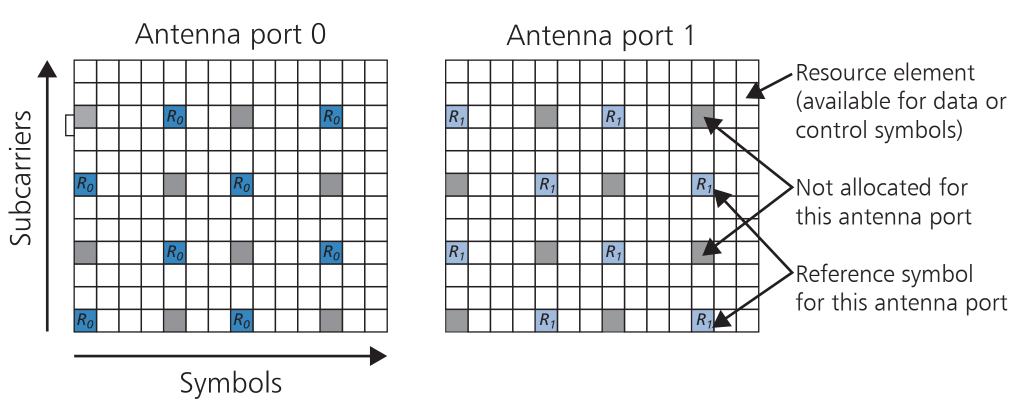

Figure 1. LTE reference signals in time and frequency.

a reference signal that the user equipment uses to determine channel conditions and whether there is sufficient SNR to allow MIMO transmission. However, as shown in Figure 1, these reference signals only occur in specific 70 microsecond time slots and their locations in frequency are a function of the identification number of the base station that is transmitting them. The Public Safety Broadband Research project has been able to recover this signal using high-speed sampling spectrum analysis and decode these reference signals.

Application of these techniques requires knowledge of the antenna properties as well as the radio channel characteristics within the operational area. The Public Safety Broadband Research 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. Research is also ongoing to use the fine structure properties of the reference signals to determine propagation conditions and establish the specific requirements under which real-world channels can support MIMO propagation. 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 (Figure 2). Signal processing algorithms are being tested to develop methods of determining the channel transfer matrix from measured radiated signals.

SDR Test Instrument Technologies

The effort described above requires the use of laboratory grade test instruments, but another aspect of the Public Safety Broadband Research project involves the use of inexpensive software-defined radio (SDR) platforms to accomplish many of the field measurements needed. MIMO measurements require the use of multiple phase locked receivers to assure time synchronization in the channels being measured. Meeting this requirement is expensive with current test instruments, but the function has recently become available in the universal software radio peripheral (USRP) class of devices. This raises the possibility of relatively inexpensive signal logging devices that could be used in the field to study MIMO signal characteristics.

Another capability of the SDR devices under investigation is their use as radio transceivers, rather than just passive listening instruments. As the LTE signal characteristics become better understood, ITS believes that SDR test instruments could be used to produce specialized test waveforms as well as act as "lite" user equipment nodes for existing LTE base stations, with the closed loop communication and control that would be required for an experiment of this type. This capability would be nearly unique among existing LTE test instrumentation, and would allow much greater flexibility in active network testing.

Conclusions

Both of these efforts are by no means restricted to use in the public safety spectrum, but could easily be expanded to include civilian LTE. Although the immediate goal is to provide the public safety community with guidelines and measurements about network tuning to optimize the MIMO capabilities and maximize spectral efficiency, the information being gathered is useful across a wide range of scenarios. Indeed, MIMO promises to be one of the most useful tools needed to achieve the spectral efficiency targets in current Federal policy. This work can help ensure informed decisions about its use in Federal high-speed wireless data systems.

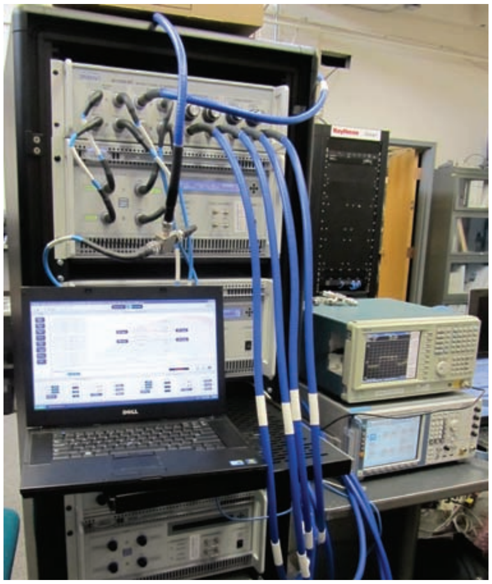

Figure 2. Public Safety Broadband Research laboratory test instruments. Photo by Ken Tilley.

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Over the past 12 years, ITS has employed approximately 75 students from across the country through the Student Temporary Employment Program (STEP). These STEP participants are vital to ITS projects and are critical for the future of ITS and telecommunications research. Some students transition to the Student Career Experience Program (SCEP). After graduation, SCEPs have the option to remain at ITS. ITS retains approximately 10% of its student employees. Currently, three SCEPs have graduated and stayed in the E Division.

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University of Colorado at Denver

Sarah McKenna
BS Biology
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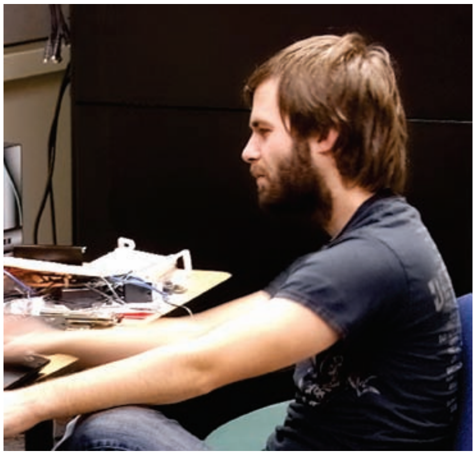
Kristen Davis
BS Computer Information Systems
Metropolitan State College of Denver



George Engelbrecht
BS Electrical Engineering
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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 Working Party (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.

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.

Integration of the Empirical and the Undisturbed-Field Models: 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.

Earth-to-Space Propagation Models: ITS propagation engineers build on existing models previously developed for other agencies to accomplish technology transfer on a global level to standards groups such as the International Telecommunications Union (ITU).

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Inter-system interference is a significant challenge to the increasing numbers of wireless communications systems and users crowding into the available spectrum. The ability to design effective technologies to mitigate and avoid such interference depends on accurate models derived from a clear understanding of interference issues. However, such tools are not effective without agreement on their use and a standardized approach to dealing with interference affecting mobile communication systems.

Interference Issues Affecting Land Mobile Systems

Outputs

- *Contributions to industry-supported efforts for predicting, identifying, and mitigating interference-related problems*
- *Technical support for international and national standards development organizations*
- *Self-interference model for evaluating CMRS technologies and deployment of adjacent-channel systems as described in a NTIA Report*

Overview

In 2010, the President signed a Memorandum[1] proposing to release 500 MHz of Federal and commercial spectrum over a 10 year period to support the development and deployment of next-generation commercial communication systems. As a result, existing (legacy) systems will be forced to share the remaining spectrum without operational degradation. Even with this additional spectrum, 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

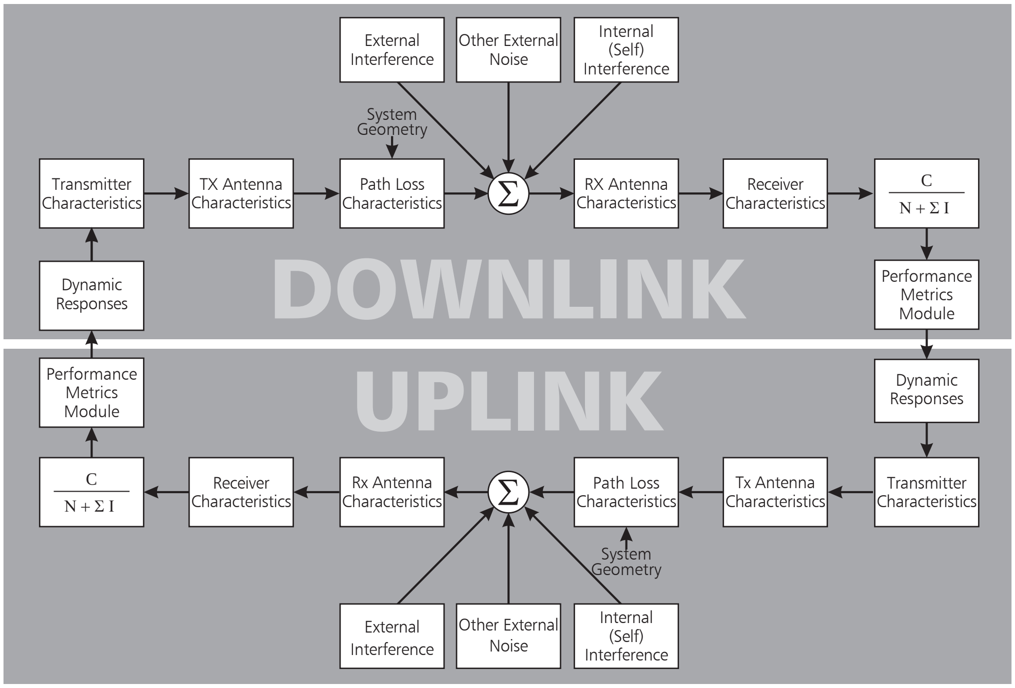
Until advanced dedicated communication systems for emergency services are deployed, Commercial Mobile Radio Services (CMRS) will continue to be used for backup emergency communications. As a result, wired and wireless communication services experience elevated usage rates during emergency situations. 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.

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.

Industry Efforts Concerning Interference Issues

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 systems and competing technologies by proposing methods to identify, avoid, and mitigate (see figure) various forms of interference. 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

1. The White House, Presidential Memorandum: "Unleashing the Wireless Broadband Revolution," June 28, 2010, http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution



Detailed diagram of proposed process to estimate interference between competing land mobile systems.

(Wireless Technologies and Systems Committee – Radio Access Networks). Work on the successor to TSB-84A is currently underway through a joint ATIS/TIA effort, *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.

Support for International Standards Development

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 (WP 5D) has been coordinating the efforts of government and industry in the development of a global broadband multimedia international mobile telecommunication system, known as IMT. Coordinating world-wide frequency allocations is a near-impossible task, given the disparity in the historical evolution of frequency use and the requirements and regulations of individual countries. 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 WP 5D.

An Interference Model for Spread Spectrum Technologies

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." The model produces representations of instantaneous air-interface signals for scenarios involving multiple base stations with variable numbers of mobile handsets for each base station, and includes both forward- and reverse-link processes. The sampled signal contribution of each base station and handset is calculated separately, including power control as a gain factor of the baseband filter. Then all signals identified in a specified scenario are summed 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.

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Public safety practitioners rely heavily on video technology as a tool by which to keep the Nation safe. Poor quality video footage can have serious implications and may mean the difference between life and death. As video technology has evolved, the equipment options have become increasingly complex. Unbiased guidance is essential for practitioners to clearly articulate their video quality needs and make informed video system purchasing decisions.

Public Safety Video Quality (PSVQ)

Outputs:

- *Guide to Defining Video Quality Requirements, 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 VQiPS WG is to provide the public safety community with the knowledge 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 (GUCs)
- Development of *Defining Video Quality Requirements: A Guide for Public Safety* (Figure 1) to help public safety agencies perform the following:
  - Assess video needs
  - Match needs to technical performance specifications and standards to support procurement
  - Develop a glossary of common terms
  - Compile an inventory of existing standards and specifications that address various components of the video system for specific GUCs
  - Develop a common library of test clips that represent GUCs

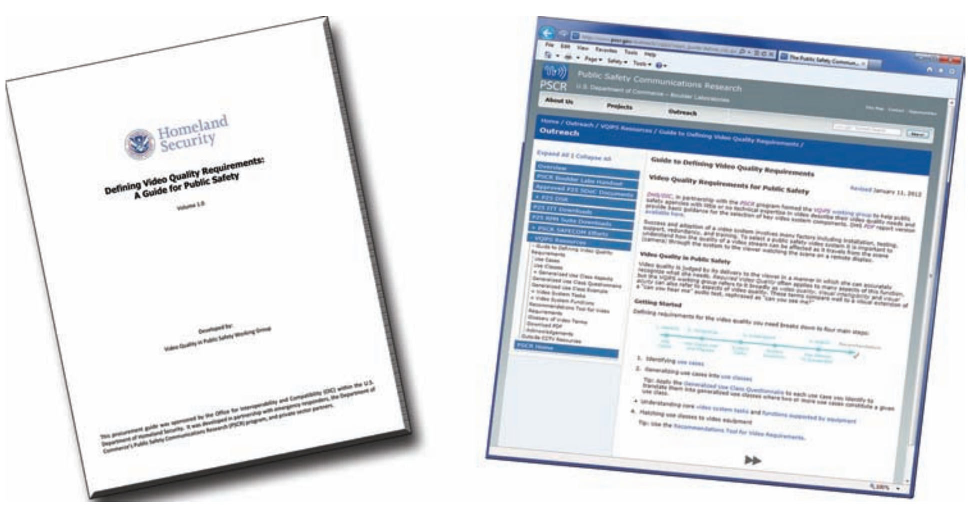

Figure 1. Defining Video Quality Requirements: A Guide for Public Safety is available as both a printable PDF (from the DHS SAFECOM site) and as an interactive online primer (from PSCR.gov).

The 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 all technical guidelines for use in video system design and specification that achieve the desired system usage across multiple disciplines. The 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 2011, PSVQ hosted the fourth VQiPS workshop (Figure 2). 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 Guide was published in July 2010, and VQiPS will continue as an annual workshop to address the WG initiatives on an ongoing basis.

Network Performance Specification Testing

In support of the 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 Guide.

Figure 2. VQiPS Working Group meeting during the February 2011 VQiPS Workshop in Boulder, Colorado. Photo by Ken Tilley.

Web Sites 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/currentprojects/videoquality

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Fading channel models are used to predict signal loss in telecommunications and ensure reliable wireless communications. The most commonly used model incorporates the Rayleigh continuous probability distribution, first derived over a century ago. As telecommunications equipment becomes increasingly complex in response to increased spectrum crowding, it is important to verify that these models are accurately informing design decisions by comparing theoretical predictions to actual measurements.

Fading Characteristics Verification

Outputs

- *40 GB of measurements taken in residential and low-rise urban environments at 162 and 793 MHz*
- *NTIA Technical Memorandum describing the measurement effort and analysis results*

Overview

Wireless communications experience temporal variations in received signal level characteristic of the propagation channel; these variations are referred to as fading. Fading at VHF and above is predominantly caused by the complex scattering environment through which the radio waves travel. Large and small scale scattering from either stationary or mobile objects creates a multitude of propagation paths between the transmitter and the receiver. Each scatterer reflects the transmitted signal at an attenuated level and with a unique phase. The received signal is an aggregate of all these scattered paths and results in multipath fading.

As a result of this characteristic of the propagation environment, receivers need to be highly sophisticated to maintain reliable communications. More complex modulation techniques are needed to minimize the effects of fading due to the constraints of limited spectral resources. In an effort to increase spectral efficiency, the typical digital modulation constellation relies on high levels of symbol discrimination in amplitude, phase, and frequency. The ability of a receiver to detect slight variations in the modulated signal requires that error-inducing channel effects be well understood and accommodated.

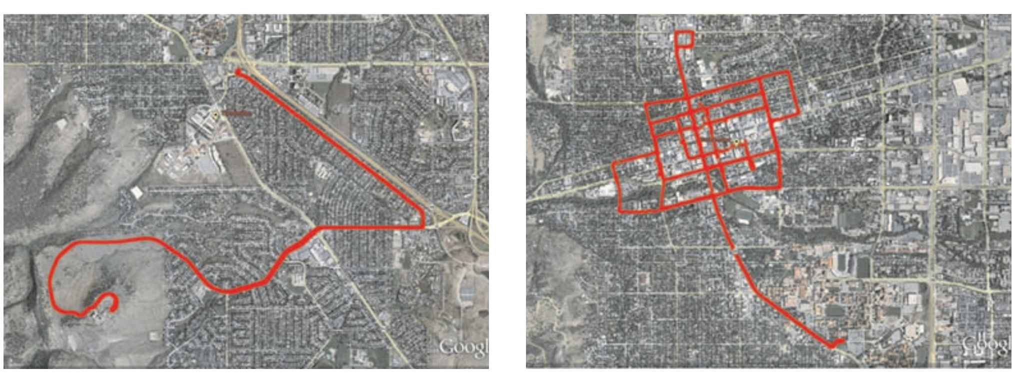
Project Challenges

Since scattering can be described statistically, most theoretical models are the result of matching statistical models to measured data. Most models were developed long before the advent of complex modulation techniques (and, in some cases, before the advent of radio communications itself). ITS undertook a re-examination of the fading channel to determine if assumptions implicit in the understanding of fading channels are appropriate in light of the persistent desire to increase bit density in limited spectral bandwidths. This effort involved the measurement, analysis, and assessment of propagation fading to understand the limitations of classical fading theories when applied to increasingly sophisticated modulation techniques. The ultimate purpose of this effort was to investigate the statistical fading behavior of the radio channel within time frames significant to the reception of digitally-modulated signals.

Fading is typically modeled as a statistical distribution, either Rayleigh or Rician, depending on whether a line-of-sight (LOS) component is present. The Rayleigh fading model has been the most widely-used distribution model and is considered to represent the worst case condition because it does not contain an LOS component. This worst case assumption is suspect since there are known conditions where Rayleigh predictions are too ideal. Three assumptions must be met for true Rayleigh behavior:

1. The interfering waves must be randomly varying in phase and of nearly equal power
2. The phases of the component waves must be randomly distributed between 0 and 2π

Figure 1. Satellite images showing the routes taken during fading measurements in residential (left) and low-rise urban (right) environments (map data © 2009 Google, imagery U.S. Geological Survey).



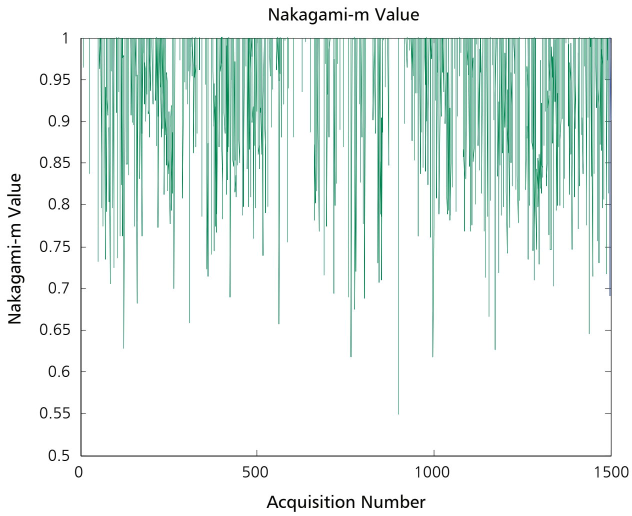


Figure 2. Plot of Nakagami-m values <1.0 for all data files in a single run.

3. There must be a minimum of five interfering waves

While assumptions 2 and 3 are borne out in most urban/suburban environments in the 800/900 MHz band, it is more difficult to satisfy assumption 1. It is improbable that the condition of nearly equal power interfering waves would be met in an actual environment and the randomness criteria can be easily violated by the presence of a direct (or predominant) wave component. This supports the contention that measurement results rarely compare well with the Rayleigh distribution across the entire fading signal range.

The phase variation of the channel has not been well studied, probably because empirical data about channel phase is hard to obtain. Although some analytical results about channel phase correlation based on Rayleigh assumptions are available, questions as simple as the typical rate of channel phase variation in real environments are not addressed in the research literature. This is troubling, since most digital modulations in use today depend heavily in whole or in part on phase modulation. If the channel is causing rapid phase variations in time regimes on the order of a symbol period, bit errors will result in the decoded signal.

This project attempted to verify whether the Rayleigh fading model is an appropriate model for land mobile radio (LMR) channels at public safety frequencies by analyzing the statistical characteristics of measured fading data. Measurements were also conducted on a Rayleigh channel simulator and the significance of channel fading on the Project 25 protocol was analyzed.

Measurements

To provide different fading conditions that are relevant to public safety, measurements were conducted in residential and low-rise urban environments at both 162 and 793 MHz frequencies. The residential environment was located in south Boulder and the low-rise urban in downtown Boulder (Figure 1).

The measurement system simulated an LMR base station and mobile subscriber scenario and consisted of a transmitter placed at a static location and a mobile receiver. The transmitter was configured to transmit a 400 ms long continuous-wave (CW) signal once per second. The receiver and transmitter were synchronized via a Global Positioning System (GPS) unit, which also supplied the location of the receiver at the instance of each measurement. Data was collected at speeds between 8 and 100 km/h (i.e., walking and vehicular speeds).

Analysis

The recorded data was analyzed to determine how closely it aligned with the Rayleigh fading distribution model. Approximately 26,000 measurements were collected at the two propagation environments and two frequencies. A number of analyses were performed on the data and the results suggested that the Rayleigh model did not accurately reflect the measured fading environment. In one telling analysis, the data was fitted with a Nakagami-m distribution curve at the 95% confidence level (Figure 2). In over half of the cases (51.2%) the m parameter was less than one, indicating worse than Rayleigh conditions. The high incidence of this channel behavior argues for more study using the fast sampling short time regime conditions suggested by this experiment. It is clear that, in the time regimes characteristic of high-speed data radio operation, the incidence of worse than Rayleigh conditions is much higher than previously suspected.

Related Publication:

C. Redding, C. Behm, T. Riley and R. Stafford, "Examining the validity of Rayleigh distribution assumptions in characterizing the fading channel at 162 and 793 MHz," NTIA Technical Memorandum TM-11-477, Jun. 2011.

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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*

Telecommunications Analysis Services enables the transfer of ITS propagation models developed over seven decades of research to private industry and other Government agencies. The TA Services Web site provides access to user-friendly tools that assist in the design of effective wireless systems. Organizations ranging from large Federal agencies and Fortune 500 U.S. companies to single person consulting businesses can use these models and tools on a cost reimbursable basis.

Overview

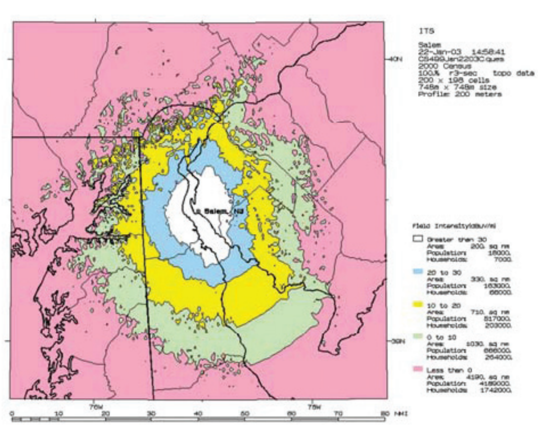
The Telecommunications Analysis (TA) Services program provides U.S. industry and Government agencies with access to the latest ITS research and engineering outputs on a cost-reimbursable basis. Services are provided through a series of computer programs designed for non-technical users with minimal computer 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 (30 m) and 3 arc-second (90 m) 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 via the TA Services Web site. 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. Specifically, TA Services offers raster-based population maps that support more accurate population



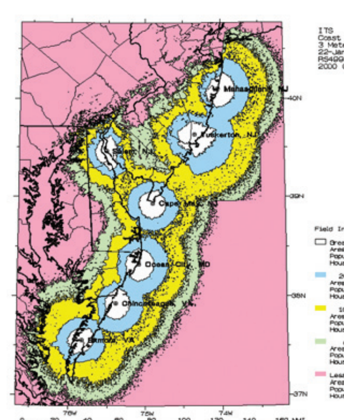


Figure 1 (left). Sample output of the CSPM model of a broadcast transmitter in New Jersey. Figure 2 (right). Composite coverage of several Coast Guard stations located along the East Coast.

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

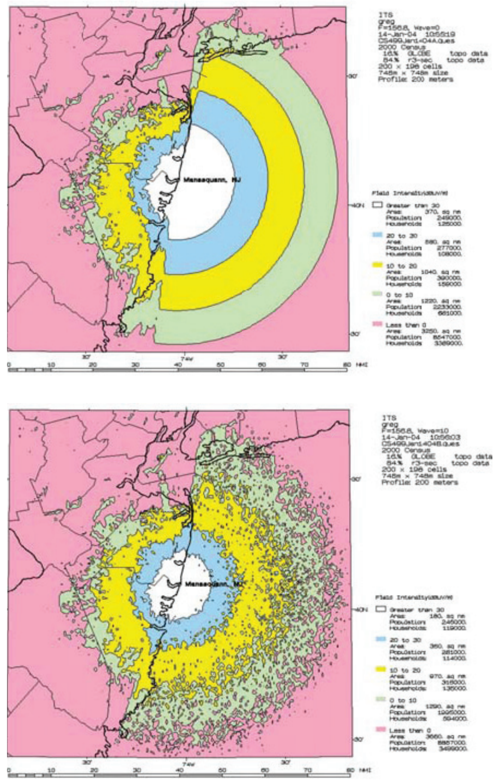


Figure 3. Coverage studies without (top) and with (bottom) an ocean clutter loss addition to CSPM.

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 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 plan 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 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 84) or call one of the contacts listed here.

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Accurate propagation modeling is an essential component of wireless communications planning, and accurate geographic information is a critical input for accurate modeling. ITS has developed openly available propagation modeling tools that use commercial Geographic Information Systems (GIS) to both acquire geographic data and display geographic coverage areas. As users migrate to Web-based systems, the tools must also migrate to being Web-accessible.

Propagation Modeling Website

Outputs

- *A custom-tailored and installed Propagation Modeling Website (PMW) Geographic Information System (GIS) software suite for multiple 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*
- *Ability to composite thousands of transmitter analyses to predict regional wireless network coverage for system planning and interference detection for national security and public safety*

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 four 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) sponsors.

The PMW project builds on 30–40 years of ITS expertise in 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 10 years ago ITS created a desktop tool called the Communication Systems 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) from 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

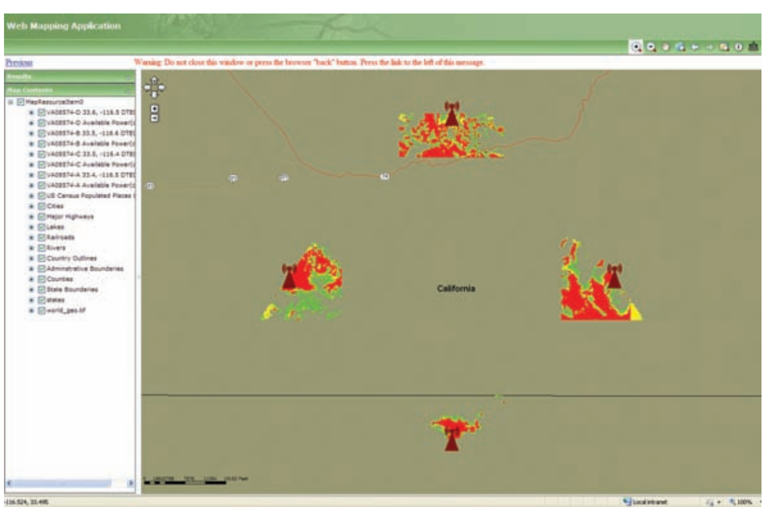

Figure 1. An example of the PMW GIS Web map page showing an analysis of four transmitter coverage plots.

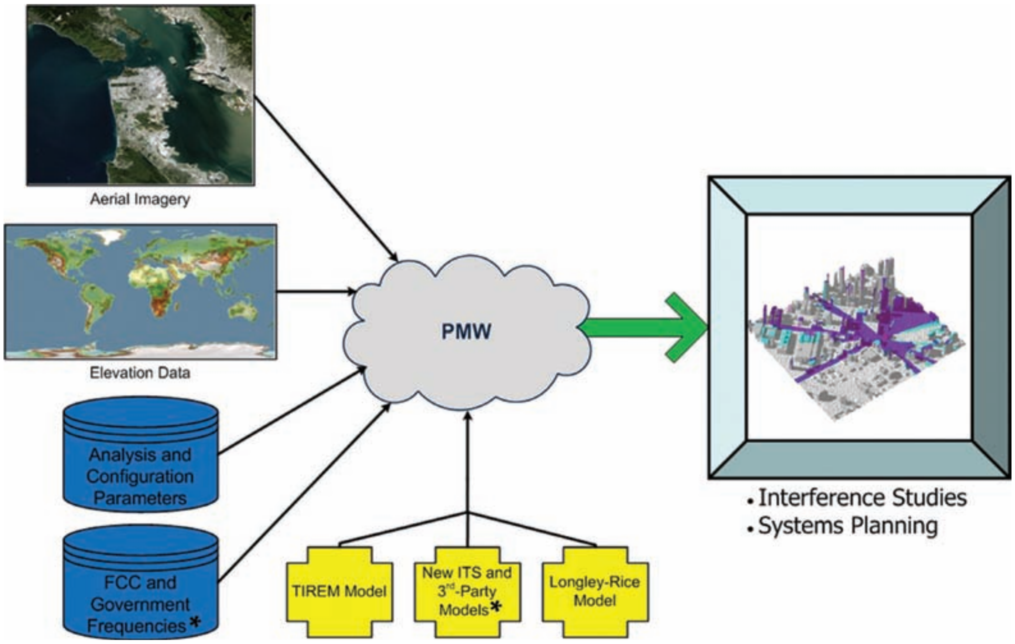

Figure 2. A block diagram of the PMW architecture; asterisks indicate planned future functionality.

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 need to be copied onto each CSPT machine or made available via a shared network system.

Four 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.

The software currently includes the capacity to perform: TIREM 3.15 and Longley-Rice propagation analysis, analysis composite creation for thousands of transmitters, 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 and third-party GIS applications, and login access control. The PMW also incorporates a parallel threaded design that offers speed improvements over the CSPT single threaded model.

Over the next several years, as the PMW continues to mature, the DOD and other sponsors may choose several software enhancements, including but not limited to: interference studies, new analysis results export formats (Google Earth™ (KML/KMZ) or open-source GIS maps), new terrain formats (HRTe, LIDAR, IFSAR, etc.), and other propagation models (the ITS undisturbed-field model, HF models and indoor-outdoor models).

The PMW is currently customized to fit the needs of our DOD sponsors and operate on their internal, secure networks, 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 choose 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.

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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 U.S. To achieve these goals and further its objectives with regard to all forms of wireless communication on a global basis, the U.S. Administration participates in the single most important worldwide telecommunications regulatory and standardization body, the International Telecommunication Union – Radiocommunication Sector (ITU-R).

Broadband Wireless Standards

Outcomes

- *Preparation for and Support of the 2011 Block Meetings of ITU-R Working Parties 3J, 3K, 3L and 3M and Study Group 3*
- *Development of sections of the handbook on the use of ITU-R propagation recommendations for interference and sharing studies*
- *Ongoing measurements of interference from/to radar systems and communications systems*

Overview

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

In recognition of this projected increase in spectrum demand, a recently issued Presidential Memorandum[1] directed the Commerce Department, working cooperatively with the Federal Communications Commission (FCC), to identify and make available a combined new bandwidth of 5×10^8 hertz of radio frequency spectrum, over the next 10 years for expanded wireless broadband use. The Wireless Innovation and Infrastructure Initiative[2] (Wi3) also highlights the Administration's commitment to an expanded wireless broadband policy.

NTIA released a "Ten-Year Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband" (the Plan) to meet the President's broadband spectrum goals. With inputs from the Policy and Plans Steering Group (comprised of Assistant Secretaries from Federal agencies), the Plan identifies over 2.2×10^9 hertz of combined radio frequency spectrum for evaluation, all presently allocated to other Federal exclusive and Federal/non-Federal shared services. The Plan[3] also describes a process for evaluating each of the candidate bands and the steps necessary to make them available for wireless broadband services. An essential component of the Plan is its formal recognition of the critical importance of electromagnetic interference protection for all Government missions/services that rely on spectrum use.

In addition to its domestic activities in support of the Plan's ambitious goals, NTIA has worked diligently with other Federal agencies and the FCC to promote international broadband wireless access. There is now a U.S. Administration contribution, in the form of a draft Agenda Item to the ITU-R World Radiocommunication Conference-2015 (WRC-2015), containing several key elements that extend domestic policy goals for expanded wireless broadband use to the international arena. The ITU-R WRC is the only venue through which changes can be made to the ITU Radio Regulations, the international treaty that defines the rights and obligations for use of the radio spectrum worldwide.

Fundamentally, this U.S. Administration contribution (which must be adopted by WRC-2012 in order for action to be taken by WRC-2015) seeks to expand global allocations of spectrum for wireless broadband by modifying the Radio Regulations to provide for additional primary allocations to the mobile service, with no limitations being placed on the frequency bands to be considered. The U.S. contribution has four basic objectives:

- Flexibility, in terms of frequency bands to be considered

1. The White House, Presidential Memorandum: "Unleashing the Wireless Broadband Revolution," June 28, 2010, http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution
2. The White House, "Fact Sheet: President Obama's Plan to Win the Future through the Wireless Innovation and Infrastructure Initiative," February 10, 2011, http://www.whitehouse.gov/sites/default/files/microsites/ostp/Wi3-fs.pdf
3. National Telecommunications and Information Administration, "Ten Year Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband," http://www.ntia.doc.gov/report/2010/ten-year-plan-and-timetable-make-available-500-megahertz-spectrum-wireless-broadband-pre

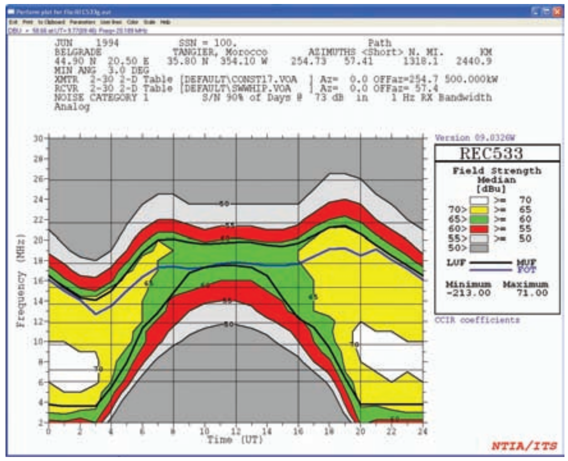
- Harmonization through common spectrum allocations to the mobile service
- Joint studies across the ITU-R, to ensure consideration of all critical existing services
- Timely action at WRC-2015

To meet the objectives of spectrum flexibility and harmonization for the joint studies to be conducted by the ITU-R, prudent spectrum management practice dictates that predicted harmful interference must be minimized both to and from the existing, incumbent services and the new (i.e., mobile) services. General purpose radio propagation prediction models are powerful tools for building international consensus around the introduction of these new services. They provide accurate methods for the evaluation of the potential for interference arising from proposed spectrum reallocation and/or sharing scenarios. When these radio propagation prediction models are also recommended international standards (i.e., Recommendations), they are generally perceived as technically neutral and unbiased bases for multilateral coordination, regulation, and harmonization of spectrum.

Within the Broadband Wireless Standards project, four ITS engineers participate in one or more Working Parties for the development of ITU Recommendations. Notably, ITS engineers currently serve as the Chairman of the ITU-R Working Party (WP) 3K and the Head of Delegation (i.e., the official spokesperson) for the U.S. Administration at the meetings of ITU-R Study Group (SG) 3 and its Working Parties.

Technical Contributions

Member states provide input to the ITU standardization process by preparing technical contributions that are presented to WPs and SGs to inform the discussion and provide a basis for the language of the Recommendations that are eventually released. Among recent U.S. contributions that ITS helped prepare, one concerned a handbook on the use of SG 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 has specific expertise and experience.



Median Field Strength Predictions using Rec. ITU-R P.533 as described in the Handbook.

Certain of these sections involved detailed descriptions of how to use the model(s) 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 using 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 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. At its meeting, SG 3 decided to delegate adoption and approval of this handbook to the next meeting of ITU-R WP 3M in 2012.

A second U.S. contribution, prepared by ITS, proposed revisions to the irregular terrain diffraction method employed in Recommendations ITU-R P.526, P.452 and P.1812, using a variant of the delta-Bullington multiple knife-edge plus smooth sphere diffraction method. Major revisions of two of these Recommendations (P.526 and P.1812) were approved for adoption by SG 3. The revision of Recommendation ITU-R P.452 was appended to the WP 3M Chairman's Report in order to permit Administrations to conduct further testing of the proposed revision.

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Accurate radiowave propagation models are vital for interference analysis and coverage predictions. ITS continues to improve model accuracy by developing new methods better suited to the rapidly changing radio environment. In particular, ITS developed a new model which is more accurate than previous models when predicting propagation at low antenna heights, close distances, low power, and in cluttered environments. These characteristics are typical of broadband wireless uses, like cellular and mobile devices in a downtown area. Drive tests through various cluttered environments provided the necessary data to support development of each of these individual models and their integrated result.

Integration of the Empirical and the Undisturbed-Field Models

Outputs

- *ITS Undisturbed-Field and Empirically Derived (ITS_UFED) radio-wave propagation model based on analytical predictions and measured data developed for use with ultra-low antenna heights and close-in distances*
- *A new tool to meet the needs of spectrum management and electromagnetic compatibility analysis processes*

Overview

The tremendous growth in demand for mobile wireless devices requires that the problems of interference between existing and new radio spectrum users be addressed. An accurate and flexible radio-wave propagation model is essential to meet the needs of spectrum management and electromagnetic compatibility analysis processes. ITS was tasked by the Office of Spectrum Management to integrate two previously developed radio-wave propagation models into a self-contained model.

One model is the Empirical Model based on the least squares fit to measured data resulting from an ITS measurement campaign performed in three vastly different environments: rural, urban low-rise/suburban, and dense urban high-rise/city. The other is the deterministic and analytically based Undisturbed-Field Model, which is suitable for very short-range propagation distances and very low antenna heights. The result was the ITS Undisturbed-Field and Empirically Derived (ITS_UFED) Model for radio-wave propagation loss prediction for very low antenna heights (1 to 3 meters) and close-in distances (2 meters to 2 kilometers) between antennas over the frequency range of 150 to 6000 MHz.

The model is unique in its ability to work seamlessly over these difficult combinations of parameter ranges. The combined model can be applied for use in system performance prediction as well as prediction of interference phenomenon. It is based on both analytical calculations from the physics of electromagnetic theory and actual measurements. The model is the result of a combined program at ITS of measurements and model development to more accurately predict radio signal propagation.

The Empirical Model

The Empirical Model was developed in response to a need for an accurate radio-wave propagation model for interference analysis and coverage predictions in an environment where broadband wireless networking services would be deployed. Low antenna height and low power broadband wireless terminals are needed to permit operation of these systems and at the same time avoid interference with other systems in a crowded electromagnetic spectrum. In this type of environment, the antennas are situated at heights so low that they are immersed in the surrounding environmental clutter. The antennas may also be very close to each other.

The Empirical Model is a slope-intercept model based on measured data taken by ITS in a cluttered and complex radio environment. The data was collected from radio-wave measurements performed in and around Denver and Boulder, Colorado, using a pseudo-mobile

The ITS receiver van performing propagation measurements in the downtown Denver dense urban high-rise city environment. Photo by Robert Johnk.

test procedure with a fixed transmitter location while the receiver van was driven over a specified route. The measurements were obtained at seven nominal frequencies: 183, 430, 915, 1602.5, 2260, and 5750 MHz, since the propagation characteristics are expected to be frequency dependent. The raw signal-strength measurements and positions were post-processed to yield basic transmission loss values versus distance for each nominal frequency and transmitter location.

Based on these measurements, the Empirical Model attempts to mirror some of the general trends in the data. In the case of distance dependence, the model fits a power law via linear least-squares estimation. For the frequency and environmental dependences, where only discrete values are available, the model maintains separate categories. If a prediction at a frequency other than one of the nominal values is required, interpolation between the mean values and standard deviations is performed to estimate the basic transmission loss.

The Undisturbed-Field Model

The Undisturbed-Field Model is a deterministic method suitable for very short range mobile-to-mobile propagation, for distances of 2 to 30 meters. The model has been shown to be accurate for flat terrain up to 2 kilometers. The minimum distance is based on staying at distances greater than the distance where the reactive field of the antenna is present. Extensive testing with exact models at close-in distances has verified the computation accuracy for distances as close as 2 meters over the 150 MHz to 6000 MHz frequency band.

The method involves the calculation of the undisturbed electric field and calculation of the loss based on the amplitude of the electric field as a function of distance, frequency, and the ground constants. The undisturbed field is the electric field produced by a transmitting antenna at different distances and heights above ground without any field-disturbing factors in the proximity of the receiver antenna location.

The undisturbed electric field technique includes near-field effects, the complex two-ray model, antenna near-field and far-field response and the surface wave. Since this is a line-of-sight model, the ground is assumed to be flat over the distance of 2 kilometers or less with no irregular terrain present. For distances of less than 5 kilometers the curvature of the Earth has a negligible effect and can be assumed to be flat for frequencies less than 6 GHz over a smooth Earth. The Undisturbed-Field Model as a separate model can be used for antenna height ranges from 0 to 3 meters and frequencies from 150 MHz to 6000 MHz, but when integrated into the ITS UFED Model the antenna heights are limited to the range of 1 to 3 meters for smooth transitions with the Empirical Model.

ITS Undisturbed-Field and Empirically Derived Model

The ITS Undisturbed-Field and Empirically Derived Model is a combined model with a hybrid procedure using both the Empirical and Undisturbed-Field models. The principal motivation for its development is the fact that the empirical model adjustments at "short" ranges were less accurate than making adjustments based on the Undisturbed-Field Model.

The combined model avoids discontinuities between the two models as users vary the model parameters of antenna heights, distance, frequency and the combined percentage of time and locations. It does this by establishing a set of breakpoint distances.

The breakpoint distances were selected by observing where computations made with both models were equal for the same scenario of frequency, antenna heights, and environment. For the median quantile of (combined) time and locations and at distances less than the breakpoint distance, the combined model uses the Undisturbed-Field Model to predict the basic transmission loss. For the median quantile of (combined) time and locations and at distances greater than the breakpoint distance, the combined model uses the empirical model to predict the basic transmission loss. These breakpoint distances are functions of the environments, the antenna heights and the frequency. The breakpoint distances also depend on the desired quantile of time and locations.

Related Publication:

N. DeMinco, "Propagation loss prediction considerations for close-in distances and low-antenna height applications," NTIA Report TR-07-449, Jul. 2007.

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Radio propagation models are empirical mathematical equations that predict path loss along a transmission link or the effective coverage area of a transmitter. Each telecommunication link encounters different conditions, so different models are needed to predict propagation for different types of links under different conditions. Many international standards for propagation modeling are based on models developed by ITS from our uniquely extensive data collection. ITS continues to make significant contributions to updating those models—some of which were first published over half a century ago—to reflect contemporary conditions and equipment.

Earth-to-Space Propagation Models

Outputs

- *Technical support for international telecommunication standards organizations*
- *Producing U.S. technical contributions to the ITU-R.*
- *Major revision to Recommendation ITU-R P.528-2.*
- *Participation in domestic and international working groups studying Earth-to-space communication links.*

Overview

In describing the President's broad approach to freeing up spectrum for mobile and fixed wireless broadband use, the White House reported: "In recent years, the amount of information flowing over some wireless networks has grown at over 250 percent per year."[1] The "spectrum crunch" is further exacerbated by the fact that only a limited portion of the regulated radio spectrum—the frequencies between approximately 600 MHz and 20 GHz—is the most viable to use for practical systems. This means that in addition to reallocation and repackaging of individual bands, spectrum sharing will be increasingly relied on to accommodate rising demand. On a global level, several wireless communication systems are investigating the possibility of sharing frequency spectrum.

Propagation Modeling for Spectrum Sharing

Successful spectrum sharing requires careful planning to avoid interference between different users. Any study for sharing the spectrum in a frequency range needs to apply an appropriate propagation model in order to obtain reasonably realistic predictions of the results of a particular sharing scenario. Satellite systems are especially vulnerable candid ates for spectrum sharing: mistakes are costly to correct and might even be unfixable. Unfortunately, there are few appropriate propagation models available for aeronautical and satellite wireless links.

ITS is committed to supporting the effort to use frequency spectrum efficiently. Our work includes ensuring that the methods for accurate and realistic planning are available to both Federal and civilian users.

1. The White House, "Fact Sheet: Doubling the Amount of Commercial Spectrum to Unleash the Innovative Potential of Wireless Broadband," June 28, 2010. http://www.whitehouse.gov/the-press-office/fact-sheet-doubling-amount-commercial-spectrum-unleash-innovative-potential-wireles

Supporting International Standards

ITS uses its technical work and expertise to support U.S. interests in the Radiocommunications sector of the ITU (ITU-R), a technical agency within the United Nations. The ITU-R develops international standards called Recommendations. Entities such as administrations, businesses, or academia can use these Recommendations to study, plan and develop radiocommunication systems.

Study Group 3 of the ITU-R is responsible for Recommendations in the P-series, which pertain to propagation issues. ITS, with its history of propagation modeling, is well suited to support Study Group 3 work. Of particular interest this past year has been Recommendation ITU-R P.528-2. This Recommendation was developed from an ITS model, IF-77.

Recommendation ITU-R P.528

It is critical that the model used in frequency sharing studies involving aeronautical and satellite systems be appropriate for the situation. In many cases, Recommendation ITU-R P.528-2 is the appropriate model to use. In the 2010 Study Group 3 Working Party meetings, the study group received questions about two separate issues. One issue concerned frequency sharing studies between the Earth stations of mobile satellite services (MSS) and satellite remote sensing (SRS) services. The other concerned frequency sharing studies between terrestrial mobile systems and aeronautical radionavigation systems (ARNS). The appropriate Recommendation to use was P.528. Recommendation ITU-R P.528-2, however had not been updated since 1986. The recommendation was technically correct, but almost unusable in its existing form.

ITS headed a correspondence group effort to revise P.528-2 using the IF-77 model developed at ITS for the FAA. The correspondence group expanded the set of graphs and added

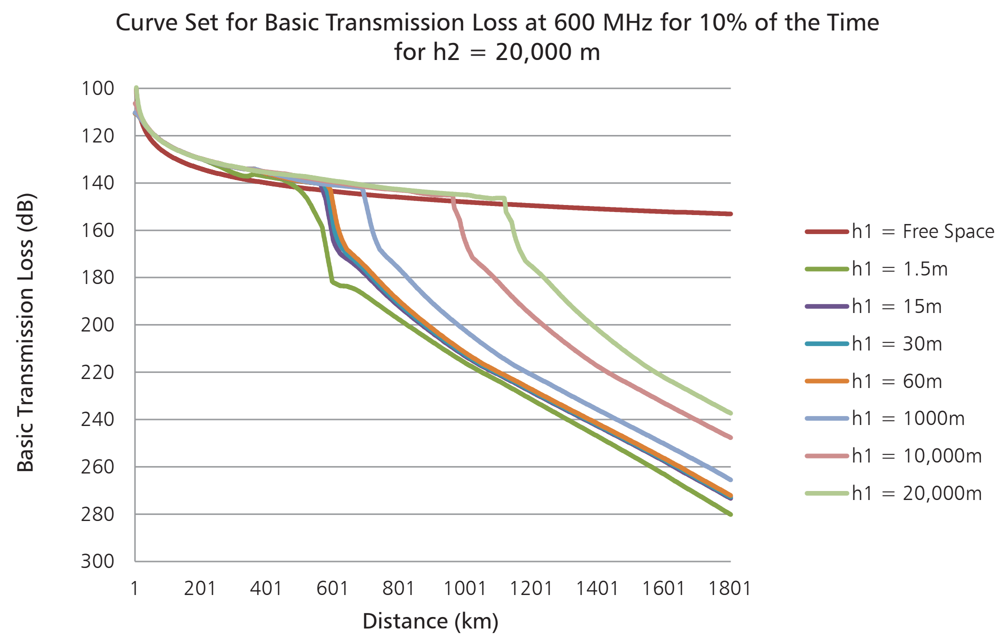

Figure 1 (top). Graph showing basic transmission loss curves for 600 MHz, one of the added frequencies in the expanded curve set for the proposed revision of Recommendation ITU-R P.528-2. Figure 2 (above). ITS staff (fifth row) as part of the U.S. delegation to working party meetings of the ITU-R Study Group 3 in Geneva, Switzerland. Informal photo courtesy ITU-R SG3 archives.

frequencies, time percentages and antenna heights that were badly needed. The group also added a method for interpolating across five parameters, making the document more usable. The revision to the Recommendation was accepted in October 2011 and is being circulated for final approval before adoption.

System Planning

ITS is supporting U.S. interests by continuing the work of the correspondence group in revising Recommendation P.528. The group is presently developing a computational method for the Recommendation in the next ITU-R study cycle. Again, the basis for this work will be the ITS propagation model IF-77. Users could use this computational method to calculate interference levels with other systems and separation distances between Earth-based stations.

Such calculations are essential to studies to evaluate frequency sharing proposals. The calculations based on the computational method are also important in planning both satellite and aeronautical systems.

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Investigations are performed in the major areas of broadband wireless systems performance in the presence of interference; the 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 the further development of advanced spectrum sharing concepts.

Dr. Robert Johnk of the ITS Theory Division prepares a maritime radar receiver for interference-effects testing for an other-agency sponsor. Such work is critically important in spectrum-sharing studies performed by the Institute. Photo by Frank Sanders.

Telecommunications Theory

As demand for telecommunication spectrum grows, more bandwidth is sought by governments and industry. Wireline networks meet many needs, but some needs can only be met by using radio spectrum—a limited resource. In response, spectrum use is migrating toward self-controlled, interference-limited technologies that use spectrum dynamically. Historic spectrum band allocations on a service basis (i.e., separate bands for different systems) are being blurred and supplanted by more sharing between services. But the successful development and implementation of new sharing depends on development of new capabilities in radio systems to avoid interference.

New knowledge, focused on improvements in network performance, is needed to understand the levels of interference that radio systems can withstand from other systems. Tools to monitor the quality of audio and video information on communication channels are also needed so that quality levels can be adjusted in real time to achieve maximal quality with minimal bandwidth.

To achieve these goals for the U.S. Government and the private sector, the Institute's Telecommunications Theory Division performs telecommunications research, improving systems at fundamental levels of physics and engineering. Through technical publications, cooperative research and development agreements (CRADAs), and interagency agreements, ITS continuously transfers the results of its research to both the public and private sector, where the knowledge is transformed into better telecommunications for the U.S., new and better products for consumers and the Government, and new opportunities for economic development and growth for the economy.

Audio Quality Research

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

Effects of the Channel on Radio System Performance

ITS researches the effects of interference and noise on the performance of radio receivers and networks. Current work is focused on the effects of noise and interference as limiting factors in the performance of radar and communication systems. The project is funded by NTIA.

Electromagnetic Analysis and Compatibility Solutions

In response to radio and radar interference problems, ITS performs analyses and measurements jointly with NTIA's Office of Spectrum Management (OSM). The work is funded both by NTIA and by other Federal agency or CRADA sponsors. In FY 2011, ITS worked with the U.S. Coast Guard to analyze electromagnetic compatibility and proactively determine solutions for potential problems between maritime radars and other services in the event that 3 GHz spectrum is shared between radars and other services. This work is being continued in FY 2012.

Electromagnetic Compatibility Assessments for Radars and Communication Systems

In response to interference problems to radar receivers from non-radar systems operating in and adjacent to radar bands, ITS performed extensive analyses and measurements jointly with OSM, including on-site measurements at locations across the country. Two different problems recently caused widespread interference to Government weather radars in two radio bands; in FY 2011 technical solutions were developed and initial tests were performed that demonstrated methods and approaches that solve these problems for radars in both bands.

RSEC Compliance Measurements on New Radars

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

Video Quality Research

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

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As the variety of devices and complexity of the infrastructure for wireless transmission of audio signals increases, methods and protocols for digital audio encoding and transmission also become more complex and varied. Many factors influence the perceived quality of audio transmissions. The ITS Audio Quality Research Program studies the ways in which all these factors interact and can be configured to efficiently and effectively optimize perceived quality. New tools and algorithms developed by ITS are transferred to industry, Government, and academia to promote innovation, entrepreneurship, existing market development, and commercialization of competitive new technologies.

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

Digital audio encoding and transmission have enabled a host of telecommunications and entertainment services and products. These include voice over Internet Protocol (VoIP), cellular telephones, automatic speech recognition, Internet digital audio streaming, and digital audio broadcasting. Digital audio encoding and transmission has matured but efficient, robust, and flexible signal transmission at reduced bitrates with good fidelity remains an elusive goal governed 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 undertakes research efforts that lead to new understandings of the complex relationships between these factors. As such, the program generates and communicates new scientific understandings of the complex technical system known as "telecommunications." More specifically, 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 often requires measurement of speech and audio quality and measurement can be very challenging due to the interplay between technical parameters, human perception, and human judgment.

Speech Quality Dynamics

Telecommunication systems are increasingly heterogeneous and adaptive. The network resources available to support a call are likely to change during the that call, especially when one or more call participants are mobile. The inevitable result is that speech quality increases

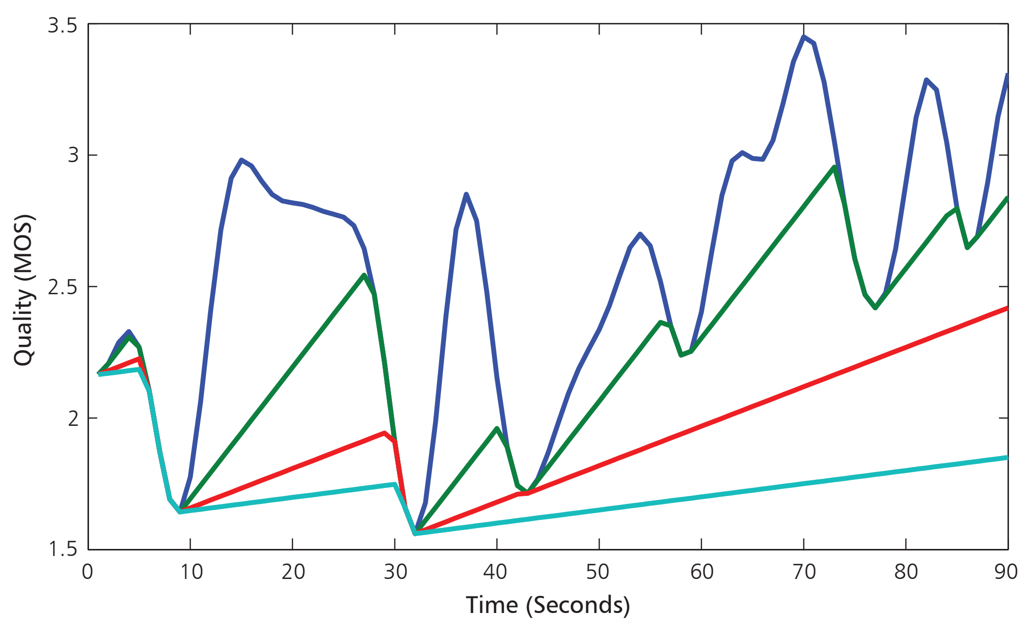

Figure 1. Example speech quality time history (in blue) along with three versions with reduced variation. Vertical axis shows speech quality in Mean Opinion Score (MOS) units.

and decreases during a call. An example time-history of speech quality is shown by the blue line in Figure 1.

Through laboratory and literature research, Program staff have determined that quality variations are generally detrimental to overall quality. It is no surprise that drops in quality are undesirable. But it is also true that in some cases increases in quality are also undesirable. Overall perceived speech quality for a call is determined jointly by the average quality, the minimum or worst-case quality, and the amount of quality variation during the call.

Following from these results, staff have been experimenting with techniques that reduce quality variations. Robust coding techniques can mitigate decreases in speech quality in some cases. But once those techniques are exhausted, the only remaining avenue to reducing quality variations is to place artificial limitations on quality increases. In Figure 1 the green, red, and cyan lines illustrate examples of mild, moderate, and strong limitations respectively. The progression blue, green, red, cyan in Figure 1 is a progression of reduction of speech quality variation, and this is desirable. But at the same time it is inevitably a progression of reduction of average speech quality, and this is undesirable. The goal is to balance these two forces (quality variation and average quality). This balance point is linked to several different parameters associated with the original quality.

Ultra-Low Complexity Speech Coding

Program staff are also developing a new approach to encoding high quality speech at reduced bit rates. This approach uses only look-up tables and thus requires virtually no numerical processing. It achieves a modest rate reduction. This approach stands in vivid contrast to conventional speech coding algorithms that require extensive numerical processing but also achieve greater reductions in bit rate. The new approach may be beneficial in specialized applications where power or processing resources are highly constrained, including some mobile communication applications and remote sensing applications.

Additional Work

Throughout FY 2011, program staff performed 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 through technical publications along with lectures and poster presentations. Staff also served in numerous peer reviewer and associate editor capacities for the technical paper publication process 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.

Figure 2. Audio mixer that controls subjective tests. Photo by Andrew Catellier.

Related Publications

S. Voran and A. Catellier, "Gradient Ascent Subjective Multimedia Quality Testing," *EURASIP Journal on Image and Video Processing,* vol. 2011, Article ID 472185, 14 pages, March 15, 2011. doi: 10.1155/2011/472185

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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ITS broadband wireless research develops more accurate radio channel measurement methods and tools, performs real-world measurements, and supports development of better propagation models. The results of this research—disseminated through publication and technology transfer—help to improve the competitiveness of the U.S. information and communications technology sectors, and enhance scientific knowledge through a greater understanding of the radio channel.

Broadband Wireless Research

Outputs

- *Identification of flaws and development of corrections for a widely-disseminated channel-power model*
- *Measurement system for propagation model development sponsored by the Office of Spectrum Management (NTIA/OSM)*
- *Measurements to support ITS propagation model development*
- *Development of new fast-fading measurement tools for mobile propagation measurements*
- *First prototype development of a new wideband channel sounder using commercial-off-the-shelf equipment*

Strategic Objective

The goal of the NTIA/ITS Broadband Wireless project is to measure the radio channel in real-world environments and to provide data to facilitate the development of improved radio channel models. The results of this research are disseminated to the wireless community through NTIA technical reports, journal publications, conference presentations, seminars, and national and international standards bodies such as ANSI and the IEC. Results are also provided to other NTIA and ITS groups for the development, maintenance, and improvement of radio channel propagation models.

Program Overview

The Broadband Wireless project is currently engaged in the development of ultrawideband, wideband, and narrowband propagation measurement systems, channel modeling, statistical data analysis, signal processing algorithms, and development of specialized RF emissions measurement systems.

Mobile Propagation Measurements

The program is developing propagation measurement systems to study the mobile propagation channel. Two systems have been developed:

- A patented wideband pseudorandom noise (PN) channel sounder system that performs both time- and frequency-domain channel parameter measurements
- A narrow-band system that has high dynamic range and excellent interference immunity

Under the sponsorship of the NTIA's Office of Spectrum Management (NTIA/OSM), ITS used these systems to build a comprehensive propagation database for the development of mobile-to-mobile propagation models covering ranges of two meters to eight kilometers. These systems were deployed in seven different environments ranging from the deep urban canyon of downtown Denver (Figure 1) to the open rural farm country outside of Boulder, Colorado (Figure 2). Both wideband and narrow band systems were deployed over a wide frequency range of 183–5750 MHz. The data obtained were used to develop sophisticated path loss models that will help OSM develop interference models of portable and mobile radios. Through technology transfer, these systems and the data obtained can be made available to commercial entities such as AT&T, other Government agencies such as the Department of Defense, and academic research institutions such as Ohio University for further research and development.

Modeling and Research

Measuring the average power of a mobile radio signal is important for mobile radio system design because it is used for various controls, especially for handoff decisions. It is therefore important that this power be measured accurately. A well-known paper by Lee[1] presents a criterion for determining the uncertainty and associated confidence level of the average measured power. A close examination of this paper revealed a number of mathematical errors that make this criterion overly optimistic. In view of the fact that this is a well-known rule of thumb, it is important that the engineering community be made aware of its fallacies. ITS researchers

1. Lee, W.C.Y., "Estimate of local average power of a mobile radio signal," *IEEE Transactions on Vehicular Technology*, vol. 34, no. 1 , pp. 22- 27, Feb. 1985. doi: 10.1109/T-VT.1985.24030.

are writing a report that identifies and corrects the mathematical errors and presents corrected conclusions.

Ultrawideband Propagation Measurement System Development

The Broadband Wireless Research project is currently developing a short-range ultrawideband propagation measurement system that covers a frequency range of 10 MHz–18 GHz. It uses a combination of a vector network analyzer, an optical link, and a pair of transmit/receive antennas. This system performs low power stepped-frequency measurements that are post processed to obtain high-dynamic range data in both the time and frequency domains. It has been deployed in a variety of environments ranging from short-range indoor environments with antenna separation of a few meters to outdoor environments with antenna separation of 250 meters. This system has provided precision path loss information and delay-spread data for the development of propagation models.

Boeing, United Launch Alliance (ULA), Hewlett-Packard, the National Aeronautics and Space Administration (NASA), and the U.S. Navy have expressed interest in either having ITS engineers apply this system to a particular problem they are researching or having this capability transferred to them. The system has also been used collaboratively to support other programs within NTIA/ITS, most notably to measure soil properties at the ITS Table Mountain Field Site (see the paragraph on Free Field Measurements of the Electrical Properties of Soil in the article "Table Mountain Research Program," page 16).

Figure 1. An "urban canyon" contains a large variety of materials, angles and shapes that can reflect or scatter radio waves and present one type of challenge for propagation modeling.

Figure 2. Open rural areas and long distances present different challenges for accurate modeling. In this photo, the ITS Radio Spectrum Measurement Science (RSMS) truck has been deployed to take measurements in a rural location.

Photos by Robert Johnk.

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Effective spectrum sharing and spectrum reallocation can only be accomplished if both legacy and new services operating in the same or adjacent bands can be protected from interference so they can fulfill their missions. First, the interference potential must be understood and quantified. Then mitigation methods can be devised, tested and standardized.

Coast Guard Spectrum Reallocation Study

Outputs

- *Radar interference protection criteria*
- *Interference testing methodologies*

Overview

Spectrum reallocation is often necessary to accommodate new services which can potentially increase business productivity and enhance the private lives of citizens. However, reallocating services to bands near legacy services or, in some cases, in the same band used by the legacy service can cause interference which prevents the legacy service from fulfilling its mission.

Reallocation can cause interference in three ways. First, reallocating services to nearby bands can introduce weak unwanted out-of-band or spurious signals into the legacy radio detection bandwidth. This interference cannot be mitigated by legacy receiver filtering. The reallocated service must mitigate the interference by reducing unwanted power and maintaining a minimum separation distance.

Second, reallocating services to nearby bands can cause legacy radio receivers not properly protected from strong signals outside the detection bandwidth to behave non-linearly. This can cause gain compression, higher receiver noise levels, and intermodulation. This problem can be mitigated by legacy receiver filtering. However when this is not feasible, the reallocated service must also mitigate the interference by reducing power and maintaining a minimum separation distance.

Third, reallocating services to the legacy radio band can cause co-channel interference. For example, reallocation could combine different radar services into the same band. In another example, communications links using spectrum sharing techniques could be reallocated into the radar band. This can cause interference when the sharing technique fails.

In FY 2010, the U.S. Coast Guard contracted with ITS to investigate effects of reallocation on S-band marine radars. There are two aspects to this problem. First, the marine radar community needs to define interference protection criteria (IPC) that can be used by regulatory agencies to determine maximum transmitted power levels for the reallocated service and minimum separation distances between the reallocated service transmitters and marine radar receivers. Regulatory agencies of interest in this regard are the International Telecommunications Union (ITU), National Telecommunications and Information Administration (NTIA), and Federal Communications Commission (FCC).

Second, the marine radar community needs to know how to test whether a marine radar can perform in the presence of other radio systems which satisfy the IPC. The testing methodology must be approved by test standards groups such as the United Nations/International Electrotechnical Council (UN/IEC).

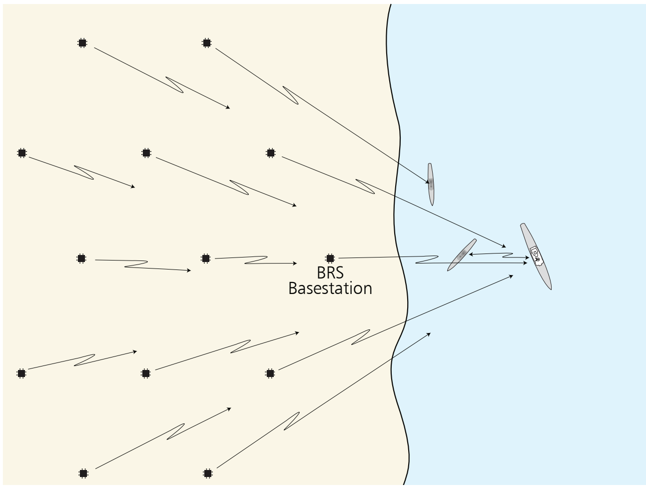

Figure 1. Interference scenario showing a network of BRS basestations contributing to the interference power. BRS basestation height allows the BRS signal to travel significant distances. The BRS signal can cause the radar to not see the boat between the BRS basestation and the ship using the radar. This can be hazardous in foggy conditions.

Current Work

In FY 2011 we investigated the first potential threat: weak unwanted spurious signals from a communications link. In this case the communications link is from the broadband radio service (BRS). The BRS is the next generation of personal communication services which will provide wideband Internet communications to mobile users.

Figure 1 depicts the interference scenario. The BRS basestations are laid out in a grid on land. The BRS antenna is attached to a tower which is high enough to transmit the BRS signal to significant distances over the water. The larger ship is using an S-band marine radar to detect the presence of the smaller ship between it and the shore.

Analysis began with creating an interference model as shown in Figure 2. The model can be divided into five sections: the radar transmitter, radar propagation channel, radar receiver, BRS transmitters, and interfering signal propagation channel. The radar propagation channel is assumed to be free space due to the narrow radar antenna beamwidth. The interfering signal propagation channel includes the effects of ducting.

Next, the allowable degradation was determined, based on a degradation of the probability of detection required for various radar targets. The ITS radar model was then used to determine the allowable interference to noise ratio (INR).

Once the allowable INR was known, a link power budget was developed to determine the propagation loss needed to meet the allowable INR. The link power budget included the power from all the basestations. This is referred to as aggregate power by spectrum engineers. Propagation and antenna pattern losses determine how much of each basestation's power is included in the aggregate power.

Finally, the minimum separation distance is determined from the propagation loss using propagation models. Propagation loss in the maritime temperate environment varies with location and time. Statistics of these variations allow one to predict the percentage of time the radar will not meet its performance objective—i.e., its percent outage.

In preparation for work in FY 2012, ITS also assembled a test bed for evaluating the effect of strong signals on radar IPC and began measurements. The test bed consists of a radar circulator, limiter, and low-noise front end components. The first measurements evaluated the frequency response of these components. Subsequent measurements evaluated LNFE gain compression and noise enhancement.

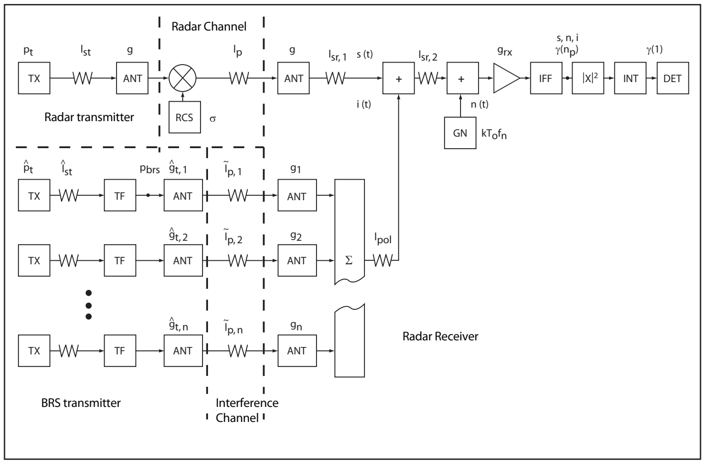

Figure 2. Interference model showing radar transmitter, radar propagation channel, radar receiver, BRS transmitters, and interference propagation channel. TX represents a transmitter, ANT an antenna, RCS a radar cross section modulation source, GN a Gaussian noise source, MF a matched filter, ED an envelope detector, INT an integrator, and DET a detector. The sawtooth shaped symbol represents a loss.

Finally, work began on assembling a test bed for measuring radar to radar interference. This test bed will allow researchers to inject interfering signals into the radar antenna terminal and digitize the received radar pulse and interfering signal just before and just after the radar detector. Of particular interest is evaluating the effect of high duty cycle solid state radars on the performance of low duty cycle magnetron radars.

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The radio channel is the "information super-highway" over which a wireless signal travels. As channels become increasingly crowded, the traveling signal encounters more impediments. Undesired signals, attenuation, and multipath can all cause degradation of a wireless transmission. Characterizing these impediments and their impact on radio transmission is a necessary prerequisite to designing and regulating wireless systems that can deliver their information intact despite the impediments in the channel.

Effects of the Channel on Radio System Performance

Outputs

- *Error statistics for degraded radio channels*
- *Definition of 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 caused 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.

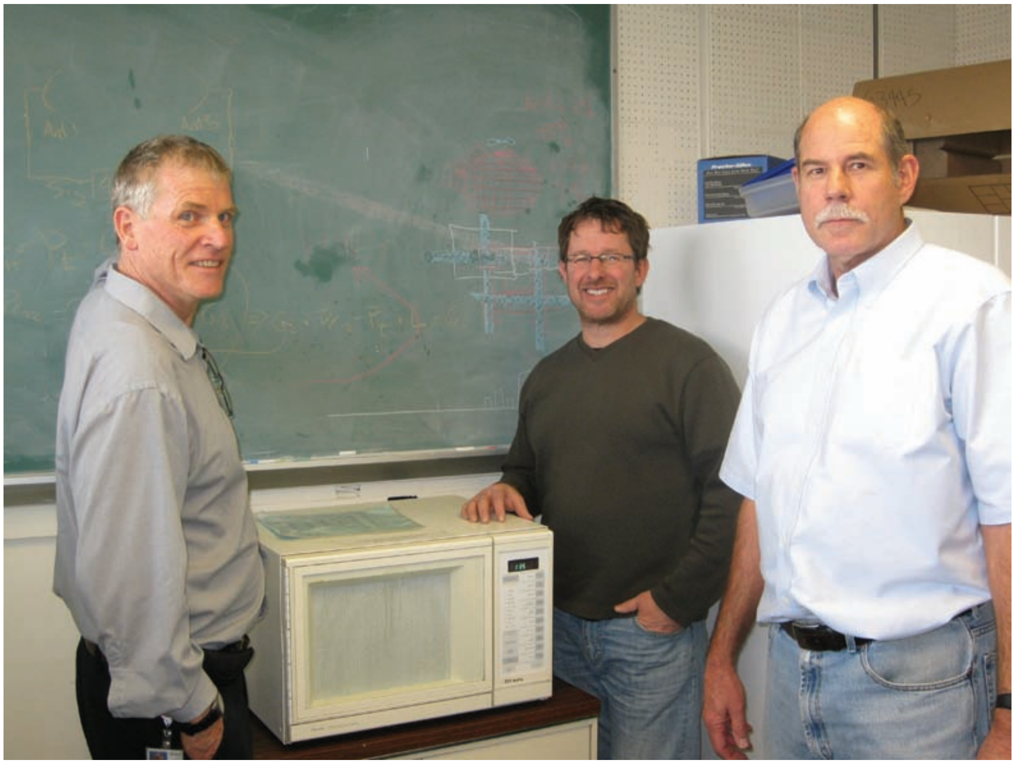
One of the more challenging tasks for this project is to devise methods of collecting error statistics while the radio link is being degraded. Depending on the link, these statistics are obtained through mathematical analysis, simulation, or hardware measurements. Ideally, they are obtained by two or more methods to improve reliability.

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. Regulators use these statistics in determining interference protection criteria (IPC), which designate the maximum amount of interfering signal power a receiver can tolerate without compromising its own performance. Reliable IPC become more important as pressure increases for Government services to share radio spectrum with private services in accordance with the recently introduced National Broadband Plan.

Current Work

Work this year consisted of the continued development of a radar model, investigating radar IPC, measuring the effects of strong signals on low noise amplifier noise floors, and planning and hosting spectrum sharing forums for the International Symposium on Advanced Radio Technologies (ISART) 2011.

One area of focus is the development of a radar model for radar interference studies. This model is timely, since radars use a large portion of the federal radio spectrum and industry is currently advancing a number of proposals for sharing it. The focus has shifted from modeling magnetron radars using non-coherent integration to more modern solid state radars using



Project team members. From left to right Robert Achatz, Mike Cotton, and Roger Dalke. Photo by Frank Sanders.

coherent integration. The coherent integration is implemented with a discrete Fourier transform. In FY 2012, the radar model will be used to assist the U.S. Coast Guard in analyzing the effect of signals from 4th generation broadband personal communication service devices on the performance of marine radar systems in nearby radio bands.

In FY 2011, ITS investigated how using fluctuating radar targets would affect radar IPC values. In the past, radar IPC have been derived from measurements which assume a static radar target. However, aviation and marine radar specifications and acceptance tests typically assume fluctuating radar targets. Analysis showed that using a fluctuating radar target would increase the amount of interference power that the receiver would tolerate. Additional work is needed to verify this result in the laboratory.

Development of a low noise amplifier test bed was also started. The test bed will be used to analyze the effect of a strong signal on the noise floor of a low noise amplifier. For some time, radio engineers have known that strong signals drive low noise amplifiers into gain compression. Radio engineers have also known that strong signals raise the noise floor of the low noise amplifier. The test bed will be used to determine if the strong signal changes the statistics of the noise. The results of this experiment will help to determine whether Gaussian noise assumptions can be used for determining IPC for strong signal situations.

In FY 2011, ITS contributed to developing meaningful IPC by planning and moderating a variety of spectrum sharing forums for ISART 2011, the 12th annual ISART sponsored by the NTIA and hosted by ITS. Through these forums, leaders from government, industry, and universities are brought together to present and discuss their views on various spectrum sharing issues.

Knowledge gained through research in one project is often applied towards other projects at ITS. For example, in FY 2011, the Institute's knowledge of the radio channel was applied to evaluating the effectiveness of public safety in-building radio enhancement systems (IBRES). The results of this evaluation are an important resource for municipal public safety communications professionals tasked with assisting building owners to install reliable IBRES.

Related Publication:

R.J. Achatz, R.A. Dalke, and J.J. Lemmon, "In-building radio enhancement systems for public safety," NTIA Report TR-11-480, Sep. 2011.

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As radio spectrum crowding increases, interference issues arise more frequently. Mitigation depends on accurately identifying both the source and the mechanism of interference. ITS is skilled at interference root cause analysis, as well as developing mitigation techniques.

Interference Effect Tests, Measurements, and Mitigation for Weather Radars

Outputs

- *Predictions of the effects of interference from non-radar systems to weather radars*
- *Measurements of interference characteristics at weather radar sites and identification of interference sources and mechanisms across the US in two bands (3 GHz and 5 GHz)*
- *Development of new dynamic frequency selection (DFS) test-and-certification protocols to prevent future interference to 5 GHz weather radars from DFS wireless transmitters*
- *Determination of interference sources and mechanisms affecting 3 GHz weather radars across the U.S.*
- *Development of interference-mitigation techniques for 3 GHz weather radars*

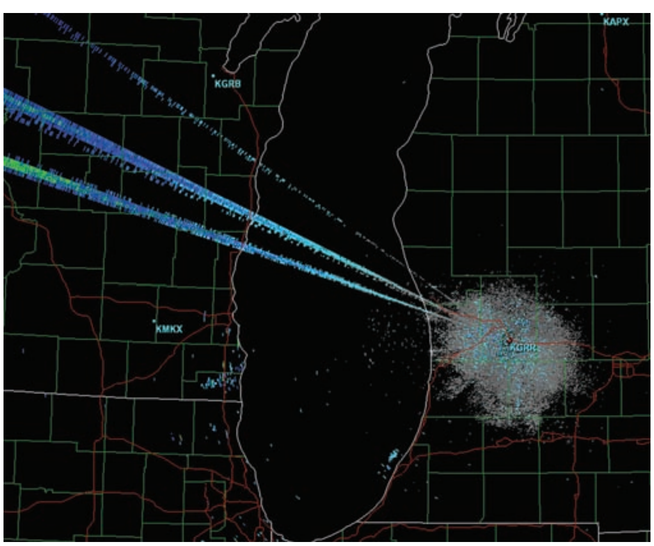
Overview

In FY 2011, ITS and OSM engineers investigated and provide solutions for ongoing radio interference to weather radars in two bands (3 GHz and 5 GHz) at sites across the United States. An NTIA Technical Report, the second in a three-part series, was issued on the 5 GHz problem. It followed up on original field work (described in Part I of the series) by describing controlled-condition laboratory work that provided solutions for the 5 GHz weather radar interference.

Interference to Weather Radars in the 5 GHz Band

The 5 GHz interference, originating 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, has occurred 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.

It was determined that most models of DFS-equipped 5 GHz U-NII devices are operating properly; a small sub-set of models, however, have not detected 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. The problem is being corrected by using



Interference effects in a weather radar receiver.

better test-and-certification DFS waveforms, provided by ITS to the FCC.

Interference to Weather Radars in the 3 GHz Band

Interference to weather radars at 3 GHz has been caused by an entirely different problem. Here, the problem has turned out to be due to adjacent-band emissions. ITS, working jointly with the National Weather Service (NWS), the FCC, the Federal Aviation Administration (FAA), and the private sector, has determined the sources of the interference and has provided a range of solutions that are now being implemented. This work involved extensive field operations at locations across the US and laboratory work in 2011. The field operations used ITS suitcase measurement systems to determine the sources of interference and to gather the data that were needed to identify a solution to the problem. An NTIA Report describing this work will be issued in 2012.

Above: ITS and other Government engineers performing field measurements to identify interference sources. Below: An ITS engineer performs electromagnetic compatibility measurements inside a weather radar bubble 24.4 meters (80 feet) above the ground while observers from the FCC, FAA, and NWS observe. Photos by Frank Sanders

Related Publication

John E. Carroll Geoffrey A. Sanders Frank H. Sanders Robert L. Sole, "Case Study: Investigation of interference into 5 GHz weather radars from unlicensed national information infrastructure devices, Part II," NTIA Technical Report TR-11-479, Jul. 2011.

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ITS is a recognized leader in radio channel measurement and modeling whose resources and expertise are sought after both by other Government agencies and by private sector companies. In addition to performing measurements, and analyses on request, ITS engineers transfer knowledge to others through training in spectrum measurement techniques developed over more than half a century of research.

Lockheed Martin Radar Measurement CRADA

Outputs

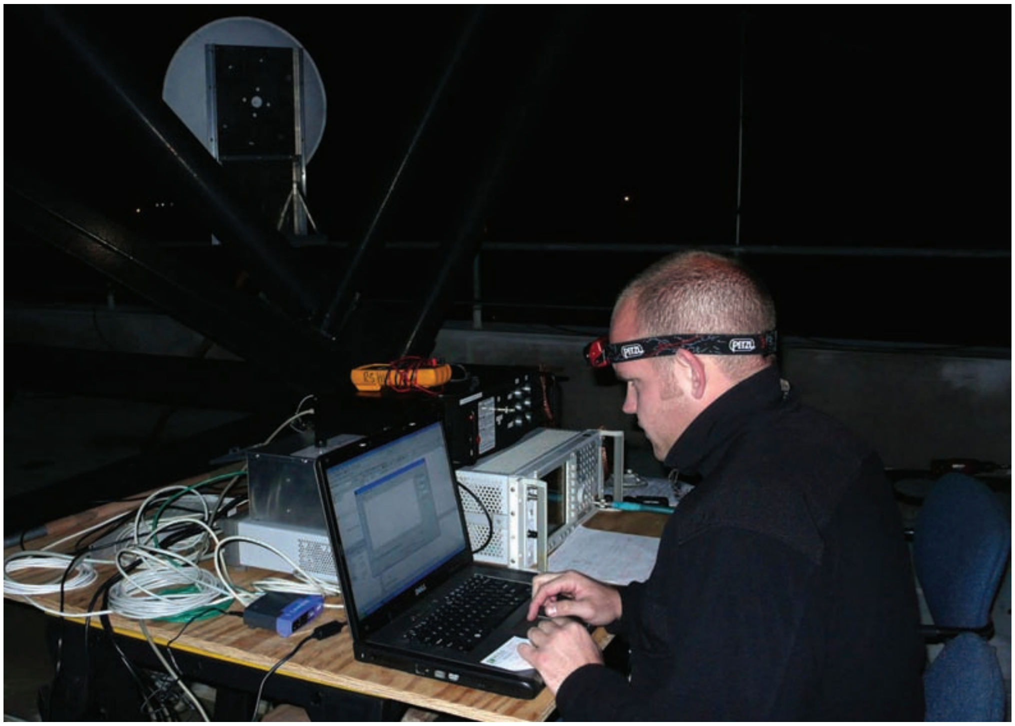
- *Emission spectrum measurements of a new air-search radar.*
- *Emission measurements of a new battlefield radar.*
- *Seminars for LMCO on radar spectrum emissions.*

The Institute makes its capabilities available for use with partners in the private sector via Cooperative Research and Development Agreements (CRADAs); these agreements provide benefits for both the Government and the private-sector partners.

One CRADA completed in FY 2011 was with the Lockheed Martin Company (LMCO). Under this CRADA, ITS engineers performed emission-spectrum measurements on new LMCO radars and also delivered a seminar for LMCO on spectrum management, spectrum emission criteria, and spectrum measurement techniques.

Emission spectrum measurements were performed on a new air search radar system at Syracuse, NY, and other measurements were performed at a southwestern test and training range. The measurement results were analyzed by ITS engineers and provided to the sponsor per the terms of the CRADA.

Above: ITS engineers on the roof of an LMCO building during a radar emission spectrum measurement. Facing page, top: An ITS engineer during outdoor, nighttime measurements of an LMCO radar. Facing page, bottom: An LMCO radar measured under the ITS-LMCO CRADA. Photos by Frank Sanders



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Maintaining public safety increasingly depends on sophisticated radio and radar equipment. New technologies for surveillance and intrusion detection promise more accurate and detailed information for public safety agencies, but before they can be fully deployed testing, measurement, and analysis is needed to ensure that they are both safe and compatible with existing wireless devices.

U.S. Navy Shore Line Intrusion Monitoring System (SLiMS) Emissions Measurements

Outputs

- *A full characterization of the emission characteristics of the SLiMS ultrawideband radar system*
- *A comprehensive study and model of interference potential of the SLiMS system to incumbent electronic systems (e.g., GPS and radar altimeters) at deployment locations*

Overview

The United States is currently engaged in a global war on terror, and the security risks to U.S. personnel and assets have increased significantly overseas and at home. The DOD is currently developing a number of surveillance radars to detect and identify intruders on the ground. In order for these systems to be deployed, they must be proved to be compatible with incumbent electronics systems and not to pose safety hazards. ITS has a unique combination of expertise, equipment, and facilities to measure and evaluate these systems for deployment.

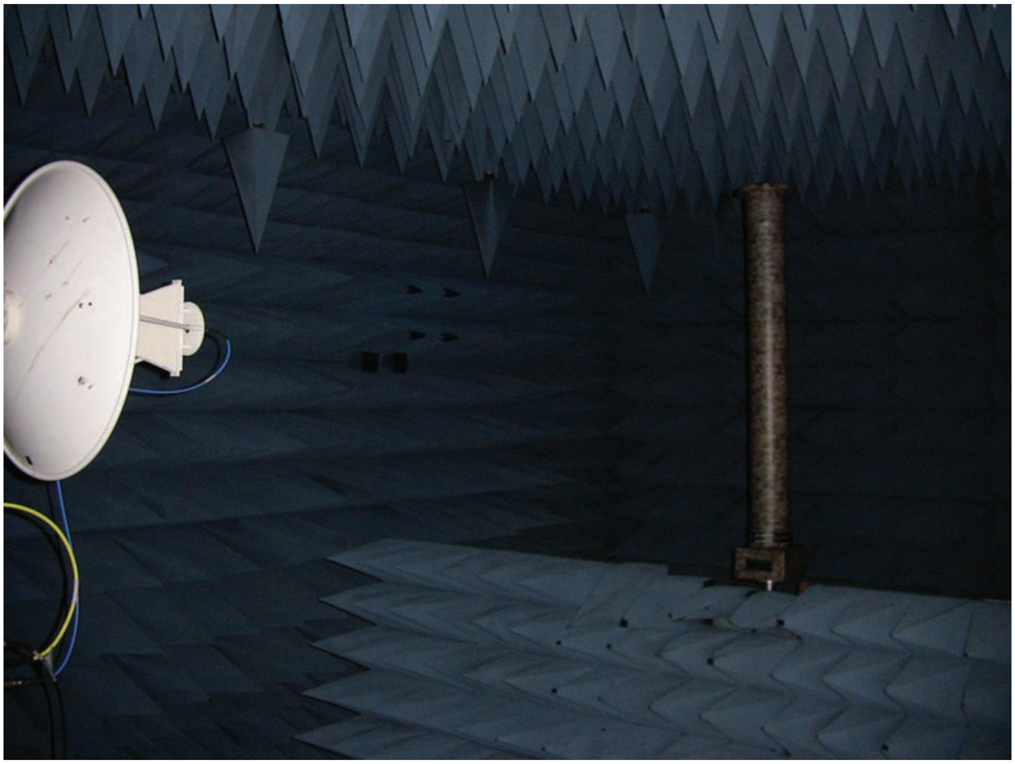
Project Background

The Navy Facilities Engineering Command (NAVFAC) is sponsoring the development of an ultrawideband (UWB) radar that can track as well as image intruders. It has been designated the Shore-Line Intrusion Monitoring System (SLiMS) system. The radar consists of a distributed system of autonomous transmit/receive modules mounted on poles, which are deployed around a facility to be protected. The number of poles and modules varies depending on the coverage needed. There are currently plans to deploy this system at military bases in the continental United States and in Alaska. The U.S. Department of Energy (DOE) wants to deploy this system around a nuclear power plant. The Navy has asked ITS to perform a comprehensive set of emissions measurements on a shortened pole structure containing a single radar module. In coordination with the Naval Surface Warfare Center (NSWC), ITS will:

- Ensure that the Navy system is compliant with NTIA and FCC UWB emissions limits.
- Ensure that the system does not constitute a hazard to either personnel or ordinance
- Perform an incumbent system study at SLiMS deployment locations to make sure that interference does not occur

Progress and Deliverables

ITS engineers have completed a comprehensive series of emissions measurements on a SLiMS "short pole" in a fully anechoic chamber, as shown in the accompanying figure. An anechoic chamber provides an interference-free environment with high measurement precision. ITS measured antenna patterns, random losses, and peak/average radiated power levels. Emission levels were measured over a frequency range of 1–15 GHz using a high-speed sampling oscilloscope and precision spectrum analyzer. ITS conducted a series of antenna calibrations in conjunction with the emissions measurements to provide high precision and excellent measurement fidelity. The data obtained will be used in a comprehensive electromagnetic compatibility study at the SLiMS system deployment locations.



A "short pole" mounted Shore-Line Intrusion Monitoring System (SLiMS) autonomous transmit module is set up in an anechoic chamber at the Department of Commerce Boulder Laboratories, with a receive antenna to capture and measure its emissions. Photo by Robert Achatz.

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Mobile video traffic surpassed 50% of all mobile traffic in 2011,[1] more than doubling for the fourth year. Video content has much higher bitrates than other mobile content types; at current bitrates, it is predicted that monthly global mobile data traffic will surpass 10 exabytes, or 70% of mobile data traffic, by 2016. Content providers continuously struggle to manage the trade-offs between perceived video quality and bitrate through improved compression and encoding algorithms. To test the effectiveness of these algorithms, researchers and developers need software tools that can provide rapid and economical ways to measure video quality.

1. Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016, Feb. 2012.

Video Quality Research

Outputs

- *Improved techniques to measure video quality*
- *Development of software tools*
- *Distribution of test video*
- *Publication of technical papers*
- *Representation of US interests in international standards bodies*

Overview

There are three ways to measure video quality:

- Look at a test signal
- Ask a person's opinion of a video
- Use a computer algorithm

Test signals were an effective way to measure video quality in the days of analog television. For example, the camera focused on a picture of wide and narrow lines. Video quality was measured by finding the narrowest line on a television monitor. This does not work for modern digital systems.

Asking a person's opinion of video—also known as subjective testing—is by far the most accurate way to measure video quality. The cost and the time required are often a problem. For example, industry needs rapid feedback while fine tuning a new product, but subjective testing is a lengthy and expensive process.

An objective video quality model is a computer algorithm that attempts to predict human perception of video quality by trying to imitate human perception, object recognition and judgment. This is difficult to do well.

Reliable Objective Video Quality Models

ITS has been developing objective Video Quality Models (VQM) for over two decades. ITS's VQM software offers an inexpensive alternative to subjective tests. The VQM software can be downloaded royalty-free for commercial or non-commercial use from www.its.bldrdoc.gov/vqm. In the last three years, 1245 people have downloaded the VQM software.

The VQM software includes a variety of algorithms to suit different needs: the Peak Signal to Noise (PSNR) Model, the NTIA General Model, and the NTIA Fast Low Bandwidth Model

The PSNR Model has wide industry acceptance but the two NTIA models offer improved accuracy. All three models were evaluated by the Video Quality Experts Group (VQEG, www.vqeg.org) and standardized by the prestigious International Telecommunications Union (ITU).

In FY 2011, ITS completed development of the most accurate model to date: the Video Quality Model with Variable Frame Delay (VQM_VFD). This new model includes a neural network that was trained on people's opinions of the quality of 11,255 test videos in resolutions ranging from cell phone size to HDTV.

Consumer Digital Video Library

Finding—and getting rights to use—relevant test video is an obstacle to some interesting research topics. The Consumer Digital Video Library Web site (CDVL, www.cdvl.org) was created to address this problem. ITS developed, hosts, and supports the CDVL website.

The CDVL makes high quality, uncompressed video clips available for download, free. Content owners can also upload and share their content. Clips hosted on CDVL are ideal for use by the education, research, and product development communities. CDVL content is also useful to:

- Develop new products
- Choose video equipment
- Improve video coding algorithms
- Optimize video system performance
- Train objective video quality models
- Conduct subjective video quality tests

HDTV camera used to film content for research and development. This camera lets ITS create broadcast quality videos, with the legal rights to redistribute them. Photo by Andrew Catellier.

Examples from the Consumer Digital Video Library (www.cdvl.org). This website encourages research and development into video topics. ITS hosts this library. Composition by William Ingram.

In FY 2011, 242 people downloaded video from CDVL. Approximately 75 percent were from the U.S. and 25 percent from other countries around the world. About 75 percent of those who registered are from academia and 25 percent from industry. ITS made 1000 video clips available on CDVL in its first year (FY 2010) and another 1000 video clips in FY 2011.

Leadership

VQEG determines whether objective video quality models are accurate enough for industry to trust. ITS helped establish VQEG in 1997 and continues to participate in VQEG by:

- Co-chairing VQEG meetings
- Providing independent oversight to promote fairness and accuracy
- Analyzing data from VQEG sponsored subjective tests
- Writing subjective test plans and reports

Once an objective video quality model has been tested by VQEG, the next step is an international standard. This provides reputable proof that the algorithm is reliable. The video quality project supports video standardization efforts in the Video Services Forum (www.videoservices-forum.org), ITU-T Study Group 9, ITU-T Study Group 12, and ITU-R Working Party 6C.

ITS provides information to U.S. industry and other Government agencies through responding to e-mail and phone inquiries, lab visits, technical presentations, and publications. ITS sometimes performs subjective tests to answer questions raised during this exchange of information, as reported in the related journal publication.

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

Related Publication:

G. Cermak, M. Pinson, S. Wolf, "The Relationship Among Video Quality, Screen Resolution, and Bit Rate," *IEEE Transactions on Broadcasting*, vol. 57, no. 2, pp. 258–262, Jun. 2011 doi: 10.1109/TBC.2011.2121650

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> “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)*

Technology Transfer

Outputs

- *Collaborative research and development agreements*
- *Technical papers and royalty-free data and software releases*
- *Collaborative standards contributions*
- *Conferences, workshops and symposia*

ITS is a member of the Federal Laboratory Consortium for Technology Transfer, the nationwide network of federal laboratories organized to promote the fullest application and use of Federal research and development. Technology transfer aims to rapidly integrate Federal research outcomes into the mainstream of the U.S. economy to enhance U.S. competitiveness in the global marketplace. Cooperative research and development agreements (CRADA), technical publications, and leadership and technical contributions in the development of telecommunications standards are the three principal means by which ITS transfers the fruits of our research efforts to the private sector.

Cooperative Research and Development Agreements

In FY 2011, ITS participated—as it has for a number of years—in CRADAs with private-sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. CRADAs, authorized under the Federal Technology Transfer Act of 1986 (FTTA), allow ITS 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. These partnerships aid in the commercialization of new products and services, as well as enhancing the capabilities of ITS laboratories and providing researchers with insights into industry's needs for productivity growth and competitiveness. This enables ITS to adjust the focus and direction of its programs for effectiveness and value, and to undertake research in commercially important areas that it would not otherwise be able to do.

To date, major contributions to personal communication services (PCS), local multipoint distribution service (LMDS), ultrawideband (UWB), and broadband over power line (BPL) technologies have been achieved through CRADAs. These have aided U.S. efforts to rapidly introduce new communications technologies. More recently, CRADAs in the areas of objective audio and video quality, advanced antennas for wireless systems, and remote sensing and global position (GPS) technology have allowed ITS to contribute to the development of new products and services.

CRADAs for Use of Table Mountain

The Table Mountain Field Site is also made available for telecommunications research to other Government agencies and to private industry through CRADAs. Access to this unique resource particularly benefits small businesses, who would otherwise be unable to perform research that may be crucial to bringing a product to market. For more information on FY 2011 Table Mountain CRADAs, see page 16.

Technical Publications

Historically, ITS has transferred research results to other researchers, the commercial sector, and Government agencies through publication of results either directly as NTIA publications or by submission of articles to peer-reviewed external scientific journals. Many of these publications have become standard references in several telecommunications areas.

Technical publication remains a principal means of ITS technology transfer. An internal peer review process managed by the ITS Editorial Review Board (ERB) ensures quality of publication. In FY 2011, ITS authors released eleven NTIA Technical Reports, Memoranda or Handbooks through the ERB process and four journal articles or conference papers, which underwent additional peer review outside ITS. A list of FY 2011 publications begins on page 76.

Development of Telecommunication Standards

This method of technology transfer directly addresses improvement of U.S. competitiveness in telecommunications. For several decades, ITS has provided leadership and technical contributions to national and international organizations responsible for developing telecommunication standards. For example, a plurality of the technical recommendations of the International Telecommunication Union (ITU), a treaty organization, are based on research conducted at ITS. Also, key national quality-of-service standards developed under the American National Standards Institute (ANSI) T1 committee for video, audio, and digital data incorporate research results obtained at ITS. ITS chairs many committees and working groups in the ITU, the Alliance for Telecommunications Industry Solutions (ATIS), and other telecommunication standards organizations, providing technical leadership that is trusted by commercial-sector participants. ITS's technical inputs are relied on as technically advanced, scientifically sound, and unbiased by commercial interests.

In FY 2011, ITS continued its technical leadership and contributions to communications standards for public safety, particularly for first responders. ITS's primary area of contribution has been interoperability standards and testing procedures. ITS's objective video quality measurement method has been made a national standard by ANSI. This method was also the best-performing metric in ITU comparison testing with other methods from around the world.

Conferences, Workshops and Symposia

ISART 2011

For over a decade, ITS has hosted the International Symposium on Advanced Radio Technologies (ISART). This symposium brings together government, academia, and industry leaders from around the world for the purpose of forecasting the development and application of advanced radio technologies.

The 12th Annual ISART was held at the Department of Commerce Laboratories in Boulder, Colorado, July 27–29, 2011. Its focus was "Developing Forward-Thinking Rules and Processes to Fully Exploit Spectrum Resources—Case Study 1: Radar." Radar spectrum bands have frequently been identified as candidates for sharing, and important precedents have been set, such as FCC rules allowing 5 GHz U-NII wireless networks that use Dynamic Frequency Selection (DFS) radar avoidance and NTIA fast-track recommendations to share the 3550–3650 MHz frequency band (currently used by DOD maritime radar systems).

ISART 2011 was designed to present a comprehensive evaluation of radar spectrum management and usage. It provided a unique forum where prominent radar and telecommunications engineers from all countries and sectors could explore the interactions between these distinctive technologies, contemplate enhanced spectrum engineering and sharing approaches, and exchange information.

PSCR Technical Workshop

ITS hosted the Public Safety Communications Research (PSCR) Winter 2011 Technical Workshop on the topic of "Network Identifiers and Roaming/Clearing" November 30–December 1, 2011. This invitational workshop gathered representatives from the Public Safety Spectrum Trust Operator Advisory Committee, PSCR's 700 MHz Public Safety Broadband Demonstration Network participants, and Federal partners to share information and discuss issues surrounding Network Identifiers and Roaming/Clearing in the context of building out a nationwide, interoperable public safety broadband network.

VQiPS

ITS hosted the 3rd annual Video Quality in Public Safety (VQiPS) conference and workshop February 16–18, 2011 in Boulder, CO. The meeting brought together practitioners, industry, government and academia for the purpose of creating tools and standards to assist agencies in purchasing video equipment appropriate for their applications.

The opportunity for extensive interaction among participants is one of the most valuable aspects of ISART. Here, a representative of private industry questions Commerce Assistant Secretary for Communications and Information Larry Strickling during the extensive Q&A that followed his Keynote Address.

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FY 2011 Private Sector CRADAs

Outputs

- *Eight Cooperative Research and Development Agreements that allowed companies or universities to leverage Federal resources to bring product to market or complete research and development efforts faster and more safely*

Areté Associates

Laser Radar (LADAR) Testing on Table Mountain

Areté Associates is developing a variety of Laser Radar (LADAR) technologies for the U.S. Department of Defense. This CRADA allowed Areté to use the Table Mountain Field Site as a field location to safely test and demonstrate these technologies in atmospheric conditions and at distances relevant to potential applications.

Boombang:

NWR Measurements

Boombang is a venture incubator that assists clients in multiple areas, including product engineering, design, and development. The company asked ITS to test the functionality of several prototype NOAA Weather Radio receivers using simulated emergency broadcasts in order to identify strengths and weaknesses in each as part of their product development cycle.

AUGNet is a project of the University of Colorado's Research and Engineering Center for Unmanned Vehicles (RECUV), a university, government, and industry partnership for the development and application of unmanned vehicle systems. RECUV research encompasses scientific experiments, commercial applications, mitigation of natural and man-made disasters, security, and national defense. Pictured above is a flock of unmanned aircraft under test. Research on unmanned aircraft systems (UAS) includes work on mobile ad-hoc communications, delay-tolerant, ad-hoc protocols that allow UAS to operate in stressed or fractured networks. Cognitive radios being developed to support this research scan the RF spectrum to select frequencies with the best performance, behavior that has myriad applications for other communications systems. At right, a picture of the Tempest UAS. Tempest is an aerial robot system designed to perform in situ sampling of supercell thunderstorms, including those that produce tornadoes, and was a vital component of the VORTEX2 study to gather data on tornadoes that will be used to improve tornado forecasting. Photo above courtesy University of Colorado Boulder. Photo at right by Jack Elston.

Chaney Instrument Co.

NWR Measurements

Chaney Instrument Co. designs and manufactures NOAA Weather Radios. Cheney entered into two CRADAs with ITS during FY 2011 under which ITS performed functional testing of All Hazards receivers using simulated emergency broadcasts. Cost-effective comprehensive testing is an integral part of the product development cycle for new or improved receivers.

University of Colorado Boulder

AdHoc UAV Ground Network (AUGNet) Test Bed

The University of Colorado is experimenting with communication networks between low-cost small unmanned aircraft (UA) similar to model radio-controlled airplanes and ground-based radios. The networking is used to coordinate UAV activities and the goal is to develop autonomous "flocking" where the UAVs collectively and autonomously complete sensing and communication tasks. This project is part of the Ad hoc Ground Network (AUGNet) research activity which is part of the Research and Education Center for Unmanned Vehicles (RECUV) at the University of Colorado. This CRADA allowed the university to use the Table Mountain Field Site as a field location to safely and accurately test these technologies; test data and reports were shared with ITS, providing ITS insights into wireless network operations using commercial-off-the-shelf (COTS) wireless LAN equipment.

FIRST RF Corporation

Installed Performance of Antennas Under Test

FIRST RF Corporation is a small business that designs and manufactures radio antennas and systems. This CRADA allowed FIRST RF to use the Table Mountain Field Site as a field location to fully test the functionality of new antenna designs as part of the product development cycle.

Lockheed Martin/Coherent Technologies

Laser Radar (LIDAR) Testing

Lockheed Martin Coherent Technologies entered into a CRADA with ITS to engage in field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar at the Table Mountain Field Site. The instruments being tested use Light Detection and Ranging Systems (LIDAR), an advanced remote sensing technique that uses pulsed laser light instead of radio waves (radar) to detect particles and varying conditions in the atmosphere. The technology is used, among other things, to improved flight safety by detecting hazardous winds and aircraft wakes.

Lockheed Martin

Radar RSEC Measurements

Lockheed Martin is developing a new deployable radar system designed to rapidly establish airfield operations anywhere in the world for both military and disaster relief efforts. Under this CRADA, ITS was tasked with measuring the emission spectrum and related emission characteristics of the two types of radar and to ascertain that both comply with the NTIA Radar Spectrum Engineering Criteria (RSEC) emission mask limits. This is critically needed data for electromagnetic compatibility analyses between these radars and other radars with which they will need to share spectrum. See more information about this CRADA on page 62.

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Technical standards formally document common norms or requirements for technical systems. Establishing uniform engineering or technical criteria, methods, processes, and practices for telecommunications helps to overcome technical barriers in international trade, minimize interference, and maximize interoperability. ITU-R international technical standards, called Recommendations, are developed by small Working Parties, finalized by the larger Study Groups, and approved by the 193 member states. Though not mandatory, in practice ITU-R Recommendations are implemented worldwide.

ITU-R Standards Activities

Outputs

- *Technical support for U.S. Administration activities in ITU-R Study Group 3 and Working Parties 1A, 3J, 3K, 3L, 3M, 5B, 5D, and 6C*
- *Leadership roles in U.S. Study Group 3, U.S. Working Party 3K, U.S. Working Party 3J*
- *Development of a new version of ITU-R Recommendation SM.1541, Unwanted Emissions in the Out-of-Band Domain*
- *Development of a new version of ITU-R Recommendation P.528, Propagation Curves for Aeronautical, Mobile and Radionavigation Services using the VHF, UHF and SHF Bands*

Overview

The International Telecommunications Union - Radiocommunication Sector (ITU-R) is the authoritative international organization for the standardization, coordination, and regulation of the radio frequency spectrum. It is the single most important worldwide telecommunications regulatory and standardization body. Within the ITU-R, Study Groups (SG) are responsible for the development and maintenance of Questions, Recommendations, Reports, and Handbooks, as well as undertaking studies assigned to them as a result of decisions by World Radiocommunication Conferences. Within the Study Groups, Working Parties (WP) are set up as needed to study specific Questions assigned to them. ITS provides ongoing technical support to the U.S. Administration in ITU-R Study Groups 1, 3, 5 and 6 and their Working Parties; in particular, Working Parties 1A, 3J, 3K, 3L, 3M, 5B, 5D, and 6C. Study Group 1 deals with spectrum management, sharing, monitoring, and utilization. Study Group 3 deals with radio propagation phenomena. Study Group 5 deals with systems and networks for fixed, mobile, radiodetermination, amateur and amateur-satellite services. Study Group 6 deals with radiocommunication broadcasting, including vision, sound, multimedia, and data services principally intended for delivery to the general public.

Participation in Study Group 1

In FY 2011 the Institute supported the U.S. Administration on radar issues in ITU-R WP 1A. (Figure 1) The critical issue that had to be addressed this year was out-of-band (OOB) limits on radar transmissions. ITU-R Recommendation SM.1541 contains an annex that governs the characteristics of these emissions. The U.S. Administration seeks consistency between the SM.1541 OOB limits and the domestic limits of the Radar Spectrum Engineering Criteria (RSEC). This ensures that systems that meet the domestic limits also comply with international limits.

Such consistency is especially important for Department of Defense radar operations within and close to the edges of other administration's territories (e.g., Air Force and Navy radar operations around Europe, the Middle East and the Far East). In preparation for the WP 1A meeting, ITS engineers performed a series of measurements in the field to document actual emissions from the relevant radars (Figures 2 and 3). In a series of negotiations in Geneva, especially with Japan, Germany, and the UK, ITS engineers obtained agreement on a revised version of SM.1541 that sets the same limits on OOB radar emissions as the existing US RSEC. This was an important milestone in the continuing effort to allow U.S. radars to support critical national security operations internationally.

Figure 1. ITU-R WP-1A plenary meeting in Geneva, Switzerland in May 2011. Photo by Frank Sanders.

ITS engineers performed measurements on a Navy Sea Sparrow radar (Figure 2, left) and a Relocatable Over the Horizon Radar (ROTHR) (Figure 3, below) to determine actual emission bandwidths of representative Navy frequency-modulated continuous-wave (FMCW) radars. The measurement results shaped the U.S. Contribution to the May 2011 ITU-R Working Party 1A meeting. Photos by Frank Sanders.

Participation in Study Group 3

ITS engineers play important roles in SG 3 and in all four of the ITU-R SG 3 Working Parties: WP 3J (Propagation Fundamentals), WP 3K (Point-to-Area Propagation), WP 3L (Ionospheric Propagation) and WP 3M (Earth-Space and Point-to-Point Propagation). ITS engineers currently serve as the International Chair of WP 3K, the U.S. Chair of SG3, the Chair of Correspondence Group 3K-3, and the Head of Delegation (official spokesperson) for the U.S. Administration at meetings of ITU-R Study Group 3 and all of its Working Parties.

The international block meetings of ITU-R Working Parties 3J, 3K, 3L, and 3M took place in October 2011 at the ITU Headquarters in Geneva, Switzerland. The meeting of ITU-R Study Group 3 took place immediately following the block meetings of the Working Parties, at the same venue. In accordance with State Department rules, U.S. Study Group 3 held monthly preparatory meetings from late May 2011 to review and comment on proposed U.S. Administration contributions to these meetings. Four ITS engineers participated in the U.S. preparatory meetings. An ITS engineer chaired the U.S. preparatory meetings.

Three ITS engineers served as members of the U.S. delegation to the meetings of ITU-R Study Group 3 and its Working Parties. One of these engineers served as acting Chair of ITU-R Working Party 3K during its meetings, a second served as Head of the U.S. Delegation, while a third served as Chair of the Drafting Group and Rapporteur of the Correspondence Group responsible for preparing a major revision of Recommendation ITU-R P.528 (Propagation Curves for Aeronautical, Mobile and Radionavigation Services using the VHF, UHF and SHF Bands).

Participation in Study Group 5

An ITS engineer has provided technical support and participated as a member of the U.S. Delegation in national and international meetings of Working Party 5D during the current Study Period, 2008–2012 (see "Interference Issues Affecting Land Mobile Systems" on page 34). As part of this work, this ITS engineer also participated in other U.S. national standards bodies (e.g., ATIS).

Participation in Study Group 6

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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The ITU exists to provide a neutral platform for shaping global consensus on the standards that enable a seamless robust, and reliable, global communications system. Developing and influencing international standards and policies supports the full and fair competitiveness of the U.S. information and communications technology sector. ITS plays a vital role in representing the interests of U.S. industry and the U.S. Administration to the ITU-T as it produces or revises over 150 information and communications technology standards each year.

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*

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 to best meet them.

One way ITS promotes telecommunications standardization efforts is by accepting leadership roles in key standards development organizations. In FY 2011, 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 high-definition television (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), and the ITU-R, the majority of work is directed to ITU-T SG9 and VQEG. In FY 2011, Arthur Webster served as international Chair of ITU-T SG9 (Figure 1), 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 (Figure 2).

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 (VQM). 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 2011, 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

Figure 1 (left). Arthur Webster Chairing the ITU-T SG9 meeting in Geneva.

Figure 2 (middle). Margaret Pinson led the U.S. delegation to the ITU-T SG9 meeting in Geneva.

Figure 3 (below). VQEG Meeting in Atlanta, November 2010.

Service (QoS)), and ITU-R Working Party (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 2011 (Figure 3). Margaret Pinson co-chaired the HDTV effort and is now spearheading the next testing effort for HDTV. The completion of the first HDTV test led to the approval in SG9 of two New Recommendations. ITS also assisted in developing the Hybrid Perceptional 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 SG9 with the audio and network quality expertise of SG12 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 coordinating VQEG activities with ITU-T SG9 and ITU-T SG12.

Approved Recommendations

FY 2010 saw the completion of VQEG's HDTV Project. The results of this validation test were reported to the ITU, and in FY 2011, ITU-T SG9, under the Chairmanship of Arthur Webster, approved two new Recommendations based on VQEG's test results:

- Recommendation ITU-T J.341 (01/11), *Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a full reference*.
- Recommendation J.342 (04/11), *Objective perceptual multimedia video quality measurement of HDTV for digital cable television in the presence of a reduced reference*.

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At the IEEE-sponsored Third International Workshop on Quality of Multimedia Experience (QoMEX 2011) in Mechelen, Belgium September 7–9, 2011, leading experts from academia and industry presented the latest developments on evaluation of multimedia quality based on user experience. The 36 presented papers included six references to NTIA/ITS authored papers, nine references to Video Quality Experts Group (VQEG) documents, and 17 references to ITU-T Recommendations produced by ITS Rapporteurs

ITS Publications and Presentations in FY 2011

NTIA Publications

John E. Carroll, Frank H. Sanders, Robert L. Sole, and Geoffrey 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, November 2010

In early 2009, the Federal Aviation Administration (FAA) became aware of interference to Terminal Doppler Weather Radars (TDWRs) that operate in the 5600–5650 MHz band and provide quantitative measurements of gust fronts, windshear, microbursts, and other weather hazards for improved safety of operations in and around major airports. This report describes field measurements and results from an examination of interference to a TDWR in San Juan, Puerto Rico from unlicensed national information infrastructure (U–NII) dynamic frequency selection (DFS) devices operating in the same frequency band. Several U–NII devices from different manufacturers were found to be causing interference into the TDWR. These devices operate in the same bands as these Federal radar systems, but employ DFS technology that is supposed to detect the presence of nearby radar systems and change operating frequencies to prevent interference with incumbent radar systems. This is the first of a three–part series of reports that describe research efforts by the Institute for Telecommunication Sciences (ITS) engineers, with assistance from FAA engineers, to determine the cause of the interference, understand why some devices fail to detect TDWR signals, and engineer solutions.

Margaret H. Pinson, Arthur Webster and William Ingram, "Preliminary Investigation into the Impact of Audiovisual Synchronization of Impaired Audiovisual Sequences," NTIA Technical Memo TM-11-474, March 2011

The quality perception of an audiovisual sequence is heavily influenced by the quality of the audio, the quality of the video, and the audiovisual time synchronization. The questions then arise: what is the relative importance of each factor, and can a model be devised that is generally applicable? Previous work either examined the relative influences of audio and video quality for synchronized video or investigated the quality impact of synchronization errors on unimpaired video sequences. This experiment is a first attempt to combine all three factors into a single experiment, to judge the complex interactions among individual measurements of audio and video quality and synchronization errors.

Stephen Wolf, "Variable Frame Delay (VFD) Parameters for Video Quality Measurements," NTIA Technical Memorandum TM-11-475, April 2011

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. Sometimes sections of the original video stream may be missing entirely (skipping without pausing). Time varying delays of the output (or processed) video frames with respect to the input (i.e., the original or reference) video frames present significant challenges for Full Reference (FR) video quality measurement systems. Time alignment errors between the output video sequence and the input video sequence can produce measurement errors that greatly exceed the perceptual impact of these time varying video delays. This document proposes several objective video quality parameters that can be extracted from variable frame delay (VFD) information, demonstrates their correlation to subjective video quality, and shows how they can be utilized in an FR video quality measurement (VQM) system.

Peter Papazian and John Lemmon, "Radio Channel Impulse Response Measurement and Analysis," NTIA Technical Report TR-11-476, May 2011

This paper describes radio channel sounding measurements and analysis using pseudo-noise (PN) codes. It presents a channel sounding model and shows how channel measurements can be made. A measurement system is described that can be implemented using a combination of radio frequency (RF) hardware, high-speed analog to digital converters (ADC), and signal processing software. Sampling requirements and models for describing the stochastic nature of the radio channel are discussed. Typical signal outputs of a PN channel sounder from the laboratory and from field measurements are shown. The field measurements are used to show how channel sounding data can be processed to develop a power law model of short-range communications. This model can be used for a statistical estimation of received power and interference analysis.

Chris Redding, Chris Behm, Tim Riley, and Rob Stafford, "Examining the Validity of Rayleigh Distribution Assumptions in Characterizing the Fading Channel at 162 and 793 MHz," NTIA Technical Memorandum TM-11-477, June 2011

Wireless communications experience temporal variations in received signal level that are characteristic of the propagation channel. Propagation channel fading at VHF and above is predominantly caused by the complex scattering environment through which the radio waves travel. The techniques used in receiver design to mitigate the effects of fading are well established, but the constraints of limited spectral resources and the insidious characteristics of the propagation environment demand increasingly complex modulation techniques to accomplish this mitigation. To maintain system reliability and usability, receivers must be built to increasingly higher tolerances to cope with propagation-induced errors. This report describes a re-examination of the fading channel. Specifically, it presents a reassessment of the assumptions implicit in the understanding of fading channels. This effort involves the measurement, analysis, and assessment of propagation fading and describes the limitations of classical fading theories when applied to ever more sophisticated modulation techniques. The ultimate purpose of this report is to investigate the statistical fading behavior of the radio channel within time frames significant to the reception of digitally-modulated signals. Measurements of the mobile radio channel were conducted to analyze the fast fading characteristics of the public safety frequency band. The measurement system is described, as are improvements made to increase its capability to measure the channel characteristics. Data analysis was conducted without bias toward conventional fading assumptions to provide an independent theoretical understanding of RF fading propagation. Finally, an assessment of the efficacy of classical fading theory in the testing of existing public safety VHF transceivers is discussed with conjectures about future transceiver testing and design.

Gregory Cermak, Margaret H. Pinson, and Stephen Wolf, "The Relationship Among Video Quality, Screen Resolution, and Bit Rate," *IEEE Transactions on Broadcasting,* vol.57, no.2, pp. 258-262, June 2011

How much bandwidth is required for good quality video for a given screen resolution? Data acquired during two Video Quality Experts Group (VQEG) projects allow at least a partial answer to this question. This international subjective testing produced large amounts of mean opinion score (MOS) data for the screen resolutions QIF, CIF, VGA, and HD; for H.264 and similar modern codecs; and for many bit rates. Those data are assembled in the present report. For each screen resolution, MOS is plotted as a function of bit rate. A plot of all four data sets together shows the bit rate that would be required to achieve a given level of video quality for a given screen resolution. Relations among the four data sets are regular, suggesting that interpolation across screen resolutions might be reasonable. Based on these data, it would be reasonable to choose a bit rate, given a screen resolution; it would not be reasonable to choose a screen resolution given a bit rate.

Jeffery A. Wepman and Geoffrey A. Sanders, "Wideband Man-Made Radio Noise Measurements in the VHF and Low UHF Bands," NTIA Technical Report TR-11-478, July 2011

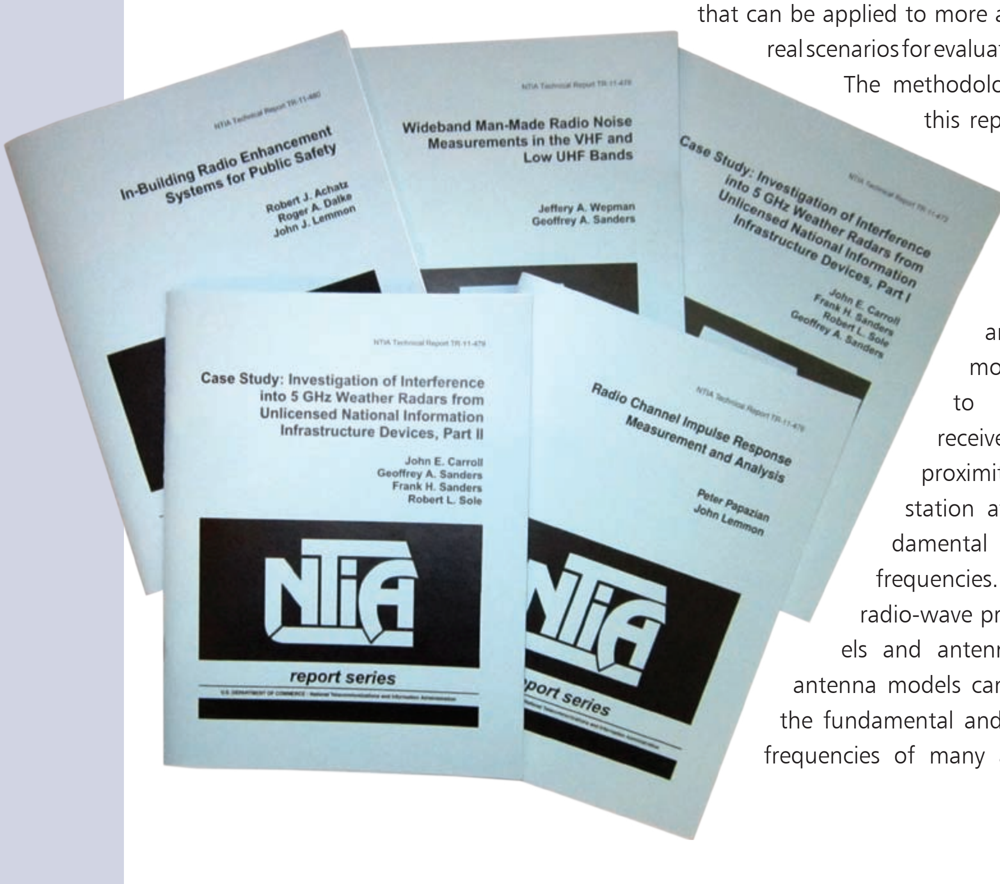
Man-made radio noise measurements were conducted in a 1.16-MHz bandwidth at 112.5, 221.5, and 401 MHz at two residential and two business locations in the Boulder/Denver, Colorado, area. The measurement frequencies and bandwidth were selected using the results of a spectrum survey performed over the 104– 1060-MHz frequency range. The noise measurement data were collected as a complex baseband noise data record (consisting of six million in-phase (I) and quadrature-phase (Q) samples) every 10 minutes over a 24-hour period for each frequency and location. The data were processed to provide various statistical descriptions of the noise such as amplitude probability distributions (APDs). Median values of the antenna noise figure Fam were determined for each measurement frequency and environment type and compared to predicted values from existing man-made radio noise models. The measured values of Fam, while larger than the values predicted by the International Telecommunication Union (ITU) man-made radio noise model, were still within one standard deviation of the predicted values. Further noise measurements are recommended in a greater number of locations to provide more statistically significant results.

John E. Carroll, Geoffrey A. Sanders, Frank H. Sanders, and Robert L. Sole, "Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure Devices, Part II," NTIA Technical Report TR-11-479, July 2011

In early 2009, the Federal Aviation Administration (FAA) became aware of interference to Terminal Doppler Weather Radars (TDWRs) that operate in the 5600–5650 MHz band and provide quantitative measurements of gust fronts, windshear, microbursts, and other weather hazards for improved safety of operations in and around major airports. Institute for Telecommunication Sciences (ITS) engineers, with assistance from FAA engineers, determined the interference to be from unlicensed national information infrastructure (U-NII) dynamic frequency selection (DFS) devices, from several manufacturers, operating in the same frequency band as TDWR systems. These devices operate in the same bands as these Federal radar systems, but employ DFS technology that is supposed to detect the presence of nearby radar systems and change operating frequencies to prevent interference with incumbent radar systems. This report describes measurements and results from controlled laboratory and field testing of these U-NII devices. This is the second of a three-part series of reports that describe research efforts by the ITS engineers, with assistance from FAA engineers, to determine the cause of the interference, examine the effects of the interference on TDWR systems, and engineer solutions.

Eric D. Nelson and Nicholas DeMinco, "Improved Estimation of the Third-Order Harmonic Emissions of Land Mobile Radio Base Stations," NTIA Technical Report TR-11-481, September 2011

NTIA/ITS has developed an improved electromagnetic compatibility (EMC) analysis method that can be applied to more accurately model real scenarios for evaluating interference. The methodology described in this report can be used to conduct EMC analyses for base stations that use a variety of antennas. The model can be used to determine the received power in the proximity of the base station at both the fundamental and harmonic frequencies. It uses accurate radio-wave propagation models and antenna models. The antenna models can be created for the fundamental and third harmonic frequencies of many antennas. Fields



adjacent to the base station antenna are heavily influenced by interactions with ground, and the electromagnetic fields are dominated by the side lobe structure of the elevation pattern of the base station antenna. The described rigorous EMC analysis for a base station considers all of these factors to assess interference more accurately than previous methods.

Stephen Wolf and Margaret H. Pinson, "Video Quality Model for Variable Frame Delay (VQM_VFD)," NTIA Technical Memorandum TM-11-482, September 2011

Time varying delays of the output (or processed) video frames with respect to the input (i.e., the original or reference) video frames present significant challenges for Full Reference (FR) video quality measurement systems. Time alignment errors between the output video sequence and the input video sequence can produce measurement errors that greatly exceed the perceptual impact of these time varying video delays. This document proposes a new video quality model (VQM) that properly accounts for the perceptual impact of variable frame delay (VFD). This new model, called VQM_VFD, also uses perceptual features extracted from spatial-temporal (ST) blocks of a fixed angular extent. This enables VQM_VFD to track subjective quality over a wide range of viewing distances and image sizes. VQM_VFD uses a neural network that achieves 0.9 correlation to subjective quality for subjective datasets at image sizes from Quarter Common Intermediate Format (QCIF) to High Definition TV (HDTV).

Robert J. Achatz, Roger A. Dalke and John J. Lemmon, "In-Building Radio Enhancement Systems for Public Safety," NTIA Technical Report TR-11-480, September 2011

Reliable public safety communications between system repeaters outside a building and portable radios inside a building is often not possible due to building attenuation. To circumvent this problem, increasing numbers of municipalities are requiring building owners to provide in-building radio enhancement systems (IBRESs) for public safety communications. This report is intended to be used by public safety communications professionals who are tasked with assisting building owners to fulfill this requirement. The main body describes IBRES technology, problems endemic to it, and solutions to these problems. Appendices provide detailed data tables, theory, calculations, and measurements that support assertions made in the main body.

Margaret H. Pinson and Stephen Wolf, "Batch Video Quality Metric (BVQM) User's Manual," NTIA Handbook HB-11-441d, September 2011

This handbook provides a user's manual for the batch video quality metric (BVQM) tool. BVQM runs under the Windows XP® or Windows 7® operating systems. BVQM performs objective automated quality assessments of processed video clip batches (i.e., as output by a video system under test). BVQM reports video calibration and quality metric results such as: temporal registration, spatial registration, spatial scaling, valid region, gain/level offset, and objective video quality estimates. BVQM operates on original and processed video files only, and has no video capture capability. BVQM compares the original video clip to the processed video clip and reports quality estimates on a scale from zero to one. On this scale, zero means that no impairment is visible and one means that the video clip has reached the maximum impairment level (excursions beyond one are possible for extremely impaired video sequences).

Journal Articles and Conference Papers

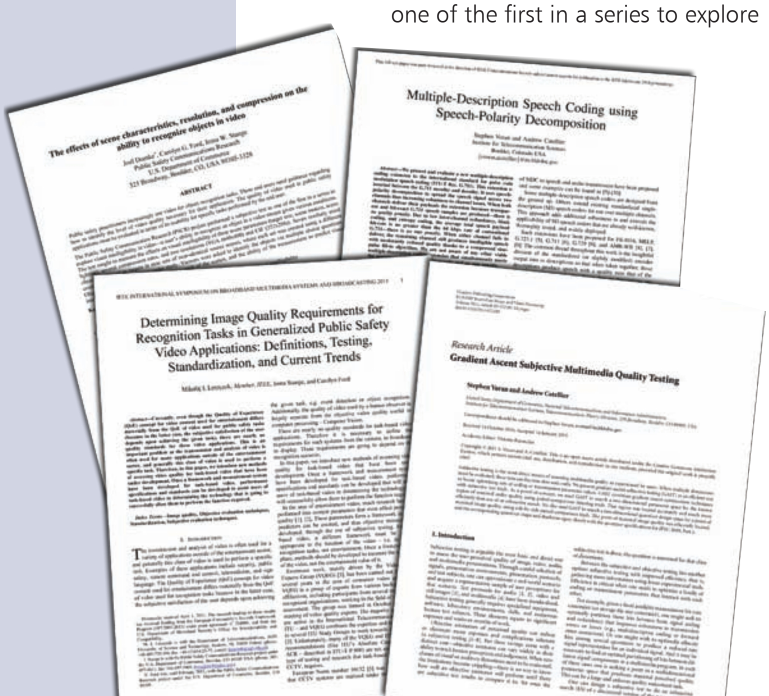
Stephen D. Voran and Andrew A. Catellier, "Multiple Description Speech Coding Using Speech Polarity Decomposition," ***Proceedings of the IEEE Global Communications Conference (GLOBECOM 2010)*****, pp.1-6, Miami, FL, December 6-10, 2010**

We present and evaluate a new multiple–description coding extension to the international standard for pulse code modulation speech coding (ITU–T Rec. G.711). This extension is inserted between the G.711 encoder and decoder. It uses speech–polarity decomposition to spread the speech signal across two channels thus increasing robustness to channel losses. When both channels deliver their payloads the extension becomes transparent and bit–exact G.711 speech samples are produced—there is no quality penalty. Due to low inter–channel redundancy, block coding, and entropy coding, the average total speech payload bit–rate is no greater than the 64 kbps rate of conventional G.711—there is no rate penalty. When either channel fails to deliver, the remaining channel still produces intelligible speech with moderately reduced quality thanks to a compressed sine–pulse fill–in algorithm. We are not aware of any other viable multiple–description coding extension that simultaneously meets the opposing goals of no quality penalty and no rate penalty.

Joel Dumke, Carolyn G. Ford, and Irena W. Stange, "The effects of scene characteristics, resolution, and compression on the ability to recognize objects in video," ***Proceedings of SPIE 7865*****, 78650P, San Francisco, CA, January 24–27, 2011**

Public safety practitioners increasingly use video for object recognition tasks. These end users need guidance regarding how to identify the level of video quality necessary for their application. The quality of video used in public safety applications must be evaluated in terms of its usability for specific tasks performed by the end user.

The Public Safety Communication Research (PSCR) project performed a subjective test as one of the first in a series to explore visual intelligibility in video—a user's ability to recognize an object in a video stream given various conditions. The test sought to measure the effects on visual intelligibility of three scene parameters (target size, scene motion, scene lighting), several compression rates, and two resolutions (VGA (640x480) and CIF (352x288)). Seven similarly sized objects were used as targets in nine sets of near-identical source scenes, where each set was created using a different combination of the parameters under study. Viewers were asked to identify the objects via multiple choice questions. Objective measurements were performed on each of the scenes, and the ability of the measurement to predict visual intelligibility was studied.



Stephen D. Voran and Andrew A. Catellier, Gradient Ascent Subjective Multimedia Quality Testing, ***EURASIP Journal on Image and Video Processing,*** **vol. 2011, Article ID 472185, 14 pages, March 15, 2011**

Subjective testing is the most direct means of assessing multimedia quality as experienced by users. When multiple dimensions must be evaluated, these tests can become slow and costly.We present gradient ascent subjective testing (GAST) as an efficient way to locate optimizing sets of coding or transmission parameter values. GAST combines gradient ascent optimization techniques with subjective test trials. As a proof-of-concept, we used GAST to search a two-dimensional parameter space for the known region of maximal audio quality, using paired-comparison listening trials. That region was located accurately and much more efficiently than use of an exhaustive search. We also used GAST to search a two-dimensional quantizer design space for a point of maximal image quality, using side-by-side paired-comparison trials. The point of maximal image quality was efficiently located, and the corresponding quantizer shape and deadzone agree closely with the quantizer specifications for JPEG 2000, Part 1.

Mikolaj I. Leszczuk, Irena Stange and Carolyn Ford, "Determining Image Quality Requirements for Recognition Tasks in Generalized Public Safety Video Applications: Definitions, Testing, Standardization, and Current Trends," ***Proceedings of the IEEE International***

Symposium on Broadband Multimedia Systems and Broadcasting, Nuremberg, June 8–10, 2011

The Quality of Experience (QoE) concept for video content used for entertainment differs materially from the QoE of video used for public safety tasks because in the latter case, the subjective satisfaction of the user depends upon achieving the given task. Yet currently there are hardly any quality standards for task-based video applications. This is an important problem as the transmission and analysis of video is used for many applications outside the entertainment sector, and generally this class of video is used in the performance of a specific task. To address this lack, in this paper we introduce new methods of assessing video quality for task-based video that have been under development. Once a framework and measurement system have been developed for task-based video, performance specifications and standards can be developed to assist users of task-based video to identify the technology that will allow them to successfully perform the required function.

Unpublished Presentations

- M.H. Pinson, "The Consumer Digital Video Library," presented at the Video Services Forum meeting, Austin, TX, October 5–8, 2011.
- R. Johnk and J. Ewan, "High-resolution propagation measurements using biconical antennas and signal processing," presented at the General Meeting of the International Electrotechnical Commission (IEC) in Seattle, WA, October 6–15, 2010
- R. Johnk and P. McKenna, "Fully-anechoic chamber performance metrics," presented at the General Meeting of the International Electrotechnical Commission (IEC) in Seattle, WA, October 6–15, 2010
- T. Riley, "A Co-Channel Interference Model for Spread Spectrum Technologies," presented at the 2011 USNC-URSI National Radio Science Meeting, Boulder, CO, Jan 5–8, 2011.
- J. Carroll, "Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure (U-NII) Devices," presented at the 2011 USNC-URSI National Radio Science Meeting, Boulder, CO, January 5–8, 2011.
- C. Redding, "Empirical Studies of Fading Channel Characteristics at VHF and UHF Frequencies," presented at the 2011 USNC-URSI National Radio Science Meeting, Boulder, CO, January 5–8, 2011.
- J. Dumke and C. Ford, "The Effects of Scene Characteristics, Resolution, and Compression on the Ability to Recognize Objects in Video," presented at the SPIE Electronic Imaging Conference, San Francisco, CA, January 23–27, 2011.
- J. Bratcher and E. Olbrich (NIST), "Public Safety 700 MHz Broadband Demonstration Network," an invited presentation at the GSMA Mobile World Congress, Barcelona, Spain, February 14–18, 2011.
- DJ Atkinson, "PSCR Audio Testing Update," presented at the International Wireless Communications Exposition (IWCE), Las Vegas, NV, March 7–10, 2011.
- A. Thiessen and D. Orr (NIST), "P25 Compliance Assessment Program Overview," presented at the International Wireless Communications Expo (IWCE) College of Technology, Las Vegas, NV, March 7–10, 2011
- A. Webster, "Introduction to International Telecommunication Union (ITU) Telecommunication Standardization Sector (ITU-T)," presented at the Telecommunications Industry Association (TIA) Global Standards Collaboration (GSC) Machine-to-Machine Standardization Task Force (MSTF) Meeting, Dallas, TX, May 18, 2011.
- J. Carroll, F. Sanders, R. Sole, "Case Study: Investigation of Interference into 5-GHz Weather Radars from Unlicensed Wireless Devices," presented at the 2011 Tri-Service Radar Symposium Spectrum Workshop, Monterey, CA, June 27–30, 2011.
- J. Bratcher and E. Olbrich (NIST), "Public Safety Broadband Demonstration Network," presented at the APCO International 77th Annual Conference and Expo, Philadelphia, PA, August 7–10, 2011.
- B. Johnk, "Time-domain Anechoic Chamber Performance Metrics," presented at the 2011 IEEE International Symposium on Electromagnetic Compatibility (EMC 2011), Long Beach, CA, August 14–18, 2011.

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ITS research and technical contributions based on that research support U.S. Administration positions in standards-setting bodies. Timely promulgation of new standards for emerging technologies is important for many reasons. Standards for public safety communications equipment impact both the safety and effectiveness of public safety practitioners by promoting increased interoperability and intelligibility of communications. A published body of applicable standards gives industry the confidence to invest by broadening the market and decreasing the limitations inherent in legacy systems.

ITS Standards Leadership and Contributions

Representative Leadership Roles held by ITS Staff

- *International Chairs of one ITU-R Working Party, one ITU-R Subgroup and one ITU-T Study Group*
- *U.S. Chairs of one ITU-R Study Group and three Working Parties*
- *Chairs of two ITU-R Correspondence Groups*
- *Head of U.S. Delegation to ITU-T Study Group*
- *Chair of NPSTC Working Group*
- *Chair of TIA Working Group*

National and international standards and policies for telecommunications support the full and fair competitiveness of the U.S. information and communications technology sectors. Technical standards establish common norms for technical systems—uniform engineering or technical criteria, methods, processes and practices that promote competition and interoperability. Office of Management and Budget Circular A-119 (February 10, 1998) promotes the use of voluntary consensus standards in order to "encourage long-term growth for U.S. enterprises and promote efficiency and economic competition through harmonization of standards" and encourages the participation of authorized Federal agency representatives in standards activities.

FY 2011 Standards Activities

Standards Leadership

As representatives of the U.S. Administration, ITS staff advocate globally standards and policies that encourage competition and innovation in communications technology through leadership roles and membership in standards development organizations. In cooperation with other interested U.S. Government agencies and industry groups, ITS staff organize and coordinate preparations for U.S. participation and negotiations in national and international telecommunications conferences and standards development organizations.

- **DJ Atkinson:** Chair of the Audio Performance Working Group of the Association of Public-Safety Communications Officials – International and Telecommunications Industry Association (APCO/TIA) Project 25 Interface Committee (APIC) within the TIA TR-8 Mobile and Personal Private Radio Standards Engineering Committee.
- **Christopher J. Behm:** U.S. Chair of International Telecommunication Union Radiocommunication Sector (ITU-R) Study Group 3 (Radiowave Propagation), Head of Delegation for Working Party 3L and delegate to WP 3L and WP 3K.
- **Randall S. Bloomfield:** Technical participant and voting representative for NIST/OLES in TIA Engineering Committee TR-8 (Mobile and Personal Private Radio Standards) and APIC; Editor of the P25 SoR (Project 25 Statement of Requirements) in the P25 UNS (Project 25 User Needs Subcommittee).
- **John E. Carroll:** Delegate to ITU-R Working Party 5B.
- **Paul M. McKenna:** International Chair of ITU-R Working Party 3K, U.S. Chair of 3J, 3L, and 3M; International Chair of Subgroup 3K-2.
- **Margaret H. Pinson:** Associate Rapporteur for Question 12/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9) in ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission); ITU-T Study Group 9 contact for Electronic Working Methods; Independent Lab Group member and Co-Chair of HDTV effort, Video Quality Experts Group (VQEG). Rapporteur in ITU-R WP6C for "Global video evaluation methodology landscape." Head of U.S. Delegation to ITU-T Study Group 9.
- **Patricia J. Raush:** U.S. Co-chair of Working Party 3J; Head of Delegation for WP3J; delegate to WP 3J, WP 3K, WP 3L, and WP 3M within ITU-R Study Group 3.

- **Timothy J. Riley:** Member of Alliance for Telecommunications Industry Solutions (ATIS) committee WTSC-RAN (Wireless Technologies and Systems Committee — Radio Access Networks) and issue champion and editor for development of a document addressing interference issues affecting wireless communication systems. Member of the U.S. delegation to ITU-R Working Party 5D (International Mobile Telecommunications (IMT) Systems), ITU-R Study Group 5 (Terrestrial Services).
- **Teresa Rusyn:** Chair of Correspondence Group 3K-3, Member of Working Parties 3K and 3M within ITU-R Study Group 3.
- **Frank H. Sanders:** Chair of ITU-R Radar Correspondence Group (radar technical spectrum issues); Delegate to ITU-R Working Party 5B (radar spectrum allocation and sharing) and Joint Rapporteurs Group 1A-1C-5B (radar spectrum efficiency issues).
- **Andrew P. Thiessen:** Vice-Chair of the Technology Committee and Chair of the Broadband Working Group, National Public Safety Telecommunications Council
- **Bruce R. Ward:** Member, Technical Specification Group for Service and System Aspects Working Group 1 (TSG SA WG1), 3rd Generation Partnership Project (3GPP)
- **Arthur A. Webster:** International Chairman of ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission), and additionally SG9 contact for public relations; SG9 representative to ITU-T standardization committee for vocabulary (SCV), and representative to ITU-T Joint Coordination Activities such as those on Interoperability and Conformance (JCA-CIT) and Identity Management (JCA-IDM); Co-chair of Video Quality Experts Group (VQEG); Co-Chair of Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA); Member of U.S. Delegations to ITU-T Study Group 9, Study Group 16, Transportation Safety Advancement Group, ITU Council, and ITU-R WP6C. U.S. Department of Commerce voting member for ATIS Committees Network Performance, Reliability and Quality of Service Committee (PRQC) and Packet Technologies and Systems Committee (PTSC).

Representative Contributions

ITS develops and presents user-oriented technical contributions to national and international standards organizations addressing requirements, functionality, performance, testing, quality of service, communication network resource management, interoperability, compliance and other topics critical to the development and implementation of standardized public safety communications, advanced IP-based networks, optical transport networks, next generation networks, and supporting broadband infrastructures. Many of the technical contributions ITS makes to standards bodies throughout the year contribute materially to the content of final published standards. Below is a representative list of draft and approved technical standards and related documents that ITS staff worked on during FY 2011.

- Project 25 Steering Committee P25 SoR, "APCO Project 25 Statement of Requirements," Apr. 2011 (R. Bloomfield)
- TIA TIA-102, "Project 25 System and Standards Definition," draft in progress (R. Bloomfield)
- TIA TSB-102-B, "TIA-102 Documentation Suite Overview," draft in progress (R. Bloomfield)
- TIA TSB-102-BACC-B, "Inter-RF Subsystem Interface Overview," draft in progress (R. Bloomfield)
- TIA TSB-102.BADA, "Telephone Interconnect Overview (Voice Service)," draft in progress (R. Bloomfield)
- TIA TIA-102.BAEA-B, "Data Overview and Specification," draft in progress (R. Bloomfield)
- ATIS-P0017 "ATIS Standard on Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems" draft in progress (T. Riley)
- ITU-R Recommendation SM.1541-4, "Unwanted Emissions in the Out-of-Band Domain," Sep. 2011 (F. Sanders)
- ITU-R Recommendation P.528, "Propagation Curves for Aeronautical Mobile and Radionavigation Services using the VHF, UHF and SHF bands," revision in progress (T. Rusyn)

ITS Tools and Facilities

A unique combination of past experience, current knowledge, specialized tools, and experimental facilities enable ITS to perform research and solve complex telecommunications problems. These resources are shared through inter-agency and cooperative research and development agreements to solve telecommunications challenges for Federal and state agencies and to support technology transfer and commercialization of telecommunications products and services.

Audio Visual Laboratory Equipment. Above: Inside a specialized video computer. This computer can play and record uncompressed HDTV in real time, so that the playback system does not distort the video.

Below: An assortment of some of the mobile devices that have been tested in the ITS Audio Video Laboratory.

Photos by Andrew Catellier

Audio Visual Laboratories

Subjective Testing Facilities

Subjective testing is simply asking a person's opinion. This is the most accurate way to measure the perceived quality of a phone conversation or video stream.

Designing a subjective test can be tricky. The way one asks a person's opinion can influence the answer the person will give. Experts create ITU Recommendations that list "best practices." These attempt to minimize unwanted influence on a person's answer. When subjective tests are designed with care, they can be highly repeatable, that is, results are the same regardless of where or when the test takes place.

A controlled test environment can enhance repeatability. A person's attention is focused on the task at hand since the lighting is controlled, there is little or no background noise, and there are no visual distractions. A controlled room also frees the experimenter from considering environmental variables when analyzing the test results. ITS has three such rooms: two are identically constructed sound isolation chambers; one is a secluded, quiet room.

The two identical rooms can be connected to allow two persons to converse using audio, video, or both. This type of testing can reveal problems that are not apparent when people only listen to audio recordings or view video. An important example is audio delay—if it is too long, conversation becomes difficult.

The third subjective test room is a larger, quiet room with a window. This room provides flexibility, but a little less control. Currently, the third test room looks like a living room. This sets a different context for questions about audio and video quality.

Unique Capabilities

Because subjective testing is so time intensive and requires such expensive resources, only a few organizations in the United States perform them. Significant expenses are:

- Subjective test facility construction and operation
- Accurate audio and video play back
- Experiment design and implementation
- Production of audio and video recordings that match the test purpose
- Simulation of audio and video systems

ITS has proven expertise in designing and conducting subjective experiments. Over the past two decades, ITS has published the results from dozens of subjective experiments.

One surprisingly difficult problem is audio and video playback. Many audio and video players cannot guarantee that every person will see and hear exactly the same audio or video. ITS uses studio-quality hardware and special purpose software tools to ensure reliable playback. These playback systems often push cutting-edge computer hardware to its limit.

Simulating modern audio and video distribution is expensive because there are many methods in use in the telecommunication industry. The ITS audiovisual lab has a variety of hardware and software tools that encode, transmit, or play audio and video, and simulate how people use audio and video today. These tools span a wide range of audio and video services:

- Broadcast quality audio and video
- Satellite TV and Cable TV
- Video on Demand
- Streaming Internet video
- Video teleconferencing
- Cell phone audio and video
- VoIP

Audio and Video Capabilities

The ITS audiovisual lab includes support for the following technologies:

- Standard definition (SD) television
- High definition television (HDTV)
- Three dimensional television (3DTV)
- Monophonic, stereophonic, and 5.1-channel audio streams
- Studio quality analog and digital video recorders with 2 to 8 audio channels
- Digital audio recorders
- Analog audio mixing, filtering, and equalization
- Studio quality video monitors, monitor loudspeakers, and headphones
- Telephone handsets

- Subjective test chambers compliant with ITU-T Rec. P.800, ITU-R Rec. BT.500, and ITU-T Rec. P.900
- Various hardware and software encoders and decoders
- Internet protocol network error simulator compliant with ITU-T Rec. G.1050

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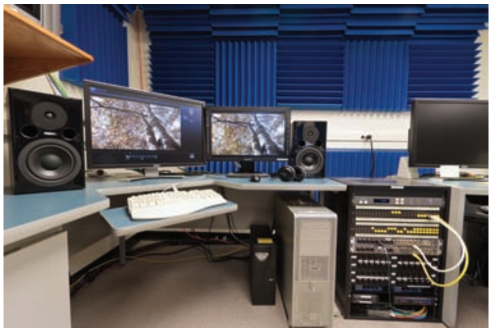

Audio Video Laboratory facilities at ITS. Top: The video workstation includes a broadcast quality television, studio quality speakers, and uncompressed capture of HDTV. Acoustical foam reduces background noise, so that subtle audio impairments can be heard. Center: Subjective test room set up as a real world living room. Bottom: Sound isolation booth set up for an audiovisual subjective test, with a broadcast quality television and studio quality speakers. Photos by Andrew Catellier.

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 ability of this system to record actual I and Q signal data in a wide bandwidth provides many options for processing and further use of the data. 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 3 dB. 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 system. This software allows the user to set the measurement frequency, bandwidth (span), number of data points, and other parameters. Once the measurement is started, the software 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. It 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.

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Frequency Allocation Forensics

In FY 2011, ITS completed development of new software to measure the radio frequency (RF) spectrum from 108 MHz to 10 GHz. The Frequency Allocation Forensics prototype software program interactively compares actual measurements to frequency allocation records

Frequency Allocation Forensics software screen capture: Statistical representations of real radio traffic in the aeronautical mobile band.

found in the Federal Communications Commission (FCC) and Government Master File (GMF) databases.

With this software, ITS measures real radio traffic in an area of the frequency spectrum, just as traffic engineers might measure real vehicle traffic at an intersection. Figure 1 shows a display of real radio traffic measured by the Radio Spectrum Measurement Science (RSMS) system. The data on the screen was post-processed to provide additional statistical analysis of the raw data. This sample screen shows data from an aeronautical-mobile band from 130.5 MHz to 135 MHz. The two graphical representations show different characteristics of the measured data. The top graph shows the maximum, mean, and minimum signal levels of the activity measured in those bands over a number of different measurement sets. The bottom graph shows the same measurements but analyzed to show the approximate amount of time that a signal was present in this band. The location shown on the screen is the NTIA labs in Boulder.

Once the measured data is processed, the tool displays allocations taken from the FCC and GMF databases in a separate window. In the future, the software will be used as a situational awareness tool to locate transmitters that might overload the RSMS system. The knowledge gained by using this software, both at the beginning of our measurements and after the processing steps, will ensure the value of the measurements being taken to NTIA and the community at large.

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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 16.8 meter (55 foot) 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, and to the Table Mountain Field Site via a microwave link. The fiber optic link provides access to the ITS local area network (LAN) while the 802.11 link connects 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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Antenna towers and control center at the Green Mountain Mesa Field Site. Photo by Ken Tilley.

High Performance Computing Cluster

The HP BLADE computing cluster is an extensible platform with 32 CPU cores and 128 GB of RAM. It is primarily used for running 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. All servers include redundant disk arrays, and backup to a large disk store. The room is physically secured through an access control and security system that logs entry by authorized personnel.

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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 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

Public Safety Audio Laboratory audio mixing equipment and head and torso simulator (HATS). Photos by Ken Tilley.

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 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 are typical of what a jurisdiction might consider purchasing. The communication systems processing includes

ITS staff examine the operational configuration characteristics of a Project 25 trunked LMR system in the ITS Public Safety RF lab. Photo by Ken Tilley.

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 Public Safety RF Laboratory (PSRF Lab) supports several different but related research 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.

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, at the beginning of a 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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Radio Propagation Measurement Capabilities

ITS maintains and is developing both mobile and static propagation measurement systems that address a number of wireless propagation scenarios. ITS systems cover 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 frequency reference. The receiver van contains multiple antennas mounted on a large aluminum ground plane, equipment racks, a multi-channel digitizer, spectrum analyzers, radio receivers, and a 5 kW on-board generator. The van has a GPS navigation system with a dead-reckoning backup.

The system has two operational modes: 1) narrowband channel probe 2) broadband channel probe. In mode 1, a continuous-wave (CW) signal is transmitted and received using a spectrum analyzer, vector signal analyzer, or sound card/communications receiver combination. The received data contain path loss, a slow-fading profile, and fast-fading information.

The narrowband mode has high dynamic range, sensitivity, and excellent immunity to interference making it suitable for measurements in RF-congested urban environments. 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 pseudorandom number code with a user-selectable number of bits. Post-processing yields a channel impulse response from which useful parameters (e.g. delay spread, basic path loss) can be extracted. It has the capability of measuring both fast- and slow-fading phenomena as well as path loss.

Over the past several years, a new ultra-wideband propagation measurement system has come on line. It consists of a commercial-off-the-shelf 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.

Radio propagation measurement equipment racked in the receiver van.

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 meters. It is configured in a stepped-frequency mode, and S21 data (amplitude and phase) are acquired and stored. The resulting frequency-domain data are post-processed, inverse Fourier transformed, and time 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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Radio Spectrum Measurement Science (RSMS) System Tools

The Radio Spectrum Measurement Science (RSMS) measurement system is a unique, state-of-the-art system designed for gathering information about spectrum occupancy, equipment compliance, electromagnetic compatibility, and interference resolution. The system provides NTIA critical measurement support for determining policies that affect 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. It is designed to be flexible enough to accommodate implementation 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, and a 20 kW diesel generator, as well as Internet connections, fiber optic control lines, and a climate

The RSMS 4G truck shown during field measurements. Two of the three antenna masts have been fitted with antennas selected for the type of measurement being performed. Inside the truck, the equipment racks have been loaded with the appropriate instruments. Antennas and instruments can easily be changed to achieve the correct configuration for each measurement target.

control system. The control and acquisition software is fully developed by ITS so that measurement techniques can be easily altered in new and innovative ways to meet immediate needs.

With the completion of the 4th generation measurement software, development of the 5th generation has begun. The objective of the 5th generation software is to provide a tool that can easily accommodate new equipment and different hardware configurations, and expand on existing measurement capabilities. The 5th generation of software makes use of modern software tools, simplifying the design and implementation of new measurement algorithms, as well as supporting multiple operating systems with fewer third party software requirements. With less dependency on third party software and compatibility with multiple operating systems, the 5th generation of software has an extended application life-cycle and reduced overall costs.

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Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older ones 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 proposed system's effects within its operating environment to determine its impact on other spectrum users.

Another problem is to adequately 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 sorts of situations, a system is needed that simulates the spectral emissions of other devices with high fidelity. An example of these needs is the requirement to determine the thresholds at which various types of interference from communication transmitters are manifested as observable interference effects in radar receivers. Another example would be to determine the source(s) of interference from terrestrial services to space-based communication links.

To meet these needs, ITS engineers have developed capabilities to generate interference signals. 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.

ITS engineers generate interference by first using high-speed digitizers, called vector signal analyzers (VSA), to record interference waveforms in bandwidths up to 36 MHz. They subsequently radiate or hardline-couple those signals into victim receivers using vector signal generators (VSG). Alternatively, VSGs may be preprogrammed with the requisite mathematical information to create particular waveform modulations, such as quadrature phase shift keyed (QPSK) signals.

The ITS interference signals can be transmitted with high-power amplifiers to generate high-power interference at frequencies up to 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 4 kilometers (2.5 miles) north-south by 2.4 kilometers (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 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.
- Two 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/resources/table_mountain.

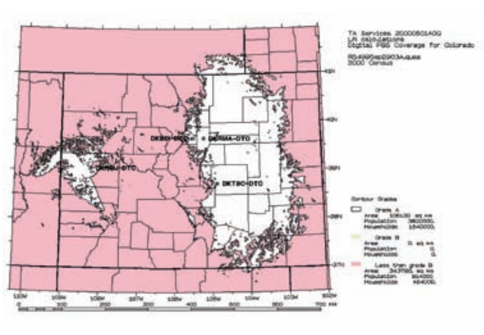
Contact: J. Wayde Allen, (303 497-5871, wallen@its.bldrdoc.gov

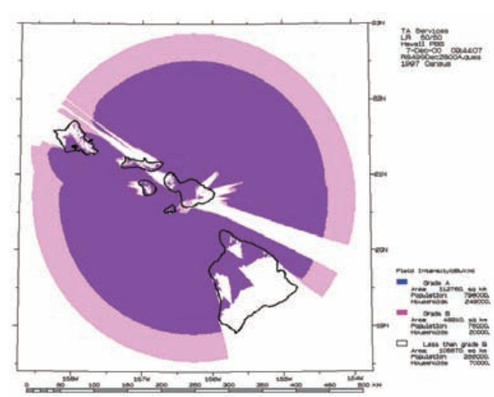
Table Mountain facilities. Above: rotatable steel turntable. Below: laboratory and control space under the turntable. Right: one of the two 18.3 meter (60 foot) parabolic dish antennas.

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. 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





Sample outputs from TA Services programs PBS (above) and CSPM (right).

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 at http://www.its.bldrdoc.gov/resources/ta-services.

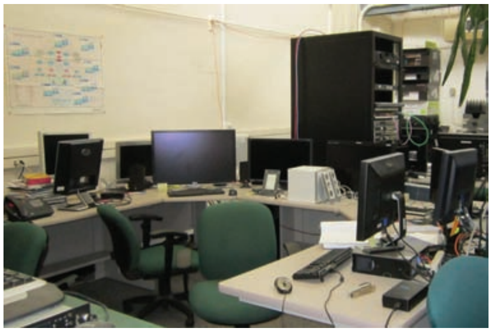
Contacts: Paul M. McKenna, (303) 497-3474, pmckenna@its.bldrdoc.gov or George Engelbrecht, (303) 497-4417, gengelbrecht@its.bldrdoc.gov

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 research in the area of inter-PCS interference, in support of the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC-RAN. ITS also has the capability to simulate PCS interference using a series of ITS-implemented interference models.

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



The ITS Wireless Networks Research Center.

ITS Projects in FY 2011

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

International Standards Support

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

Public Safety Broadband Research

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

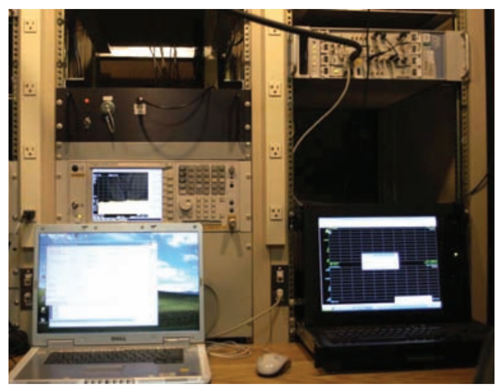
Noise and Spectrum Occupancy Measurement Research

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

Equipment used for Noise and Spectrum Occupancy Measurement Research.



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 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: Geoffrey A. Sanders

(303) 497-6736, gsanders@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

Research set-up at the Table Mountain Field Site and Radio Quiet Zone.

Wireless Interference Modeling and Characterization

Present technical contributions on PCS interference effects to ATIS Technical Subcommittee WTSC-RAN. 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: Margaret H. Pinson

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

NTIA/OSM Projects

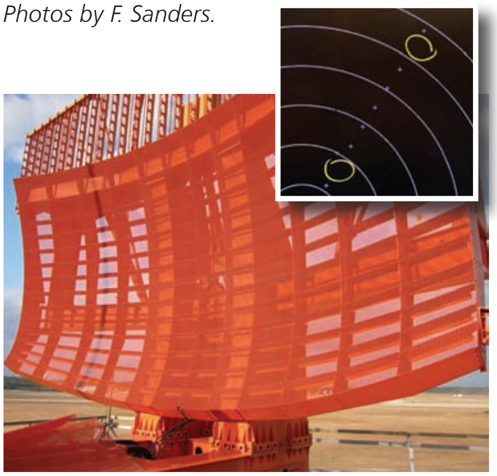
2.7 GHz Out of Band Interference

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 operating in adjacent spectrum.

Project Leader: Frank H. Sanders

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

To analyze 2.7 GHz Out of Band Interference to radar systems such as this air traffic control radar, engineers tested the radars with a set of known targets. Yellow circles on the inset image of a portion of the radar display show where targets are missing because they were blanked by interference. Photos by F. Sanders.



Bin 1 Waveform

Develop new bin 1 waveforms for use 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

Integrate the Undisturbed Field Model

Incorporate the Undisturbed Field Model into the Short Range Mobile-to-Mobile Model for use by OSM in promoting efficient and effective use of spectrum resources.

Project Leader: Paul M. McKenna

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

Propagation Engineering Support

Provide technical support to NTIA/OSM 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.

Project Leader: Paul M. McKenna

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

Radar Support Tasking

Support USWP5B, USJRG, and the U.S. Administration's positions in ITU-R WP5B and Joint Rapporteur Group (JRG) 1A-1C-5B by providing position papers, technical reports, and attendance in these forums. Also support the Radar Correspondence Group (RCG) and the JRG 1A-1C5B and RCG websites.

Project Leader: Frank H. Sanders

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

Spectrum Sharing Test Bed Support

Evaluate equipment that uses Dynamic Spectrum Access (DSA) technology within the 410-420 MHz and 470-512 MHz bands to assess and address potential interference to incumbent spectrum users.

Project Leader: Eric D. Nelson

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

Upgrade the Slope-Intercept Empirical Model

Upgrade the current single slope Slope-Intercept Empirical Model to a two-slope propagation model and provide the new models, with supporting documentation, in a format that can be used to predict radio signal attenuation.

Project Leader: Paul M. McKenna

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

Other Agency Projects

Department of Commerce / NIST / Office of Law Enforcement Standards

Analysis, Demonstration, T&E

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, and other communication system products and services supporting wireless telecommunications and information technology (IT) needs. Perform technical assessments and evaluations of existing and emerging commercial products and services that may provide interim solutions for various interoperability scenarios.

Project Leader: Jeff Bratcher

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

Public Safety Communications Research (PSCR) Program Manager Dereck Orr (NIST, right) and Technical Manager Jeff Bratcher (center) describing the technology being tested in this PSCR laboratory to Secretary of Commerce Bryson during a recent visit. A broad range of commercial communications and IT products are analyzed in this laboratory. Photo by Will von Dauster.

Assessment of Integration Strategies

Conduct engineering analyses, cost/benefit assessments, evaluations of grant proposals and research and development proposals, and technical feasibility studies of emerging technologies to facilitate the development and/or application of more effective interim integration solutions for public safety (that will be consistent with, or migrate logically to, the long-term standardization strategy), and to help identify ways to bridge the shortcomings identified through gap analyses performed as part of the long-term standardization process.

Project Leader: Kameron A. Behnam

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

Development of Requirements, RF Interoperability Standards

Provide applied science and engineering expertise to OLES, and on behalf of OLES to the Department of Homeland Security (DHS) and Project SAFECOM. Solve telecommunications interoperability and information sharing problems among local, state, Federal, tribal, and international Justice, Public Safety, Homeland

Security agencies by addressing voice, data, image, video, and multimedia information transfers.

Project Leader: Andrew P. Thiessen

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

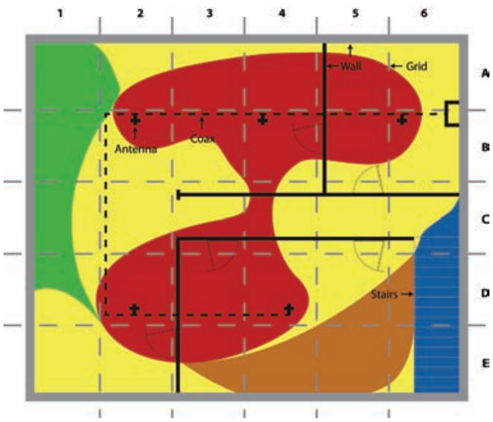
In-Building Public Safety Communications Best Practices Development

Assess and report on the state of the art of in-building radio system for public safety applications.

Project Leader: Frank H. Sanders

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

A diagram showing predicted coverage for an in-building radio system calculated using a site-specific radio-wave propagation model. Different colors represent different received signal power levels. Modeling in-building propagation in this manner as part of the design process is a recommended best practice.



P25 CAP and Public Safety Lab Equipment and Support

Investigate if and how cutting edge technologies (such as 3G & 4G systems based on OFDM, CDMA, etc.) can be integrated with existing P25 systems and/or deployed independently of traditional P25 systems in order to meet future public safety needs. Creation of a 700 MHz LTE Demonstration network using the PSCR RF Lab, Green Mountain Mesa, and Table Mountain field site. Standards development for Public Safety LTE support.

Project Leader: Jeffrey R. Bratcher

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

Public Safety Communications Research and Testing

Facilitate standards development efforts aimed at nationwide public safety communications interoperability and information sharing through direct participation and technical contribution to the appropriate Standards Development Organizations. Conduct scientific analyses, laboratory and field measurements, and test and evaluation activities to accommodate technical elements of the PSCR program and other related Federal programs supported by OLES. Maintain state-of-the-art laboratory facilities, conduct field pilots, develop formal/informal training courses, test tools, and conduct technical feasibility studies of emerging public safety interoperability technologies.

Project Leader: Jeffrey R. Bratcher

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

Video sequences filmed during a simulated accident training exercise are used in Public Safety Communications Research. Top: View of the scene through a pan-tilt-zoom security camera. Remote personnel could use such a video link to monitor developing incidents. The bottom two images show the view from a paramedic's helmet camera. Middle: An arm laceration is treated. The footage includes a variety of skin tones, so that new telemedicine systems can be used to accurately diagnose injuries on a variety of skin tones. Bottom: An emergency medical technician uses a wireless device to monitor "patient" vitals. The device transmits video, voice, and data feeds to a remote hospital. Stills courtesy of www.cdvl.org.

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. 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

Public Safety Video Quality Assessment

Determine one-way transmission minimum performance specifications for a wide range of task-based public safety video application areas that involve the ability to recognize the target of interest for a particular scenario (visual intelligibility or visual acuity).

Project Leader: Dr. Joel Dumke

(303) 497-4418, jdumke@its.bldrdoc.gov

Video Clip Preparation

Film, edit, organize, and document high quality video sequences suitable for objective and subjective analysis of the suitability of video equipment for public safety purposes, with appropriate usage permissions and content. Design and film new video sequences, edit new and existing footage, organize footage into scenario groups, document the video sequences, and convert footage into multiple formats.

Project Leader: Margaret H. Pinson

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

Department of Commerce / NOAA / NOAA Weather Radio Program Office

NOAA Weather Radio Receiver Tests

Test the responses of selected commercial NOAA Weather Radio (NWR) receivers to various simulated NWR transmissions using a series of repeatable measurement methods. Compile and report on the characteristics and responses of the tested receivers As applicable, determine whether the receivers comply with the standards set down in CEA 2009.

Project Leader: Raian F. Kaiser

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

Department of Defense (DOD)

Propagation Modeling Web site (PMW)

Develop and enhance a web-based multipurpose GIS propagation modeling tool to predict coverage, interference and overlap coverage of outdoor broadcast systems for frequencies up to 20 GHz.

Project Leader: Julie Kub

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

DOD / U.S. Air Force

FPS-124 and RNSS EMC/Spectrum Study

Assist the Air Force to examine mitigation techniques between RNSS signals and radar systems operating in the 1215–1390 MHz frequency band. Perform radar emission measurements on the AN/FPS-124. Spectral emission data will be used to quantify the amount of energy, if any, that is radiated in the EESS and WMTS bands, from 1390–1400 MHz and to provide a complete FPS-124 emission spectrum, a determination of transmitter bandwidths, calculated spurious and harmonic emission levels, and, if possible, a plot of the azimuthal antenna pattern.

Project Leader: John E. Carroll

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

Department of Homeland Security (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 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

Investigative Device Testing

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

Project Leader: Jeff Bratcher

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

DHS / U.S. Coast Guard

Radar EMC Study

Develop computer models of typical solid state and magnetron-based S-Band Marine Radar receivers and perform EMI analyses and parametric studies of potential interference from Broadband Wireless devices operating within the band, and from devices and radars operating in adjacent bands. Where necessary, supplement these computer models by measurements performed on selected radar receivers. Develop recommended Marine Radar receiver selectivity standards to minimize interference from and define reasonable adjacent band/out-of-band emissions (OOBE) limits for broadband wireless

NOAA Weather Radio (NWR) broadcasts warning and post-event information for all types of natural and man-made hazards 24 hours a day on one of seven VHF frequencies from 162.400 MHz to 162.550 MHz and cannot be heard on a simple AM/FM radio receiver. ITS assists in developing performance standards that weather radios must meet and tests for reception they must pass before manufacturers are permitted to display the NWR All Hazards logo pictured above on their radios.

devices. Monitor related Broadband Wireless spectrum reallocation efforts and FCC regulatory actions and rulemaking efforts.

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

Conduct propagation prediction studies of the Schoodic Education and Research Center (SERC) facility to establish optimum locations for transmitters to augment current cellular coverage within SERC. Determine the technical operating parameters (such as bandwidth, throughput, and capacity) required to supply researchers and students visiting the SERC with maximum service possible. Develop a technical plan that details hardware requirements to implement cellular coverage within the SERC.

Project Leader: Christopher Behm

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

Department of Transportation / Federal Railroad Administration

Railroad Telecommunications Study

Provide engineering services and products to the Federal Railroad Administration Office of Research and Development, including testing VNB digital radios' audio quality in a railroad environment, evaluating the efficacy of the VHF channel plan, evaluating propagation models as applied to railroad environments, and verifying RF performance metrics of very narrowband digital radios. Prepare technical contribution pertaining to railroad telecommunications for 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

Intentional Emitter Study

Perform a review of the current versions of the FCC licensing database and the Government Master File (GMF) to identify, charatecterize and catalog licensed or assigned radio transmitters within approximately 8 km of about 200 localities where some automotive control systems may have experienced compromising failures.

Project Leader: Dr. Robert Johnk

(303) 497-3737, bjohnk@its.bldrdoc.gov

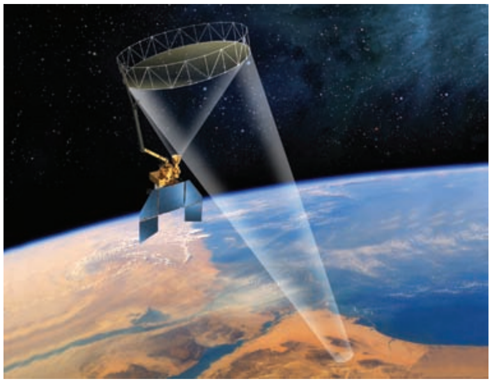
L-Band Interference Thresholds

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

Project Leader: Frank H. Sanders

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

A rendering of SMAP in orbit with a visualization of the swath of data streaming to Earth on L-band transmissions. Image courtesy of NASA/JPL-Caltech.



National Archives and Records Administration

NARA e-Government Study

Provide the technical backbone for the proposed electronic Federal Record Center (eFRC). Working closely with NARA archivists, design and implement a potentially large scale records management infrastructure to administer, store, and manage temporary e-records in compliance with well-established NARA RM requirements, including support for automation of NARA business processes through electronic workflow.

Project Leader: Michael G. Cotton

(303) 497-7346, mcotton@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

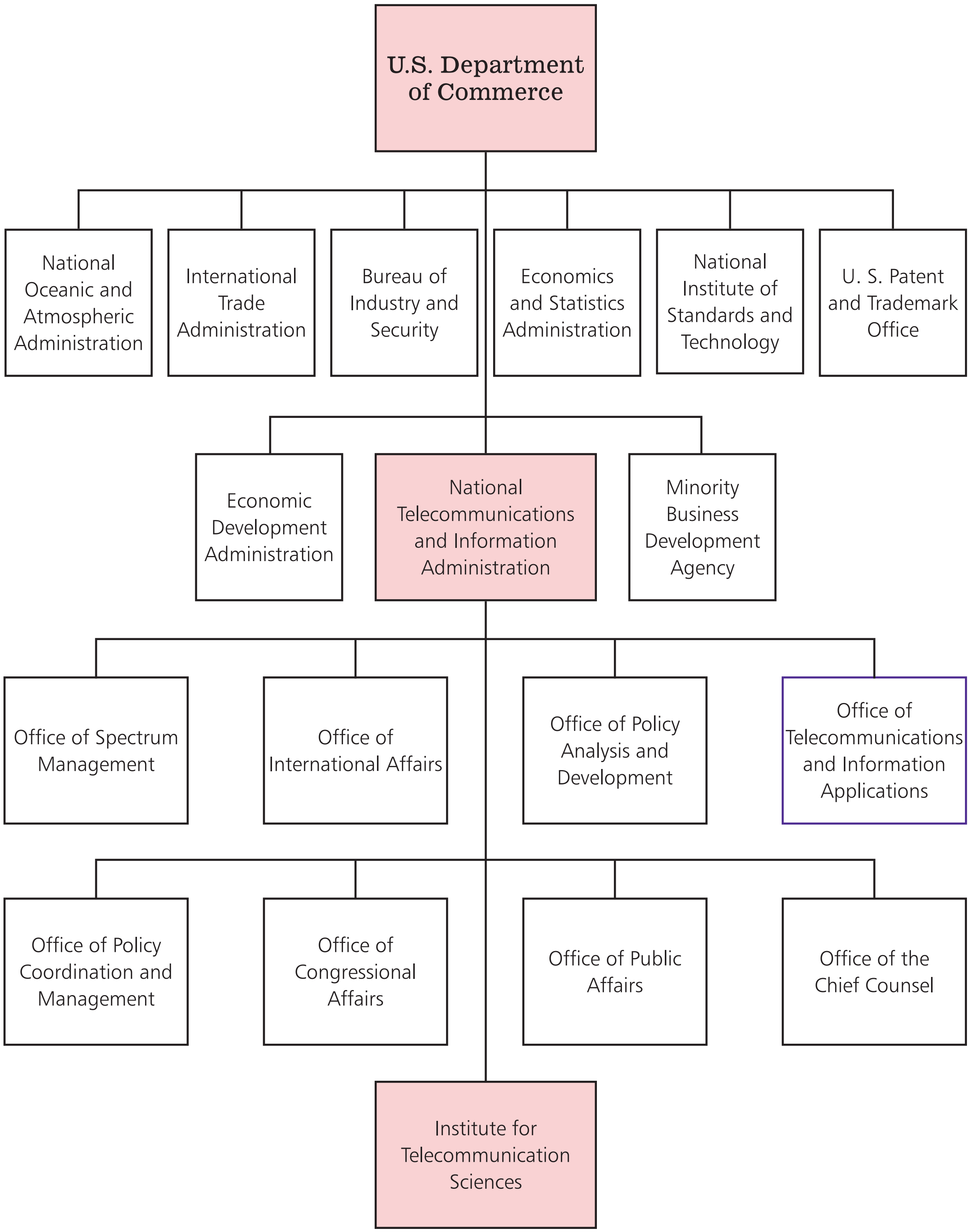
Abbreviations/Acronyms

3DTV	three-dimensional television
3G	third generation cellular wireless
3GPP	3rd Generation Partnership Project
4G	fourth generation cellular wireless
AAR	Association of American Railroads
AC	alternating current
ADC	analog to digital converter
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials – International
APIC	APCO Project 25 Interface Committee
APD	amplitude probability distribution
APWG	Audio Performance Working Group
ARNS	aeronautical radionavigation system
ARSR	Air Route Surveillance Radar
ATIS	Alliance for Telecommunications Industry Solutions
AUGNet	Ad Hoc UAV Ground Network
BPL	broadband over power line
BPSK	binary phase shift keying
BRS	broadband radio service
BVQM	Batch VQM
CAI	Common Air Interface
CAP	Compliance Assessment Program
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Acces
CDVL	Consumer Digital Video Library
CEA	Consumer Electronics Association
CIF	common intermediate format
CMRS	Commercial Mobile Radio Services
CONUS	continental United States
COPS	Community Oriented Policing Services
COTS	commercial-off-the-shelf
CRADA	cooperative research and development agreement
CARSR	Common Air Route Surveillance Radar
CSPT	Communication System Planning Tool
CSSI	Console Subsystem Interface
CW	continuous wave
DAT	digital audio tape
dB	decibel
DCP	digital sampling channel probe
DFS	dynamic frequency selection
DHS	Department of Homeland Security
DNS	domain name system
DNSSEC	Domain Name System Security Extensions
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DSA	dynamic spectrum access
DSR	Document & Standards Reference
DTV	digital television
eFRC	electronic Federal Record Center
EMC	electromagnetic compatibility
EMS	emergency medical services
ERB	Editorial Review Board
ERIC	Emergency Response Interoperability Center
ERP	effective radiated power
ESRI	Environmental Systems Research Institute
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FLC	Federal Laboratory Consortium
FM	frequency modulation
FMCW	frequency-modulated continuous-wave
FR	full reference
FSSI	Fixed Station Subsystem Interface
FTTA	Federal Technology Transfer Act
FY	fiscal year
GAST	gradient ascent subjective testing
GHz	gigahertz
GIF	graphical interchange format
GIS	geographic information system
GLOBE	Global Land One-km Base Elevation
GMF	Government Master File
GPS	Global Positioning System
GUC	generalized use class
HATS	head and torso simulator
HD	high definition
HDTV	high definition television
HF	high frequency
HPGL	Hewlett-Packard Graphics Language
HRTe	high-resolution terrain elevation
IBOC	in-band on-channel
IBRES	in-building radio enhancement system
IEC	International Electrotechnical Commission

IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate frequency
IF-77	ITS-FAA 1977 propagation model
IFSAR	interferometric synthetic aperture radar
ILG	Independent Lab Group
IMSI	International Mobile Subscriber Identity
IMT	International Mobile Telecommunications
INR	interference to noise ratio
IOC	IMSI Oversight Council
IP	Internet protocol
IPC	interference protection criteria
I/Q	in-phase/quadrature
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
ITS_UFED	ITS Undisturbed-Field and Empirically Derived
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunication Standardization Sector
IWCE	International Workshop on Computational Electronics
JCA-CIT	Joint Coordination Activity on Interoperability and Conformance
JCA-IDM	Joint Coordination Activity on Identity Management
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 frequency/medium frequency
LIDAR	Light Detection and Ranging
LMCO	Lockheed Martin Company
LMDS	local multipoint distribution system
LMR	land mobile radio
LNA	low noise amplifier
LOS	line of sight
LTE	long term evolution
MD	multimedia definition
MHz	megahertz
MIMO	multiple input multiple output
MMES	multimedia emergency services
MOS	Mean Opinion Score
MSS	mobile satellite services
MSTV	Association for Maximum Service Television
NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NAVFAC	Navy Facilities Engineering Command
NF	noise figure
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
NSWC	Naval Surface Warfare Center
NTIA	National Telecommunications and Information Administration
NWR	NOAA Weather Radio
NWS	National Weather Service
OFDM	orthogonal frequency-division multiplexing
OIC	Office of Interoperability and Compatibility
OLES	Office of Law Enforcement Standards
OOB	out-of-band
OOBE	out-of-band emission
OSM	Office of Spectrum Management
P25	Project 25
PASS	personal alert safety system
PBS	Public Broadcasting Service
PCAP	P25 Compliance Assessment Program
PCS	Personal Communications Service
PESQ	perceptual evaluation of speech quality
PLMN ID	Public Land Mobile Network Identifier
PMW	Propagation Modeling Website
PN	pseudorandom number
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
QCIF	Quarter Common Intermediate Format
QoE	quality of experience
QoMEX	International Workshop on Quality of Multimedia Experience
QoS	quality of service
R&D	research and development
RECUV	Research and Education Center for Unmanned Vehicles
RF	radio frequency
RFSS	Radio Frequency Sub-System
ROTHR	Relocatable Over the Horizon Radar
RR	reduced reference
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement Science
SCEP	Student Career Experience Program
SCTE	Society of Cable Telecommunications Engineers
SD	standard definition
SDR	software-defined radio
SERC	Schoodic Education and Research Center
SG	Study Group
SHF	super high frequency
SLiMS	Shore Line Intrusion Monitoring System
SMAP	Soil Moisture Active/Passive orbital radar
SNR	signal-to-noise ratio
SoR	Statement of Requirements
SPIE	Society of Photo-Optical Instrumentation Engineers
SRS	satellite remote sensing
ST	spatialtemporal
STEP	Student Temporary Employment Program
TA	Telecommunications Analysis
TARGA	Truevision Advanced Raster Graphics Adapter
TDWR	Terminal Doppler Weather Radar
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TR	technical report
TSB	Telecommunications Systems Bulletin
TSC	Technical Subcommittee
TSG	Technical Specification Group
TV	television
U.S.	United States
UA	unmanned aircraft
UAS	unmanned aircraft system
UAV	unmanned aerial vehicle
UHF	ultra high frequency
ULA	United Launch Alliance
U-NII	Unlicensed National Information Infrastructure
UNS	User Needs Subcommittee
URSI	International Union of Radio Science
USNC	United States National Committee
USRP	universal software radio peripheral
UT	universal time
UWB	ultrawideband
VFD	variable frame delay
VHF	very high frequency
VNA	vector network analyzer
VoIP	voice over Internet protocol
VQEG	Video Quality Experts Group
VQiPS	Video Quality in Public Safety
VQM	Video Quality Model
VQM_VFD	Video Quality Model with Variable Frame Delay
VSA	vector signal analyzer
VSG	vector signal generator
W	watt
WCC	Wireless Communications Committee
W-CDMA	wideband CDMA
WG	Working Group
Wi3	Wireless Innovation and Infrastructure Initiative
WLAN	wireless local area network
WNRC	Wireless Networks Research Center
WP	Working Party
WRC	World Radiocommunication Conference
WTSC-RAN	Wireless Technologies and Systems Committee – Radio Access Networks

DOC/NTIA Organization Chart

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