2012

Technical Progress Report
Institute for Telecommunication Sciences
Boulder, Colorado

U.S. DEPARTMENT OF COMMERCE
NTIA
NATIONAL TELECOMMUNICATIONS & INFORMATION ADMINISTRATION

ITS Organization Chart

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Jill V. Copeland, Secretary

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Patricia J. Raush, Chief

Telecommunications and Information Technology Planning Division

Jeffrey R. Bratcher, Chief
Kathy Mayeda, Secretary

Telecommunications Theory Division

Frank H. Sanders, Chief
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Institute for Telecommunication Sciences
FY 2012 Technical Progress Report

U.S. Department of Commerce
Lawrence E. Strickling, Assistant Secretary
for Communications and Information
May 2013

The Institute for Telecommunication Sciences is an Office of the National Telecommunications and Information Administration, an agency of the United States Department of Commerce.

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 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 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.

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Cover art by A.D. Romero.

Contents

Left: From rear, the RSMS-3G measurement truck, RSMS-4G measurement truck, and the radio propagation research receiver van are parked behind the ITS laboratory while staff configure instrumentation in preparation for multiple measurement efforts. Photo by Bob Johnk.

Right: ITS technician Ron Carey configures a transportable public safety LTE base station for interference testing at a public safety land mobile radio transmitter site. Photo by John Vanderau. Below left: ITS engineer John Vanderau configures a head and torso simulator (HATS) to make recordings for audio intelligibility testing experiments. Below right: PSCR technician Sam Gomez and ITS engineer Chris Redding in the PSCR van conducting network drive testing in the field to evaluate an LTE system under test (infrastructure and user equipment) in an operational environment. Photos by Ken Tilley.

The Institute for Telecommunication Sciences

ITS serves as a principal Federal resource for the conduct of basic research on the nature of radio waves, generating and communicating new, cutting-edge scientific understanding of telecommunications technology and systems. ITS research supports the Department of Commerce objective of enhancing scientific knowledge and providing information to stakeholders to improve innovation and technology, support economic growth, and improve public safety.

Outputs

- *State-of-the-art research and analysis results of national impact in telecommunications*
- *Technical input to NTIA policy development and spectrum management*
- *Analysis and resolution of specific telecommunications problems of Federal agencies*
- *Technical assistance to the private sector*
- *Leadership and technical contributions to national and international telecommunications fora*

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). The Institute is located on the Department of Commerce Boulder Laboratories campus in Colorado, sharing advanced laboratory and test facilities with the National Institute for Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA).

Organization

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

- Spectrum and Propagation Measurements
- Telecommunications and Information Technology Planning
- Telecommunications Engineering, Analysis and Modeling
- Telecommunications Theory

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

Contributions

ITS is recognized as one of the world's leading laboratories for telecommunication research. Basic research conducted at ITS enhances scientific knowledge and understanding in cutting-edge areas of telecommunications and information technology. Applied research, testing, and evaluation help drive innovation and development of advanced technologies and services. Cooperative research with industry leverages ITS Federal research resources and promotes innovation, entrepreneurship, and commercialization.

ITS research resolves telecommunications challenges for other Federal agencies, state and local governments, private corporations and associations, and international organizations. Research results and measurements from ITS are transferred to U.S. industry and Government through peer-reviewed publication, technical contributions and recommendations to standards bodies, and cooperative research and development agreements (CRADA) with private industry and academia. ITS staff represent U.S. interests in many national and international telecommunication conferences and standards organizations, and their technical contributions and recommendations to national and international standards bodies help influence development of standards and policies to support the full and fair competitiveness of the U.S. communications and information technology sectors.

Areas of Focus

- **Spectrum Measurement and Utilization:** ITS designs, develops and operates state-of-the-art systems to measure spectrum occupancy trends and emission characteristics of Federal transmitter systems, and to identify, analyze, and resolve radio frequency interference in Federal systems. This research provides a technical foundation for NTIA's policy development and spectrum management activities to enable more efficient use of the radio spectrum. It supports optimization of Federal spectrum allocation methods by identifying unused frequencies and potential interference through field measurements, and by promoting technology advances for efficient spectrum use.
- **Public Safety Interoperability:** ITS provides systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) to foster nationwide first-responder communications inter-connectivity and interoperability at Federal, state, local, and tribal levels. ITS operates 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.
- **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.
- **Enhancing Domestic and International Competition:** ITS develops user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services. ITS research promotes enhanced competitiveness by removing technical barriers to commercialization of equipment and services. ITS research contributes to development of communications and broadband policies that enable a robust telecommunication infrastructure, ensure system integrity, support e-commerce, and protect an open global Internet.
- **Emerging Telecommunication Technologies, Systems, and Networks:** ITS research addresses emerging telecommunications, information technology, and security challenges through investigation and invention of new information and telecommunication technologies such as Voice over LTE (VoLTE), ultrawideband, and Dynamic Spectrum Access (DSA). ITS assesses telecommunications system components, evaluates network survivability, and assesses system effectiveness in national security, emergency preparedness, military, and commercial environments.
- **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 development and testing of large scale records management infrastructure for secure Federal electronic record repositories.

Awards and Honors

- *The National Public Safety Telecommunications Council (NPSTC) established an annual Technical Award in honor of a late ITS senior engineer*
- *The Alliance for Telecommunications Industry Solutions (ATIS) presented an Award for Outstanding Contributions to an ITS senior engineer*
- *Eight ITS employees received U.S. Department of Commerce awards for work performed in FY 2012*

NPSTC Award

The National Public Safety Telecommunications Council (NPSTC) established the Atkinson Technical Award in honor of ITS senior engineer David (DJ) Atkinson, whose April 2012 death in a tragic accident was a great loss to NTIA and the public safety community.

DJ made an important contribution to the Public Safety Communications Research (PSCR) program, a joint program run by ITS and the National Institute of Standards and Technology's Office of Law Enforcement Standards to research and develop common technical standards for public safety communications. As part of the PSCR program, DJ led the Public Safety Audio Quality project at ITS labs.

In announcing the new award, NPSTC said DJ's work on audio quality and intelligibility guidelines for digital two-way radios helped lead to a "shift within the industry to address issues in loud background noise environments for first responders." Firefighters who rely on radios built to standards developed through DJ's work called him "brother," and many openly credit his work with saving lives.

NPSTC awarded the first Atkinson Technical Award posthumously to DJ at a June 2012 national meeting. Deputy Assistant Secretary and NTIA Deputy Administrator Anna Gomez accepted the award on behalf of DJ's family.

ATIS Award

The Alliance for Telecommunications Industry Solutions (ATIS) presented ITS senior engineer Tim Riley with an Award for Outstanding Contributions to an ATIS Forum or Committee during the 2012 ATIS 9th Annual Meeting of Committees in April 2012. This award is presented to individuals who have provided valuable contributions to the development, acceptance or completion of ATIS standards during the past year. Riley was recognized for his leadership and valued contributions as an active member of the Wireless Technologies and Systems Committee (WTSC) Radio Access Networks (RAN) Subcommittee

Above: DJ Atkinson at the Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting in Broomfield, CO, on March 6, 2012.

Above: ATIS President & Chief Executive Officer Susan M. Miller presents an ATIS Award to Tim Riley during the Annual Awards Reception on April 17, 2012. Photo courtesy ATIS.

U.S. Department of Commerce Awards

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 team from ITS and the NTIA Office of Spectrum Management (OSM) received Gold Medals in the category of Scientific/Engineering Achievement for work performed in FY 2012. Frank Sanders and John Carroll of ITS, with Robert Sole of OSM, were recognized for identifying severe nationwide WiMAX radio interference to National Weather Service (NWS) NEXRAD safety-of-life weather radars, providing interference diagnostics to NWS, and providing solutions for the problem.

The affected radars warn U.S. citizens and airports of severe weather events such as tornados. In 2010, blanked-out zones (interference strobes) were identified on many NEXRAD displays at sites across the U.S. The group developed a test-and-measurement plan and system to identify the interference mechanism and sources, then deployed the system to a selected NEXRAD site. The NTIA engineers worked with the NWS, the FCC, and industry to identify the source of the problem and find technical solutions to it. Six technical solutions were identified and shared with stakeholders so that WiMAX interference to NEXRADs can be mitigated nationally without hindrance to the continued deployment of new broadband WiMAX services, ensuring that Americans will continue to receive NEXRAD warnings while enjoying the benefits of new WiMAX services.

This accomplishment advanced both the NWS mission to improve weather forecasting and NTIA's spectrum management mission by protecting Government radar operations while ensuring that both Government and non-Government radio spectrum are used as efficiently as possible in the long term.

Bronze Medal Award

Michael Cotton and Geoffrey Sanders received a Bronze Medal Award for rapid development and deployment of a system to measure radar spectrum occupancy in support of the President's broadband initiative.

Cotton and Sanders conducted a rapid-turnaround radio spectrum band occupancy study . They researched, developed, and experimentally demonstrated a specialized measurement system to optimally detect spectrum occupancy by incumbent radar systems in the 3550–3650 MHz band, identified by NTIA's Fast Track report as a high value band for spectrum sharing. They then used the system to conduct a maritime radar spectrum occupancy study that provided spectrum managers with vital incumbent usage data. The findings from this occupancy study were presented as an objective basis for discussions at ISART and used to prepare a proposed new FCC rulemaking.

Certificate of Appreciation

Certificates of Appreciation are granted by the head of an operating unit or Secretarial Officer for noteworthy performance. Chris Behm, Paul McKenna, Teresa Rusyn, and Jeffery Wepman of ITS, with Alaka Paul of OSM, received a Certificate of Appreciation for technical leadership across ITU-R Study Group 3 (SG3) in the area of Radio Propagation. This team filled more than eight leadership roles in the U.S. Delegation to the June 2012 ITU-R Study Group 3 meetings preparing for the 2015 World Radio Conference and provided most of the radio propagation expertise. They put together a suite of about a dozen U.S. technical contributions to firmly establish U.S. leadership on work efforts in noise, diffraction, sharing, and air-to-ground propagation models, and administered these documents through the U.S. State Department for review and ultimate submission to SG3.

Above: Acting Department of Commerce Secretary Rebecca M. Blank (far left) and Assistant Secretary for Communications and Information Larry Strickling (far right) present the Gold Medal Award to Robert Sole, Frank Sanders and John Carroll. Below left: From left, Teresa Rusyn, Jeffery Wepman, Chris Behm and Paul McKenna with Certificates of Appreciation presented by ITS Director Al Vincent (far right). Below right: Geoffrey Sanders receives a Bronze Medal Award from ITS Director Al Vincent.

> "Innovation fuels economic growth, the creation of new industries, companies, jobs, products and services, and the global competitiveness of U.S. industries. One driver of successful innovation is technology transfer, in which the private sector adapts Federal research for use in the marketplace."
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> *Presidential Memorandum — Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses, October 28, 2011*

Technology Transfer

Outputs

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

Overview

From the Stevenson-Wydler Technology Innovation Act of 1980 to the October 2011 Presidential Memorandum on Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses, there has been increasing emphasis on facilitating the transfer of intellectual property and technology emerging from federally supported research to the private sector and other Government agencies. Technology transfer to the private sector aims to rapidly integrate Federal research outcomes into the mainstream of the U.S. economy to enhance U.S. competitiveness in the global marketplace. It is a natural complement to the provisions of the Economy Act of 1932 that allow Federal agencies to benefit from the research and development resources of other agencies through interagency cost-reimbursement agreements.

ITS is very active in technology transfer. About half of ITS research programs are undertaken for and with other Federal agencies; state, local and tribal governments; private corporations and associations; or international organizations. This includes assisting the FCC and Federal defense, public safety, and other agencies that use Federal and non-Federal spectrum. Sponsored research supports the technology transfer goals of the Department of Commerce while contributing to NTIA's overall program. 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.

ITS is a member of the Federal Laboratory Consortium for Technology Transfer (FLC), a nationwide network of about 300 Federal laboratories organized in 1974 and formally chartered by the Federal Technology Transfer Act of 1986 (FTTA). FLC laboratories promote the fullest application and use of Federal research and development by providing an environment for successful technology transfer.

Government-Sponsored Research

Research results and measurements from ITS are transferred to U.S. industry and Government through peer-reviewed publication, technical contributions to standards bodies, and CRADAs with private industry and academia. This technology transfer supports the competitiveness of U.S. businesses, brings new technology to users, and expands the capabilities of national and global telecommunications infrastructures.

ITS is also a joint partner in the Public Safety Communications Research (PSCR) program with the Department of Commerce National Institute of Standards and Technology (NIST) Law Enforcement Standards Office (OLES). Other Government agency sponsors that provide significant support to various ITS programs include the Department of Homeland Security, the Department of Transportation, the Department of Defense, the National Archives and Records Administration, and the National Weather Service.

Privately Sponsored Research

ITS supports private sector telecommunications research through cooperative research and development agreements. CRADAs were authorized by the FTTA to encourage sharing of Government facilities and expertise as an aid in the commercialization of new products and services. 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.

Cooperative Research and Development Agreements

ITS participates in CRADAs with private industry, universities, and other interested parties to design, develop, test, and evaluate advanced telecommunication concepts. CRADAs protect the non-Governmental party's proprietary information, grant patent rights, and provide for user licenses to private entities.

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 positioning (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. In FY 2012, ITS participated in six CRADAs involving use of the Table Mountain Field site.

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

The University of Colorado's Research and Engineering Center for Unmanned Vehicles (RECUV) is a university, government, and industry partnership for the development and application of unmanned vehicle systems. Above, an unmanned aircraft under test at the RECUV UAS airfield on Table Mountain. The facility is used to conduct RECUV mobile networking experiments and other flight tests. Photo courtesy University of Colorado Boulder.

ITS world-class facilities and capabilities shared through CRADAs and interagency agreements 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
- Propagation Prediction Modeling Services

Read more about these and other resources at ITS in the *ITS Tools and Facilities* section, page 82.

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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.

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 during product development.

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.

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.

Radar RSEC Measurements for Two New Radar Designs

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.

Raytheon developed the AN/APY-10, a new maritime, littoral and overland surveillance radar designed to operate on the U.S. Navy's next-generation multimission patrol aircraft, the P-8A Poseidon. Under this CRADA, ITS performed the NTIA RSEC and transmitter/antenna RF tests on a production-qualified AN/APY-10 radar system and provided the data needed by the Navy for a frequency allocation application to enable deployment of these new radars.

Public Safety 700 MHz Broadband Demonstration Agreements

The vast majority of CRADAs ITS has entered into in the past two years and will likely continue to enter into for the next several years are the Public Safety 700 MHz Broadband Demonstration Agreements.

These agreements allow vendors, including equipment manufacturers and wireless carriers, who intend to supply 700 MHz LTE equipment and service to public safety organizations to operate various elements of an LTE network in the Public Safety Communications Research test bed and over-the-air (OTA) network (both hosted and managed by ITS) in order to test interoperability of public safety communications equipment under simulated field conditions. Public safety practitioners participate in this research.

At the close of FY 2012, 54 CRADAs were in place under this program. The CRADAs protect the parties' intellectual property, encouraging participation in testing that simulates real multi-vendor environments in the field. This is the first government or independent facility in the U.S. capable of testing or demonstrating public-safety-specific LTE implementation requirements.

The Public Safety 700 MHz Broadband Demonstration Network has multiple Evolved Packet Cores (EPC) from different vendors on site in various configurations (distributed and full core), several different Evolved NodeB (eNodeB) base stations, and many varieties of User Equipment (UE), all communicating over a test network with one mobile and two fixed transmitters. Top left: Test set up in the PSCR laboratory. Photo by Rob Stafford. Top right: eNodeB base station at the Green Mountain transmitter site. Photo by Ken Tilley. Bottom left: LTE user equipment from multiple manufacturers charging in preparation for testing in the laboratory. Photo by Ken Tilley. Bottom right. This fixed transmitter on Table Mountain is part of the 700 Hz test network. Photo by Ken Tilley.

Interagency Agreements

Interagency agreements, authorized under the Economy Act of 1932, offer important benefits to Federal agencies, including the ability to economically and effectively leverage Federal research investments. With almost 100 years of uninterrupted radio research history, ITS represents a unique Federal resource for agencies that have short- or long-term radio research or development needs that cannot be met effectively by existing in-house resources.

Through interagency agreements, these agencies can gain the benefit of the federally-funded expertise, equipment, and facilities of which ITS is the steward. Federal partners reimburse ITS for the costs of research conducted under an interagency agreement, but—unless the research is classified—the results are released into the public domain for the benefit of other researchers, both public and private.

In FY 2012, ITS entered into over 20 interagency agreements with ten different agencies. Research funded under these agreements includes propagation modeling, electromagnetic compatibility and interference analysis of new or proposed systems, root cause analysis and resolution of interference to existing systems, and engineering analysis and support for standards development for evolving technologies.

Several research projects funded by the National Institute for Standards and Technology Law Enforcement Standards Office and different offices of the Department of Homeland Security involve improving public safety communications. Tasks assigned to ITS under these agreements include engineering analyses, technical feasibility studies of emerging technologies, development and validation of interoperability standards, and laboratory and field measurements. ITS provides similar services to the Federal Railroad Administration Office of Research and Development to improve railroad telecommunications efficacy.

The Department of Defense and the National Weather Service of the National Oceanic and Atmospheric Administration entered into agreements with ITS to use the Institute's unique expertise in propagation modeling to provide specialized radio propagation prediction tools for coverage and interference prediction.

The U.S. Air Force, the U.S. Navy, the U.S. Coast Guard, and the office of Emergency Communications of the Department of Homeland Security entered into various agreements with ITS to perform radio spectrum emission measurements on new or proposed equipment.

The National Aeronautics and Space Administration requested ITS assistance to identify potential sources of interference into certain control systems and to conduct interference threshold studies for planned new radar satellites.

The National Archives and Records Administration entered into an agreement with ITS to leverage the Institute's experience in the management of large data stores. ITS is tasked with assisting NARA to design and implement a large scale records management infrastructure to administer, store, and manage e-records.

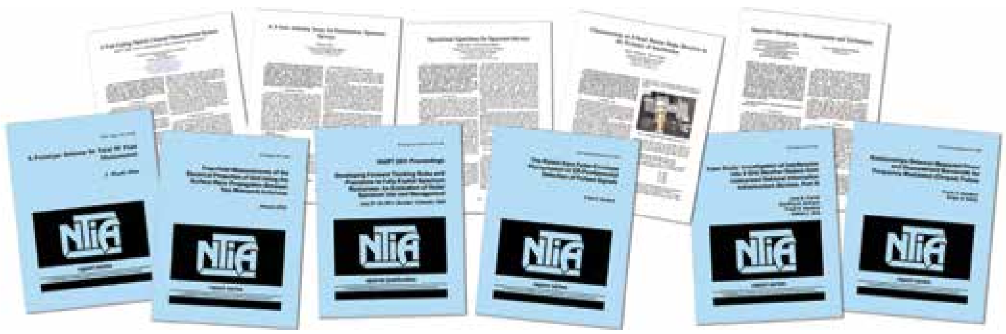
More information about individual FY 2012 interagency agreements is provided in the section on "ITS Government Projects in FY 2012" on page 98.

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 2012, ITS authors published six NTIA Technical Reports, Memoranda or Handbooks that were peer-reviewed through the ERB process and five conference papers that underwent both ERB review and additional peer review outside ITS.

In addition to formal technical publications, ITS experts are also frequently invited to participate as speakers or presenters at technical conferences, workshops, and symposia. A list of FY 2012 publications and presentations, with full citations and abstracts, begins on page 92.



Conferences, Workshops and Symposia

ISART 2012

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 13th Annual ISART was held at the Millennium Hotel and Conference Center in Boulder, Colorado, July 25–26, 2012. Its focus was "Developing Forward-Thinking Rules and Processes to Fully Exploit Spectrum Resources—Case Study 2: Exploring Approaches for Real-Time Federal Spectrum Sharing." Recent progress in dynamic spectrum access (DSA) technology highlights the critical role of the spectrum sharing infrastructure, which is more the domain of computer scientists than radio scientists. This infrastructure is architected upon databases, information exchange languages, and business processes. More than any particular radio technology, computer science has spurred the latest advancements in technologies that will enable new and innovative ways to share spectrum. Geolocation databases will dictate channel availability in the TV white spaces, and the Department of Defense is developing capabilities to generate digital spectrum policy that would govern the operation of flexible spectrum use radios with and without spectrum sensing.

Future Federal spectrum sharing will require changes to the existing spectrum management infrastructure to expand spectrum availability through use of technologies like DSA. Widespread acceptance and adoption of spectrum sharing technologies will require well-defined business practices and sharing agreements, the development of supporting automation and management systems to generate coexistence rulesets, and secure networks that implement these rulesets.

ISART 2012 brought together radio scientists and computer scientists to present a detailed view of their perspectives of spectrum use and management. Obstacles to development of spectrum sharing infrastructure for both Federal and commercial sharing were delineated and potential solutions discussed.

ISART
INTERNATIONAL SYMPOSIUM ON
ADVANCED RADIO TECHNOLOGIES
INSTITUTE FOR TELECOMMUNICATION SCIENCES

Public Safety 700 MHz Demonstration Network Stakeholder Meeting

ITS hosted the Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting at the Omni Interlocken Resort and Conference Center in Broomfield, CO, March 6–7, 2012. This was the third face-to-face stakeholders' meeting for the Demonstration Network, with over 350 attendees from public safety, Federal agencies, industry, and academia. Keynote speakers were Anna Gomez, Deputy Assistant Secretary for Communications and Information and Deputy Administrator, NTIA; Dr. David Boyd, Science and Technology Directorate Command, Control and Interoperability Division, Director, DHS; and Tom Power, Deputy CTO for Telecommunications, Office of Science and Technology Policy, Executive Office of the President. Participants learned about progress in the Demonstration Network testing, including Phase 1 test results and lessons learned, Study Item findings, recent public safety broadband requirements gathering and standards development activities, preliminary voice over broadband audio quality testing findings and future plans, and nationwide broadband modeling and simulation efforts and results.

VQiPS

ITS hosted the 4th Annual Video Quality in Public Safety (VQiPS) conference and workshop July 26–27, 2012 in Boulder, CO. The meeting brought together public safety practitioners, Federal partners, manufacturers, and representatives from academia and standards development bodies to coordinate efforts in establishing quality requirements for video use in public safety.

During this collaborative working session the draft Video Quality for Public Safety Standards Handbook, which provides voluntary guidance in deploying video quality for network video surveillance applications based on established best practices, was presented for feedback. Workshop participants also received an introduction to version 2.0 of VQiPS' online Recommendations Tool for Video Requirements. The tool matches a video user's unique needs to use cases and provides a video system requirement recommendation. PSCR researchers received additional feedback from public safety practitioners about how the online tool could be improved to be more user-friendly. Usability information gathered during the session will help to ensure that the online tool is well-suited to public safety applications in the future.

Left, top: Cuong Luu (far right) of DHS/OIC, closes the VQiPS Workshop and congratulates participants (left to right) Anna Paulson (ITS), Don Zoufal (System Development Integration), Joel Dumke (ITS), Steve Surfaro (Axis Communications), John Contestabile (Johns Hopkins University), Andrew Hartigan (SRA International for DHS/OIC). Left, bottom: PSCR staff Sam Gomez (2nd from let) Robert Stafford (center) and Chris Redding (2nd from right) observe a vendor demonstration of public safety communications equipment at the Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting. Photos by K. Tilley

National and International Standards Development

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 criteria, methods, processes and practices that promote competition and interoperability.

For decades, ITS has provided leadership and technical contributions to national and international telecommunication standards development organizations (SDO). For example, a plurality of the technical recommendations of the International Telecommunication Union (ITU), a treaty organization, are based on research conducted at ITS. Key national quality-of-service standards developed under the American National Standards Institute (ANSI) accredited Committee T1 for video, audio, and digital data also 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 SDOs, 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.

Standards Leadership

In FY 2012, ITS continued its technical leadership and contributions to communications standards for public safety, particularly for first responders and primarily in the area of interoperability standards and testing procedures. ITS's objective video quality measurement method has been made a national standard by ANSI and was the best-performing metric in ITU comparison testing with others methods from around the world. Thirteen ITS employees participated in 45 committees or working groups in seven different SDOs and held 11 Chair/Co-chair positions. Other offices of NTIA participate in the same standards bodies in different, non-technical capacities. As representatives of the U.S. Administration, NTIA/ITS staff who hold SDO leadership and membership roles advocate globally for communications technology standards and policies that encourage competition and innovation. Positions held by ITS staff in national and international SDOs are listed on page 96.

Technical Contributions

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 telecommunications conferences and SDO meetings. ITS develops and presents user-oriented technical contributions that address requirements, functionality, performance, testing, quality of service, communication network resource management, interoperability, compliance, and other issues 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. The technical contributions ITS makes to SDOs throughout the year contribute materially to the content of final published standards; a

The U.S. Administration 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"[1] and encourages the participation of authorized Federal agency representatives in standards activities. 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.

1. Office of Management and Budget Circular A-119, February 10, 1998. Available http://www.whitehouse.gov/omb/circulars_a119/

ITU standards (called Recommendations) act as defining elements in the global infrastructure of information and communication technologies. Recommendations are critical to global interoperability and to create a level playing field in which companies can compete internationally. Over 4,000 ITU Recommendations are now in force, developed by consensus in Study Groups of experts from both public and private sectors. These experts provide input towards the development of a Recommendation in the form of technical contributions.

representative list of draft or approved standards supported by FY 2012 ITS technical contributions appears on page 96.

ITU-R Standards Activities

Outputs

- *Technical support for U.S. Administration activities in ITU-R Study Group 3, Working Parties 3J, 3K, 3L, and 3M; in ITU-R Study Group 4; and in ITU-R Study Group 5, Working Party 5D*
- *Leadership roles in U.S. Study Group 3, U.S. Working Party 3K, and U.S. Working Party 3J*
- *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*
- *Development of a new version of ITU-R Recommendation P.533, the Ionospheric Propagation Model*

Overview

The International Telecommunication 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. ITU-R international technical standards, called Recommendations, are developed by small Working Parties (WP), finalized by the larger Study Groups (SG), and approved by the 193 member states. Member states provide input by preparing technical contributions to WPs and SGs to inform the discussion and provide a basis for the language of the Recommendations. Though not mandatory, in practice ITU-R Recommendations are implemented worldwide.

Within the ITU-R, Study Groups 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. Working Parties 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 3, 4, and 5 and their Working Parties; in particular, Working Parties 3J, 3K, 3L, 3M, 4A, 4B, 4C, 5D, and 6C. Study Group 3 deals with radio propagation phenomena. Study Group 4 covers fixed-satellite services. Study Group 5 deals with systems and networks for fixed, mobile, radiodetermination, amateur, and amateur-satellite services.

Participation in Study Group 3

ITS engineers play important roles in SG3 and in all four of the ITU-R SG3 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 June 2012 at the ITU Headquarters in Geneva, Switzerland. The SG3 meeting 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 (USSG3) held monthly preparatory meetings beginning in late May 2011 to review and comment on proposed U.S. Administration contributions to these meetings. An ITS engineer chaired the U.S. preparatory meetings and three others participated in them.

Four ITS engineers served as members of the U.S. delegation to the meetings of ITU-R Study Group 3 Working Parties in June of 2012 in Geneva. One of these, Paul McKenna, served as International Chair of ITU-R Working Party 3K. Paul McKenna was confirmed as International

Chair of Working Party 3K during the October 2011 meeting of Study Group 3. In June 2012, he led the meetings of Working Party 3K in Geneva. Between meetings, Mr. McKenna participated in the work of Correspondence Groups 3K3 and 3K4.

ITS engineer Chris Behm served as Head of the U.S. Delegation. Mr. Behm is the Chair of USSG3, which submits technical contributions related to radio wave propagation to SG3 on behalf of the U. S. He serves as Head of Delegation for Working Party 3L and as chair of various Subworking groups within the ITU-R SG3. Working Party 3L focuses on international issues related to high frequency (HF) radio wave propagation and radio noise. Mr. Behm is leading a correspondence group in ITU-R WP 3L to validate and verify a new implementation of Recommendation P.533-11.

ITS engineer Teresa Rusyn served as a Subgroup Chair in WP 3L and as Chair of the Drafting Group and Rapporteur of Correspondence Group 3K3, which is 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). Her work centered on Recommendation P. 528-3, covering aeronautical services. During the June 2012 meetings, Correspondence Group 3K3 was expanded to correspondence group 3K3M-9 to include path losses for airborne platforms.

ITS engineer Jeff Wepman provided a technical contribution to Study Group 3, Working Party 3L describing recent man-made radio noise measurements taken in the Boulder/Denver area and the results of the subsequent data analyses. This contribution was presented to Sub-Working Group 3L-4 during the international meetings held in June 2012. The data resulting from these measurements were approved for inclusion in the ITU Radio Noise Databank. Mr. Wepman also served as Chair of Sub-Working Group 3L-4 and Chair of the drafting group that generated a temporary document proposing changes to ITU Recommendation P.372.10.

Participation in Study Group 4

In FY 2012, an ITS engineer participated in the U.S. preparatory meetings of Study Group 4 and continued to monitor the work of SG4 from an engineering perspective. This engineer also served as the point of contact for a Liaison Statement from SG4 to SG3.

Participation in Study Group 5

An ITS engineer provided technical support to WP 5D over the phone in FY 2012. Tim Riley sat in on the U.S. conference calls and monitored WP 5D activity during the U.S. preparatory meetings and the actual working party meetings. In early FY 2012, prior to the 2012 World Radiocommunication Conference (WRC-12), the main issues were spectrum-related. Since WRC-12 ended in February of 2012, WP 5D topics have centered solely around spectrum

Every three years the Radio Regulations, the international treaty governing use of radio-frequency spectrum and satellite orbits, are revised at the World Radiocommunication Conference (WRC). From mid-January to mid-February 2012, over 3,000 participants, representing 165 of ITU's 193 Member States and more than 100 Observers from ITU's 700 private sector members and international organizations, attended WRC-12 in Geneva, Switzerland. ITS engineers began intensive preparation for WRC-15 in FY 2012. Photo courtesy ITU-R.

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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.

issues not of a technical nature: International Mobile Telecommunications (IMT) advanced procedural issues and public protection and disaster relief (PPDR).

ITU-T and Related U.S. Standards Activities

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 2012, 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 Video Quality Experts Group (VQEG), and Co-chair of the ITU-T 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 2012, Arthur Webster served as international Chair of ITU-T SG9, which is responsible for broadband cable networks and television and sound transmission. Margaret Pinson was Associate Rapporteur for Question 12/9 (Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services) and served as Head of the U.S. Delegation to ITU-T SG9.

VQEG

An ITS staff member founded the Video Quality Experts Group and has co-chaired it since 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics (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 2012, the number of participants subscribed to the main reflector grew to over 650. VQEG produces independent validation data, which the U.S. considers to be a key prerequisite for standardizing a VQM. Thus, VQEG acts as a cooperative technical advisory committee that facilitates standardization efforts in ITU-T SG9, SG12 (Performance and Quality of Service (QoS)), and ITU-R 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 2012. Margaret Pinson co-chaired the HDTV effort and is now co-chairing the VQEG's Independent Lab Group (ILG) and spearheading the current testing effort to validate objective measurements of video quality. ITS has been very active in developing the Hybrid Perceptional-Bit-Stream test plan and organizing the test. 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 VQEG's current testing efforts. ITS is spearheading new ITU-T work on audiovisual quality assessment and Internet video quality assessment through its leadership in VQEG and ITU-T SG9.

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 meets concurrently with VQEG. The JRG-MMQA provides an official mechanism for coordinating VQEG activities with ITU-T SG9 and ITU-T SG12.

Preparation for U.S. Participation in ITU World Conferences

In addition to direct participation in the technical committees discussed above, ITS engineers participated in the State Department's U.S. preparatory process for the ITU's World Conference on International Telecommunications (WCIT), ITU-T's World Telecommunications Standardization Assembly (WTSA), and the Telecommunication Standardization Advisory Group (TSAG).

ITS engineers Margaret Pinson and Joel Dumke, foreground, participate in the December 12, 2011, meeting of the Video Quality Experts Group in Hillsboro, Oregon. The meeting was hosted by Intel Corporation and took place coincident with an ITU-T JRG-MMQA meeting. Participants included researchers from seven universities, two government labs, four telcom carriers, one independent research institute, and seven manufacturers from ten countries. Photo by Arthur Webster.

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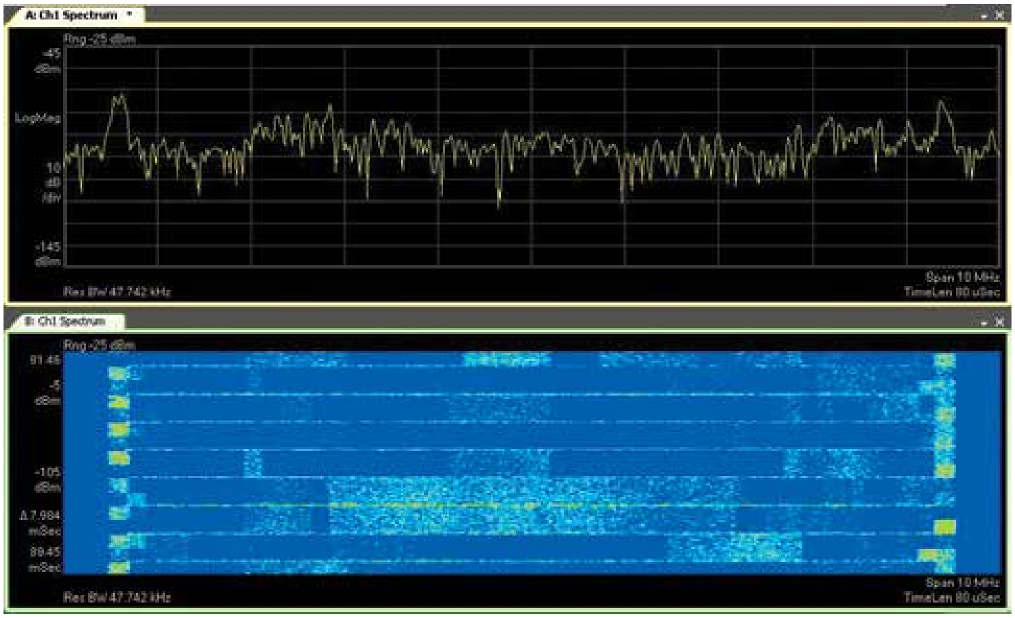
The White House, *Presidential Memorandum: Unleashing the Wireless Broadband Revolution,* June 28, 2010:[1]

“Few technological developments hold 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.”



Example LTE Measurement Capture: Spectrum and waterfall display of aggregate LTE uplink transmissions.

Configuring experimental equipment for measurement studies at the Table Mountain Field Site. Photo by Wayde Allen.

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

Spectrum and Propagation Measurements

In 2012, a new approach to increasing commercial access to wireless spectrum began to take form. NTIA's Office of Spectrum Management (OSM) issued a report, *An Assessment of the Viability of Accommodating Wireless Broadband*, that addressed the high cost and extended transition times associated with spectrum reallocation. The report proposed an alternative spectrum sharing scheme to expedite commercial access to this spectrum while minimizing the cost and impact to Federal operations. The Commerce Spectrum Management Advisory Committee (CSMAC) commissioned five working groups to study the feasibility of commercial Long-Term Evolution (LTE) networks sharing spectrum with Government systems. These groups established an analysis framework consisting of system modeling, band occupancy measurements, and interference protection criteria (IPC) measurements. Late in FY 2012, ITS entered into a CRADA with three commercial wireless operators engaged with CSMAC to assess the sharing scenario. The Spectrum and Propagation Measurements Division will use its new automated test software and preselector systems for the occupancy and IPC measurements.

As commercial communications systems proliferate, interference to Government radio services—particularly radar systems—has become more frequent. In 2012, ITS addressed two separate interference cases. ITS engineers continued to assist other government agencies seeking to implement corrective actions for dynamic frequency selection (DFS) interference to Terminal Doppler Weather Radars. An updated set of characteristic radar waveforms were developed to permit the FCC to update DFS testing systems. Meanwhile, interference to NEXRAD systems by adjacent-channel WiMAX transmitters was resolved. Field measurements and an electromagnetic compatibility analysis yielded best practices which address the situation and should prevent its reoccurrence. This latter effort earned the team a Department of Commerce Gold Medal Award.

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. Comprised of commercial and custom test equipment, the RSMS system supports ad hoc measurements to assess and resolve complaints of interference involving Government radio systems. RSMS also supports broadband spectrum surveys and band occupancy measurements, measures existing and proposed radio system emissions for electromagnetic compatibility studies and determination of IPC, and performs conformance tests on radio systems. The RSMS program funds system maintenance, performance enhancements, development of new capabilities, and operational field testing.

Table Mountain Research Program

The Table Mountain Field Site is the principal experimental field site for the DOC 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 includes propagation studies and development and evaluation of measurement methods for spectrum occupancy, radio noise, antenna design, laser testing, and radar emissions. Work is supported by ITS funding and CRADAs 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 developed a noise measurement system based on Vector Signal Analyzer (VSA) technology. The results of a two year study of environmental noise were published and presented at the ITU. 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

- *Technical contribution to ITU-R Study Group 3 Working Party 3L describing recent wideband man-made radio noise measurements and statistical data analyses*
- *Leadership of ITU-R Sub-Working Group 3L-4 on Radio Noise*
- *Inclusion of ITS noise measurement data in the ITU-R Radio Noise Databank*
- *Design of an improved outdoor radio noise measurement system*

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.

International Standards Contributions

Work in man-made radio noise research at ITS in FY 2012 included technical contributions and leadership in the International Telecommunication Union – Radiocommunication Sector (ITU-R) Study Group 3 Working Party 3L. ITS provided a contribution describing recent wideband man-made radio noise measurements conducted in the VHF and low UHF bands in the United States and the results of the subsequent statistical data analyses. As a part of this contribution, wideband complex noise data 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 were processed to provide hourly median values of the mean antenna noise figure F_a for each measurement location and frequency. This hourly median data were provided and accepted for inclusion into the ITU-R Radio Noise Databank. Figure 1 shows the hourly median values of F_a for 112.5, 221.5, and 401 MHz for the downtown Denver location. In addition to these technical contributions, an ITS radio-noise engineer served as chairman of the ITU-R Sub-Working Group 3L-4 on Radio Noise during the international meetings held in June 2012 at the ITU headquarters in Geneva, Switzerland.

Improved Noise Measurement System Design

Additional work in 2012 focused on the design of a new, improved wideband noise measurement system for outdoor measurements. Outdoor noise measurements are extremely challenging, requiring a measurement system with high sensitivity, large dynamic range, stringent filtering, and center frequency agility. While the current measurement system, based on a commercial vector signal analyzer, can and has been used for outdoor noise measurements, it has several limitations and could use improvement. Most notably, although the current system has excellent sensitivity, it is prone to signal overloads. Other limitations of the

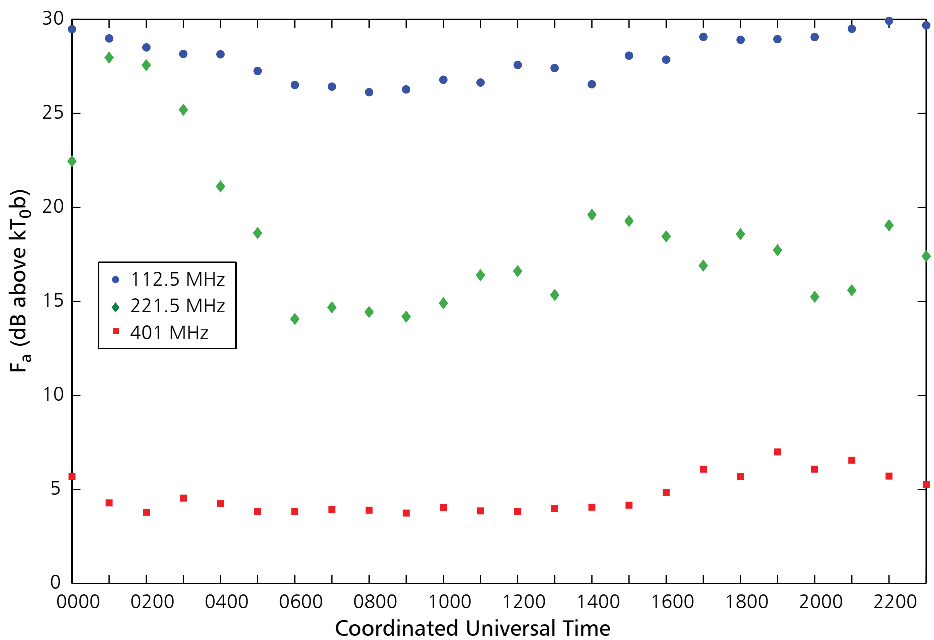

Figure 1. Hourly median values of F_a for 112.5, 221.5, and 401 MHz for the downtown Denver location.

current system include the inability to adjust the analog sampling rate, limited anti-aliasing filtering, inability to include an external IF filter before the digitizer, and reliance on very sharp rolloff, fixed RF filters that restrict center frequency agility.

Several different measurement system design strategies were considered. These included:

1. Modifying the current measurement system by replacing the vector signal analyzer with a more state-of-the-art analyzer
2. Developing a system based on a very high resolution (greater than 22 bit), high-speed digitizer
3. A two-channel measurement system

A two-channel system was chosen for the new design. This system consists of one very sensitive RF channel along with another less sensitive RF channel. Measurements are taken on both channels simultaneously with processing used to extract the composite data. A block diagram of the system is shown in Figure 2. This new measurement system will provide a significant improvement over the current system. It reduces the susceptibility to signal overloads while maintaining excellent sensitivity, provides for a flexible analog sampling rate, allows for custom IF filtering, and promotes center frequency agility.

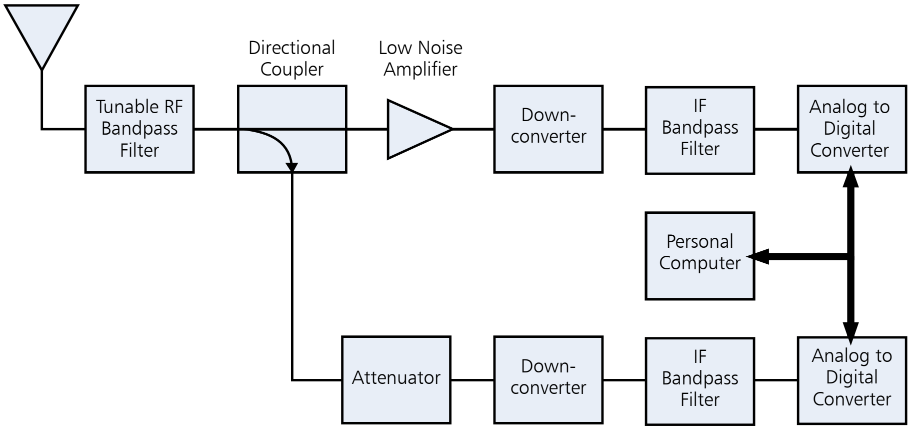

Figure 2. Block diagram of the new, two-channel noise measurement system.

Related Documents:

ITU-R WP3L Document 3L/4, "Wideband man-made radio noise measurements in the VHF and low UHF bands" (J. Wepman)

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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 primary measurement applications in the RSMS-5G software suite*
- *Completed instrument drivers in the RSMS-5G software suite for the most commonly used instruments*
- *Completed a three-week-long spectrum survey in San Diego, CA*
- *Completed a two-week-long spectrum survey in Chicago, IL*
- *Presented preliminary spectrum survey data and methodology at three conferences*

Overview

The Radio Spectrum Measurement Science (RSMS) 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 has the most advanced software and hardware to perform accurate and complete measurements.

To sustain this function, development of the 5th generation of RSMS software (RSMS-5G) began in FY 2012. Many of the core measurement capabilities of the RSMS-4G software suite have been incorporated into the new software suite and development will continue in FY 2013. To determine spectrum usage, the RSMS system was used to conduct spectrum surveys at three locations (Denver, CO, San Diego, CA, and Chicago, IL). Preliminary results of these surveys and the techniques used to perform them have been presented at three conferences, and reports detailing the findings are being produced.

Next Generation of RSMS Software (RSMS-5G)

In FY 2012 development of the next generation of RSMS measurement automation software, called RSMS-5G, began. The software is designed as a collection of software tools and core measurement capabilities that make it possible to rapidly develop new measurement techniques or use existing measurement applications to quickly perform any spectrum measurements that are needed to support policy makers.

Instrument drivers have been developed for the instruments most commonly used by ITS. These include drivers for several types of spectrum analyzers, preselectors that are custom-built by ITS, and several peripheral instruments that are commonly used when conducting spectrum measurements. Core measurement applications have also been completed for the most high-priority algorithms. These include measurement applications to calibrate measurement systems and to record and compute the numerous spectrum analyzer sweeps from which statistics regarding spectrum occupancy are calculated, as well as the stepped measurement algorithm that is described in NTIA Report TR-05-420, "Measurement Procedures for the Radar Spectrum Engineering Criteria (RSEC)."

Development of the RSMS-5G software will continue in FY 2013. Modules scheduled for development in FY 2013 include more instrument drivers, more measurement applications, data processing tools, and a scheduler.

Spectrum Survey Effort

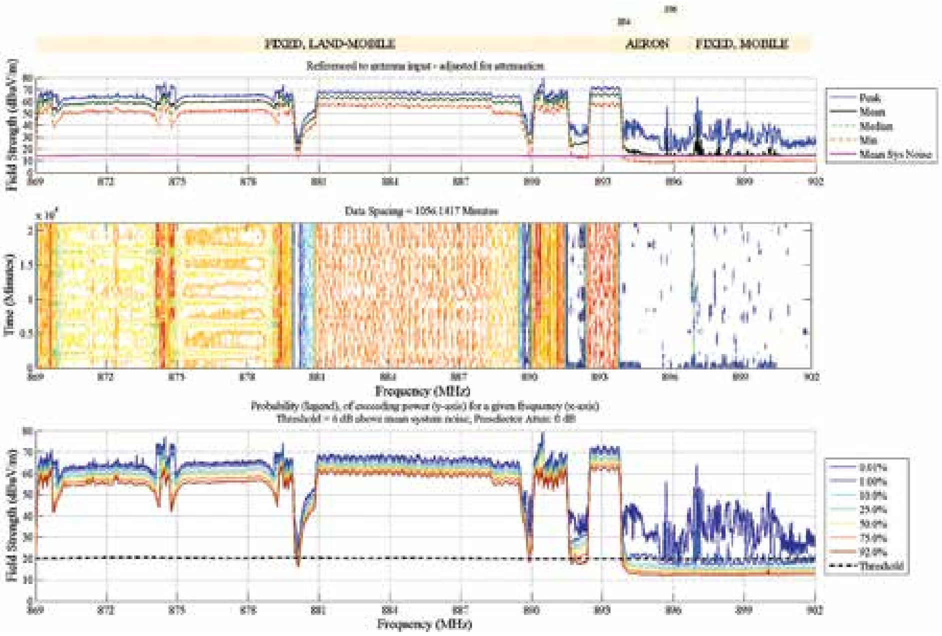
A comprehensive spectrum survey was conducted to measure spectrum usage in the frequency range from 108 MHz to 10.5 GHz in San Diego, CA during the spring of 2012. Figure 1 shows the RSMS-4G vehicle, which serves as a mobile lab, set up to conduct these measurements. Two separate systems were run simultaneously in the RSMS vehicle, making it possible to collect twice as much spectrum data. Figure 2 shows a plot of data taken from 869 to 902 MHz. This plot shows several downlink cellular transmissions from 869 to 894 MHz. The spectrum above this frequency range is part of the ISM (Industrial, Scientific, and Medical) band used for low-power devices. Similar spectrum surveys have been completed in Denver, CO, and Chicago, IL.

Spectrum survey measurements provide NTIA with critical scientific data to support the development and determination of telecommunication policies affecting both the public and private sectors. This has become a very prominent issue due to the development of new wireless technologies, and the need for additional bandwidth to support higher data rates over the air. This increased demand for spectrum requires that the spectrum be managed and used more efficiently, and these spectrum surveys can provide policy makers and system developers with current usage statistics to inform their decisions.

Preliminary results from the spectrum surveys completed to date, as well as the techniques used to perform these surveys have been presented at three conferences: the United States National Committee – International Union of Radio Science (USNC-URSI) National Radio Science Meeting; the International Symposium on Advanced Radio Technologies (ISART); and the Institute of Electrical and Electronics Engineers (IEEE) International Symposium on Electromagnetic Compatibility (EMC 2012). In FY 2013, processing of the spectrum survey data will be completed and NTIA reports presenting these data will be released for each of the three sites.

Figure 1 (right). The RSMS-4G vehicle set up to conduct spectrum usage measurements in San Diego, CA. Photo by Chriss Hammerschmidt.

Figure 2 (below). Graphs showing NTIA spectrum survey results from 869 to 902 MHz in San Diego, CA.



Related Publication

H. E. Ottke and C. A. Hammerschmidt, "Specialized Algorithms for Spectrum Surveys," in *Proceedings of the 2012 IEEE International Symposium on Electromagnetic Compatibility (EMC2012)*, Pittsburgh, PA, Aug. 5-10, 2012, pp. 565-570

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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 a newly-developed Air Force radar system used in combat theaters as well as training*
- *Emission measurements of a Navy radar system verifying the emissions are in compliance with domestic and international regulations*
- *Follow-up field testing of Unlicensed National Information Infrastructure devices in the presence of a 5 GHz weather radar*
- *Continued 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

Aircraft Radar Emission Measurements

In FY 2012, ITS engineers, in conjunction with engineers from Boeing and Raytheon, performed a two-week-long set of emission measurements on a newly-developed radar system that will be integrated into existing Air Force aircraft platforms to expand capabilities and extend service life while reducing maintenance costs. The measurements were performed in an anechoic chamber (operated by the Department of Defense) with the aircraft inside (Figure 1). Equipment from the RSMS program was used to successfully collect all the necessary data. The data gathered from the effort was later processed and used to verify the radar emissions met the requirements of Military Standard 461E (MIL-STD-461E) and the United States Radar Spectrum Engineering Criteria (RSEC). MIL-STD-461E and the RSEC promote efficient spectrum use and help minimize the possibility of harmful interference between the many critical systems used simultaneously in a combat environment.

Navy Radar Emission Measurements

International Telecommunication 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' RSEC. At the request of the Navy, the RSMS Operation program in FY 2012 performed emission measurements of a Navy radar system. Subsequently, the measured data was used to develop a report that was submitted to the Navy to confirm the radar meets the requirements of Recommendation SM.1541 Annex 8. Compliance with SM.1541 Annex 8 is especially critical to the Department of Defense, as many of its radar operations occur inside, or close to, other countries' territories.

Terminal Doppler Weather Radar Interference

In early 2009, the Federal Aviation Administration (FAA) became aware of interference to their 5 GHz Terminal Doppler Weather Radar (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 2012, 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 several meetings with the FAA, FCC, OSM, and private industry representatives. ITS engineers worked with private industry representatives to field test newly-developed U-NII devices and made time-domain recordings of TDWR emissions (Figure 2) that may eventually be used by the private sector to test their systems prior to submitting them for official FCC certification.

Finally, ITS publicly released the final in a three part series of NTIA technical reports detailing the 2009–2010 NTIA study of electromagnetic compatibility between TDWR systems and 5 GHz U-NII devices.

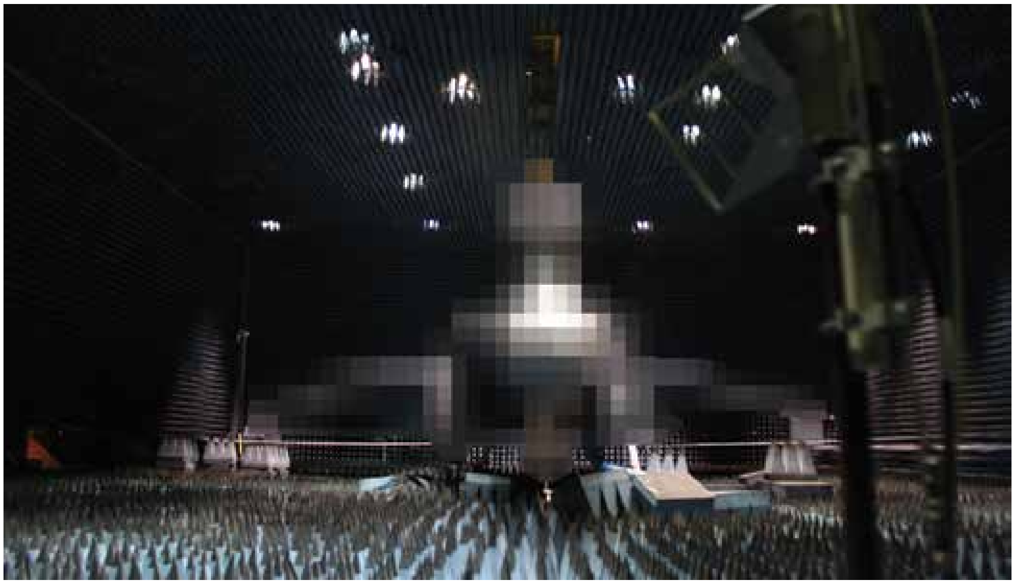

Figure 1 (top). Air Force aircraft (masked in photo) in DOD anechoic chamber during emission measurements. Figure 2. ITS engineer John Carroll and OSM engineer Robert Sole make time-domain recordings of TDWR emissions. Photos by Frank Sanders.

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.

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 III," NTIA Report TR-12-486, Jun. 2012.

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The Spectrum Sharing Innovation Test Bed Pilot Program provides an opportunity for Federal agencies to work cooperatively with researchers from industry and academia to investigate new technologies that might improve management of the nation's airwaves. Dynamic spectrum access may permit new radios to share spectrum with land mobile radio systems in the same band. But is this technology mature enough to ensure availability and preclude interference to mission critical public safety systems?

Spectrum Sharing Innovation Test Bed Pilot Program

Outputs

- *Completed and released the Phase II/III field test plan.*

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 permits a transceiver to appraise its radio frequency environment using spectrum sensing and to opportunistically exploit vacant spectrum in time and frequency on a non-interference basis.

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 key performance indicators for DSA devices that might permit a rulemaking and allow spectrum sharing without harmful interference to incumbent LMR systems.

The program is divided into two categories of testing. Phase I involves bench-top laboratory measurements of DSA radio characteristics such as transmitter emissions, sensor performance, and policy-based radio etiquettes. This is performed under controlled conditions at ITS's lab in Boulder. NTIA's Office of Spectrum Management uses the lab measurement results to develop models that predict the interference potential of the devices. Key performance indicators measured in the lab suggest conditions in which DSA devices might operate without causing harmful interference to incumbent systems. Follow-on field testing performed in Phases II and III test the assumptions developed in Phase I through system-level field tests of DSA radios in live LMR environments.

Phase I Testing

By the beginning of FY 2012, test bed engineers had completed Phase I laboratory testing on two DSA devices, drafted a field test plan, and concluded an abridged set of tests on two other DSA devices. Testing on the latter two devices was cut short due to irregularities in the devices' detect-and-avoid algorithms and incompatible test mode interfaces. (The test mode is required to facilitate automated detection performance measurements needed for statistical analysis.) These devices were returned to the participants for further examination and modification. Unfortunately, due to resource constraints, neither participant was able to implement the necessary modifications, so testing was either halted or postponed for these systems.

Phase II and III Testing Begins

In FY 2012 the field test plan for Phases II and III was circulated for Federal agency and test bed participant review and comment. Comments were reviewed and addressed and the final Phase II/III Test Plan was published in July 2012. Phase II testing then began on the first DSA device. Phase II of the test plan examines DSA devices' spectrum sensing capabilities in a live LMR environment while restricting their transmissions.

The subsequent Phase III suite of tests permits the DSAs to transmit freely within a controlled LMR system. Phase III introduces the DSA devices to a variety of controlled LMR operating scenarios and examines their behavior while monitoring LMR receivers for harmful interference. A number of preparations for Phase III testing were accomplished this year. A number of exploratory drive tests were conducted and a suitable outdoor test range was chosen. We procured and installed base station antennas at two ITS managed communications sites (Figure 1) and installed a pneumatic mast on a drive test vehicle (Figure 2). Finally, we developed and configured a base station simulator using a vector signal generator, and selected a suitable trunked LMR system.

Figure 1 (above). Omnidirectional base station antenna (top of left tower) at the ITS Green Mountain communications facility.

Figure 2 (right). Test van with pneumatic mast deployed for Phase II field measurement of DSA sensor performance.

Photos by Eric Nelson.

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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 telecommunications research designed to enhance scientific knowledge, other research is performed at Table Mountain by other Department of Commerce laboratories collocated on the Boulder Labs campus and by other Federal and non-Federal entities. Cooperative research and development agreements (CRADA) with private industry allow companies to benefit from the unique resources available at ITS to test and optimize new and improved products prior to bringing them to market. Interagency agreements allow agencies other than Commerce to also make use of this Federal resource.

Antenna Research

When performing a comprehensive survey of the radio signals present at some location, it is necessary to include signals arriving from any direction with any possible polarization. Most antennas commonly used for spectrum surveys are typically limited in their response to specific polarizations and signals coming from a certain direction. ITS researchers have been studying a hybrid antenna array or 3-axis antenna (see figure) that has the potential to detect signals arriving from any direction, at any time, and with any polarization. This will enable surveys that provide a better understanding of the multidimensional aspect of the radio environment, rather than just taking a narrow sampling of signals with specific characteristics.

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. 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

Prototype 3-axis antenna design under development at ITS. Photo by Wayde Allen.

Mountain. Work in this area serves to improve the capability of these systems, especially for operation in high clutter and dusty environments.

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.

ITS has developed simulated broadcasts and a series of repeatable measurement methods to test the performance of NWR receivers. NOAA allows receivers that meet the required Consumer Electronics Association (CEA) performance specifications to bear the NWR logo, which certifies to the public that a model is 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 can enter into CRADAs with ITS in order to have equipment tested, problems uncovered, and improvements made to weather radio receiver models before the choice is made to apply to NOAA to use the NWR logo. Receivers that meet the standards during the ITS and subsequent NWS evaluations will be recommended for use of the logo. ITS serves as NWS's independent CEA-2009-B surveillance test lab for NWR receivers.

The compiled results of numerous tests made by ITS also help NOAA determine the possible cause of receiver malfunctions reported by the public when receivers do not respond during a weather event or other broadcast emergency.

FY 2012 CRADA Partners

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

CRADA Partner Publications

- Jason Roadman, Jack Elston, Brian Argrow, and Eric W. Frew. "Mission Performance of the Tempest UAS in Supercell Storms." *AIAA Journal of Aircraft*, (accepted Mar. 2012).
- Cory Dixon and Eric W. Frew, "Optimizing Cascaded Chains of Unmanned Aircraft acting as Communication Relays." *IEEE Journal on Selected Areas in Communications*, 30(5): 883-898, June 2012.
- Eric W. Frew, Jack Elston, Brian Argrow, Adam Houston, and Erik Rasmussen. "Unmanned Aircraft Systems for Sampling Severe Local Storms and Related Phenomena." *Robotics and Automation Magazine*, 19(1):85-95, March 2012.
- Neeti Wagle and Eric W. Frew. "Transfer Learning for Dynamic RF Environments." In *Proceedings 2012 American Control Conference*, Montreal, Canada, Jun. 2012.
- Anthony Carfang and Eric W. Frew. "Real-Time Estimation of Wireless Ground-to-Air Communication Parameters." In *Proceedings IEEE International Conference on Computing, Networking and Communications (ICNC 2012), Wireless Ad Hoc and Sensor Networks Symposium*, Maui, Hawaii, January/February 2012.
- Neeti Wagle and Eric W. Frew. "Spatio-temporal Characterization of Airborne Radio Frequency Environments." *Wireless Networking for Unmanned Autonomous Vehicles (IEEE GlobeCom11 Workshop - Wi-UAV)*, Houston, TX, December 2011.

CRADA Publications Indirectly Supported by Table Mountain Activities

- T. X. Brown, N. M. Balasubramanya, "Dynamic Outage, Availability, and Interference Models for Mobile Cognitive Radios." In *Proceedings of the 2011 IEEE Global Communications Conference (GlobeCom)*, Houston, TX, December 6–8, 2011.
- A. L. Houston, B. Argrow, J. Elston, J. Lahowetz, E. W. Frew and P. C. Kennedy. "The Collaborative Colorado-Nebraska Unmanned Aircraft System Experiment." *Bulletin of the American Meteorological Society*, 93(1):39-54, January 2012.

Related Publications

J.W. Allen, "A prototype antenna for total RF field measurement," NTIA Report TR-12-483, Oct. 2011

N. DeMinco et al., "Free-field measurements of the electrical properties of soil using the surface wave propagation between two monopole antennas," NTIA Technical Report TR-12-484, Jan. 2012

J.W. Allen, "A 3-axis antenna array for polarimetric spectrum surveys," in *Proceedings of the 2012 IEEE EMC International Symposium on Electromagnetic Compatibility*, Aug. 2012

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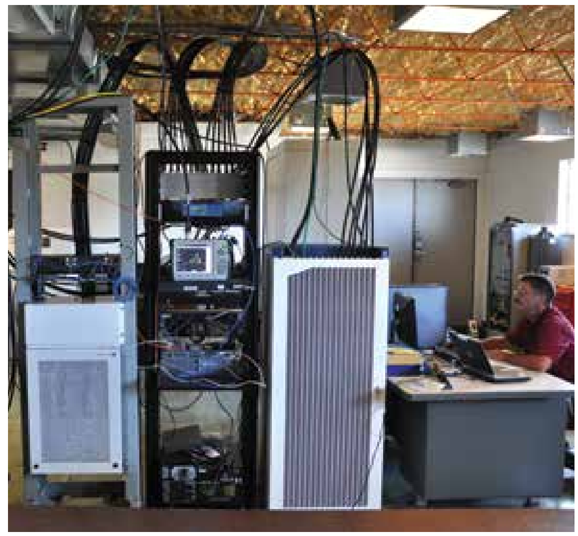
In a joint research effort between ITS and NIST/OLES, the PSCR program has built a 700 MHz Public Safety Broadband Demonstration Network over which public safety communications systems can be tested in a multi-vendor, neutral, host environment. The network comprises three stationary eNodeB base stations, and one mobile eNodeB station housed on a trailer. 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.

Right top: ITS engineer, DJ Atkinson (podium), well known for his public safety audio quality research, moderates a Digital Radio for Firefighters session at the 2012 International Wireless Communications Exposition (IWCE). We were deeply saddened by the loss of our talented team member and friend when DJ died April 24, 2012. Also shown are firefighters Ken Link (left) and Paul Roberts (right) who both supported DJ's research over the years. Photo by Jeff Bratcher.



Right bottom: ITS IT Specialist Ted Mullen monitors Long-Term Evolution (LTE) eNodeB data throughput at the Table Mountain Field Site and Radio Quiet Zone, one of three stationary eNodeB sites in the PSCR demonstration network that supports broadband communications research for the Nationwide Public Safety Broadband Network (NPSBN). The others are at the Green Mountain Mesa Field Site and the ITS Public Safety Radio Lab. Photo by John Ewan.

Left top: Over 350 meeting participants filled two ballrooms for the PSCR-hosted Spring 2012 Public Safety Broadband Demonstration Network Stakeholder Meeting in Broomfield, Colorado. Keynote speaker Anna Gomez, NTIA's Deputy Assistant Secretary for Communications and Information, spoke to the importance of state and local representatives on the 15 member First Responder Network Authority (FirstNet) board to ensure its process includes a local voice.

Left bottom: Stakeholder Meeting participants view the PSCR demonstration network's mobile eNodeB cell. The mobile cell allows ITS researchers to study network interference and throughput in different locations. Photos 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 Law Enforcement Standards Office (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. The program has been shifting focus to broadband technologies in support of an upcoming nationwide public safety broadband network.

Below is a summary of the significant project areas that researchers in the Telecommunications and IT Planning Division worked on during FY 2012. Details pertaining to each project are described in separate sections on the following pages.

Public Safety Communications Research Program

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 (DHS) Office for Interoperability and Compatibility (OIC) and the DHS Office for Emergency Communications (OEC).

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 Requirements and Standards
- Public Safety Broadband Demonstration Network
- Public Safety Broadband Research

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.

International Standards

Standards development organizations (SDO) exist 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 supports the full and fair competitiveness of the U.S. telecommunications technology sector. ITS plays a vital role in representing the interests of U.S. industry and the U.S. Administration to the ITU-T and other SDOs. In this project ITS provides leadership and technical input to the ITU Standardization Sector (ITU-T), the Video Quality Experts Group (VQEG), and the Alliance for Telecommunications Industry Solutions (ATIS).

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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 2012, 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 is an important research contribution as it 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.

Impact of Mobile Devices and Usage Location on Perceived Multimedia Quality

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. The existence of these devices makes the task of ensuring high-quality content delivery much more complicated.

Additionally, in some developing countries, Internet-connected mobile devices are the primary way people can view multimedia. The use of these devices makes the task of ensuring high-quality content delivery 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, two laptops, and a broadcast-quality television and speakers. This experiment was conducted in two different environments. One was a traditional lab environment and the other was a simulated living room. The quality ratings obtained in the lab and in the living room were statistically identical (Figure 1).

Analysis, a publication, and several presentations reporting on the results of this experiment took place this year. For example, an ITS engineer presented the paper "Impact of Mobile Devices and Usage Location on Perceived Multimedia Quality" at the International Workshop on Quality of Multimedia Experience (QoMEX) in July.

Extending the research results of the previous tests, ITS began research on 3DTV in FY 2012. Initially, the project established a laboratory capability and obtained a selection of high-quality 3DTV video sequences which were used in preliminary testing. Further research in 3DTV will be carried out in future years under the video quality research project.

In another extension of previous efforts, research on multimedia quality and its relationship to effective lip-reading and sign-language communication began in FY 2012. ITS staff conducted a literature search and video-taped subjects conversing to use in task-based tests designed to determine the quality needed for effective communication using lip reading and/or sign-language. See Figure 2 for example frames of these test sequences. Follow-on research efforts in this area will be carried out in future years under the video quality research project.

This project concluded at the end of FY 2012 and further work in audiovisual quality research will be addressed in the video and audio projects.

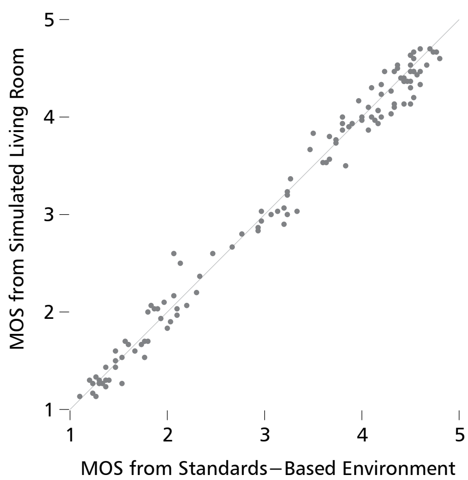

Figure 1. Mean opinion scores (MOS) for each sequence used in subjective tests performed in two different environments on six devices are shown in a scatter plot, with the MOS from the standards-based environment on the x-axis and the MOS from the simulated living room on the y-axis. The data has a correlation of 0.992, indicating that a less-controlled environment did not have a significant effect on MOS.

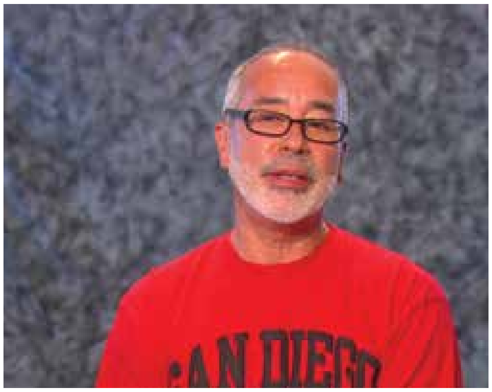

Figure 2. A series of stills from videos of subjects conversing that were filmed for use in task-based subjective multimedia quality testing.

Related Publications:

A. Catellier, M. Pinson, W. Ingram, A. Webster, "Impact of mobile devices and usage location on perceived multimedia quality," *2012 Fourth International Workshop on Quality of Multimedia Experience (QoMEX)*, pp. 39–44, 5–7 July 2012

Margaret H. Pinson, William Ingram, Arthur Webster, "Audiovisual quality components: An analysis," *IEEE Signal Processing Magazine*, vol. 28, no. 6, pp. 60–67, November 2011

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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.

ITS is assisting NIST/OLES and DHS OIC in the process of transitioning the assessment and recognition of participating P25 CAP test laboratories to commercially available ISO/IEC 17011 based accreditation bodies. 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 is working independently of TIA to develop conformance tests appropriate for compliance assessment for inclusion in the P25 CAP. ITS also 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.

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

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The overall goal of Project 25 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. ITS involvement in P25 standards development directly supports NTIA's objectives to advance public safety communications and support first responder needs.

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

Project 25 (P25) was established in 1989 by governmental entities and the Association of Public-Safety Communications Officials – International (APCO) to realize the benefits of digital narrowband land mobile radio (LMR) technologies for public safety practitioners and other users. Manufacturers, public safety, government, and other 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; and users specify, procure, and operate P25 radios and communications infrastructure.

The deployment of P25 equipment and systems continues to grow among the more than 60,000 public safety organizations in the U.S. and others in over 54 countries. Congress recognized P25 standardization as the preferred solution for narrowband LMR public safety users, and several key P25-defined open interfaces as critical for near-term completion. The P25 Inter-RF Subsystem Interface (ISSI) and the P25 Common Air Interface (CAI) were singled out as the most important 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 NIST/OLES sponsorship, in FY 2012 support continued for accelerated development of P25 standards and Telecommunications Systems Bulletins (TSB) to meet increasing needs for functionally enhanced, compliant equipment and systems, and to satisfy Congressional mandates. ITS's P25 standards development support efforts are an integral part of the Public Safety Communications Research (PSCR) program, a joint effort of ITS and NIST/OLES. ITS also supports related areas of emphasis, such as public safety audio quality research and the P25 Compliance Assessment Program. In FY 2012, ITS provided technical and organizational representation for NIST/OLES and directly assisted the approval of new and revised P25 requirements and standards in several critical areas, including the ISSI and CAI. For example, TIA published three key P25 documents that incorporate many technical and editorial contributions submitted by ITS in FY 2012 and prior fiscal years:

- TSB-102-B, Project 25 TIA-102 Documentation Suite Overview, which provides a critically needed overview of the LMR systems, services, and interfaces currently supported by the TIA-102 series of documents.
- TSB-102.BACC-B, Project 25 ISSI Overview, an umbrella document to the ISSI TIA-102 documentation suite, which reflects the significant progress made since 2003 by providing a high-level overview of the ISSI features, published documents, and drafts in progress.
- TIA-102.BAEC-B, Project 25 Data Overview and Specification, which provides a comprehensive overview of TIA-102 data services and specification of TIA-102 packet data services, and establishes the technical basis to facilitate development of relevant test documents.

TIA-102 Interface	Representative Snapshot of TIA-102 Series of Documents (110): Standards and *TSBs* in effect Standards and *TSBs* in development			
	Overview & Other	Service	System	Test
FDMA CAI	*102-B*, *AABA-B*	AABB-B, AABC-C, AABC-C-1, AABC-C-2, AABD-A, AABD-A-1, AABD-A-2, AABD-A-3, AABF-C, AABF-C-1, AABF-C-2, AABG	BAAA-A, BAAC-C, BAAD-A	BAAB-B, CAAA-C, CAAA-C-1, CAAA-D, CAAB-C, CAAC, *CABA*, CABC-B, CABC-B-1, CAEA, CAEB, CAEC, CBAA, *CBAB*, *CBAC*, *CBAF*, *CBBA*, *CBBE*, *CBBF*, *CBBJ-B*
TDMA CAI	*102-B*, *BBAA*	-	BBAB, BBAC, BBAC-1	BCAD, BCAE, CAEF, CCAA, *CCAB*, *CBAA*, *CBAB*
ISSI	*102-B*, *BACC-B*	-	BACA-A, BACA-A-1, BACA-A-2, BACA-A-3, BACA-B, BACD-B, BACE, BACF	BAxx, Cxxx, CACA, CACA-1, CACB, CACB-1, CACC, CACC-1, CACD-A, CACD-B, CACx, *CBAA*, *CBAB*, *CBBK-A*
Other	*102-B*, *AABA-B*, BADA, BADA-1, BADA-A, BAEA-B, *BAGA*, BAHA, BAHA-A, *BAJA-A*, BAKA, *BAFA-A*	AAAD-A, AACA, AACA-1, AACA-2, AACA-A, AACB, AACB-x, AACD, AACD-1, AACD-A, AACE-A	BABA, BABA-1, BABD, BADA, BADA-1, BADA-A, BAEA-B, BAEB-A, BAEB-B, BAEE-B, *BAFA-A*, BAHA, BAHA-A, BAJB, BAJC, BAJD, BAKA	AAAC, AAAC-A, AACC-A, BABB, BABC, *BABE*, *BABF*, BABG, Cxxx, CABB, CADA, *CBAA*, *CBAB*, *CBBC*, *CBBH*

TIA-102 series of documents in relation to principal TIA-102 interfaces and document type. (Representative snapshot based on TSB-102-B and the PSCR P25 DSR "P25 Document Quick Status" chart available at http://www.pscr.gov/outreach/p25dsr/menu_top/p25_documents_quick_status.php.)

Status of P25 Open Interfaces

TSB-102-B describes 13 TIA-102 interfaces: Conventional FDMA CAI, Trunked FDMA CAI, Trunked Two-Slot TDMA CAI, ISSI, Console Subsystem Interface, Fixed Station Subsystem Interface, Data Host Interface, Network Management Interface, Telephone Interconnect Interface, Subscriber-Mobile Data Peripheral Interface, Key Fill Device-Mobile Radio Interface, Key Management Facility-Key Fill Device Interface, and Inter-Key Management Interface. As part of the PSCR program, ITS maintains the P25 Document & Standards Reference (P25 DSR, available at http://www.pscr.gov/outreach/p25dsr/p25dsr.php), which tracks the current state of TIA documents that have been, or are expected to be, adopted as part of the P25 Standard. The table shows a snapshot summary of the over 100 documents covering these interfaces.

TSB-102-B identifies as future work items only eight of the 68 combinations of high-level TIA-102 services (within the categories of Teleservices, Bearer, Data, Supplementary, Mobility and Registration, Security, Network Management, and Local to the Subscriber) requiring support by the CAI or ISSI. Realization of the P25 open interfaces and the defining P25 standards documents was significantly accelerated by ITS efforts over the past decade. In their current state, the P25 interfaces and standards largely fulfill the project's original interoperability goals; the generic LMR standards now being developed by TIA may be adopted by the P25 Steering Committee for use by Project 25.

Leadership and Participation

Formal participation by ITS in the P25 process continued into FY 2012, with the submission of numerous technical and editorial contributions and letter ballot comments enabling standards to be approved consistent with ITS and sponsor objectives. An ITS staff member was publicly recognized by the P25 Steering Committee for his efforts from 2005 to 2011 as Editor of the Project 25 Statement of Requirements (P25 SoR). ITS played a key role in assisting the Steering Committee's development of an important document describing the current P25 process, and also submitted at the Steering Committee's request a proposal for development of a P25 System and Standard Definition document to clarify the purpose, scope, and content of the P25 Standard as it evolves in relation to the TIA-102 documentation suite and to provide traceability to the P25 SoR.

After the February 2012 passage of legislation promoting rapid deployment of FirstNet's Nationwide Public Safety Broadband Network, ITS was tasked to expand its work on broadband requirements and standards development for public safety. In light of the current status of Project 25, ITS suspended its formal and technical participation in TIA TR-8 and Project 25 in mid-FY 2012 to redirect resources accordingly.

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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 lives depend on their ability to communicate with their coworkers and 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 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, the operational environment, and common practices of public safety personnel. Typically, these field studies produce two different types of recordings. First, examples of communications encountered during typical field operations are recorded so as to help increase the understanding and comprehension of public safety operational requirements. Second, high-quality digital recordings of specific environmental noises are collected so that they can be shared with the community and used in audio quality research 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) (see figure). 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 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]

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.

Broadband's Impact on Audio Quality

Two audio quality research studies were completed in 2012, both of which investigated the possible impact of broadband audio codecs on public safety communications. A broadband public safety network that uses 3GPP Long-Term Evolution (LTE) radio technology may likely utilize the Adaptive Multi-Rate (AMR) speech coder found in some versions of voice over LTE (VoLTE) for its mission-critical communications.

The first study, *Objective Speech Quality Estimates For P25/VoLTE Interconnection*, looked at the Interactions between the type of codec found in Project 25 (P25) digital radios (Multi-Band Excitation (MBE)) and the codec used in LTE and third generation mobile telephones (AMR). The results of the study suggest that a conversation between users of a P25 radio and an LTE device would sound worse than if both users had used the same type of device. Automated evaluation of Mean Opinion Scores (MOS) via the Perceptual Evaluation of Speech Quality (PESQ) algorithm for AMR-MBE interactions resulted in scores lower than three, or worse than "fair."

The second study, *Intelligibility of the Adaptive Multi-Rate Speech Coder in Emergency-Response Environments*, expanded the results of a previous landmark comparison of analog and digital radios operating under fireground noise conditions. The most recent study used live test subjects to compare the intelligibility of phrases communicated via three types of devices under the types of background fire-specific noise conditions discussed above—analog, P25, and two different AMR bit rates (12.2 and 7.5 kb/s). The results of the study showed that, in general, 12.2 kb/s AMR performed better than analog in high-noise conditions and slightly worse than analog in low-noise conditions, while P25 was most often less intelligible than its other three counterparts.

Future Work

In FY 2013 the project will continue to investigate the impact that emerging broadband wireless network technologies will have on public safety voice communication and publish full technical reports on the two studies completed in FY 2012.

An ITU-Standard Head and Torso Simulator (HATS) is set up in a sound-isolated booth in the Public Safety Audio Laboratory. Loudspeakers behind the HATS are used to reproduce a desired background noise field. Researchers use this set up in a controlled acoustic environment to prepare speech samples for subjective testing. In this way, audio samples used for a subjective audio quality test are identical except for the variables under test. Photo by Andrew Catellier.

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The Middle Class Tax Relief and Job Creation Act of 2012 included provisions to fund and govern a single Nationwide Public Safety Broadband Network. Public safety land mobile radio (LMR) networks have traditionally been built by individual localities or on a statewide basis. Deploying new cellular technologies nationwide will be far 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.

Public Safety Broadband Demonstration Network

Outputs

- *Technical contributions to the public safety community specific to Long-Term Evolution (LTE) technology*
- *Technical contributions and support to the First Responder Network Authority (FirstNet)*
- *Cooperative Research and Development Agreements with public safety broadband vendors*

Overview

Stove-piped proprietary systems and non-contiguous spectrum assignments have long impeded effective cross agency/jurisdiction public safety land mobile radio (LMR) communications. To 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 Law Enforcement Standards Office (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 testing for emerging Long-Term Evolution (LTE) broadband equipment specific to public safety.

Title VI—Public Safety Communications and Electromagnetic Spectrum Auctions of the Middle Class Tax Relief and Job Creation Act of 2012, enacted as Public Law 112-96 on February 22, 2012, created the First Responder Network Authority (FirstNet). FirstNet is tasked with establishing a nationwide public safety broadband network (NPSBN). This legislation also re-allocated the D Block spectrum to public safety and created funding mechanisms for the network via spectrum auctions. The PSCR Broadband Demonstration Network will be leveraged for the research, development, and testing aspects in support of FirstNet's vision for the NPSBN.

As part of its role in assisting FirstNet activities to build out the NPSBN, the PSCR Broadband Demonstration Network will also support technical contributions to the 3rd Generation Partnership Project (3GPP)—a collaboration among six telecommunications standards bodies to produce globally-applicable cellular system specifications.

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 (LTE Bandclass 14), leverages the expertise of the PSCR staff and the unique assets of the Boulder Laboratories—specifically, the Table Mountain Radio Quiet Zone and the Green Mountain Mesa Test 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 PSCR Broadband Demonstration Network's goals are to:

- Assess the defined open interfaces associated with LTE that will ensure interoperability for the public safety broadband system.
- Demonstrate broadband air-interface and core network capabilities to provide proof of concepts, improve quality of future systems, and create new technology and requirement benchmarks.
- Evaluate broadcast capabilities for wide-area simultaneous data delivery.
- Assess interoperability concepts with existing LMR, cellular, and broadband technology, leveraging several past PSCR projects.
- Explore roaming functionality with LTE and non-LTE systems, including how quality of service, billing, priority, 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 2013, the Public Safety Broadband Demonstration Network project will continue to conduct studies of LTE technology to drive the development of the NPSBN in support of the FirstNet vision.

The PSCR drive-test van and the Cell on Wheels (COW) ready for testing. Photo by Ken Tilley.

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❝There is little doubt that the potential benefits of a nationwide 700 MHz broadband network are enormous—the ability to transmit medical data, to run complex criminal database queries and to download blueprints of a burning building are just a few of the examples noted by public-safety officials.❞

D. Jackson, "Commentary: 700 MHz demonstration network a step in the right direction," Urgent Communications, January 5, 2010

Public Safety Broadband Requirements and Standards

Outputs

- *Development of public safety broadband requirements documents*
- *Representation of the First Responder Network Authority in standards development*
- *Public safety ranked as top priority for 3GPP in Release 12*
- *Normative standards-track work for Proximity Services and Efficient Group Communications*

Overview

In 2010 the FCC published the National Broadband Plan, which outlines how broadband spectrum will be utilized in the future. The Plan also detailed the development and implementation of a nationwide interoperable public safety broadband communications network. In order to assure that the nationwide network would be interoperable across agencies, jurisdictions, and regardless of manufacturer, PSCR actively participated in the requirements gathering and standards development process on behalf of public safety. Following enactment of the Middle Class Tax Relief Act of 2012 and the creation of the First Responder Network Authority (FirstNet), the PSCR standards team now directly represents FirstNet, and thus all public safety in the United States, in all broadband standards development. Coordinated implementation of a public safety broadband network under a single network operator—FirstNet—presents a unique opportunity for public safety to define their requirements before deployment and to potentially preemptively eliminate the interoperability problems that have plagued public safety in land mobile radio.

Background

PSCR has been active in the requirements gathering and standards development process for public safety broadband communications since its inception in 2003. PSCR actively participated in the TIA standards process for land mobile radio and has long-standing relationships with many public safety organizations that focus on defining requirements for public safety communications. PSCR is uniquely positioned to represent public safety as new broadband technologies are tested in PSCR's Demonstration Network and as the nationwide network is built out.

Approach

PSCR has been active in the following requirements gathering efforts for public safety broadband since the spring of 2003:

- PSCR led the creation of the SAFECOM Statement of Requirements in 2004, which was a spectrum and technology agnostic perspective of advanced public safety communications
- PSCR led the National Public Safety Telecommunications Council's (NPSTC) Broadband Working Group to develop a 700 MHz Broadband Statement of Requirements in 2007
- PSCR led the NPSTC Broadband Task Force Technology Working Group, which addressed interoperability issues and delivered its report and recommendations in August 2009
- PSCR led the NPSTC Broadband Working Group in the creation of the qualitative Mission Critical Voice Requirements document in 2011
- PSCR led the NPSTC Broadband Working Group in the creation of the Local Control and Priority & Quality of Service Requirements documents in 2012
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Public Safety Launch Requirements to the FirstNet Board in 2012

In its standards development efforts, PSCR also represents FirstNet as a member of ATIS, 3GPP, and GSMA—the organizations that are collectively responsible for developing the standards for the LTE technology selected by public safety for 700 MHz broadband. As a result of PSCR's involvement, public safety was identified as the top priority in 3GPP for Release 12. PSCR currently represents FirstNet in ensuring Release 12 LTE products contain two critical features for public safety: efficient group communications capabilities and direct mode capability.

As part of its requirements and standards work, PSCR is coordinating with public safety organizations in the United Kingdom, continental Europe, Canada, and Australia as they begin to develop public safety broadband efforts for their first responders.

Value to Public Safety

Broadband technology presents a significant opportunity for public safety agencies to use a nationwide interoperable communications network that meets the unique needs of first responders and is deployed by a single network operator (FirstNet). There are as many as five million public safety users in the country. The newly available 700 MHz spectrum will let public safety adopt broadband technologies that support high-speed data transmission across long distances creating access to video, mapping, GPS applications, and more. It is crucial that public safety's requirements be incorporated into the standard so that Federal grant dollars and taxpayer dollars are spent only on equipment that is interoperable and allows first responders to better carry out their mission of protecting lives and property.

Principal Relevant Requirements and Standards Documents

- SAFECOM Statement of Requirements (SoR) for Public Safety Communications Interoperability (2006–2008)
- NPSTC Public Safety 700 MHz Broadband Statement of Requirements (SoR) (2007)
- NPSTC Broadband Task Force Requirements
- NPSTC Mission Critical Voice Communications Requirements for Public Safety Functional Description (2011)
- NPSTC LC21 "Local Control in the Nationwide Public Safety Broadband Network," Rev. F, March 19, 2012
- NPSTC "Priority and QoS in the Nationwide Public Safety Broadband Network," Rev 1.0, April 17, 2012
- NPSTC Public Safety Broadband High-Level Launch Requirements, Statement of Requirements for FirstNet Consideration (December 7, 2012)
- 3GPP TR22.803 Feasibility study for Proximity Services (ProSe) (Release 12) v12.0.0 (December 2012)
- 3GPP TS22.468 Group Communications System Enablers for LTE (Release 12) v0.2.0 (November 2011)

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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.

Public Safety Broadband Research

Outputs

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

Overview

With the assignment of new spectral resources and congressional funding for a mandated public safety nationwide broadband network, the public safety community is ready to fully embrace broadband technologies as a vital tool for their mission requirements. Unlike civilian networks, however, public safety networks must often offer coverage in areas where no billable customers normally reside (for example, forests or desolate mountainous areas).

Of course, public safety coverage must also extend to densely populated urban areas, and both coverage situations must offer the flexibility and scalability to accommodate small numbers of users in regular situations as well as capacity-straining usage scenarios during critical emergencies. In these situations, additional personnel may be brought in from other jurisdictions to meet mission requirements, greatly increasing the number of users on the network during the emergency period.

The public safety broadband network must also operate under more severe reliability constraints than those faced by civilian networks and it must keep operating over long periods of time during widespread disasters like floods and hurricanes. These and other factors drive the need for public safety broadband research.

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 signal-to-noise ratio (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 United States 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 have not been extensively studied and 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. However, all current LTE networks provide a test signal embedded in their LTE transmissions that is being used for the current measurement.

The reception of the MIMO signal proceeds in two phases. During the channel characterization phase, which occupies a small fraction of the total signal transmission time, a known reference signal is sent from each of the two cross polarized transmission antennas in turn—i.e., only one of the two transmitting antennas is on at any given instant with the two antennas alternating their transmissions. Both "legs" of the dual polarized receiving antenna, shown in Figure 1, receive the test signal from whichever transmitting antenna is active and the receiver can use the known properties of the signal to measure the characteristics of the radio channel between the active transmitting antenna and the two cross-polarized receiving antennas. A short time later, the other transmitting antenna sends out its reference signal, and the process is repeated to determine the characteristics for its radio channel. In LTE, this entire cycle occurs over a time period of about 428 microseconds, or just over 2000 times per second, with each reference signal sent for just over 70 microseconds.

In the second phase of the process, both transmitting antennas are energized at the same time to send two different signals in the same frequency band. The receiver uses the channel information acquired in the first phase to separate the two received signals using one of several possible algorithms.

In order to study this signal, a special dual receiver system capable of synchronized sampling is required, as shown in Figure 2. Using these two components, we have investigated the fine structure properties from civilian networks as well as public safety systems. Differences in the quiescent behavior between infrastructure devices from different manufacturers is evident, as is the need for robust signal processing algorithms to achieve synchronization under poor signal propagation conditions. Although the complexity of the LTE signal makes these investigations difficult, it also offers the promise of helping to identify radio channel behaviors in situ and in greater detail than has previously been possible. Furthermore, these "digital fingerprinting" concepts may prove of interest in the future to help determine the security and health of public safety wireless systems.

SDR Test Instrument Technologies

The effort described in the previous paragraphs requires the use of laboratory grade test instruments, but another aspect of the Public Safety Broadband Research project concerns 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. This requirement is expensive to achieve in current test instruments, but 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, we believe 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 the efforts mentioned above are by no means restricted to use in the public safety spectrum, but could easily be expanded to include civilian LTE as well. 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 here 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 1 (top). A dual polarized antenna used to receive broadband LTE signals in the 700 MHz spectral range. Figure 2 (bottom). A synchronized dual sampling receiver scanning system that allows examination of the cross-correlation properties of two radiated MIMO signals. Photos by R. Stafford.

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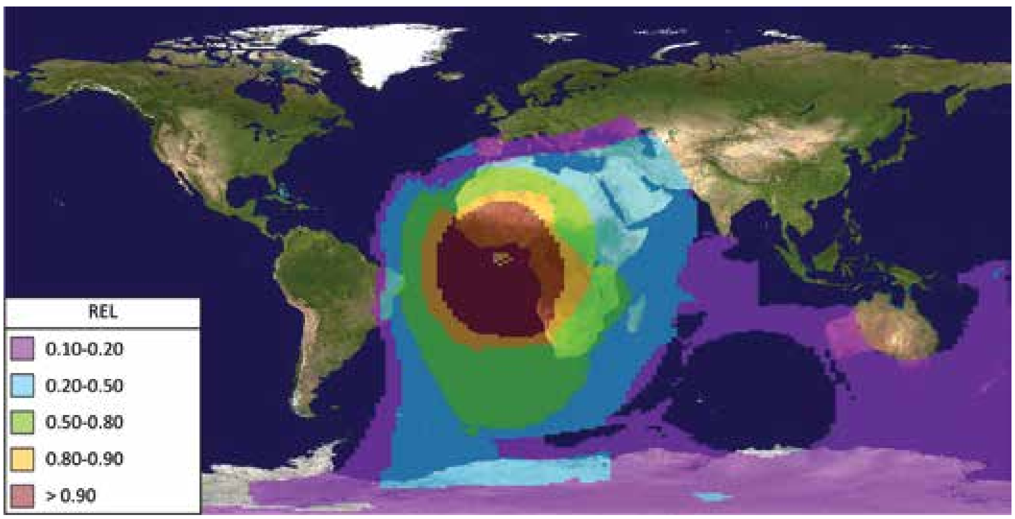
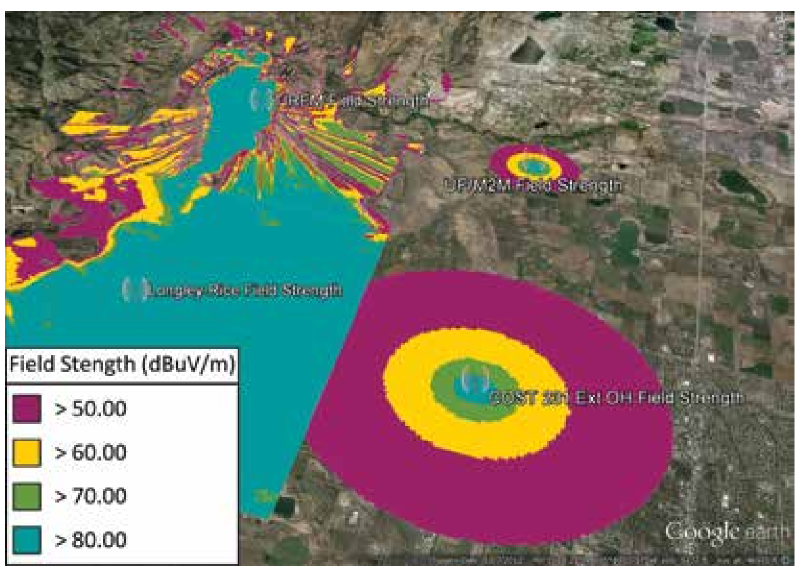
A radio propagation model is an empirical mathematical computer program that predicts radio wave propagation—and hence wireless communications coverage—as a function of frequency, distance, and other conditions. There are different models for different types of radio links under different terrain and environmental conditions. These models are used to help plan equipment deployment. ITS has developed models for many different scenarios based on large collections of measurement data acquired over half a century of continuous research.

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, spectrum sharing, jamming, and interfering signals on system effectiveness in Government and commercial operational environments. Analysis is often performed in association with the Propagation Modeling Website (PMW) Program, which offers custom tools and propagation prediction models incorporated into GIS formats and web-based access. Modeling is one of ITS's core engineering strengths, enabling technical 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. ITS engineers use field measurements and laboratory simulations to verify and validate the models. Custom tools and unique propagation models are developed for specific applications to meet sponsor requirements.





Output from PMW VHF 3.0 and PMW HF 1.1. Top: Worldwide REL (time availability, % time SNR exceeds required SNR) output from the ICEPAC PMW HF model, displayed in Esri's ArcMap™. Bottom: .kmz Field Strength output from all four PMW VHF propagation models (TIREM, Longley-Rice, Undisturbed Field/Mobile-to-Mobile, and COST 231 Extended Okumura-Hata), displayed in Google Earth™.

Engineering

Interference Analysis, Simulation, and Testing in Proposed Shared Spectrum Band 1675–1695 MHz: In support of the President's spectrum policy initiatives, ITS engineers are researching the potential interference between a Federal video surveillance system (VSS) and the existing Government incumbents in the proposed shared bands. Engineers were able to use laboratory simulation, a cost savings over field measurements. This work was funded by DHS.

Public Safety Video Quality (PSVQ): With the participation of expert viewers, the PSVQ project conducts subjective tests on video compression and artifacts. The results help public safety agencies specify video equipment for their specific applications. Using these data, ITS has participated in technology transfer via technical recommendations for needs-based video standards like Rec. ITU-T P.912. ITS engineers lead VQiPS workshops and working groups. This project is funded by NIST/OLES.

Analysis

Propagation Modeling Website (PMW): The Institute continues development of 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 (DOD) through multiple agencies. One of DOD's goals is to leverage this program across as many agencies as possible to ensure maximum cost-effectiveness.

Web-Based Propagation Analysis Services: ITS provides network-based access to research and development of models and various databases required for wireless system design and evaluation. These services are available to Government and non-Government customers and are funded through interagency agreements or cooperative research and development agreements (CRADAs), respectively. In particular, this year's efforts were funded by NWS.

Modeling

Ionospheric Propagation Modeling: ITS propagation engineers maintain models for LF/MF, both ground wave and sky wave, and for HF sky wave. Recent work on the HF models includes a C implementation of Recommendation ITU-R P.533 being shared with WP 3L via technology transfer. This work is funded by DOD.

Integration of the Empirical and the Undisturbed-Field Models: ITS continues development of a model for short-range (2 m to 2 km) propagation between mobile radios and with very low antenna heights, down to the ground. This work includes propagation model development and field measurements. In FY 2012, this project was funded by NTIA/OSM.

Earth-to-Space Propagation Models: ITS propagation engineers build on existing models previously developed for other agencies to accomplish global technology transfer. IF-77, originally developed by ITS for the FAA, is being updated for the ITU-R SG3 Correspondence Group 3K3M-9 and is currently being used in a modified version for an ITS CRADA. Several potential sponsors are interested in this work because of its applicability to Unmanned Airborne Systems (UAS). This work is currently funded partially through a CRADA and partially by NTIA.

Broadband Wireless Standards: ITS develops radio propagation algorithms and methods to improve spectrum usage. ITS prepares technical contributions in the form of propagation models to support the International Telecommunication Union – Radiocommunications Sector (ITU-R) across multiple Study Groups as well as the U.S. private sector. The U.S. is interested in broadband wireless systems for Study Group 3, Radio Propagation. ITS is very active in path-specific model development like Recommendations ITU-R P.1812 and P.452, earth-to-space modeling using Recommendation ITU-R P.528, and ionospheric modeling involving Recommendation ITU-R P.533. This work is funded partially by DOD and partially by NTIA.

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> “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.”
>
> *Presidential Memorandum: Unleashing the Wireless Broadband Revolution, June 28, 2010*

Interference Analysis, Simulation, and Testing in Proposed Shared Spectrum Band 1675–1695 MHz

Outputs

- *Interference potential assessment*
- *Interference mitigation techniques*
- *Interference simulation via propagation modeling*

To support the President’s spectrum policy initiatives, ITS is examining the interference potential between various Federal communication systems that are targeted for sharing common spectrum. One of the initiative’s proposals involves the spectrum relocation of Federal video surveillance systems (VSS) into the 1435–1525 MHz, 1675–1695 MHz, or 2200–2290 MHz bands, which are already in use by existing systems (incumbents).[1] This project’s objective is to study the interference potential from relocating Federal VSS services into the incumbent band used by NOAA’s Geostationary Operations Environmental Satellite (GOES) and Radiosonde. Based on the results of the study, ITS will make recommendations to the affected agencies regarding the feasibility of maintaining seamless and mission critical communications in the shared band.

ITS uses simulation, analysis, and testing to address the feasibility of successfully sharing spectrum. Simulation, analysis, and testing are, of course, interrelated. Each one of these techniques reveals complementary information about the potential interference interaction between systems. The comprehensive and detailed analytical evaluation that ITS engineers provide forms a strong basis for simulating and testing interference interactions.

Analysis and Modeling

Interference between systems has to be characterized to allow for a methodical engineering analysis of the potential interference environment. Once the important parameters that define a given communication system are determined, ITS uses an array of tools to model the interference environment. ITS then uses range- and frequency-dependent propagation models to characterize the shared propagation environment. Parameters, such as antenna patterns, modulation, transmit powers, and receiver sensitivity, are used to accurately describe the interference environment. In addition, system use patterns are also parameterized to further refine the analysis. This process can be used to quickly identify benign and troubling interference scenarios. Once the latter are identified, ITS can focus greater attention on the troubling scenarios to inform users of the engineering issues that will result from shared spectrum use, as well as to develop effective mitigation techniques.

Simulation

Simulation of the propagation channel, the communications systems, and use patterns can help illuminate the complexities of the potential interference environment. Since the degree to which a system can be characterized analytically may be limited, simulation will be used to supplement the analytical information. Simulation can also help in the development of mitigation techniques in scenarios where interference is found to be significant. To explore how to mitigate against interference, simple simulations can be performed using combinations of temporal, spatial, and spectral separations between the communications systems. All these mitigation techniques can be simulated to assure either that the services that share the band are unaffected or that any performance degradation is evident to all those involved. Simulation has the added benefit of replacing expensive field measurements that may be too resource-intensive.

Laboratory Testing

Laboratory testing is used to verify and validate the conclusions and the inevitable assumptions that are required to analyze and simulate systems. For example, in this project, a test

1. U.S. Department of Commerce, National Telecommunications and Information Administration, “An Assessment of the Viability of Accommodating Wireless Broadband in the 1755–1850 MHz Band,” March 2012.

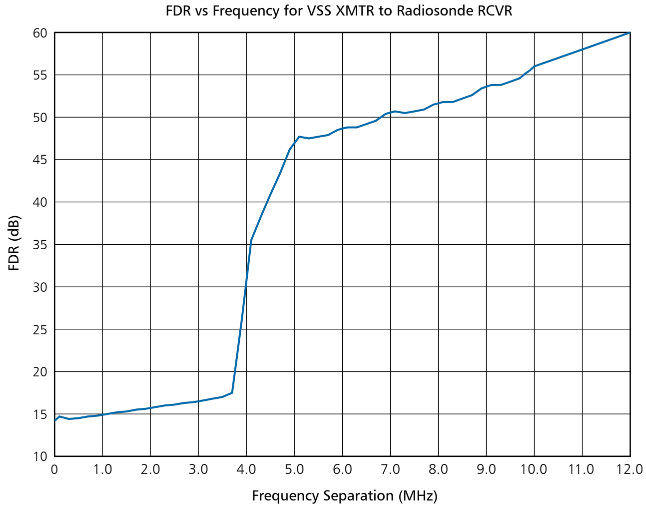
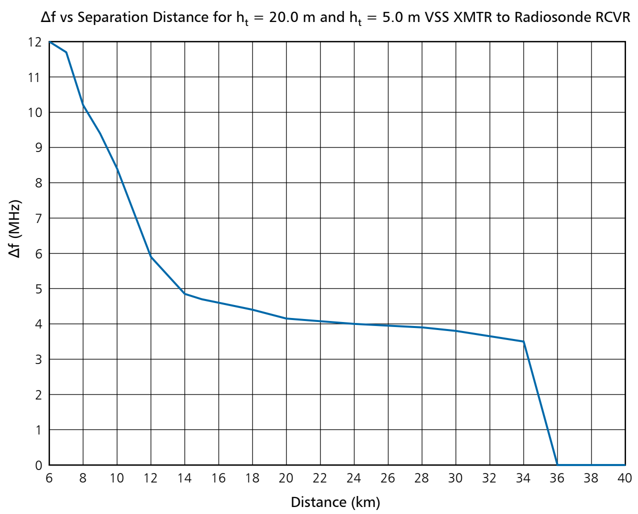


Figure 1 (left). FDR versus frequency for VSS transmitter to radiosonde receiver.

Figure 2 (below). Frequency separation versus separation distance for VSS transmitter to radiosonde receiver.



circuit was devised to simulate an interference environment to establish the video performance threshold. Testing is valuable in assuring users that the shared spectrum for critical communication functions will be preserved. Tests also can be used to identify the limitations within the shared band. During the discovery phase of this project, laboratory and field tests were performed to fully determine the range of operations of each receiver and transmitter in an interference-free environment, and determine and confirm system specifications that are relevant to interference-free transmission and reception (e.g., output power, sensitivity, signal-to-noise levels, isolation, processing gain, etc.).

Pulling it All Together

Over the course of this project, the techniques of simulation, analysis, and testing were used in an iterative fashion. Parameters that are critical to the analysis may not be available until work progresses in the testing and simulation of systems. This is true in determining the frequency dependent rejection (FDR) for the system proposed for relocation. FDR is a figure of merit which indicates how well the receiver can discriminate desired transmissions from those that are unwanted. An example FDR curve is shown Figure 1. The graph shows that the receiver has increasing interferer rejection as the separation distance increases. Figure 1 also shows that a substantial improvement in interferer rejection occurs for frequency separations greater than 5 MHz.

Figure 2 shows the improvement in performance of the target receiver for frequency offset versus distance separation. This type of plot graphically aids users sharing the band to develop frequency plans or to establish geographic protection zones. Figure 2 indicates that the receiver will have less difficulty with interferers at distances greater than 36 km.

ITS's objective was to reduce the complex interference environment to a judicious number of parameters, forging cooperation between the affected users. When decision-makers are aware of the engineering trade-offs, the resulting decisions are more sound. This approach ensures that Federal systems remain able to meet the communications needs of their owner agencies, even while freeing precious spectrum for innovation.

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Public Safety Video Quality (PSVQ)

Outputs:

- *Guide to Defining Video Quality Requirements, to help public safety agencies specify video equipment*
- *Recommendations Tool for Video Requirements, to provide specific technical recommendations to public safety agencies based on their needs*
- *Technical contributions to standard bodies to establish video quality measurements and standards for the public safety community*
- *Technical publications and presentations on video quality*

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. 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 deliver suitable content based on user needs.

VQiPS Working Group

The PSVQ project formed the Video Quality in Public Safety (VQiPS) Working Group (WG) under DHS in 2009 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* 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

The Guide is the central framework for illustrating 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 informs 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

PSVQ hosted the fourth VQiPS workshop in July 2012 (Figure 1). 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 helps to coordinate efforts in establishing quality requirements for video used in public safety applications.

Public safety practitioners are starting to rely 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 the technology evolves, equipment options become increasingly complex. Unbiased guidance is essential for practitioners to be able to clearly articulate their video quality needs and make informed purchasing decisions.

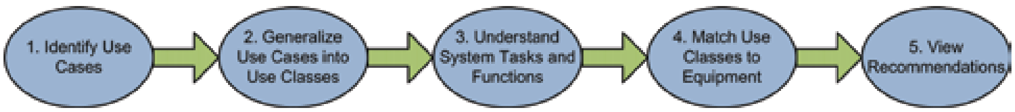
Web Sites for Additional Information

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/current-projects/videoquality

Figure 1 (left). The fourth annual VQiPS Workshop saw good attendance, with participants from five countries. Figure 2 (below). The interactive Video Requirements Web Tool guides practitioners in choosing appropriate requirements for video procurement by asking questions about intended use. Figure 3 (bottom). The user interface for side-by-side visual acuity and recognition performance testing.



Volume 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. The Video Requirements Web Tool (Figure 2) was released in July 2012 to provide recommendations for a single use case. The Generalized Use Class Questionnaire, released in May 2011, provides recommendations that apply to multiple use cases belonging to one or more use classes.

Network Performance Specification Testing

In support of the Guide, PSVQ performed two experiments to determine network performance specifications that apply to the VQiPS GUCs. These experiments 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 PSVQ project also incorporated a new video quality metric, visual acuity, into these experiments (Figure 3). By measuring acuity and recognition performance side-by-side, PSVQ was able to match user requirements with specifications for sufficient video systems. The test report contains a set of recommendations for H.264 compression and video resolution specifications for each VQiPS GUC. These recommendations were incorporated into version 2.0 of the Recommendations Tool for Video Requirements (available at: http://www.pscr.gov/outreach/vqips/vqips_guide/rec_tool_vid_reqs.php).

Related Publications:

U.S. Department of Homeland Security, "Assessing Video Quality for Public Safety Applications Using Visual Acuity," Public Safety Communications Technical Report DHS-TR-PSC-12-11, Nov. 2012. Available: http://www.pscr.gov/outreach/safecom/vqips_reports/assessing_video_quality_for_public_safety_applications_using_visual_acuity.pdf

U.S. Department of Homeland Security, "Video Quality in Public Safety (VQiPS) 2012 Workshop Report," Jul. 2012. Available: http://www.safecomprogram.gov/SiteCollectionDocuments/Final_VQiPSWorkshopReport_092912.pdf

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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 HF (High Frequency) and VHF (Very High Frequency) Propagation Modeling Website (PMW) Geographic Information System (GIS) software suite for multiple DOD, NWS, and future government 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 the ability to successfully predict propagation in a variety of environments and conditions. ITS has developed the Propagation Modeling Website (PMW) VHF (Very High Frequency) 3.0 and PMW HF (High Frequency) 1.0, web-based GIS propagation modeling tools, customized to meet the propagation prediction needs of the Department of Defense (DOD) and National Weather Service (NWS) sponsors. The PMW VHF 3.0 covers 1 MHz to 20 GHz, whereas the PMW HF covers 2 to 30 MHz.

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 15 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.

Over the last five years, ITS has been developing the newest generation of propagation prediction tools, the PMW HF and VHF web-based GIS solutions. The PMW VHF and HF 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 1. Maintaining, operating, and upgrading the system are streamlined.

PMW VHF 3.0 and HF 1.0

The PMW VHF 3.0 software currently includes the capacity to perform propagation analysis using any of four models: Longley-Rice, TIREM

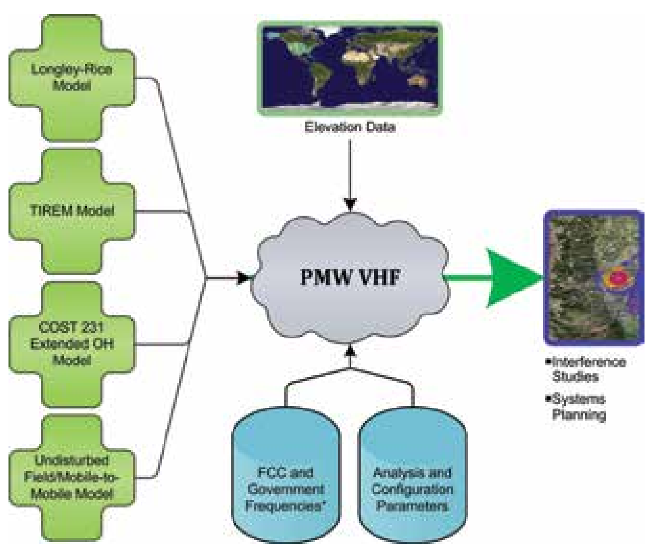

Figure 1. PMW VHF 3.0 System Architecture (indicates future functionality).*

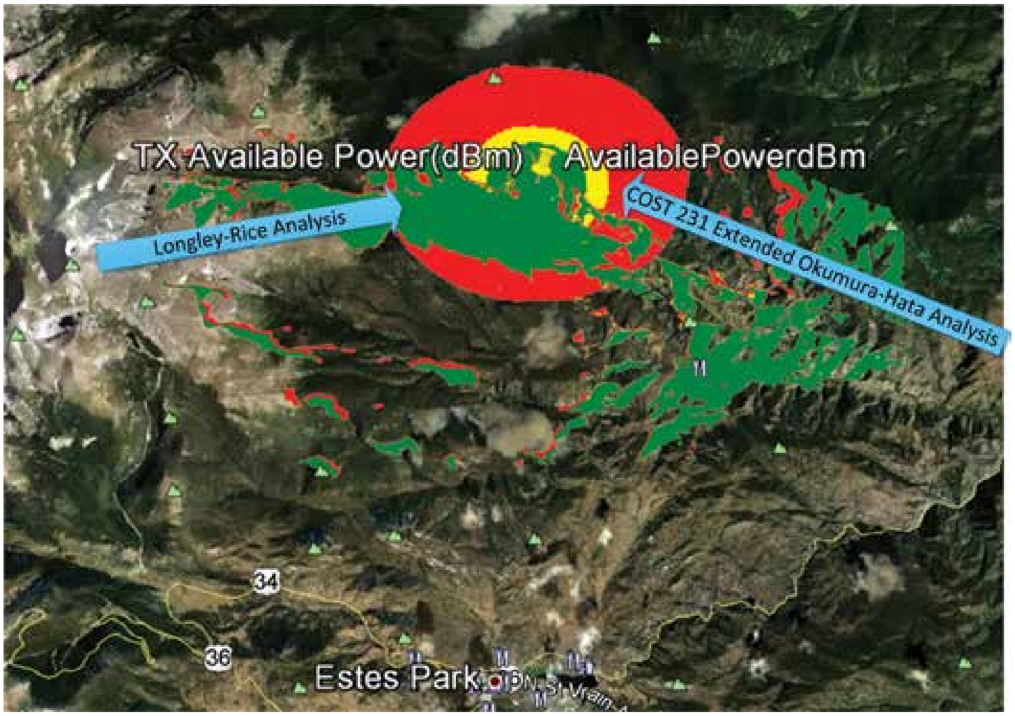

Figure 2. COST 231 Extended Okumura-Hata to Longley-Rice comparison.

3.15, COST 231 Extended Okumura-Hata, and Undisturbed Field/Mobile-to-Mobile. Figure 2 shows two available power analyses—one using the COST 231 Extended Okumura-Hata model and the other using the Longley-Rice model—displayed in Google Earth™. Other features include: login access control, data input validation, the ability to create analysis composites for thousands of transmitters, database propagation parameter and measurement storage, and data analysis export to 3-D Google Earth (KML/KMZ) and ESRI ArcMap®. Users can choose from antenna pattern and terrain data included with the software to run an analysis or upload their own files to the site.

The PMW VHF 3.0 also incorporates a parallel-threaded design that offers speed improvements over a single-threaded model. The PMW HF 1.0 software allows users to perform HF studies using the ICEPAC propagation model; the system queues up multiple HF study iterations to run automatically without minimal user intervention. Both PMW VHF 3.0 and PMW HF 1.0 contain a Windows® "service" module which reads XML propagation model files created by the website and runs each XML process according to priority and availability of system resources. The "service" monitors and communicates the status of all processes back to the PMW VHF 3.0 or PMW HF 1.0 website for users to monitor the system progress.

Over the next several years, as the PMW HF and VHF continue to mature, current and future sponsors may choose several software enhancements, including but not limited to: interference studies, a GIS map server within the website, combining terrain cells for longer propagation analysis distances, new terrain formats (HRTe, LIDAR, IFSAR, etc.), and other propagation models (LF/MF, IF-77, updated HF models, and indoor-outdoor models).

The PMW VHF 3.0 and PMW HF 1.0 are currently customized to fit the needs of our sponsors and operate on either their internal, secure networks or hosted on a secure ITS website, allowing only our sponsors to have access to their data. 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 PMW VHF 3.0 and PMW HF 1.0, ITS has aided Government agencies in efficiently managing their telecommunications infrastructure through sound system planning and interference detection for national security and public safety.

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ITS is developing an online capability to enable other Government agencies to use ITS propagation models developed over seven decades of research. The on-line propagation services Web portal provides access to the user-friendly Propagation Modeling Website (PMW) tool that assists in the design of effective wireless systems.

Web-based Propagation Analysis Services

Outputs

- *Internet access linking 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*

Overview

In FY 2009, ITS began the effort to upgrade the Telecommunication Analysis (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 Government agencies. This Propagation Modeling Website (PMW) presently offers two tools: the Very High Frequency (PMW VHF) tool and the High Frequency (PMW HF) tool. PMW is discussed in greater detail on page 52. This work continues as funding becomes available.

The Online Propagation Analysis Services program provides U.S. Government agencies with access to the latest ITS research and engineering outputs via the internet. All servers and databases are behind the ITS firewall for security. Services are provided through the PMW, which is designed for non-technical users with average computer expertise and minimal knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

The online propagation services also allow users to work closely with ITS engineering staff to customize research and development models to fit their respective programs.

Available Models and Databases

The PMW VHF Site provides the ability to run a number of propagation models. These models include the Terrain Integrated Rough Earth Model™ (TIREM), the Integrated Terrain Model (ITM) sometimes called the Longley-Rice model, the COST 231 Extended Okumura-Hata model, and the Undisturbed Field/Mobile to Mobile model. ITS plans to add low frequency/medium frequency (LF/MF) and indoor-outdoor models in the next two years. The PMW HF tool uses the ICEPAC propagation model.

These general purpose models are applicable to a wide range of frequencies and scenarios. For models that integrate terrain we provide ability to store and manage DTED1, DTED2, GLOBE, and user uploaded terrain files. Analyses are stored with all constituent parameters in an SQL database. The user can query their runs and see all parameters using a variety of options. Large numbers of analyses can be run in parallel by using Excel® batch files, and large numbers of analyses can also be exported as a group using various export options that specify compression method (.zip or .7z) or define inclusion of various output products.

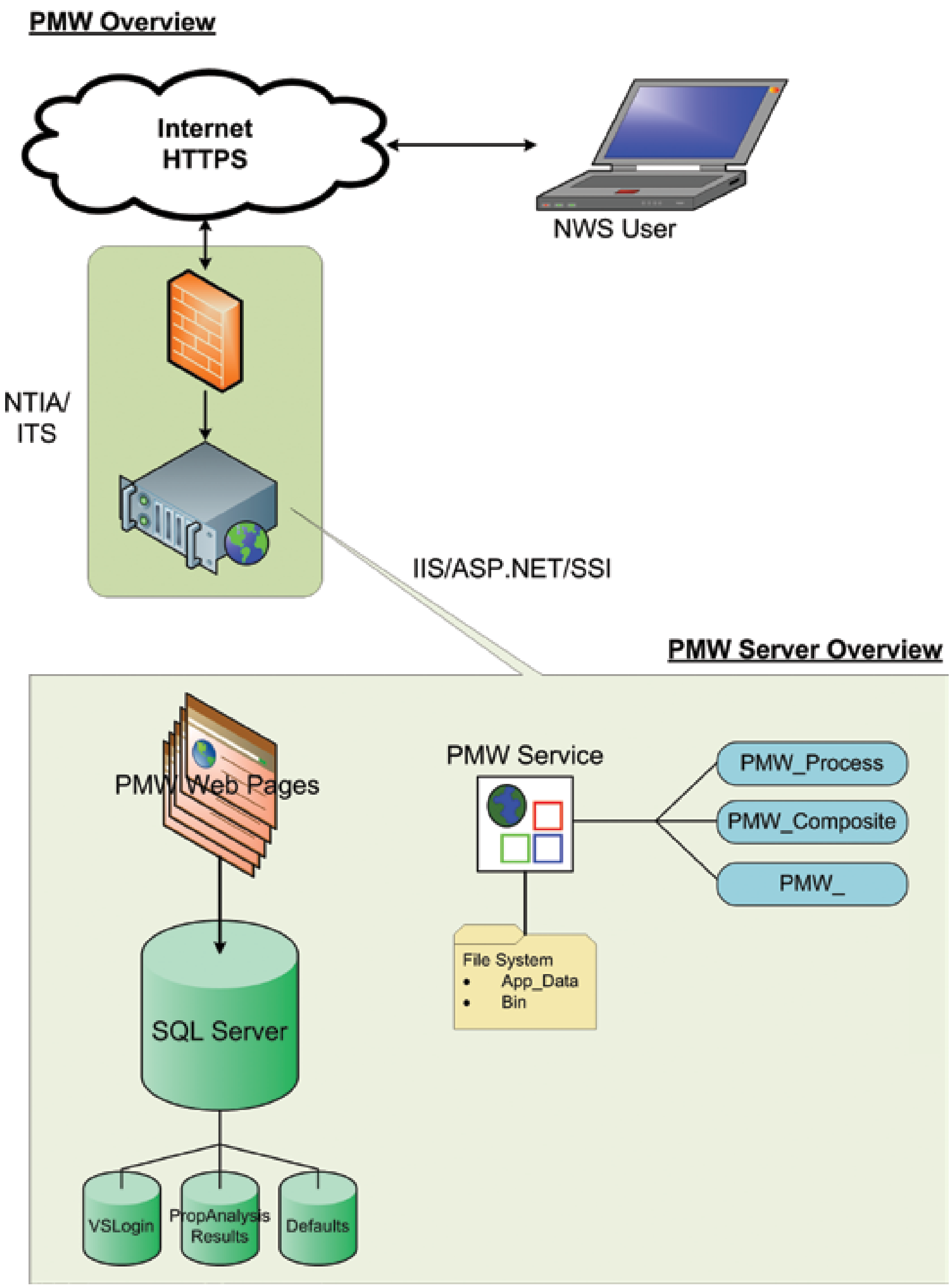
ITS also provides a database of country information for tagging locations, as well as a user modifiable defaults database. User access is coordinated by a separate login database which could be shared among other applications for unified log-in by users.

National Weather Service (NWS)

Under an interagency agreement, ITS is providing the NWS with Online Propagation Analysis Services based on the PMW VHF service. The NWS is the office of the National Atmospheric and Oceanic Administration (NOAA) charged with providing the Nation a round-the-clock source of weather reports and timely hazard information. This is accomplished through the NOAA Weather Radio system, which broadcasts continuously on specified frequencies. It is the goal of this system to provide access to potentially life-saving information to at least 95 percent of the U.S. population in the event of a national emergency.

To continue to meet or exceed its broadcast coverage goal, the NWS engages in ongoing expansion efforts that provide new or upgraded transmitters in many locations around the country. ITS provides the NWS with customized Online Propagation Analysis Services used to plan the location and characteristics of new transmitters to optimize coverage. Through the use of the PMW system and databases, this national alert system will be able to verify and improve coverage by their large, diverse radio transmission system. The figure below shows the architecture of the NWS PMW system. In the future, ITS will add 2010 census data processed into smaller 90 square meter components to this system in order to more accurately predict population coverage.

For more information on available programs call one of the contacts listed here.



System Architecture for the NWS PMW system.

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The ionosphere, extending from about 50 to 2000 km above the surface of the Earth, contains enough free ions and electrons to affect the properties of radio waves propagated within and through it. Because its structure is highly variable, the performance of telecommunication systems whose signals are propagated via the ionosphere is also highly variable. ITS and its predecessors have been building and improving models to predict the performance of ionospheric-dependent radio systems for close to 100 years.

Ionospheric Propagation Modeling

LF/MF Ground Wave and Sky Wave Model and HF Sky Wave Models

Outputs

- *Unique LF/MF ground wave and sky wave propagation models*
- *Antenna models specific to LF/MF/HF frequencies incorporated into analyses*
- *LF/MF/HF communication circuit reliability and performance*
- *LF/MF interference analysis capability*

Overview

ITS is the preeminent source for ionospheric propagation modeling. In any given year, ITS does numerous in-depth propagation studies for Federal agencies, including the Department of Defense. The Institute has developed and continues to improve propagation models that analyze coverage and interference in the high frequency (HF, 3–30 MHz), medium frequency (MF, 300 kHz–3 MHz), and low frequency (LF, 30–300 kHz) bands. The LF/MF communication/broadcasting system performance model was designed to run on a PC and includes three ground wave and three sky wave propagation loss prediction methods. ITS also developed and maintained several high frequency propagation models.

LF/MF Ground Wave and Sky Wave Model

The ITS propagation models perform radio wave propagation and antenna analysis in addition to interference prediction analysis. The sky wave propagation models are valid from 150 to 1705 kHz, and the ground wave models are valid from 10 kHz to 30 MHz. The LM/MF model is unique, since no other model can perform these analyses in these frequency ranges. This model has been used for interference and coverage analysis for two versions of the Nationwide Differential Global Positioning System (NDGPS) in two frequency bands (285–325 kHz and 435–495 kHz), and the AM broadcast band (150–1705 kHz). The LF/MF model is freely available to all Federal agencies, including military agencies.

For the 150 to 1705 kHz frequency band, the propagation of radio waves at night includes both a ground wave and a sky wave. The sky wave combined with the ground wave may be compared to an idealized radio noise environment (consisting of atmospheric, galactic, and man-made noise components). The model predicts the likelihood that the communication link will operate satisfactorily and whether interference will occur for such an environment.

The presence of the sky wave at night could create potential interference problems between distant stations on the same frequency or frequencies that are near to each other. The sky wave models estimate the expected field strengths of signals to assist in frequency allocation and to avoid potential interference problems. At night, undesirable interference from the sky wave can manifest as adjacent and co-channel interference to stations that would not normally be affected in the daytime.

The absence of the sky wave during the day precludes the use of systems in this band for reliable long distance communication, since the sky wave at frequencies from 150 to 1705 kHz is strongly attenuated by the electron density in the D region during the daytime.

Antenna Modeling

Antenna and propagation modeling in the LF/MF band is unlike that in other bands. In this band, antenna performance on or near the surface of the Earth is very dependent on the interaction with the lossy Earth. Consequently, antenna models have been included that correctly launch the ground wave at the horizon angle and the sky wave at the appropriate elevation angle. Propagation modeling in this band also requires consideration of the losses and reflections caused by the Earth air interface. Free space loss estimates that do not include these effects in the loss predictions are inaccurate.

HF Propagation Modeling

In the HF band, communication occurs predominately via the sky wave. ITS developed a model of sky wave propagation for HF communication called the Ionospheric Communications

Analysis and Prediction Program (IONCAP) in the early 1970s.

Sky wave propagation in the HF band relies on the phenomenon of ionospheric layers, principally the E and F2 layers, to bend HF signals aimed at them back to earth. ITS maintains three modern variants of the IONCAP program that were each developed to serve the different needs of the national and international HF communities. These variants are VOACAP, ICEPAC and REC533. VOACAP was developed for the special broadcast needs of the U.S. Voice of America.[1,2] ICEPAC includes code that more accurately models polar propagation paths. REC533 was created to help develop the international agreements for HF communication through the International Telecommunication Union (ITU). All of these programs were designed to run on a PC.

IONCAP and its successor programs model a number of propagation paths with mean month statistics to predict HF channel characteristics such as maximum usable frequency (MUF), path loss, and receive signal reliability. Each program models a series of propagation modes that are associated with E and F2 layer reflections. Ionospheric and temporal characteristics of the path and spectral characteristics of the signal are used to estimate the effectiveness of the communication link. The modeling approach used in these programs relies on differing assumptions that are dependent on the path length and geographic location. Each program contains two models: one for shorter range paths and one for long range paths, with an interpolation zone in between.

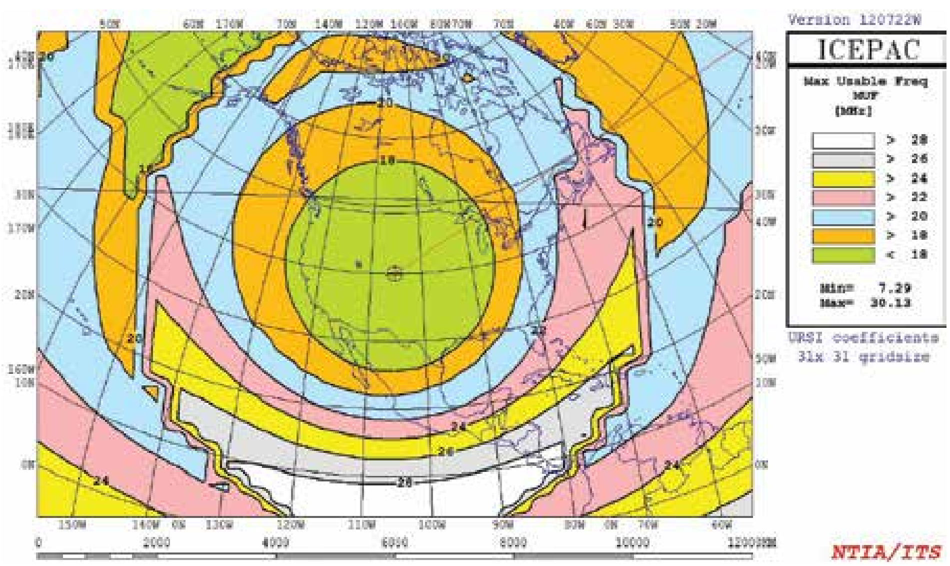
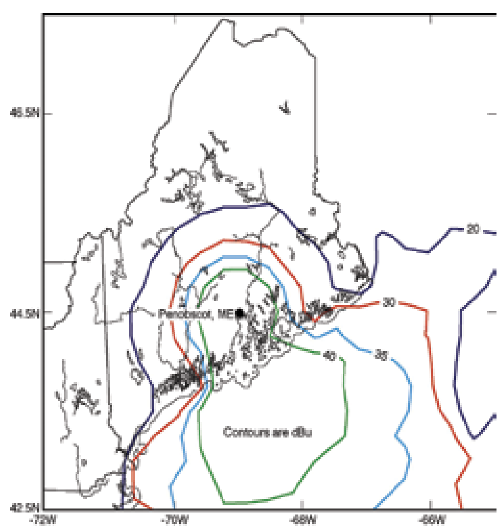


Figure 1 (above): Maximum Usable Frequency (MUF) for a 5000 kW transmitter in Boulder, Colorado. Figure 2 (right): Radio coverage for an AM broadcast station in Penobscot, Maine, generated by the low and medium frequency propagation model.



1 N. DeMinco, "Ground-wave analysis model for MF broadcast systems," NTIA Report 86-203, September 1986.

2 N. DeMinco, "Medium frequency propagation prediction techniques and antenna modeling for intelligent transportation systems (ITS) broadcast applications," NTIA Report 99-368, August 1999.

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Accurate radio wave 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 data needed to develop 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*
- *Verification of the Undisturbed-Field Model via analysis and multiple sources of measured data*
- *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 Undisturbed-Field Model has also been verified with several measurement campaigns, as described in the related publication. The result of the model integration 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 phenomena. It is based on both analytical calculations from the physics of electromagnetic theory and actual measurements. The model is the result of an ITS program that combined 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 test procedure with a fixed transmitter location while a 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.

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.[1] 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.[1] The model has also been shown to be accurate for flat terrain up to 2 kilometers.

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, antenna heights, 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, ground effects, 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. Extensive measurements, reported in the related publication, have verified the separate Undisturbed-Field Model for antenna heights of zero to 3 meters.

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

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.

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

Related Publication:

N. DeMinco et al., "Free-field measurements of the electrical properties of soil using the surface wave propagation between two monopole antennas," NTIA Report TR 12-484, Jan. 2012.

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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*
- *U.S. technical contributions to the ITU-R.*
- *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] In addition to expanded demand driven by increasing use of established consumer technologies such as "smart" cellphones, this growth is fueled by the need to accommodate new technologies such as unmanned aircraft systems (UAS).

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 40 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 candidates 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.

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

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.

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 government agencies, 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 SG3 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.

The ITS model IF-77 has gained further interest for its high altitude component. This high altitude component is critical for spectrum sharing studies between satellite services. In addition, propagation models with a high altitude component are needed to plan for the expanding role of unmanned vehicles and consequent spectrum required for communication and control of such vehicles.

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 SG3 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 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. Future work includes a step-by-step method for calculating the transmission loss for user defined parameters.

Unmanned Aircraft Systems (UAS)

The FAA Modernization and Reform Act of 2012 includes a section on expanding the use of UAS into the national airspace system. Internationally, several study groups in the ITU are studying the effects of the expanding uses of airborne platforms and the consequent communication requirements in the shrinking available frequency spectrum.

Again, ITS is heading a correspondence group to produce prediction methods for the radio frequency signal parameters necessary for communications and control for airborne platforms which may be unmanned. There are two methods presently being considered, and one is based on updating the ITS IF-77 model.

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.

The expanded ITU SG3 investigations into all airborne platforms (Question ITU-R 233/3) fit well into ITS's work in both aeronautical and unmanned airborne systems. This work is essential to studies to evaluate frequency sharing proposals. The calculations based on the future computational method for P528-3 and prediction method(s) likely to come out of the SG3 investigations for airborne platforms will also be important in planning both satellite and aeronautical systems.

UAS are used by the National Atmospheric and Oceanic Administration (NOAA) for weather prediction and scientific research. A pilotless hurricane hunter is shown on the left and on the right an unmanned air vehicle carrying a surface imaging system and instruments for measuring ocean color and atmospheric composition and temperature. Photos courtesy NOAA.

Related Documents:

ITU-R WP3K Document 3K/21, "Aeronautical and satellite link propagation method" (T. Rusyn)

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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

Outputs

- *Preparation for and support of the 2012 Block Meetings of ITU-R Working Parties 3J, 3K, 3L and 3M and Study Group 3*
- *Technical contributions on the use of ITU-R propagation recommendations for interference and sharing studies*

Overview

As wireless dissemination, collection, manipulation and analysis of digital information becomes increasingly ubiquitous, demand that more bands of radio frequency spectrum be made available for commercial broadband use, either by reallocation or sharing, also increases. In recognition of this increased demand, the U.S. Administration and Congress have directed NTIA to undertake a number of initiatives to make more spectrum available. A 2010 Presidential Memorandum directed the Commerce Department, working cooperatively with the Federal Communications Commission (FCC), to identify and make available 500 MHz of radio frequency spectrum for expanded wireless broadband use over the next 10 years.[1] This goal was reinforced in the Wireless Innovation and Infrastructure Initiative (Wi3).[2] The Middle Class Tax Relief and Job Creation Act of 2012, enacted in February 2012, set a timetable for clearing or sharing 15 MHz in the 1575–1710 MHz band and evaluating other specific scenarios for potential sharing or reallocation of specific bands.[3]

With input from the Policy and Plans Steering Group (comprised of Assistant Secretaries from Federal Government Departments and Agencies), NTIA released a "Ten-Year Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband" (the Plan). The Plan identified over 2.2 GHz of radio frequency spectrum for evaluation, all presently allocated to other Federal exclusive and Federal/non-Federal shared services. It described a process for evaluating each of the candidate bands and the steps necessary to make them available for wireless broadband services. The Plan also formally recognized the critical importance of electromagnetic interference protection for all Government missions/services that rely on spectrum use and the need for coordination with international standards bodies.[4]

World Radiocommunication Conference Contributions

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. NTIA joined other federal agencies participating in the 2012 World Radiocommunication Conference (WRC-12), a treaty conference that was held in Geneva, Switzerland, from January 23 to February 17, 2012. NTIA worked with the Federal agencies and the FCC to develop the United States' proposal for a future conference agenda item seeking additional global spectrum allocations for wireless broadband services, including International Mobile Telecommunications (IMT) systems.

The U.S. succeeded in securing an agenda item for the 2015 World Radiocommunication Conference (WRC-15) to consider allocation of additional spectrum to the mobile service on a primary basis to facilitate the development of terrestrial mobile broadband applications (WRC-15 Agenda Item 1.1). Another agenda item (1.2) will consider the use of the 694–790 MHz band by the mobile, except aeronautical mobile, service.

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. Public Law 112–96—Feb. 22, 2012. Middle Class Tax Relief and Job Creation Act of 2012, http://www.gpo.gov/fdsys/pkg/PLAW-112publ96/pdf/PLAW-112publ96.pdf
4. 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

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 evaluating 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.

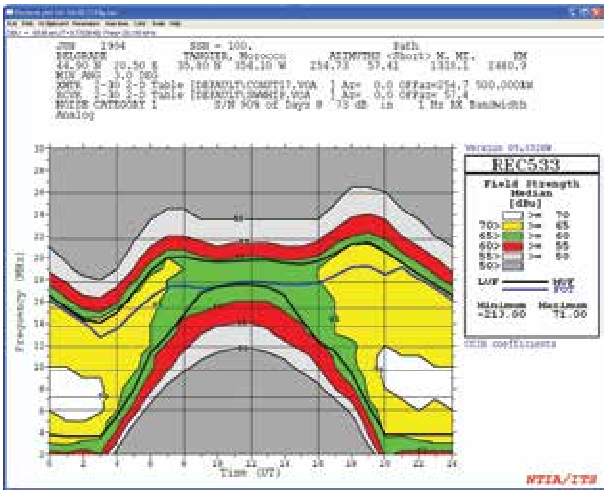
Working in conjunction with other agencies and countries, NTIA promoted the establishment of a Joint Task Group (JTG) to conduct the necessary sharing studies and to develop the necessary preparatory text. The Conference Preparatory Meeting for WRC-15 adopted the joint study approach and established Joint Task Group (JTG) 4-5-6-7 as the responsible group for WRC-15 Agenda Items 1.1 and 1.2, ensuring the opportunity for all stakeholders to participate during the sharing study work, and setting the international framework in motion to advance the Broadband Wireless Initiative at WRC-15.

Owing to the importance of the work of JTG 4-5-6-7 and the very aggressive schedule for completion of its work, WP 3K has continued its work inter-sessionally via correspondence. In particular, ITS engineers have participated in Correspondence Groups 3K-3 (Rec. ITU-R P.528) and 3K-4 (Rec. ITU-R P.1546 and aggregation of low time percentage signals).

Technical Contributions

Two extensive contributions were produced under this year's effort. The first, Doc. 3K/21, is a comprehensive description of the physical bases and methods used to provide propagation loss predictions for aeronautical (and satellite) links in Recommendation ITU-R P.528. This represents a major development for this recommendation, since it provides the information needed to evolve the recommendation from a curves-based method into a more general computational method based on physical phenomena, thus allowing for predictions for arbitrary radio climates, terminal heights, frequencies, and terrain irregularities. This material was carried forward as an attachment to the WP 3K Chairman's report. The research is described on page 60.

The second notable contribution, Doc. 3L/7, is a complete rewrite of the Recommendation ITU-R P.533 software (i.e., a reference implementation) in the C programming language. The rewrite is intended to provide a clear, readable implementation of the recommendation which will be much easier to maintain than earlier implementations. The program P533 provides methods for the prediction of available frequencies, signal levels, and reliability for both analog and digitally modulated HF systems, taking account not only of the signal-to-noise ratio but also of the expected time and frequency spreads of the channel. This program calculates the HF path parameters described in ITU-R P.533-10 (2010). In this implementation great care has been taken to follow ITU-R P.533-10 as closely as possible. It is the intent of this project that users will be able to freely use the model with public domain compilers and tools.



Example of signal level prediction using Rec. ITU-R P.533 as described in the Handbook 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 2–30 MHz.

Related Documents:

ITU-R WP3L Document 3L/7, "Reference implementation of the ITU-R P.533-10 HF propagation model and an example of use" (C. Behm)

ITU-R WP3K Document 3K/29, "Report on the meeting of Working Party 3K (Geneva, 18–27 June 2012)" (P. McKenna)

ITU-R WP3K Document 3K/156 Study Period 2007-2012, "Report of the Meeting of Working Party 3K (Geneva, 17-26 October 2011)" (P. McKenna)

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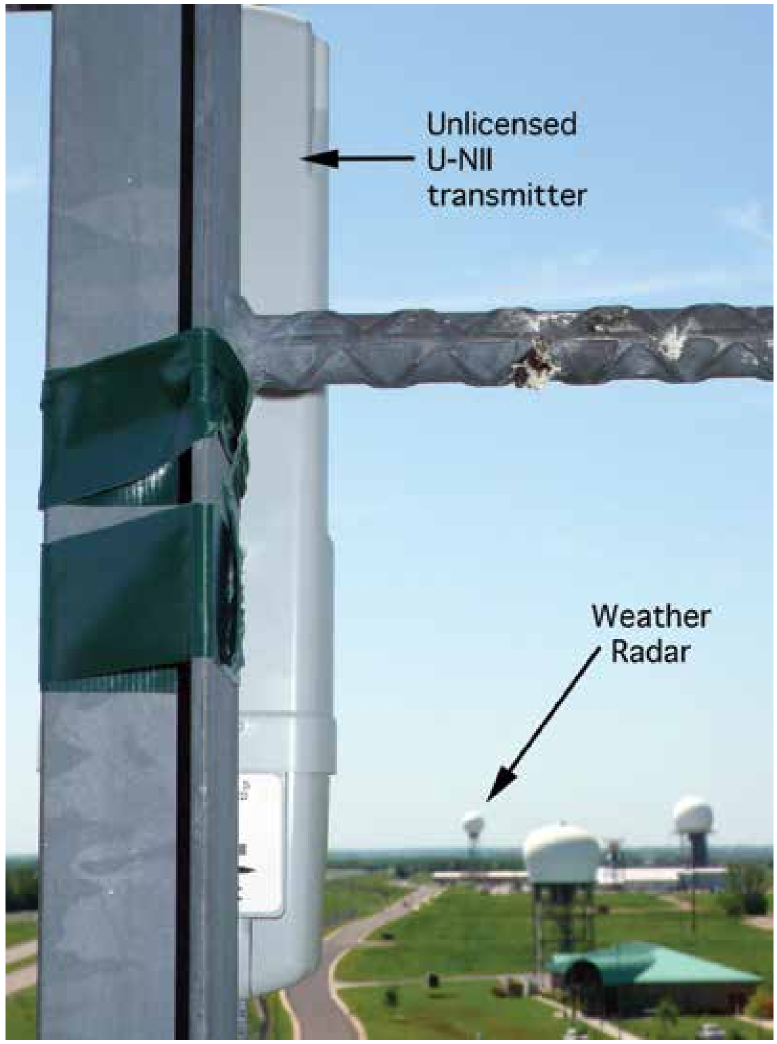
“Spectrum sharing can take a number of forms, but its purpose is to ensure that when the primary user does not need the spectrum, another party can put it to good use, as opposed to allowing it to remain fallow.[1] ”

“The ultimate goal is to achieve dynamic heterogeneous spectrum sharing, in which spectrum users can co-exist closely in frequency, time, and geography, dynamically adapt to both the environment and the presence of other users.[2] ”



An unlicensed national information infrastructure (U-NII) transmitter (left) set up to transmit toward a distant weather radar (right) during NTIA interference-solution testing at an FAA facility. Performance verification is critically important in spectrum-sharing studies performed by the Institute. Photo by Frank Sanders.

1. Jason Furman and John P. Holdren, “Making the Most of the Wireless Spectrum,” The White House Office of Science and Technology Policy, July 20, 2012. http://www.whitehouse.gov/blog/2012/07/20/making-most-wireless-spectrum.
2. *Report to the President: Realizing the Full Potential of Government-held Spectrum to Spur Economic Growth*, Executive Office of the President, President’s Council of Advisors on Science and Technology, July 2012, p. 30. http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf

Telecommunications Theory

Worldwide demand for telecommunication spectrum by governments and the private sector continues to grow. Wireline networks can meet many needs and be expanded almost indefinitely, but some needs can only be met by wireless systems that must use radio spectrum—a limited resource. In response, spectrum use is migrating toward more sharing. Many sharing schemes rely on dynamic spectrum use by self-controlled, interference-limited technologies. Allocations on a service basis (i.e., separate spectrum bands for each system) are being supplanted by increased sharing between services. But successful implementation of more sharing depends on developing new capabilities in radio systems to avoid, or work in the presence of, interference from other systems.

New knowledge, focused on improvements in network performance, is required 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 must be developed and used so that audio and video 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, Theory Division research targets system improvements at fundamental levels of physics and engineering.

The major areas of investigation are: broadband wireless system performance in the presence of interference; development of new, short-range radio propagation models; the effects of noise and interference as critical limiting factors for advanced communication systems; automated tools for assessing audio and video quality; and further development of advanced spectrum sharing concepts.

Audio Quality Research

The Institute, an internationally recognized leader in audio quality research, 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.

Compliance Measurements on New Radars

Theory and Measurement Division personnel performed spectrum compliance measurements on emissions of new radars for a Government agency and a private company. Laboratory measurements on a prototype of a new U.S. Navy Shore Line Intrusion Monitoring System (SLiMS) radar led to spectrum certification for this important perimeter security system. Under a CRADA with the Lockheed Martin Company, ITS engineers performed spectrum emission compliance measurements in the field on a new counter-fire radar, the TPQ-53, that tracks artillery rounds, short-range rockets and mortars.

Effects of the Channel on Radio System Performance

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

Radar Interference Solutions

In response to interference problems to radar receivers resulting from non-radar systems operations in and adjacent to radar bands, Theory Division personnel performed extensive analyses and measurements jointly with the ITS Measurements Division and NTIA's Office of Spectrum Management (OSM). Investigating widespread interference to 3 GHz Government weather radars from digital communication systems, ITS and OSM engineers performed a major series of measurements and tests at field sites. Technical solutions were developed and an NTIA Report released documenting the problem and its solutions. For the U.S. Coast Guard, ITS engineers analyzed technical issues and possible solutions associated with potential spectrum sharing at 3.5 GHz between maritime radars and non-radar communication systems.

Video Quality Research

The Institute, an internationally recognized leader in video quality research, 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 speech and audio encoding and transmission have become pervasive. Transmissions over wireless links and over the Internet have become particularly popular and these channels are not static. The laws of physics and sharing of resources dictate that the throughput of these channels is not constant, but rather varies markedly. In the limiting case, portions of transmitted speech and audio data streams may never arrive at the receiver, or may arrive too late for playback in real-time services. Thus robustness to missing data is a highly desirable property for speech and audio encoders. Redundancy is one simple way to increase robustness, but it also increases bit rate. This highlights one of several important trade-offs inherent in speech and audio coding.

Similarly, the ability to adapt to different signal classes, bandwidths, quality levels, coding rates, or robustness levels is very desirable. This adaptive nature allows encoders to be well-matched to channel conditions even though those conditions are evolving.

Overall, speech and audio encoding entails a delicate balance between bit-rate, speech or audio quality, robustness, delay, and complexity.

The ITS Audio Quality Research Program identifies, develops, and characterizes innovations for speech and audio coding and transmission that may increase quality, robustness, or adaptability, or that may decrease bit-rate, delay, or complexity. In addition, the program seeks to improve tools and techniques for characterizing and optimizing the trade-offs between these factors. This often requires measurement or estimation of speech or audio quality, and this can be very challenging due to the interplay between technology factors, human auditory perception, and human judgment.

Time-Varying Speech Quality Research

In FY 2012 program staff continued their research on time-varying speech quality. This topic is highly relevant to the current telecommunications scenario. As mentioned above, commonly used telephony channels do not provide constant throughput. If a speech encoder can adapt to the current channel conditions, then the result is speech quality that can dramatically improve or worsen even over relatively short time-scales. For example, this may be experienced when using a cell phone while moving.

Experiment Design

Program staff designed, implemented, and analyzed an experiment centered on the question "When should quality increases be allowed?" This is a counterintuitive but relevant question. It is counterintuitive because at first glance it might seem that improvements are always desirable.

It is relevant because quality variations should be minimized, so increasing quality for short periods of time, or at a late point in a talk-spurt is not necessarily a desirable procedure.

Staff used a recognized statistical model for talk-spurt durations to build a mathematical framework for answering the question. The main variables in the experiment were the talk-spurt length, the time within the talk-spurt at which the quality increased, and the type of quality increase. A selection of current narrowband (NB), medium band, and wideband (WB), speech coders was employed, and quality improvements were created by switching from one coding mode to another.

The resulting recordings were presented in a controlled laboratory environment to 30 listeners. Each listener heard 222 recordings. Each listener provided a single rating of overall speech quality for each recording, but each recording actually contained two different quality levels.

Experiment Results

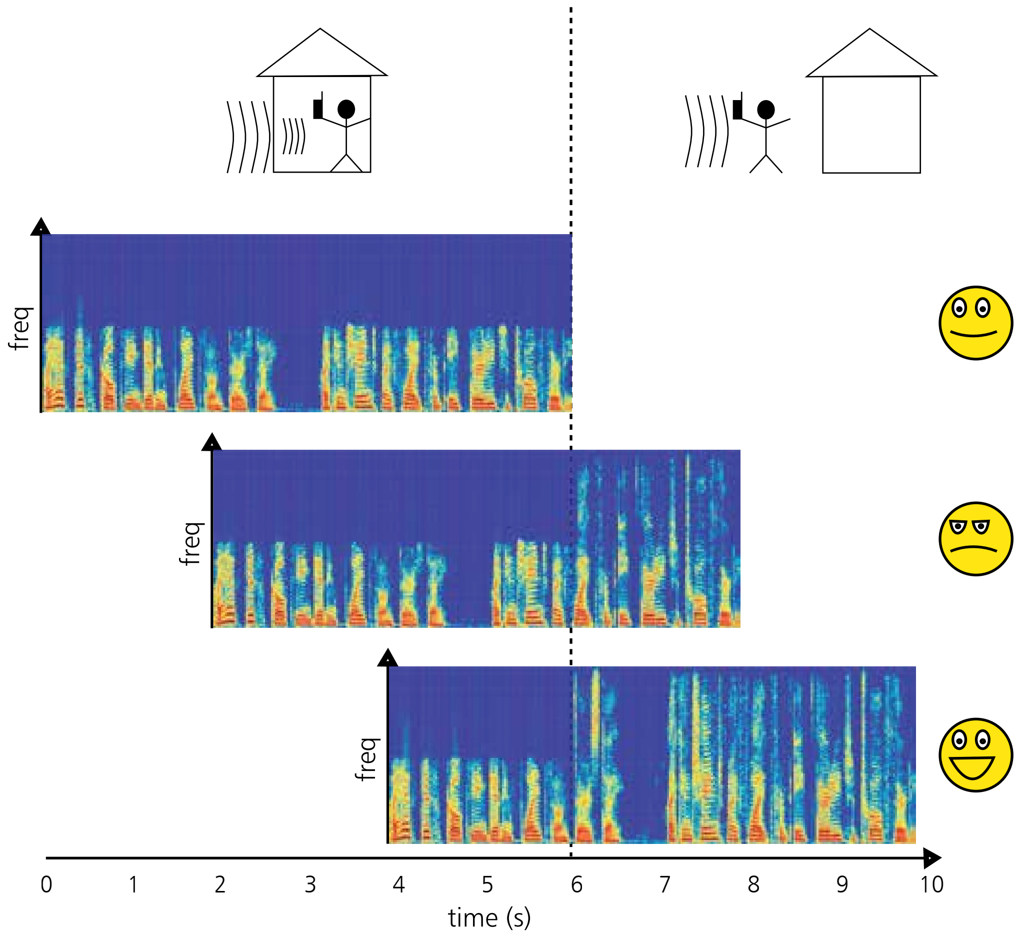
A detailed statistical analysis of the results showed that, on average, quality improvements should be allowed early in a talk-spurt, but not later in a talk-spurt. The exact cut-off point depends on the type of the speech-quality improvement. It is expected that these results can guide adaptations in speech encoding and transmission so that the highest possible speech quality is delivered under a given set of channel conditions.

A graphical example is given in the figure. The top of the figure portrays a cell phone user who leaves a building at the six-second point on the horizontal time scale. This improves the radio channel and in turn allows for the speech coder to switch from an NB mode to a WB mode. Three spectrograms show three different timing cases for the speech signal that the user is hearing. The top spectrogram shows the case where the entire speech signal is heard in NB, and the user finds the quality of the result acceptable. The middle spectrogram shows the case where the first four seconds are heard in NB and the final two seconds are heard in WB.

The user's opinion is lower than in the first case, even though WB is well documented to provide higher speech quality. The bottom spectrogram shows the case where the first two seconds are heard in NB and the final four seconds are heard in WB. Now the user's opinion is higher than in the first case, because the NB to WB transition happened early enough in the speech signal.

Additional Work

Throughout FY 2012, 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 draft technical documents detailing laboratory procedures and research results. 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.



Graphical depiction of the impact of the timing of NB to WB transition on user quality perception.

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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. This research helps to improve the competitiveness of the U.S. information and communications technology sectors, and enhances 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*
- *Measurements to support ITS propagation model development*
- *Development of new fast-fading measurement tools for mobile propagation measurements*
- *First prototype development of a new narrowband, laboratory-grade 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 engaged in developing 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 novel narrowband system mobile channel fading system that has high dynamic range and excellent measurement fidelity
- A patented wideband pseudorandom noise (PN) channel sounder system that performs both time- and frequency-domain channel parameter measurements

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 to the open rural farm country outside of Boulder, Colorado. Both wideband and narrowband 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.

Narrowband Mobile Channel Measurements

ITS researchers developed a novel narrowband measurement system that has exceptional measurement fidelity. This system is based on a signal generator and vector signal analyzer and two rubidium clocks to provide high-precision signal measurement capabilities. The system can be deployed in either a fixed-to-mobile or a mobile-to-mobile configuration. It can measure both time- and frequency-domain radio channel parameters such as envelope fading and the power spectrum. We used this system to perform a comprehensive series of measurements in residential areas adjacent to the Department of Commerce Laboratories in Boulder, Colorado. Good results were obtained and both Rayleigh and Rician channels were observed along with a wide variety of channel power spectra. The results of this effort were presented at a special session on spectrum management (TC-6) at the IEEE EMC symposium in Pittsburgh in 2012.

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 are writing a report that identifies and corrects the mathematical errors and presents corrected conclusions. We expect this report to be published in 2013.

UWB Measurement System Development

The Broadband Wireless Research project is currently developing a short-range ultrawideband (UWB) 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 developing 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 28).

Above: ITS-developed propagation measurement system undergoing laboratory evaluation. Photo by Bob Johnk.

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.

Related Publication:

Robert T. Johnk, Chriss A. Hammerschmidt, Mark A. McFarland, and John J. Lemmon, "A Fast-Fading Mobile Channel Measurement System," *2012 IEEE International Symposium on Electromagnetic Compatibility (EMC2012)*, pp. 584–589, 6–10 Aug. 2012

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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 that 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 legacy services, can cause interference that 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 experience front end overload. This can cause gain compression, higher receiver noise levels, and intermodulation. This problem can be mitigated by legacy front end 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, or allocate communications links using spectrum sharing techniques into the radar band. Interference could occur if the sharing technique fails.

In FY 2010 the U.S. Coast Guard contracted ITS to investigate effects of reallocation to accommodate the broadband radio service (BRS) on S-Band marine radars. 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.

There are two aspects to this problem. First, the marine radar community needs interference protection criteria (IPC) that can be used by regulatory agencies to determine maximum transmitted power levels and minimum separation distances. Regulatory agencies of interest are the International Telecommunication 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).

In FY 2010 our work focused on examining prior work and assembling relevant models for our investigation. In FY 2011 we investigated the first potential threat—weak unwanted spurious signals from a communications link.

Current Work

In FY 2012, we investigated the second potential threat, i.e., marine radar front end overload from the BRS signal outside the radar detection bandwidth. Our goal was to determine how much radar front end filter attenuation is needed to prevent overload over a range of separation distances. Results from this work are being published in an NTIA report which is currently in review.

The first step was to determine the allowable interference power at the input to the front end. Front end overload is a non-linear effect which is difficult to analyze mathematically. Consequently we chose to determine the allowable interference power through laboratory measurement. Figures 2 and 3 show the laboratory measurement test fixture and magnetron marine radar front end assembly tested by it.

Once the allowable interference power was known, we developed a link power budget to determine the front end filter attenuation and propagation loss needed to meet the allowable interference power. The link power budget included the power from all the basestations (the aggregate power). Propagation and antenna pattern losses determine how much of each basestation's power is included in the aggregate power.

Finally, the minimum separation distance was determined from the propagation loss using propagation models. Because of atmospheric conditions, propagation loss in the maritime temperate environment varies with location and time. Hence we can only predict minimum separation distances needed to satisfy particular reliability requirements.

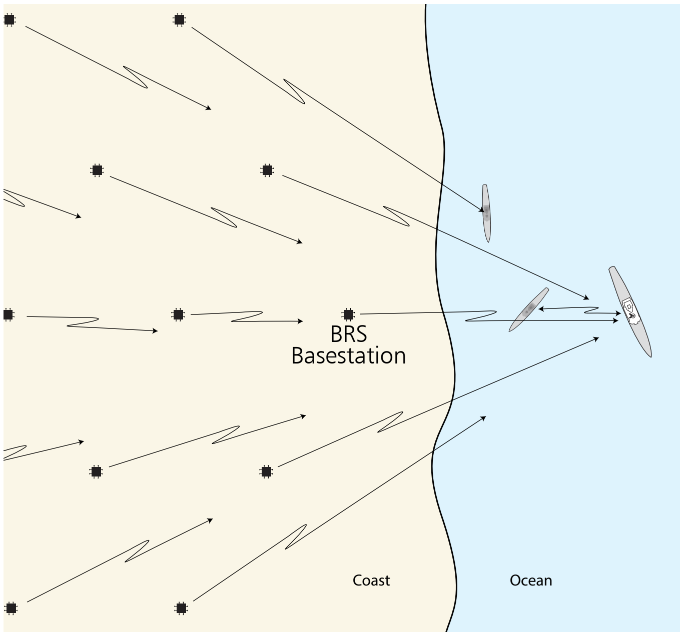
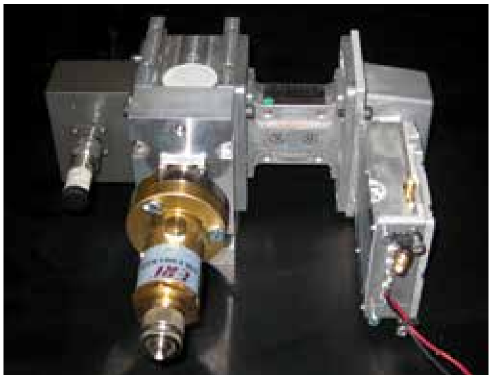


Figure 1 (left). Interference scenario showing a network of BRS base stations contributing to the interference power. BRS basestation height allows the BRS signal to travel significant distances. The BRS signal can cause the radar to not see the boat between the BRS basestation and the ship using the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

Figure 2 (lower left). Front end overload laboratory test fixture. From top to bottom in equipment rack: vector signal generator, vector signal analyzer, bandpass filter, signal generator to emulate the radar signal, reference front end and IF, magnetron front end, power supplies, and local oscillator signal generator. Photo by R. Achatz.

Figure 3 (lower right). Magnetron front end assembly. Components (from left to right) are waveguide terminator, circulator, limiter, and low noise front end. Photo by R. Achatz.



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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*
- *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.

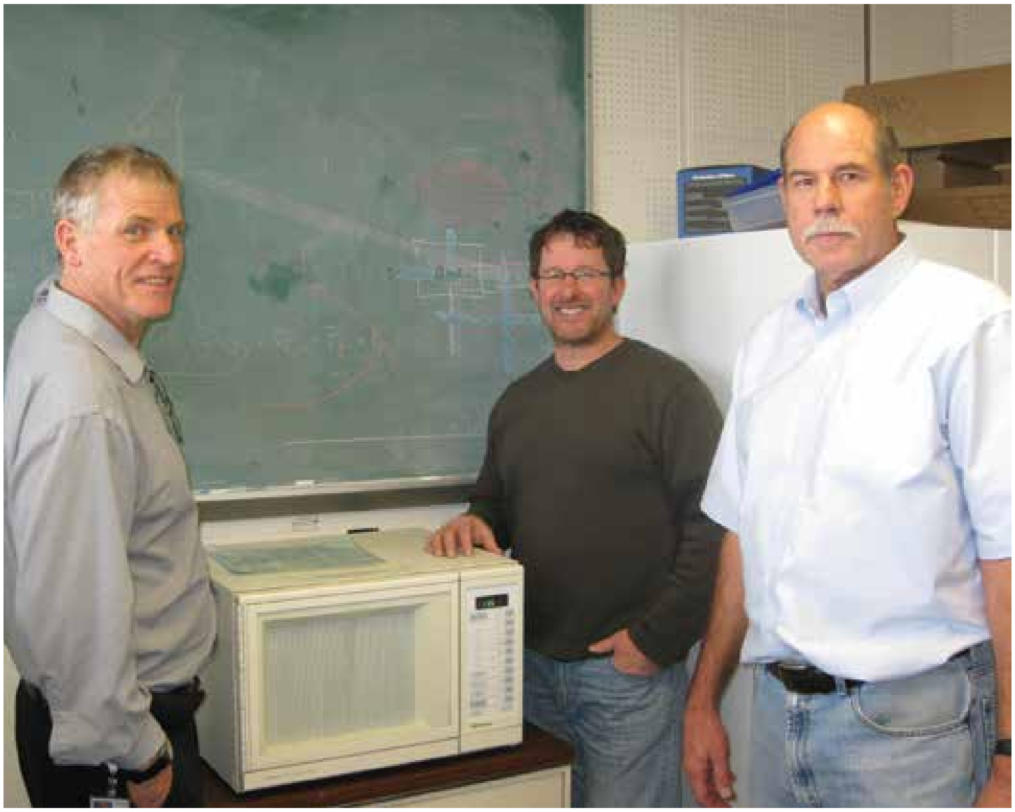
Current Work

Work this year consisted of the continued development of a radar model, investigating the effects of desired-link path-loss variability when establishing IPC, developing new methodologies for spectrum occupancy analysis, and publishing the proceedings of the 2012 ISART conference.

We continued 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 that use non-coherent integration to modeling the more modern solid state radars that use matched filter detection with coherent integration. Solid state radars are preferred by industry due to their lower maintenance costs and the ease with which signal characteristics can be controlled. This year we demonstrated that the matched filter detection used by solid state radars was not compromised by target movement at slower speeds. At higher speeds, error is introduced but it can be compensated for through signal processing.

Interference protection criteria are often established with path-loss variability in the interfering-signal path but not in the desired-link path. The reason path-loss variability is not often included in the desired-link path is the complicated way statistics from the propagation model must be manipulated to determine the joint statistics of interfering and desired paths. However, this omission could potentially introduce significant error in estimating IPC. In FY 2012 we demonstrated how the joint statistics of interfering and desired paths could be used to determine IPC to protect marine radars from broadband radio service spurious emissions.

Spectrum band occupancy measurements are often performed over large spectrum ranges. This approach often results in long time periods between measurements of the same band and, consequently, poor estimates of band occupancy. In FY 2012, we investigated how reducing the time between measurements would allow us to estimate channel occupancy second-order statistics, such as statistics of how long a channel within a band is continuously occupied, and use the statistics to better predict band occupancy. This technique was used to estimate the occupancy of a Federal radar band which could potentially be shared with private industry. We are currently working on an NTIA report that will discuss results of the measurement.



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

Related Publication:

Michael Cotton, Madelaine Maior, Frank Sanders, Eric Nelson, and Douglas Sicker, "ISART 2011 Proceedings - Developing Forward Thinking Rules and Processes to Fully Exploit Spectrum Resources: An Evaluation of Radar Spectrum Use and Management," NTIA Special Publication SP-12-485, March 2012

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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

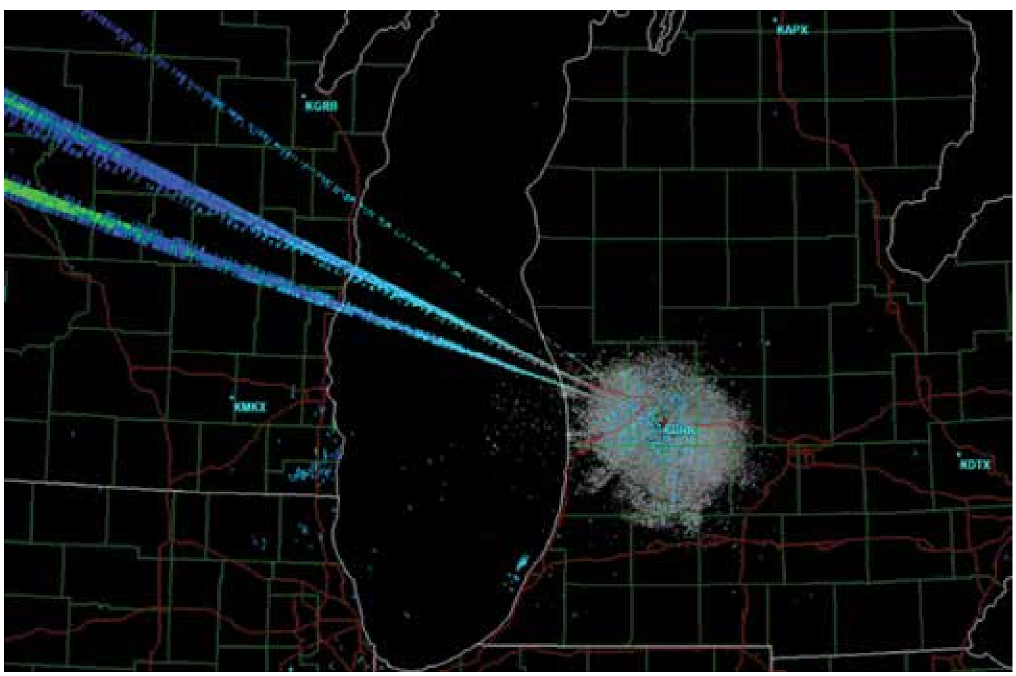
- *Predictions of the effects of interference from non-radar systems to weather radars*
- *Measurements of interference effects at 3 GHz NEXRAD weather radar sites and measurements of emission spectra of interference sources*
- *Development of interference-mitigation techniques for 3 GHz NEXRAD weather radars*
- *Release of an NTIA Report detailing the NEXRAD interference and technical solutions to mitigate the interference*

Overview

In FY 2012, ITS and OSM engineers found solutions for ongoing radio interference to 3 GHz NEXRAD weather radars operated by the National Weather Service (NWS) and other agencies at locations across the United States. An NTIA Technical Report was released which described the problem and technical solutions for it. It followed up on work that NTIA engineers had earlier performed at field sites at Grand Rapids, Michigan; Jacksonville, Florida; and Herndon, Virginia, and on analysis performed by ITS engineers in Boulder and OSM engineers in Washington, DC.

Interference to weather radars at 3 GHz has been caused by adjacent-band emissions from communication transmitters. ITS, working jointly with the NWS, the Federal Communications Commission, the Federal Aviation Administration and the private sector, measured not only the interference in the victim receivers but also the emission spectra of the interference sources.

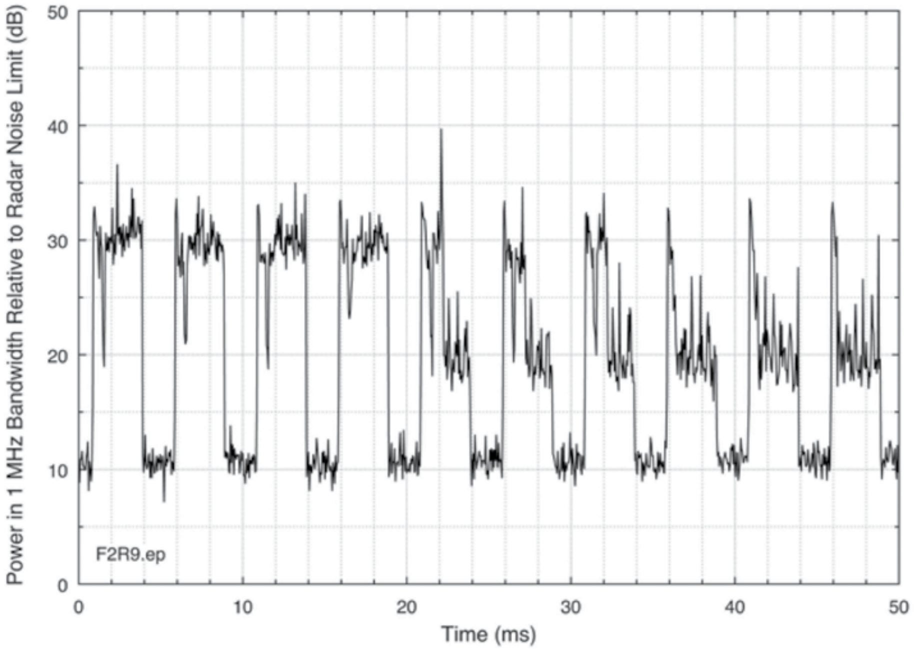
These measurements, made under controlled conditions, provided confidence that the interference can be resolved via technical means at nearly all sites where it occurs. Careful planning has been identified as a critical component for compatible operations between broadband communication transmitters and sensitive adjacent-band radar receivers.



Interference effects (radial lines, called strobes) from a communication transmitter as seen on a NEXRAD weather radar display screen.

Left: A tower with communication transmitters that can interfere with NEXRAD weather radars.
Right: A NEXRAD weather radar tower. Photos by Frank Sanders.

Left: A tower with communication transmitters that can interfere with NEXRAD weather radars. Right: A NEXRAD weather radar tower. Photos by Frank Sanders.



Communication signal (raised pulses) observed by NTIA engineers in a NEXRAD weather radar receiver. The pulses form the lines seen in the figure on the previous page.

Related Publication

Frank H. Sanders, Robert L. Sole, John E. Carroll, Glenn S. Secrest and T. Lynn Allmon, "Analysis and Resolution of RF Interference to Radars Operating in the Band 2700–2900 MHz from Broadband Communication Transmitters" NTIA Technical Report TR-13-490, October 2012.

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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 TPQ-53 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 other Government agencies and in the private sector via Interagency Agreements (IA) and Cooperative Research and Development Agreements (CRADA), respectively. These agreements provide benefits for both the Government and the private-sector partners.

The Institute has developed highly specialized capabilities for performing radar spectrum engineering criteria (RSEC) measurements on radar transmitters.[1] Procedures for RSEC measurements are provided in available literature, but building measurement systems that can perform these measurements can be prohibitively difficult and expensive for an organization, as compared to working directly with ITS to perform the measurement.

When organizations set up IAs or CRADAs with ITS, the Institute's specialized capabilities can be made available for RSEC measurements. This includes the use of ITS measurement systems in the Radio Spectrum Measurement Science (RSMS) program. The RSMS systems are well adapted for measurements at field sites. The RSMS systems can be especially useful when RSEC measurements have to be performed at remote locations where the measurement system has to sit in the open, at an extended distance from any power sources or other local support infrastructure.

In FY 2012 ITS undertook and completed a CRADA with the Lockheed Martin Company (LMCO). Under this CRADA, ITS engineers performed RSEC emission-spectrum measurements on a new LMCO battlefield counter-fire radar, the TPQ-53. Emission spectrum measurements were performed on this new radar at the Yuma Proving Ground in Arizona, using a specialized radar emission measurement system housed in the RSMS vehicle.

The TPQ-53 radar detects and tracks artillery rounds, short-range rockets and mortar rounds in flight. Live fire tests were conducted while the ITS measurements were in progress. The measurement results were analyzed by ITS engineers and provided to the sponsor per the terms of the CRADA; the final data set provided for spectrum certification for the radar under the NTIA RSEC. These measurements, and the analysis results, helped to move this important new system forward to deployment with U.S. and allied forces worldwide.

1. F. H. Sanders, R. L. Hinkle and B. J. Ramsey, "Measurement procedures for the radar spectrum engineering criteria (RSEC)", NTIA Report TR-05-420, U. S. Department of Commerce, Mar. 2005. http://www.its.bldrdoc.gov/publications/2450.aspx

A TPQ-53 counter-fire radar during RSEC compliance measurements at the Yuma Proving Ground. Photo by Frank Sanders, courtesy LMCO and U.S. Army release.

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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 Department of Defense 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 to not 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. An NTIA Technical Report that provides a comprehensive discussion of the measurement methods and results obtained was written and published at the beginning of FY 2013.

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.

Related Publication

Robert T. Johnk, Frank H. Sanders, Kristen Davis, Geoffrey A. Sanders, John D. Ewan, Ronald L. Carey, Steven J. Gunderson, "Conducted and Radiated Emissions Measurements of an Ultrawideband Surveillance Radar" NTIA Technical Report TR-13-491, November 2012.

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The advent of digital video compression, storage, and transmission systems has exposed fundamental limitations of techniques and methodologies traditionally used to measure video performance. A new measurement paradigm is needed, one that is tailored to the performance characteristics of digital video systems. Ideally, it will perceive and measure video impairments like a human being. The ITS Video Quality Research Program develops software tools to implement this new paradigm by rapidly and economically measuring video quality.

Video Quality Research

Outputs

- *Improved techniques to measure video quality*
- *Development of software tools*
- *Distribution of test video*
- *Publication of technical papers*
- *Representation of U.S. 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.

Subjective Testing

In FY 2012, ITS began research into improved subjective testing techniques to measure the impact of video on speech perception. These techniques will be useful for follow-on studies into the level of video quality needed to communicate using a visual language such as American Sign Language (ASL).

As a first step, ITS filmed interviews of people signing conversations. To ensure accurate measurements, the filming included a large variety of people with different signing behaviors. With the assistance of a Deaf ASL Specialist, this footage will enable future experiments to determine the level of video quality that allows participants to sign freely over any video link—without having to change/modify their signing to be understood via video.

ITS leads an effort within the ITU-T Study Group 9 to produce a draft new Recommendation for audiovisual subjective testing. This document seeks to accommodate the needs of researchers and developers to test modern video devices in non-traditional environments, such as a noisy cafeteria.

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 four years, over 2400 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, the NTIA Fast Low Bandwidth Model, and the Video Quality Model with Variable Frame Delay (VQM_VFD).

The PSNR Model has wide industry acceptance but the NTIA models offer improved accuracy. The NTIA General Model and NTIA Fast Low Bandwidth Model were evaluated by the Video Quality Experts Group (VQEG, www.vqeg.org) and standardized by the prestigious International Telecommunication Union (ITU).

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

In FY 2012, 187 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 has made 2500 video clips available on CDVL, including VQEG's high definition television (HDTV) dataset.

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.

Sample frames from videos depicting people who sign in American Sign Language (ASL) as their main means of communication. Each participant was filmed signing a natural conversation in ASL. The conversation in the footage looks like it took place over a high quality video link. Photos by Tom McDonald of Fire Side Productions

Related Publication:

Margaret H. Pinson, Lucjan Janowski, Romuald Pépion, Quan Huynh-Thu, Christian Schmidmer, Phillip Corriveau, Audrey Younkin, Patrick Le Callet, Marcus Barkowsky, and William Ingram, "The Influence of Subjects and Environment on Audiovisual Subjective Tests: An International Study," *IEEE Journal of Selected Topics in Signal Processing*, Vol. 6, No. 6, October 2012, pp. 640–651

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A unique combination of past experience, current knowledge, specialized tools, and experimental facilities enable ITS to perform advanced telecommunications research and solve complex telecommunications problems. These resources are shared through interagency 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.

ITS Tools and Facilities

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.

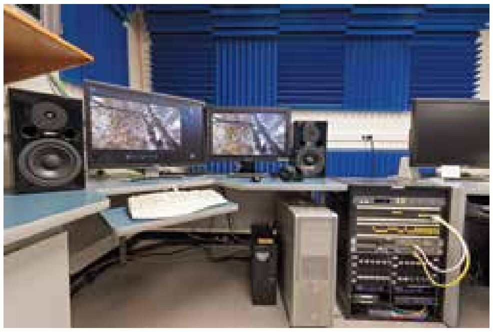
Unique Capabilities

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.



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. Middle: 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.

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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Automated Wideband Noise Measurement System

Several years ago, 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 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.

While the system is fully capable of, and has been used for, conducting outdoor noise measurements, several limitations of the system have become apparent. These limitations include a susceptibility to signal overloads, the inability to adjust the analog sampling rate, limited anti-aliasing filtering, no capability to include an external IF filter before the digitizer, and a restriction on center frequency agility. A new two-channel measurement system has recently been designed that will overcome these limitations. The new system consists of one very sensitive RF channel and another less sensitive RF channel. Measurements are taken on both channels simultaneously with processing used to extract the composite data.

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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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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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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 system 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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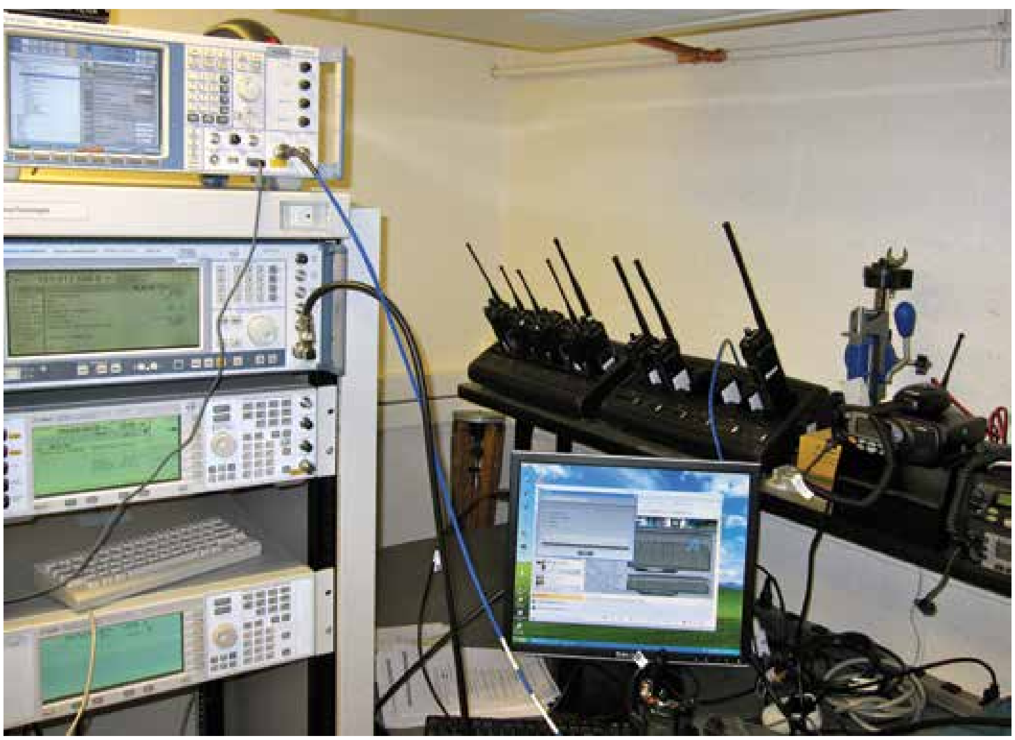
Public Safety Audio and Video Laboratories

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 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.



Racks of commercial off-the shelf public safety communications equipment used for testing in the Public Safety Audio Quality Research Laboratory. Photo by Ken Tilley.

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 narrowband 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 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 research in accordance with the Telecommunications Industry Association (TIA) Project 25 (P25) standards (TIA 102). Another ongoing effort supports activities related to the P25 CAI testing standards in order to further the goals of the Project 25 Compliance Assessment Program (P25 CAP).

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. This effort also includes development of techniques to bridge LTE and P25 technologies.

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

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Pulsed Radar Target Generator

The Pulsed Radar Target Generator is an electronic tool used to produce targets on a radar screen. The generator produces signals that simulate the returns that would normally be seen by a radar from targets in the environment. The signals are injected into the radar's receiver at the normal frequency of operation. Some radar models transmit modulated pulses. The generator can produce modulated pulses such as chirped and phase coded modulations (including the popular Barker code set).

Several parameters of the signals can be adjusted over a wide range to be compatible with several different radar models. For the same model radar, the number of targets and the range to the targets can be adjusted. Other adjustments include the displayed bearing of the targets and whether the targets are stationary or moving along concentric circular paths. Compensation adjustments can be made for radars that have large tolerances in their operating specifications.

The targets can be set to occur at a fixed time interval after a timing pulse (for example, beginning of scan) supplied by the radar. The generator can be used to verify operation or troubleshoot the radar under test. ITS has used the generator to provide simulated desired signals in interference studies where interference is injected into the radar and the effect on the targets is recorded.

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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 four years, a new ultrawideband 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.

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. 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 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.

Controlling the RSMS system is the custom measurement automation software, developed internally. The software suite, now in its 5th generation, provides functionality that can easily accommodate new equipment and different hardware configurations, and expand on existing measurement capabilities. The RSMS 5th generation software suite (RSMS-5G) makes use of modern software development environments, 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

Two monopole-on-a-ground-plane antennas set up for near-Earth propagation measurements at Table Mountain. Photo by S. Carroll.

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:

LTE antenna at the Table Mountain site—one of two fixed transmitters on the Public Safety 700 MHz Broadband Demonstration Network test network. Photo by Ken Tilley

- 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 entities are encouraged at the site. Learn more online at: http://www.its.bldrdoc.gov/resources/table_mountain.

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Telecommunications Analysis Services

The Telecommunications Analysis (TA) Services program provides the latest ITS-developed engineering models and research data to industry and other Government agencies via the web. 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 developed models that predict communication system coverage and interference for many broadcast applications. New models in the GIS environment have been developed. Programs available through TA Services include:

- HAAT—Calculates Height Above Average Terrain for an antenna at a specified location.
- PCS/LMDS—Allows the user to create or import surfaces which may include terrain, buildings, vegetation, and other obstructions in order to perform line of sight (LOS) and diffraction studies. FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND—Allows the user to search the FCC database for particular stations or by search radius around a point of interest.
- PROFILE—Extracts path profiles according to user-specified input parameters. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also receive plots of the profiles adjusted for various K factors. For microwave links, Fresnel zone clearance can be determined so that poor paths can be eliminated from a planned circuit or network.
- SHADOW—Plots the radio line of sight (LOS) regions around a specified location in the U.S. using digitized topographic data. The program shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS.
- TERRAIN—Plots terrain elevation contours from any of the terrain databases available (1 arc-second Spatial Data Transfer Standard for CONUS, 3 arc-second U.S. Geological Survey, and GLOBE for the whole world).
- COVERAGE—Calculates the received signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial

and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model (ITM) can be chosen for calculations.

- CSPM—Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical maps, or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses the ITS ITM in a point-to-point mode, or other user-chosen algorithms for path loss calculation.
- HDTV—Allows users to analyze interference scenarios for proposed digital television (DTV) stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all program users. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in his/her catalog.
- NWS—A specialized application that helps the National Weather Service maintain its catalog of weather radio stations (currently about 920).
- PBS—An analysis model similar to the HDTV model, but specialized for Public Broadcasting Services (PBS) stations. Typical outputs may consist of composite plots showing Grade A and B coverage of several stations or "overlap" plots which show areas covered by more than one station.
- ICEPAC/VOACAP/REC533—High frequency prediction models that can be downloaded free and executed on Windows based platforms.
- ITM—Source code available for the ITS Irregular Terrain Model (Longley/Rice).
- IF-77—Source code available for the IF-77 Air/Ground, Air/Air, Ground/Satellite prediction software (.1 to 20 GHz).

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Wireless Networks Research Center

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

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

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❝Scientific progress relies on the broad and open dissemination of research results.❞

Department of Commerce Administrative Order DAO 219-1, Public Communications

ITS Publications and Presentations in FY 2012

NTIA Publications

Frank H. Sanders and Roger A. Dalke, "Relationships between measured power and measurement bandwidth for frequency-modulated (chirped) pulses," NTIA Technical Report TR-12-488, August 2012

Measured power levels for radio frequency (RF) pulses that are frequency modulated (chirped) vary as a function of the bandwidth in which the measurement is performed; if chirped pulses cause RF interference, the power levels of the pulses in victim receivers will likewise vary as a function of receiver bandwidth. This report provides both heuristic and rigorous derivations of the relationships among chirped pulse parameters and the measured peak and average power levels of chirped pulses as a function of measurement bandwidth. These relationships may be best understood via a single graph (Figure 3) presented in this report. This report supplements NTIA Technical Reports TR-05-420, TR-10-465 and TR-10-466, in which the formula for minimum bandwidth needed for measurement of full peak power in chirped pulses is presented but not derived.

Frank H. Sanders, "The rabbit ears pulse-envelope phenomenon in off-fundamental detection of pulsed signals," NTIA Technical Report TR-12-487, July 2012

When radiofrequency pulse envelopes are observed away from their fundamental frequency their shapes differ from those at their fundamental frequency. Off-fundamental pulse envelopes tend to exhibit spikes at their rising and falling edges with lower-amplitude energy between the spikes. This phenomenon, called the rabbit ears effect, is described in this NTIA Report. Examples of rabbit ears pulse envelopes are provided in a mathematical simulation and from measurements of off-fundamental pulse envelopes of two models of 5 GHz weather radars. Morphologies of rabbit ears pulses are examined. A method is provided for using this effect to determine the durations and bandwidths of chirped pulses in bandwidth-limited measurement systems. Implications for off-fundamental detection of pulsed signals for dynamic frequency selection (DFS) algorithms are considered.

John E. Carroll, Geoffrey 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 III, NTIA Technical Report TR-12-486, June 2012

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 measurements of gust fronts, windshear, microbursts, and other weather hazards for improved safety of operations in and around airports. National Telecommunications and Information Administration (NTIA) engineers, with assistance from FAA engineers, determined the interference to be caused by some unlicensed national information infrastructure (U NII) dynamic frequency selection (DFS) devices operating in the same frequency band as TDWR systems. These devices use DFS technology that is supposed to detect the presence of nearby co-channel radars and change operating frequencies to prevent interference to those radars. This report, the third of a three-part series, describes some U NII emission spectra and introduces an additional set of TDWR test waveforms that the Federal Communications Commission (FCC) may use during DFS U NII device testing. This report also explores the distances and geometries at which interference to TDWRs from U NII devices is likely to occur.

Michael Cotton, Madelaine Maior, Frank Sanders, Eric Nelson, and Douglas Sicker, "ISART 2011 Proceedings - Developing forward thinking rules and processes to fully exploit spectrum resources: An evaluation of radar spectrum use and management," NTIA Special Publication SP-12-485, March 2012

These are the proceedings for the 2011 International Symposium on Advanced Radio Technologies hosted by the National Telecommunications and Information Administration's Institute for Telecommunication Sciences in Boulder, Colorado. The conference focused on radar spectrum usage and management. It included radar tutorials; spectrum inventory briefings; and moderated discussions about radar policy, spectrum management, research and technology, and regulatory issues related to sharing radar spectrum. Overall, ISART 2011 successfully brought together the radar and communications communities to identify spectrum issues and discuss ways to make radar systems and spectrum more efficient. Conclusions drawn at this year's conference were that better spectrum management in radar bands is a multi-faceted problem spanning economic, regulatory, and technical issues. Technical concepts and solutions were identified that could improve radar spectrum efficiency. Examples include radar transmitter upgrades to improve out-of-band emissions; using adaptive and cognitive antennas and signal processing to avoid, mitigate, and prevent interference; and consolidation of multiple radar systems, functions, and/or operational bands into a single platform. In regards to sharing radar spectrum as a means to increase spectrum utilization, radar usage models that offer whitespace opportunities were identified. Radar spectrum improvement projects, however, have technical challenges and tend to be large and expensive. Further, current funding models do not support wide scale development for the sake of spectrum efficiency. The path forward involves the development of a cohesive long-term radar spectrum strategy that reduces large radar projects into incremental and manageable steps with limited risk. Similarly, incremental regulatory reform is needed to enable spectrum sharing rules to be implemented in manageable increments with a "crawl-walk-run" approach.

Nicholas DeMinco, Robert T. Johnk, Paul McKenna, Chriss A. Hammerschmidt, and J. Wayde Allen, "Free-field measurements of the electrical properties of soil using the surface wave propagation between two monopole antennas," NTIA Technical Report TR-12-484, January 2012

This report describes one of three free-field radio frequency (RF) measurement systems that are currently being developed by engineers at the Institute for Telecommunication Sciences (NTIA/ITS). The objective is to provide estimates of the electrical properties of the ground (permittivity and conductivity) over which the measurement systems are deployed. This measurement system uses transmission loss measurements between two monopoles placed close to the ground at specific separation distances. Soil properties are extracted by comparing measured data with known analytical models and optimizing the results.

Journal Articles

Margaret H. Pinson, William Ingram, and Arthur Webster, "Audiovisual quality components: An analysis," ***IEEE Signal Processing Magazine*****, vol. 28, no. 6, pp. 60-67, November 2011**

The perceived quality of an audiovisual sequence is heavily influenced by both the quality of the audio and the quality of the video. The question then arises as to the relative importance of each factor and whether a regression model predicting audiovisual quality can be devised that is generally applicable.

Conference Papers

J.W. Allen, "A 3-axis antenna array for polarimetric spectrum surveys," ***2012 IEEE International Symposium on Electromagnetic Compatibility (EMC)*****, pp. 575–578, 6–10 Aug. 2012**

Complete and accurate characterization of the radio environment is necessary for effective management of an increasingly congested radio spectrum. Unfortunately most antenna systems commonly used to perform spectrum surveys only respond strongly to signals with one polarization and from a limited number of directions. This paper describes an easily constructed antenna array that can detect signals from a very broad range of directions, determine the total RF power at a given location regardless of polarization, and provide information about the polarization and arrival direction of signals.

R.T. Johnk, C.A. Hammerschmidt, M.A. McFarland, and J.J. Lemmon, "A fast-fading mobile channel measurement system," ***2012 IEEE International Symposium on Electromagnetic Compatibility (EMC)*****, pp. 584–589, 6–10 Aug. 2012**

We describe a prototype propagation measurement system based on a combination of a spectrum analyzer and a vector signal analyzer. The system is designed to measure the characteristics of a narrowband mobile radio channel.

Four ITS-authored Conference Papers were accepted at the 2012 IEEE International Symposium on Electromagnetic Compatibility (EMC).

We present results from a commercially-available fading simulator and fixed-to-mobile measurements performed in Boulder, Colorado. The results obtained look promising and the system demonstrates excellent measurement fidelity.

M.A. McFarland and R.T. Johnk, R.T., "Characterizing an S-band marine radar receiver in the presence of interference," *2012 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, pp. 579–583, 6–10 Aug. 2012

Characterizing the effects that out-of-band interference has on the performance of an S-band marine radar receiver's IF output normally requires non-linear network analysis. We have developed a non-linear network analyzer from commonly available laboratory instruments. Our automated system operates over a broad range of interferer frequencies and power levels. It enables the collection of the data required for an extensive analysis of a radar receiver's AM-AM and AM-PM performance in the presence of interference. With this data, engineers can begin to make recommendations on protecting these radars from potential interference.

H. Ottke and C. Hammerschmidt, "Specialized algorithms for spectrum surveys," *2012 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, pp. 565–570, 6–10 Aug. 2012

With increased demand in the radio spectrum, there have been multiple recent campaigns to quantify spectrum occupancy through measurements. These measurements can pose many challenges, one of which is created by impulsive noise. Below 500 MHz, impulse noise can be particularly prominent and mimic narrowband LMR emissions during measurements that use common swept spectrum measurement techniques. This paper discusses methods to properly measure the intentionally radiated signals in the environment while minimizing measurement of unintentional emissions and describes processing algorithms that may be used to assist in distinguishing between LMR emissions and impulsive noise.

A. Catellier, M. Pinson, W. Ingram, A. Webster, "Impact of mobile devices and usage location on perceived multimedia quality," *2012 Fourth International Workshop on Quality of Multimedia Experience (QoMEX)*, pp. 39–44, 5–7 July 2012

We explore the quality impact when audiovisual content is delivered to different mobile devices. Subjects were shown the same sequences on five different mobile devices and a broadcast quality television. Factors influencing quality ratings include video resolution, viewing distance, and monitor size. Analysis shows how subjects' perception of multimedia quality differs when content is viewed on different mobile devices. In addition, quality ratings from laboratory and simulated living room sessions were statistically equivalent.

Presentations

- Andrew Catellier, "Quality of Subsampled Video on Mobile Devices," Video Quality Experts Group (VQEG), December 12-16, 2011.
- Joel Dumke, "Evaluating Video Quality in Public Safety Applications," 4th IEEE International Workshop on Future Multimedia Networking, 2012 IEEE Consumer Communications & Networking Conference (CCNC 2012), Las Vegas, NV, January 14, 2012.
- Margaret Pinson, Keynote Address: "NTIA Video Quality Metrics: Calibration, Models and

ITS engineer Andrew Catellier presenting at the Video Quality Experts Group (VQEG) meeting in December 2011. Photo by Arthur Webster.

Validation," Sixth International Workshop on Video Processing and Quality Metrics (VPQM), Scottsdale, AZ, January 20, 2012.

- DJ Atkinson, "P25/VoLTE Interconnection: Initial Voice Performance Indicators," International Wireless Communications Exposition (ICWE), Las Vegas, NV, February 22, 2012.
- Jeffrey Bratcher, "Public Safety Broadband Demonstration Network," International Wireless Communications Exposition (ICWE), Las Vegas, NV, February 22, 2012.
- DJ Atkinson, "Where are we with audio intelligibility in P25?," International Wireless Communications Exposition (ICWE), Las Vegas, NV, February 22, 2012.
- Jeffrey Bratcher, "Demo Network Test Results: Background and Methodology," Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting, Broomfield, CO, March 6, 2012.
- Dr. Rob Stafford, "Public Safety Communications Research," Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting, Broomfield, CO, March 6, 2012.
- Andrew Thiessen, "NPSTC Broadband Requirements," Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting, Broomfield, CO, March 7, 2012.
- DJ Atkinson, "Initial LTE Voice Performance Indicators," Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting, Broomfield, CO, March 7, 2012.
- Andrew Thiessen, "Public Safety Communications Research (PSCR) Program," Public Safety 700 MHz Demonstration Network Spring 2012 Stakeholder Meeting, Broomfield, CO, March 7, 2012.
- Jeffrey Bratcher, with Dereck Orr (NIST), "Project 25 Compliance Assessment Program (P25CAP)," Association of Public-Safety Communications Officials Australasia (APCO Australasia) 2012 Conference & Exhibition, Queensland, Australia, March 12–14, 2012.
- Andrew Thiessen, "Public Safety Communications Research (PSCR) Program," Urgent Communications Webinar on *Next Generation Communications: What does it Mean to You?*, March 15, 2012.
- Paul McKenna, "Integration of the Irregular Terrain Model into the Federal Spectrum Management System, Release 2.0 (FSMS R 2.0)," Teleconference, April 11, 2012.
- Chriss Hammerschmidt, "Initial Results from Three Spectrum Survey Campaigns," 13th Annual International Symposium on Advanced Radio Technologies (ISART 2012), Boulder, CO, July 25, 2012.
- Mike Cotton, "Spectrum Occupancy Measurements of the 3500-3650 MHz Maritime Radar Band Near San Diego, CA,"
- Jeffrey Bratcher, Rob Stafford, and Andrew Thiessen, with Dereck Orr, Emil Olbrich, and Michael Souryal (NIST), "A Nationwide 700 MHz Public Safety Broadband Network," presented at the 78th Annual Association of Public-Safety Communications Officials – International (APCO International) Conference & Expo, Minneapolis, MN, August 20, 2012.
- Arthur Webster and Margaret Pinson, with Philip Corriveau (Intel Labs) and Vittorio Baroncini (Fondazione Ugo Bordoni, Italy), " Tutorial on Standardization Trends in Video/Multimedia Quality Assessment," presented at the 2012 IEEE International Conference on Image Processing (ICIP), Orlando, FL, September 30, 2012.

ITS engineer Dr. Rob Stafford presenting at the Public Safety Demonstration Network Spring 2012 Stakeholder Meeting. Photo by Ken Tilley.

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Technical standards formally document common norms or requirements for technical systems. Timely promulgation of new standards for emerging technologies gives industry the confidence to invest in new products, broadens the market, and protects buyers' investments. This technology transfer method directly promotes U.S. competitiveness in telecommunications.

ITS Standards Leadership Roles and Technical Contributions in FY 2012

ITS provides technical contributions to standards development organizations (SDO), standards related organizations (SRO), and other organizations that informally contribute to standardization. For over half a century, ITS has held technical leadership roles and provided research-based technical contributions to support U.S. Administration positions in formal national and international SDOs. These include:

- International Telecommunication Union Radiocommunication Sector (ITU-R)
- International Telecommunication Union ITU Telecommunication Standardization Sector (ITU-T)
- Alliance for Telecommunications Industry Solutions (ATIS)
- Telecommunications Industry Association (TIA)
- 3rd Generation Partnership Project (3GPP)

In recent decades, the scope of this technology transfer effort has expanded to support the technical working groups of organizations such as the National Public Safety Telecommunications Council (NPSTC) and the Video Quality Experts Group (VQEG). Reports produced by these bodies inform the deliberations of SDOs and are important precursors to technical standardization. They also inform the policy deliberations of regulatory bodies such as NTIA, FirstNet, and the FCC. ITS provides technical leadership and expertise to these groups through formal and informal contributions.

Standards Leadership

Below is a list of positions held by ITS staff members on various standards development organizations (SDO).

- **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. Delegate to Working Parties 3L and 3K. Subgroup Chair in WP3L.
- **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 (APCO Project 25 Interface Committee). U.S. Department of Commerce Delegate to 3GPP SA (Service and System Aspects) Working Group 2 (Architecture).
- **John E. Carroll:** Delegate to ITU-R Working Party 5B.
- **Paul M. McKenna:** International Chair of ITU-R Study Group 3 Working Party 3K. U.S. Chair of Working Party 3K. International Chair of Subgroup 3K2.
- **Margaret H. Pinson:** Head of U.S. Delegation to ITU-T Study Group 9 (SG9: Integrated broadband cable networks and television and sound transmission). 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 SG9. SG9 contact for Electronic Working Methods. Co-chair of the Video Quality Experts Group's (VQEG) Independent Lab Group (ILG) and Co-chair of its AVHD Group.
- **Patricia J. Raush:** U.S. Co-chair and Head of Delegation of ITU-R Study Group 3 Working Party 3J. Delegate to Working Parties 3J, 3K, 3L, and 3M.
- **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.
- **Teresa Rusyn:** Chair of the Drafting Group and Rapporteur of ITU-R Study Group 3 Correspondence Group 3K3. Member of Working Parties 3K and 3M. Subgroup Chair in Working Party 3L.
- **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 (TSGSA WG1), 3rd Generation Partnership Project (3GPP)

- **Arthur A. Webster:** International Chair of ITU-T Study Group 9 (SG9: Integrated broadband cable networks and television and sound transmission). SG9 representative to ITU-T standardization committee for vocabulary (SCV) and to several 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 ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). Member of U.S. Delegations to ITU-T Study Groups 9 and 16, and to the Telecommunication Standardization Advisory Group. 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). NTIA voting member for the Society of Cable Telecommunications Engineers (SCTE).

Standards Development

Below is a representative list of draft and approved technical standards to which ITS staff contributed in FY 2012. The table shows an approximate count of technical contributions ITS researchers provided in FY 2012 to support the development of these standards and other standards-related activities.

FY 2012 Approximate Count of Technical Contributions to SDOs, SROs, and others	
ITU-R Technical Contributions to SG3	13
ITU-T Technical Contributions/Reports to SG9	9
ATIS Technical Contributions	11
3GPP Technical Contributions	30
VQEG contributing documents	44
NPSTC task group report contributions	2

- TIA TSB-102-B, "TIA-102 Documentation Suite Overview," June 2012 (R. Bloomfield)
- TIA TSB-102-BACC-B, "Project 25 Inter-RF Subsystem Interface Overview," November 2011 (R. Bloomfield)
- TIA TSB-102.BADA, "Telephone Interconnect Overview (Voice Service)," June 2012 (R. Bloomfield)
- TIA TIA-102.BAEA-B, "Project 25 Data Overview and Specification," June 2012 (R. Bloomfield)
- ATIS-P0017 "Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems" draft in progress (T. Riley)
- 3GPP TR22.803, "Feasibility Study for Proximity Services (ProSe) (Release 12) v1.0.0," August 2012 (B. Ward)
- ITU-R Recommendation P.528, "Propagation curves for aeronautical, mobile and radionavigation services using the VHF, UHF and SHF bands," under revision
- ITU-R Recommendation P.533, "Method for the prediction of the performance of HF circuits," under revision
- ITU-R Recommendation P.1546 "Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz," under revision
- ITU-T Draft new Recommendation J.bitvqm, "Hybrid perceptual bitstream video quality assessment" (Study Group 9, Question 12)
- ITU-T Draft New Recommendation J.av-dist, "Methods for subjectively assessing audiovisual quality of internet video and distribution quality television, including separate assessment of video quality and audio quality"

ITS Government Projects in FY 2012

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 SG3/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

Emerging Wireless Technologies

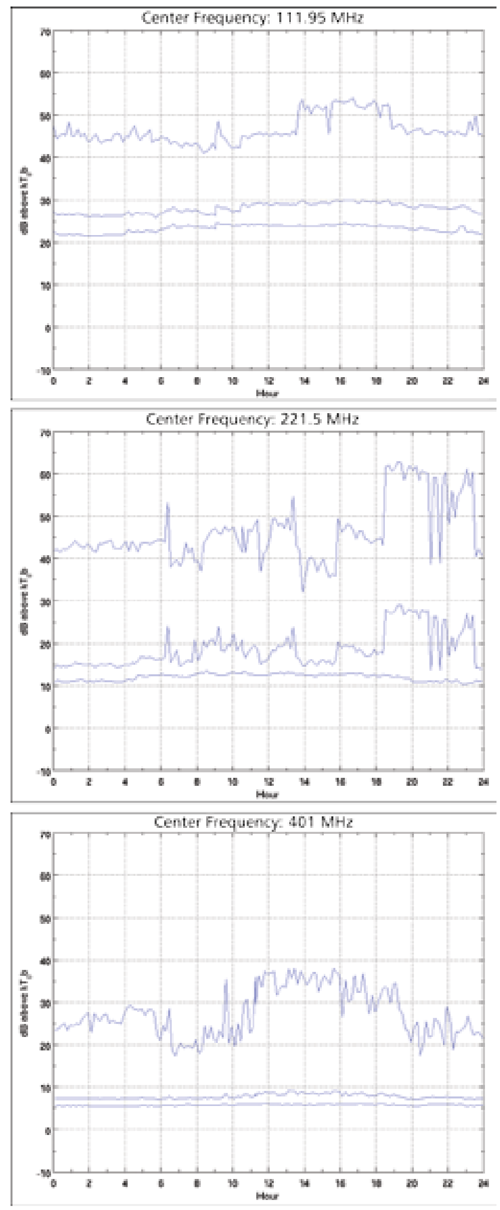
Present technical contributions on PCS interference effects to ATIS Technical Subcommittee WTSC-RAN. Contribute to related fora (e.g., ITU-R Working Parties 5D, 3K, and 3M) as appropriate. Develop a technology-independent, multi-channel PCS interference model for use in the evaluation of CMRS and other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

Project Leader: Timothy J. Riley
(303) 497-5735, triley@its.bldrdoc.gov

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, webster@its.bldrdoc.gov



Graphs of median, mean, and peak noise power in a 1 MHz bandwidth at three different center frequencies measured over a 24 hour period at a business area location during a spectrum usage survey conducted as part of the Noise and Spectrum Occupancy Measurement Research project.

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, webster@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

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

This mini preselector is one of several custom components of the RSMS measurement system designed and built by ITS. Photo by Steve Engelking.

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

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 Interference Resolution

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

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

Setting up the RSMS measurement truck in preparation for taking spectrum occupancy measurements as part of ongoing support to OSM, Photo by Chriss Hammerschmidt.

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

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

Video sequences filmed during a simulated accident training exercise are used in Public Safety Communications Research. Remote personnel could use such links to monitor developing incidents. Top: View of the scene through a pan-tilt-zoom security camera. Middle: Emergency medical technicians and firefighters extract a patient from an automobile wreck, seen through a firefighter or paramedic's helmet camera. Bottom: Emergency medical technicians respond to a burn patient inside an ambulance. One paramedic is calling patient information in to the hospital. An audiovisual communication link is used, so the doctor can see the patient's condition. Stills courtesy of www.cdvl.org.

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, andrew@its.bldrdoc.gov

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

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

Enhancements to Propagation Modeling Website (PMW VHF)

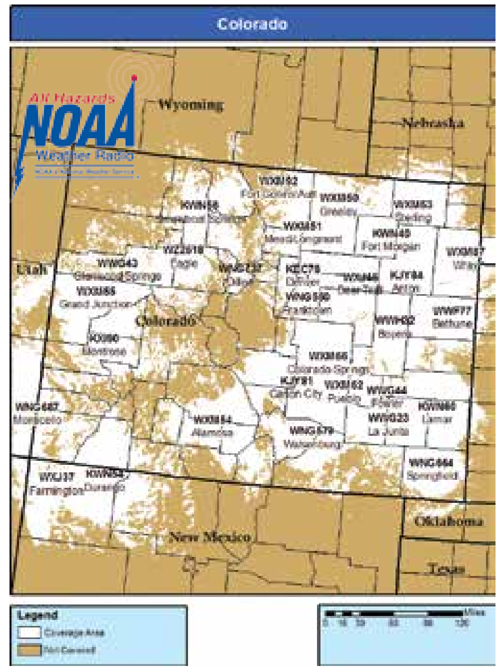
Develop and enhance a web-based multipurpose GIS propagation modeling tool to predict NOAA Weather Radio coverage and integrate 2010 population data to verify that NWR "All Hazards" radio transmissions reach 95% of the population of the U.S. as mandated by law.

Project Leader: Teresa Rusyn
(303) 497-3411, trusyn@its.bldrdoc.gov

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



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 weather radio performance standards and reception tests they must pass before manufacturers are permitted to display the NWR All Hazards logo on their radios. Above, NWR coverage map for the state of Colorado as displayed on the NWS web site. Below, log in page for the PMW VHF web-based modeling tool used to develop coverage maps.

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, 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

DOD / U.S. Navy

SLiMS Testing

Perform a comprehensive set of emissions measurements on a Shore-Line Intrusion Monitoring System (SLiMS) ultrawideband (UWB) radar fence module to ensure that system transmission levels fall below NTIA and Federal Communications Commission (FCC) UWB radiated emissions limits and that the system does not constitute an electromagnetic radiation hazard to either personnel or ordinance (HERP/HERO).

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

Department of Homeland Security (DHS) / Office of Emergency Communications

Coordination Support for the Office of Emergency Communications

Provide support for public safety stakeholder involvement with the PSCR Public Safety Broadband Demonstration Network and the development of public safety broadband requirements and standards in applicable broadband committees and meetings.

Project Leader: Andrew P. Thiessen
(303) 497-4427, andrew@its.bldrdoc.gov

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

DHS / U.S. Coast Guard

Evaluation of Interference to Marine Radars

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

FPS-124 radar on which ITS performed emission measurements. Photo by Frank Sanders.

recommended Marine Radar receiver selectivity standards to minimize interference from and define reasonable adjacent band/out-of-band emissions (OOBE) limits for broadband wireless 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 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

Railroad yardmaster console position uses 6.25 kHz bandwidth digital trunked FDMA radios to communicate with railroad yard personnel. Photos by John Vanderau.

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, characterize 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

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: George Engelbrecht,
(303) 497-4417, gengelbrecht@its.bldrdoc.gov

Abbreviations/Acronyms

3DTV	three-dimensional television
3G	third generation cellular wireless
3GPP	3rd Generation Partnership Project

A

AAR	Association of American Railroads
AC	alternating current
AMBER	America's Missing: Broadcast Emergency Response
AMR	Adaptive Multi-Rate
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials – International
APIC	APCO Project 25 Interface Committee
ARNS	aeronautical radionavigation system
ARSR	Air Route Surveillance Radar
ATIS	Alliance for Telecommunications Industry Solutions
AUGNet	Ad Hoc UAV Ground Network

B

BPL	broadband over power line
BPSK	binary phase shift keying
BRS	broadband radio service

C

CAI	Common Air Interface
CAP	Compliance Assessment Program
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Access
CDVL	Consumer Digital Video Library
CEA	Consumer Electronics Association
CMRS	Commercial Mobile Radio Services
CONUS	continental United States
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

D

DAT	digital audio tape
dB	decibel
DCP	digital sampling channel probe
DFS	dynamic frequency selection
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DSA	dynamic spectrum access
DSR	Document & Standards Reference
DTV	digital television

E

eFRC	electronic Federal Record Center
EMC	electromagnetic compatibility
EMS	emergency medical services
ERB	Editorial Review Board
ERP	effective radiated power
ESRI	Environmental Systems Research Institute

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDMA	frequency division multiple access
FEMA	Federal Emergency Management Agency
FirstNet	First Responders Network Authority
FLC	Federal Laboratory Consortium
FM	frequency modulation
FTTA	Federal Technology Transfer Act
FY	fiscal year

G

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
GSM	Global System for Mobile Communications
GSMA	GSM Association
GUC	generalized use class

H

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

I

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
IMT	International Mobile Telecommunications
IP	Internet protocol
IPC	interference protection criteria
I/Q	in-phase/quadrature
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

J

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
JTG	Joint Task Group

K

kHz	kilohertz
km	kilometer
kW	kilowatt

L

LADAR	laser detection and ranging
LAN	local area network
LF	Low frequency
LF/MF	low frequency/medium frequency
LIDAR	Light Detection and Ranging
LMDS	local multipoint distribution system
LMR	land mobile radio
LNA	low noise amplifier
LOS	line of sight
LTE	Long-Term Evolution

M

MBE	Multi-Band Excitation
MD	multimedia definition
MF	medium frequency
MHz	megahertz
MIL-STD	Military Standard
MIMO	multiple input multiple output
MOS	Mean Opinion Score
MSS	mobile satellite services
MSTV	Association for Maximum Service Television

N

NARA	National Archives and Records Administration
NASA	National Aeronautics and Space Administration
NAVFAC	Navy Facilities Engineering Command
NBSPN	Nationwide Public Safety Broadband Network
NF	noise figure
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPSTC	National Public Safety Telecommunications Council
NSWC	Naval Surface Warfare Center
NTIA	National Telecommunications and Information Administration
NWR	NOAA Weather Radio
NWS	National Weather Service

O

OEC	Office for Emergency Communications
OFDM	orthogonal frequency-division multiplexing
OIC	Office of Interoperability and Compatibility

OLES	Law Enforcement Standards Office
OOBE	out-of-band emission
OSM	Office of Spectrum Management

P

P25	Project 25
PASS	personal alert safety system
PBS	Public Broadcasting Service
PCS	Personal Communications Service
PESQ	perceptual evaluation of speech quality
PMW	Propagation Modeling Website
PN	pseudorandom number
PPDR	public protection and disaster relief
PRQC	Network Performance, Reliability and Quality of Service Committee
PSAL	Public Safety Audio Laboratory
PSBB	public safety broadband
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

Q

QoMEX	International Workshop on Quality of Multimedia Experience
QoS	quality of service

R

R&D	research and development
RAN	radio access networks
RECUV	Research and Education Center for Unmanned Vehicles
RF	radio frequency
RR	reduced reference
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement Science

S

SCTE	Society of Cable Telecommunications Engineers
SD	standard definition
SDO	standards development organization
SDR	software-defined radio
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
SRS	satellite remote sensing

T

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
TSAG	Telecommunication Standardization Advisory Group
TSB	Telecommunications Systems Bulletin
TSG	Technical Specification Group
TV	television

U

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
UN	United Nations
URSI	International Union of Radio Science
USNC	United States National Committee
USRP	universal software radio peripheral
UT	universal time
UWB	ultrawideband

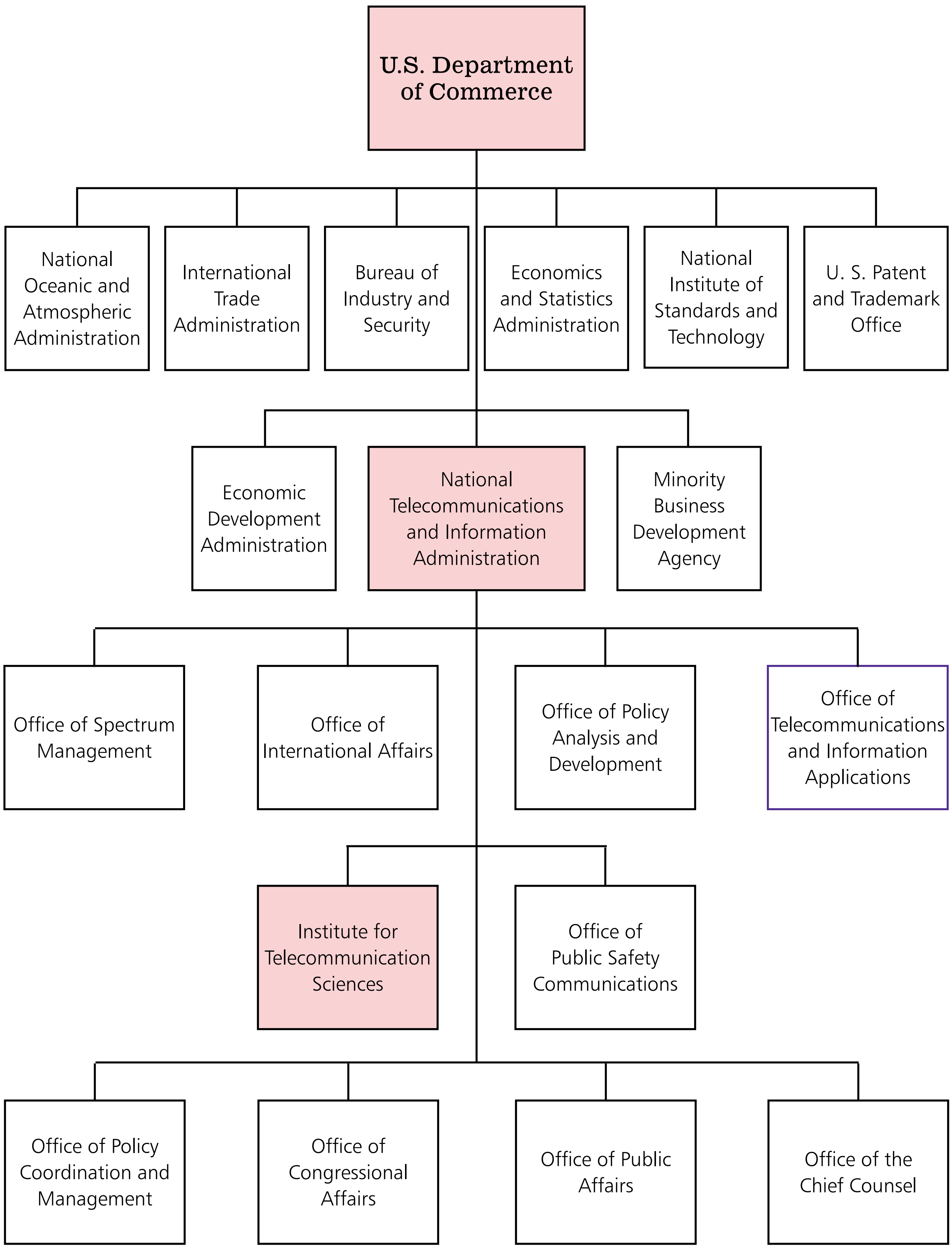
V

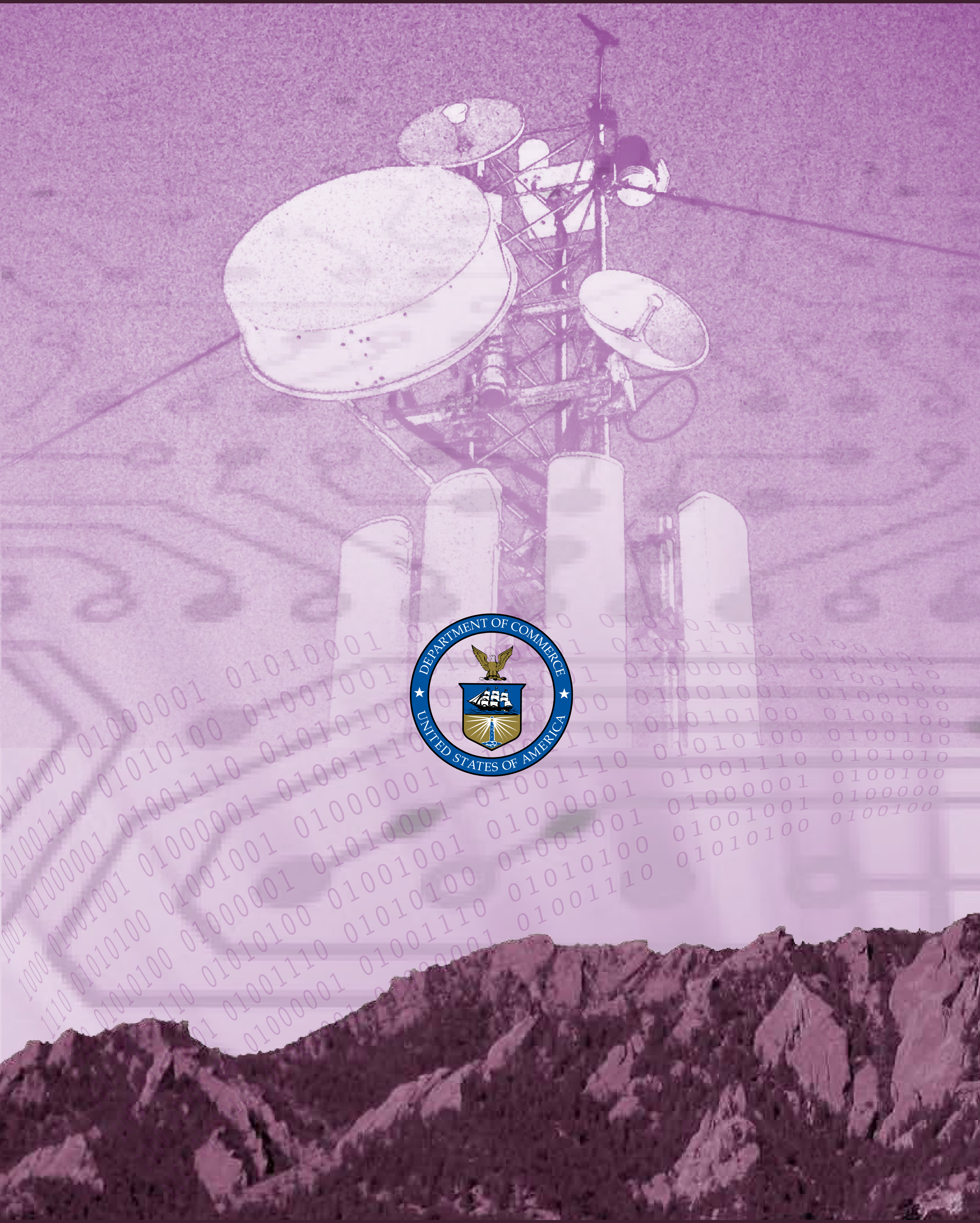
VHF	very high frequency
VNA	vector network analyzer
VoIP	voice over Internet protocol
VoLTE	voice over Long-Term Evolution
VQEG	Video Quality Experts Group
VQiPS	Video Quality in Public Safety
VQM	Video Quality Model
VQM_VFD	Video Quality Model with Variable Frame Delay
VSA	vector signal analyzer
VSG	vector signal generator

W

W	watt
WCC	Wireless Communications Committee
WCIT	World Conference on International Telecommunications
WG	Working Group
Wi3	Wireless Innovation and Infrastructure Initiative
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	wireless local area network
WNRC	Wireless Networks Research Center
WP	Working Party
WRC	World Radiocommunication Conference
WTSA	World Telecommunications Standardization Assembly
WTSC-RAN	Wireless Technologies and Systems Committee – Radio Access Networks

DOC/NTIA Organization Chart

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