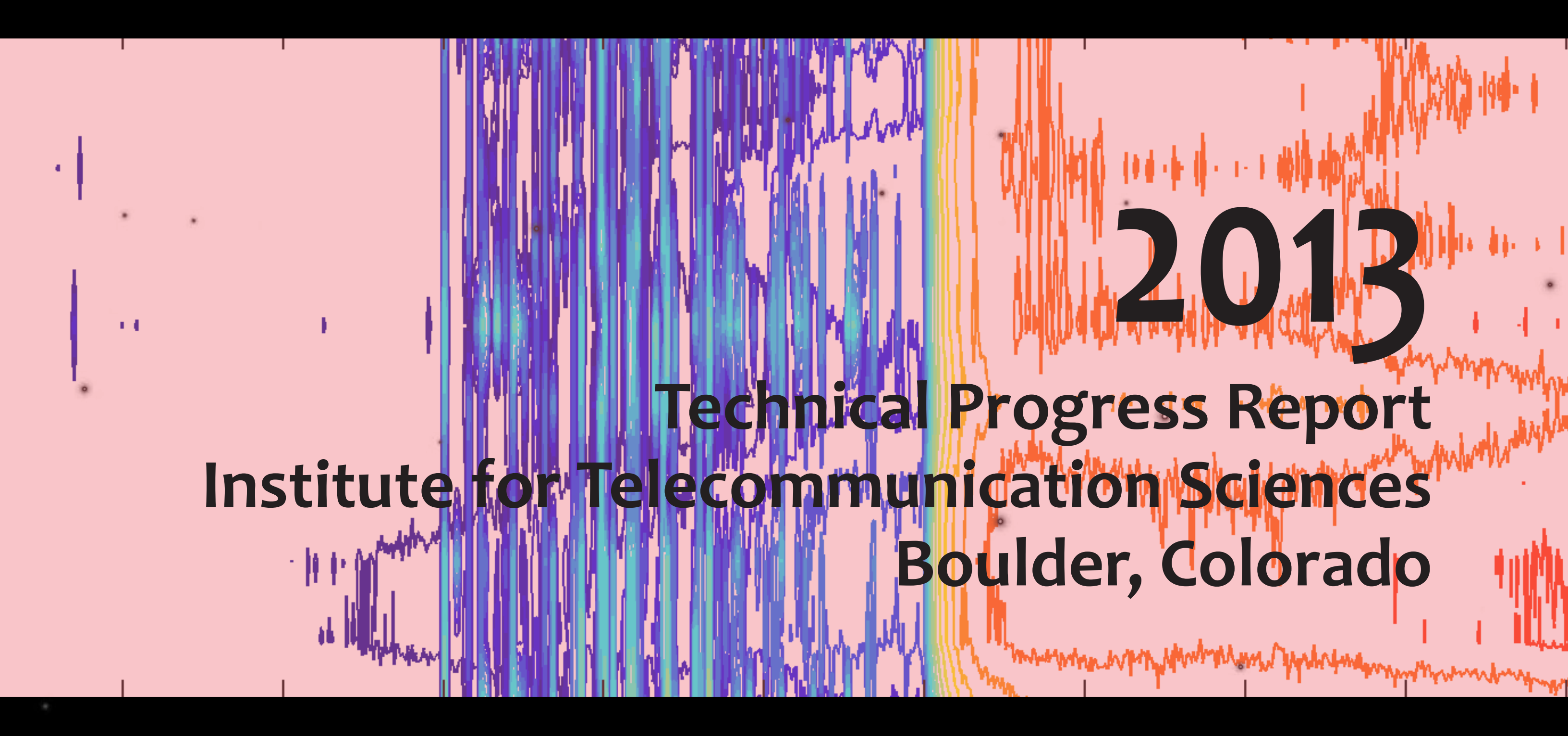
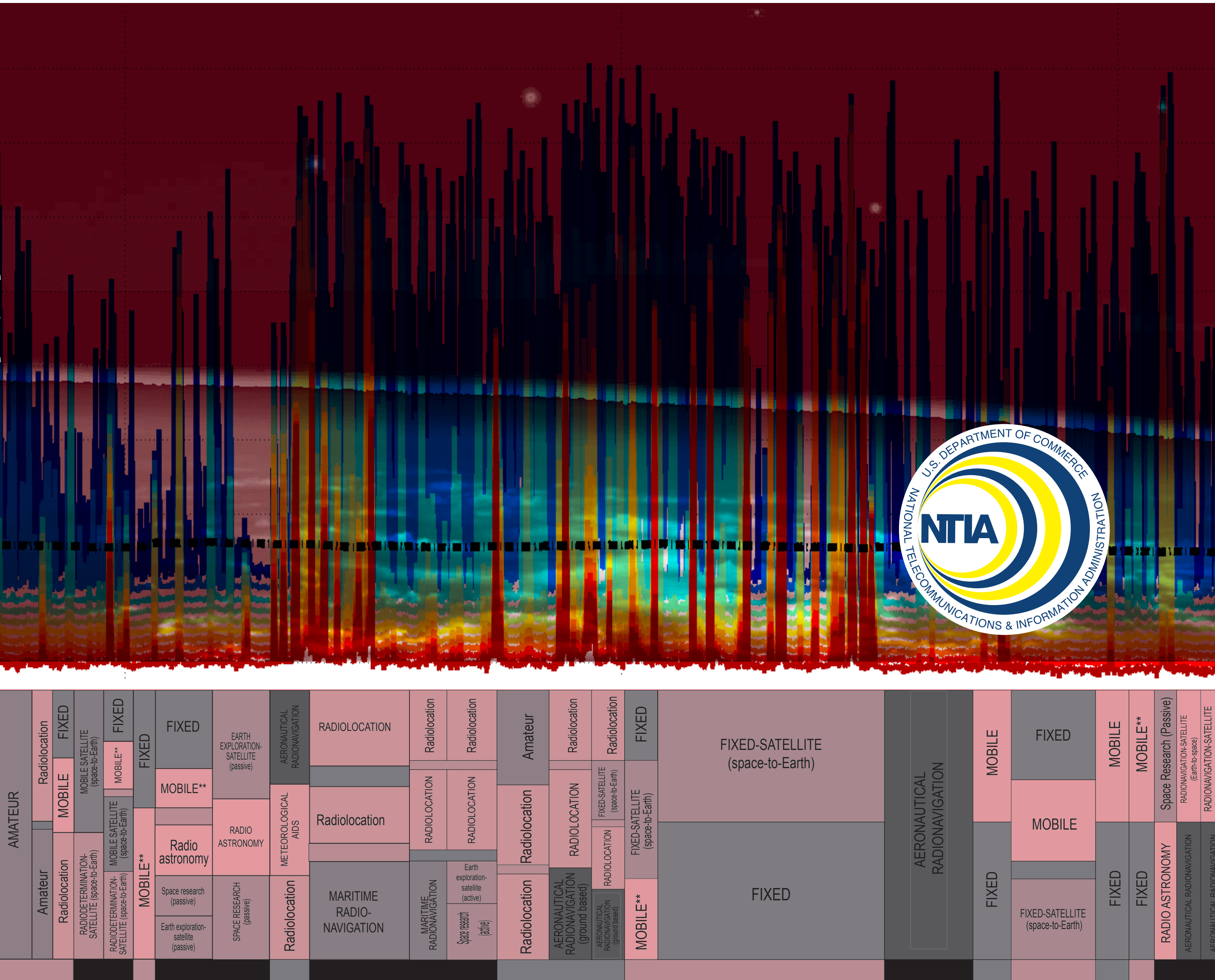


2013
Technical Progress Report
Institute for Telecommunication Sciences
Boulder, Colorado



ITS Organization Chart

Office of the Director
Al Vincent, Director
Amy Weich, Administrative Specialist

Administrative Office
Brian D. Lane, Executive Officer
Carol B. Van Story, Budget Analyst
Amanda C. Alsafi, Budget Analyst
Lilli Segre, Publications Officer

Information Technology
James Rieke, IT Security Officer

Spectrum and Propagation Measurements Division
Eric D. Nelson, Chief
Lisè Matthews, Administrative Specialist

Telecommunications Engineering, Analysis, and Modeling Division
Patricia J. Raush, Chief
Joanne Krumel Administrative Specialist

Telecommunications and Information Technology Planning Division
Andrew P. Thiessen, Chief
Kathy Mayeda, Administrative Specialist

Telecommunications Theory Division
Frank H. Sanders, Chief
Jill Copeland, Administrative Specialist

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Institute for Telecommunication Sciences
FY 2013 Technical Progress Report

Lawrence E. Strickling
Assistant Secretary for Communications and Information
National Telecommunications and Information Administration
United States Department of Commerce

June 2014

"Scientific research supported by the Federal Government catalyzes innovative breakthroughs that drive our economy".[1]

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.

* * *

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

* * *

Cover art by A.D. Romero.

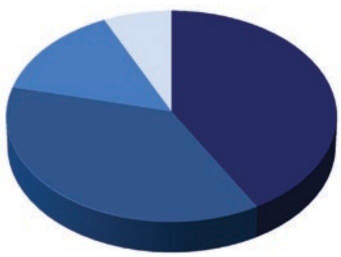
1. Executive Office of the President. Office of Science and Technology Policy. Memorandum for the Heads of Executive Departments and Agencies, Increasing Access to the Results of Federally Funded Scientific Research, February 22, 2013. (Accessed http://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp_public_access_memo_2013.pdf December 9, 2013.)

Contents

“The electromagnetic frequency spectrum has been called the “6th natural resource.” Just as land, water, minerals, forests and energy sources are husbanded as essential resources for a nation’s development, use of the electromagnetic frequency spectrum must be “conserved”, “developed”, and allocated for the greatest value and yield to the nation’s economy, welfare and defense.”[1] *(October 1966)*

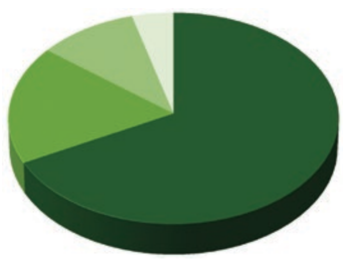
At a Glance ...

Research Areas Funded in FY 2013



- Public Safety Communications Interoperability
- Enhancing Spectrum Utilization
- Improving Telecommunications Network Performance
- eGovernment Research and Engineering

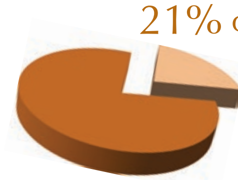
Funding Sources in FY 2013



- Interagency Agreements
- Direct Appropriation
- Fees
- CRADAs

Tech Transfer in FY 2013

ITS participated in 81 CRADAs
591 people downloaded the VQM software
ITS publications were downloaded 7174 times
224 people downloaded video from CDVL



21% of CRADAs were with small businesses

1. U.S. Department of Commerce, Commerce Technical Advisory Board, Telecommunication Science Panel, *Electromagnetic Spectrum Utilization—The Silent Crisis. A Report on Telecommunication Science and the Federal Government*, October 18, 1966. Available http://www.its.bldrdoc.gov/publications/2512.aspx.

The Institute for Telecommunication Sciences

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 scientific understanding of cutting-edge telecommunications technology and systems to promote continuous improvement of telecommunications network performance. ITS is the research and engineering laboratory of The National Telecommunications and Information Administration (NTIA), an agency of the Department of Commerce (DoC). It is located on the Department of Commerce Boulder Laboratories campus in Colorado, sharing advanced laboratory and test facilities with the National Institute of Standards and Technology (NIST) and the National Oceanic and Atmospheric Administration (NOAA).

ITS research supports the Department of Commerce key strategy of fostering advanced communications technologies to strengthen the Nation's digital economy. ITS is recognized as one of the world's leading telecommunication research laboratories.

- Basic research enhances scientific knowledge and understanding in cutting-edge areas of telecommunications and information technology to improve the performance of telecommunications networks.
- Applied research, testing, and evaluation help drive innovation and development of advanced technologies and services, contribute to improving public safety communications, provide technical input to NTIA policy development and spectrum management, and help to resolve specific telecommunications problems of other Federal agencies and state and local governments.
- Cooperative research and development agreements (CRADAs) with industry and academia leverage Federal research resources by providing technical assistance to the private sector that promotes innovation, entrepreneurship, and commercialization.
- Leadership and technical contributions to national and international telecommunications fora 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 Research

- **Enhancing Spectrum Utilization:** design, develop, and operate 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; perform measurements and analysis to improve spectrum management practices and policies, troubleshoot and resolve interference issues, and define technical parameters such as transmitter emission limits, frequency offsets, or separation distances for proposed rulemakings in support of new spectrum uses/sharing requirements; develop ultrawideband, wideband, and narrowband propagation measurement systems, radio channel models, statistical analysis techniques, and signal processing algorithms to facilitate more agile and efficient uses of the radio spectrum for both government and commercial applications; develop advanced propagation modeling algorithms and tools incorporating field measurement data, advanced antenna designs, and noise as a limiting factor for advanced communication systems.
- **Public Safety Communications Interoperability:** systems engineering, planning, and testing of interoperable communications systems (e.g., voice, video, and data) to foster nationwide first-responder communications inter-connectivity and interoperability at Federal, state, local, and tribal levels.
- **Improving Telecommunications Network Performance:** investigate and assess broadband wireless telecommunications system components, evaluate network survivability, and assess system effectiveness in national security, emergency preparedness, military, and commercial environments.
- **eGovernment Research and Engineering:** support agencies and industry in the evaluation and development of innovative eGovernment tools aimed at improving government services, expanding Internet access, and promoting technology transfer opportunities.

Accomplishments

Enhancing Spectrum Utilization

To support the Department of Commerce strategic objective to increase scientific knowledge and provide information to stakeholders to support economic growth and to improve innovation, technology, and public safety, NTIA undertook a strategic initiative to meet the increasing radio spectrum needs of the United States, both for Federal and commercial users, as efficiently and effectively as possible. ITS was tasked to promote the development of innovative spectrum sharing technologies by conducting the spectrum sharing test bed pilot program and by conducting, through ITS's reimbursable authority, engineering studies on behalf of other Federal agencies on in-band and adjacent band interference and interference mitigation techniques. Several such studies were conducted in fiscal year (FY) 2013:

> *“Where technically and economically feasible, sharing can and should be used to enhance efficiency among all users and expedite commercial access to additional spectrum bands, subject to adequate interference protection for Federal users, especially users with national security, law enforcement, and safety-of-life responsibilities.”* [1]

- In the winter of 2013, ITS engineers measured emissions in the 1755–1850 MHz band from key U.S. Air Force and Army flight test, training, and space launch systems at three ranges across the U.S. The measurements were performed under a CRADA with wireless industry partners and coordinated with the Department of Defense (DoD) and NTIA's Office of Spectrum Management (OSM), which used the information gathered in planning for future spectrum sharing in the 1755–1850 MHz band. Data and analysis from these surveys was provided to the industry partners and the DoD. Data from these surveys was also used by ITS to develop both terrestrial and airborne electromagnetic compatibility simulations to assess the potential aggregate interference to DoD systems from thousands of Long Term Evolution (LTE) devices. This required an adaptation of legacy airborne propagation models to include the effects of terrain by producing tens of thousands of point-to-point pathloss estimates. Measurements and models were contributed to a Commerce Spectrum Management Advisory Committee (CSMAC) working group and factored into NTIA's decision to auction a portion of the spectrum. The effort earned the project leaders a Department of Commerce Bronze Medal Honor Award (see “Awards and Honors” on page 6).
- In the spring of 2013, under funding from OSM to support future re-packing of the 2.7-2.9 GHz radar band, ITS engineers performed several sets of electromagnetic compatibility (EMC) measurements on radars operating in that band. Working with the National Weather Service (NWS) at their NEXRAD weather radar development facility, ITS engineers injected interference into a NEXRAD receiver under controlled conditions to determine the thresholds at which the radar performance is impaired. Working with the Federal Aviation Administration (FAA), ITS engineers performed a complete set of EMC measurements on an ASR-11 radar. The data were forwarded to OSM for analysis and evaluation.
- In collaboration with a wireless carrier, ITS and OSM engineers jointly performed ground-breaking interference-effects testing between radar signals and broadband digital communication receivers in the 3.5 GHz band. As part of ongoing NTIA band-sharing studies, simulated radar signals were injected into an LTE receiver at a wireless carrier company's laboratory site to determine the radar interference power levels at which degradation occurs in the receivers and the block error and data throughput rates. These data will be critically important to government and private-sector engineers and spectrum regulators

1. The White House. Presidential Memorandum for the Heads of Executive Departments and Agencies, Expanding America's Leadership in Wireless Innovation, June 14, 2013. (Accessed http://www.whitehouse.gov/the-press-office/2013/06/14/presidential-memorandum-expanding-americas-leadership-wireless-innovatio January 14, 2014.)

who need to determine the conditions under which future LTE-type broadband systems may be able to share 3.5 GHz spectrum with high-power, incumbent government radar systems. In a related effort, ITS conducted a series of emission measurements at three East Coast government facilities on a variety of government radars. The data will be used in analyses to determine the extent to which future spectrum sharing between these radars and new broadband wireless systems might be possible at frequencies near 3.5 GHz.

NTIA/ITS engineer John Carroll using a computer-controlled measurement system to gather data on radar-to-LTE interference effects. Photo by Frank Sanders.

- Under a CRADA with an industry sponsor, ITS engineers performed emission measurements on a new tactical radar for the U.S. Army. The radar emissions were compared to the NTIA Radar Spectrum Engineering Criteria (RSEC) so the manufacturer could complete Stage IV spectrum certification for this system.
- Under an interagency agreement with the Department of Homeland Security (DHS) Office of the Chief Information Officer Wireless Services, ITS has been developing standardized measurement methods for video and audio wireless systems and other investigative devices. This project developed and conducted standardized tests of wireless devices to validate baseline technical requirements and assess compatibility with NOAA weather equipment operating in the same 1700 MHz band.
- Under an interagency agreement with the U.S. Coast Guard, ITS analyzed the impact on shipboard radar systems of increased crowding in the 2.9–3.1 GHz S-band. The U.S. Coast Guard, other government agencies, civilians, and commercial enterprises all operate significant numbers of shipboard radar systems in this band for radio navigation. Legacy systems displaced from spectrum reallocated to accommodate new broadband systems as well as new broadband devices and other new radar systems are being introduced into this band. ITS performed measurements to thoroughly document the technical characteristics of existing analog and solid-state maritime radars operating in the S-Band and to quantify the potential for interference from other radio systems by engineering analysis and empirical testing. These measurements and analyses were used to develop guidelines for mitigating interference and technical contributions toward the development of national and international standards to facilitate sharing in this band.
- ITS engineers and staff from NTIA's Office of International Affairs led the development, coordination and presentation of U.S. proposals to the International Telecommunications Union (ITU) to advance U.S. interests in international standards. ITS provided direct technical support on proposed revisions to several propagation prediction models, including Rec P.533 (HF) and Rec P.528 (air-to-ground UAV applications). An ITS engineer received a Department of Commerce Bronze Medal Honor Award for developing and steering through standardization the new reference implementation of Rec P.533 during FY 2013 (see "Awards and Honors" on page 6).
- ITS engineers completed the third and final phase of testing of two transceivers that use viable dynamic spectrum access (DSA) technology. Testing in the spectrum sharing test bed, a pilot program established in collaboration with the Federal Communications Commission (FCC) to inform the rulemaking process for DSA, examined the ability of this technology to enable new devices to share spectrum with public safety land mobile radio.

Public Safety Communications Interoperability

In general, the broad-based public safety communications interoperability effort addresses four key areas: (1) development of qualitative and quantitative public safety communication and information-sharing requirements that are accepted nationally by the public safety community and industry; (2) identification and development of interface standards that satisfy defined user requirements through leadership and direct technical contribution to national and international standards bodies focused on public safety communications; (3) research, development, testing, and evaluation of concepts, products, and services for long-term interoperability solutions as well as interim improvements; and (4) research and development to accommodate technical gaps that emerge during the entire process. Research in public safety communications is sponsored by the Department of Homeland Security (DHS) and the First Responder Network Authority (FirstNet) and conducted as a multi-agency collaborative effort to leverage the expertise of Federal, state, local and tribal public safety communications practitioners.

- ITS engineers representing the Public Safety Communications Research (PSCR) program, a joint effort between ITS and the National Institute of Standards and Technology Law Enforcement Standards Office (NIST/OLES), successfully advanced the interests of public safety communications in the international standards bodies for cellular/mobile systems. In particular, in FY 2013, this work resulted in inclusion of requirements for two main LTE enhancements sought by public safety in 3GPP Release 12, now scheduled to be finalized in June of 2014. Proximity services identify mobiles in physical proximity and enable optimized communications between them, and group call system enablers support the fundamental requirement for efficient and dynamic group communications operations such as one-to-many calling and dispatcher working. If the release schedule is met, commercial off-the-shelf systems for public safety LTE that include these functions will reach market 12–24 months later.
- PSCR staff conducted measurements at two ground sites of emissions from a balloon-borne LTE repeater drifting at an altitude of 65,000 feet to help establish the viability of this technology. Engineers checked system throughput to determine whether there was interference to ground based public safety broadband LTE. Results were analyzed and reported to the FCC.
- To support the development and acceptance of qualitative and quantitative public safety communication requirements, PSCR hosted the very successful Fourth Annual Public Safety Broadband Stakeholder Conference, held coincident with the June 2013 FirstNet Board meeting. The Conference brought together 502 representatives from public safety, Federal agencies, industry, and academia to exchange information and engage in working meetings on proposed FirstNet network architecture.
- In the summer of 2013, a proposal was advanced to use the LTE public safety guard band for P25 radio transmissions. PSCR rapidly modified portions of the Phase One Broadband Demonstration Network tests to collect guard band interference measurement data on tests of eNodeBs from five different vendors. Tests were completed only two days from the time PSCR was notified of the proposed new spectrum usage. Results were reported to NTIA's Office of Telecommunications and Information Applications (OTIA).

A balloon-borne LTE repeater is deployed to test the feasibility of this technology for emergency communications. Photo by Ken Tilley.

Improving Telecommunications Network Performance

Research to improve the performance of the telecommunications network end-to-end includes investigation of network operation, management, and expansion through network interconnections and interoperation; development and assessment of methods to enhance survivability; development and assessment of methods to improve the quality of transmission; and development of next generation mobile communication systems. ITS is a world leader in the development of subjective and objective measures of transmitted audio and video quality. ITS research on describing and quantifying the effects of the channel on radio systems performance has long informed the development of trusted standardized propagation prediction methods. Current research in next generation mobile communication systems is focused on providing industry and standards bodies with the information and technology to develop technology to exploit the millimeter wave radio channel for new telecommunications applications.

- Access to appropriate test clips has always been a challenge for research in audio and video quality. ITS supports private sector research and development by making available appropriately formatted test clips for both audio and video research. In FY 2013, ITS released 600 more video clips to the Consumer Digital Video Library (CDVL), bringing the total number of clips to 3100. CDVL, which is hosted by ITS, provides royalty-free high definition video clips for use in video quality research and development efforts; ITU-T Study Group 12 is one example of an organization that uses CDVL for source clips.
- Also in FY 2013, ITS made available on line through the PSCR Web site thousands of audio source and test clips for use in intelligibility testing of public safety communications equipment. This collection includes high quality audio recordings of background noise in typical first responder environments, including fireground noise recordings collected by ITS engineers while participating in firefighter training exercises.

eGovernment Research and Engineering

The Federal government's Digital Government strategy is driven in part by the very telecommunications revolution that ITS research enables and facilitates. "New expectations require the Federal Government to be ready to deliver and receive digital information and services anytime, anywhere and on any device. It must do so safely, securely, and with fewer resources."[1] ITS eGovernment research and engineering projects generally fall into two broad categories: implementing complex propagation models and simulations in modern computing environments; and leveraging our expertise in handling large stores of digital data to build realistic test beds to assist other agencies to prototype digital platforms for data storage and retrieval.

- Ubiquitous computing means ubiquitous telecommunications, and the ability to effectively deploy the needed infrastructure depends on accurate propagation prediction models that predict telecommunications coverage using multiple variables. ITS has a long and distinguished history of building digital tools to allow non-technical users to enter information about variables such as frequency band, equipment parameters, and terrain to produce transmitter coverage diagrams for a proposed communications system. Today, this means building Web-based Internet and intranet applications for propagation prediction. Government agencies that are being asked to free up spectrum for commercial use through sharing or relocation are the primary Government-internal customers for these tools. In FY 2013, ITS ported several key propagation modeling algorithms to a new, Web based telecommunications planning system for DoD agencies.
- Practical and effective "cloud" solutions for secure storage, servicing, and management of electronic records are needed to support the Federal government's Digital Government strategy. In consultation with other Federal agencies, ITS has been researching design and architectural criteria for secure and robust remote-access systems for handling large or small volumes of records. In FY 2013, a proof-of-concept test bed for eDocument storage with remote search and retrieval was successfully scaled to hold 15 million records.

1. The White House, "Digital Government: Building a 21st Century Platform to Better Serve the American People," p. 1. http://www.whitehouse.gov/sites/default/files/omb/egov/digital-government/digital-government.html

Awards and Honors

- *One ITS staff member of the Public Safety Communications Research (PSCR) program was honored by the Project 25 Steering Committee.*
- *Two ITS staff members of the PSCR program were honored by the National Public Safety Telecommunications Council (NPSTC).*
- *Four ITS employees received U.S. Department of Commerce awards for work performed in FY 2013*

External Awards

Project 25 Honors ITS Engineer

In February 2013 ITS engineer Randy Bloomfield was honored by the Project 25 (P25) Steering Committee with a Plaque and Certificate of Appreciation for his long-standing commitment and numerous contributions to the P25 Standards Process on behalf of the public safety user community. ITS has been participating in developing P25 standards since the project was established in 1989. Steering Committee Chair James Downes (Office of Emergency Communications, US Department of Homeland Security) expressed deep appreciation for Randy's "professionalism and knowledge [as] exemplified on numerous occasions.... Through your efforts, the Project 25 User Needs Subcommittee and ultimately the P25 Steering Committee were able to meet the ultimate goal to provide the best possible product to the public safety user community."

Randy Bloomfield received a Plaque of Appreciation from the P25 Steering Committee. Photo by Lilli Segre.

NPSTC Honors Two at ITS

The National Public Safety Telecommunications Council (NPSTC) established the Atkinson Technical Award in honor of ITS engineer David (DJ) Atkinson, whose 2012 death was a great loss to NTIA and the public safety community. The first Atkinson Technical Award was awarded posthumously to DJ in June 2012. In May 2013, ITS engineer Andy Thiessen received the Atkinson Technical Award for "tirelessly [working] to support public safety communications through his work at the Public Safety Communications Research (PSCR) Program and as NPSTC Vice Chair of the Technology Committee." ITS staff member Kathy Mayeda received a Letter of Recognition acknowledging her dedicated assistance and support to NPSTC and the public safety community. Kathy facilitates practitioner involvement in subjective testing and stakeholder workshops. Over 100 practitioners participated in intelligibility tests of public safety voice communication systems in the PSCR labs at ITS between 2008 and 2013.

NPSTC Executive Director Marilyn Ward presented the 2013 DJ Atkinson Technical Award to Andy Thiessen. Photo courtesy NPSTC.

U.S. Department of Commerce Bronze Awards

Chris Behm

Chris Behm received a DoC Bronze Award for outstanding scientific and engineering achievement for rapidly developing and steering through standardization a new reference implementation of IUT-R Recommendation P.533, an intense technical effort accomplished in a very brief time. Through his joint positions as technical expert/U.S. Chair of ITU-R Study Group 3 (SG 3) Working Party 3L (WP 3L) and U.S. Chair of SG 3, Chris was able to submit the new model as a technical contribution at the June 2013 WP 3L meetings, advocate for it, and obtain acceptance in September 2013. Rec P.533, "Method for the prediction of the performance of HF circuits," is used to plan deployment of emergency and tactical communication systems worldwide. This model has been maintained by ITS since it was developed and implemented in FORTRAN in the 1980s. Users worldwide and in the DoD, which sponsored the work through an interagency agreement, needed an implementation that would run in modern computing environments. Chris developed a multi-platform C implementation with methods for prediction of available frequencies, signal levels, and reliability for analog and digital-modulated HF systems, taking into account signal-to-noise ratio and the expected time and frequency spreads of the channel. This was one in a suite of technical contributions to SG 3 by the U.S., German, and U.K. delegations. The German delegation compiled and exercised the code, which compiled in five minutes with no errors. The technical expertise demonstrated by this contribution firmly cemented the U.S. leadership position as technical experts in HF radio propagation modeling, enhancing NTIA's ability to advance spectrum sharing positions that align with U.S. interests.

Chriss Hammerschmidt and Paul McKenna

Chriss Hammerschmidt and Paul McKenna received DoC Bronze Awards for scientific and engineering achievement for leading a spectrum measurement, modeling, and simulation effort to examine the feasibility of spectrum sharing and help pave the way for an auction in the 1755–1780 MHz band to fulfill the Presidential mandate to free up 500 MHz of spectrum for commercial use. They measured incumbent Federal usage in the band at three representative DoD facilities and developed models and simulations to assess the feasibility of commercial LTE user equipment (UE) sharing spectrum with incumbent DoD systems. The effort was performed under a Cooperative Research and Development Agreement (CRADA) with commercial carrier partners. Measurements and models were shared with a Commerce Spectrum Management Advisory Committee (CSMAC) working group and NTIA's Office of Spectrum Management (OSM), and factored into NTIA's decision to auction a portion of the spectrum.

Chriss wrote the test plan and obtained DoD agreement on the methodology, configured the measurement systems, developed and validated automated testing and data processing algorithms, coordinated site access with the DoD, assembled and deployed the RF equipment, performed or oversaw six weeks of measurements, and authored or co-authored reports to the CRADA partners and the DoD.

Paul oversaw development of terrestrial and airborne electromagnetic compatibility simulations to assess the aggregate interference to DoD systems in the band from thousands of LTE UEs. The aggregate interference simulation demonstrated a novel and innovative application of the IF-77 propagation model that produces tens of thousands of point-to-point pathloss estimates. It improves analysis capability by including the previously omitted effects of terrain and can be extended for use in a host of other simulations involving airborne radio propagation and geographically distributed radio transmitters.

Eric Nelson

ITS engineer Eric Nelson shared a group Bronze Award with team members from NTIA's Office of Spectrum Management for superb leadership in industry/government collaboration resulting in industry access to 40 megahertz and new avenues toward spectrum sharing.

From left, Paul McKenna, Chriss Hammerschmidt, and Eric Nelson receive Bronze Medal Awards from ITS Director Alan Vincent. Photos by Frank Sanders.

Technology Transfer

Three-quarters 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. ITS efforts in technology transfer and commercialization foster cooperative telecommunications research in areas where U.S. companies can directly benefit from improved competitiveness and market opportunities. The principal means by which ITS transfers the fruits of federally funded research efforts to the private sector are:

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

"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."[1]

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. From the Stevenson-Wydler Technology Innovation Act of 1980 to the February 2013 Office of Science and Technology Policy Memorandum on Increasing Access to the Results of Federally Funded Scientific Research, there has been a growing emphasis on fostering innovation by increasing the rate of technology transfer and the economic and societal impact from Federal research and development investments.

There has also been a parallel push to leverage research investments within the Government by taking advantage of 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 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.

ITS is a joint partner in the Public Safety Communications Research (PSCR) program with the Department of Commerce National Institute of Standards and Technology Law Enforcement Standards Office (NIST/OLES). Other Government agency sponsors that provided significant support to various ITS programs in FY 2013 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.

1. Presidential Memorandum — Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses, October 28, 2011. Accessed http://www.whitehouse.gov/the-press-office/2011/10/28/presidential-memorandum-accelerating-technology-transfer-and-commerciali March 14, 2014.

For more information contact: Brian D. Lane, (303) 497-3484, blane@its.bldrdoc.gov

Cooperative Research and Development Agreements

ITS is authorized under the Federal Technology Transfer Act of 1986 (FTTA) to enter into cooperative research agreements with private industry, universities, and other interested parties. CRADAs protect proprietary information, grant patent rights, and provide for user licenses to private entities. They also provide the legal basis for shared use of government facilities and resources with the private sector.

In FY 2013, ITS participated—as it has for a number of years—in CRADAs with private-sector organizations to design, develop, test, and evaluate advanced telecommunication concepts. CRADAs provide insights into industry's needs for productivity growth and competitiveness that enable ITS to adjust the focus and direction of its programs for effectiveness and value. The private industry partner benefits by gaining access to the results of research in commercially important areas that it would not otherwise be able to undertake.

ITS world-class facilities and capabilities shared through CRADAs and interagency agreements include:

- *Audio and Video Quality Laboratories*
- *Public Safety RF Laboratory*
- *Public Safety Audio & Video Laboratories*
- *Radio Spectrum Measurement Science (RSMS) Program*
- *Table Mountain Field Site and Radio Quiet Zone*
- *Propagation Prediction Modeling Services*

Major contributions to personal communication services (PCS), local multipoint distribution service (LMDS), ultra wideband (UWB), broadband over power line (BPL), objective audio and video quality, advanced antennas for wireless systems, remote sensing and global positioning system (GPS) technologies have been achieved through CRADAs. These have aided U.S. efforts to rapidly introduce new socially constructive communications technologies. More recently, CRADAs in the areas of high resolution laser radar (LADAR), autonomous networks for unmanned aerial vehicles (UAVs), and broadband air-interface and core network capabilities for Long Term Evolution (LTE) mobile communications have allowed ITS to contribute to the development of new products and services.

This cell-on-wheels (COW) is a component of the 700 MHz over-the-air (OTA) LTE network hosted and managed by ITS as part of the PSCR Public Safety Broadband test bed. Photo by Ken Tilley.

Public Safety 700 MHz Broadband Demonstration Agreements

The vast majority of CRADAs ITS has entered into in the past three 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 PSCR test bed and over-the-air (OTA) network (both hosted and managed by ITS) to test interoperability of public safety communications equipment under simulated field conditions, with the participation of public safety practitioners.

At the close of FY 2013, 68 CRADAs were in place under this program. The CRADAs protect the intellectual property of vendors and manufacturers, 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.

CRADAs for the Use of Table Mountain

Established in 1954, the Table Mountain Field Site and Radio Quiet Zone is a unique radio research facility that is ideal for conducting radio experiments due to its physical characteristics and legal designation as a radio quiet zone. It supports a number of radio research activities—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, for example—as well as gravity, magnetism, solar radiation, laser, and other research. The site and its facilities are fully described in the "ITS Tools and Facilities" section on page 74.

Aerial photograph of the Table Mountain Field Site and Radio Quiet Zone, c. 1964. Photo courtesy Roberts Commercial Photography.

Partnerships and cooperative research activities with other entities are encouraged at the site. In addition to ongoing ITS basic research, other Department of Commerce laboratories collocated on the Boulder Labs campus maintain ongoing research efforts on the site. Other research is performed at Table Mountain by Federal and non-federal entities under specific project agreements. Cooperative research and development agreements (CRADAs) with private industry allow companies to use this facility to test and optimize new and improved products prior to bringing them to market. Access to Table Mountain particularly benefits small businesses, who would otherwise be unable to perform research that may be crucial to bringing a product to market. Interagency agreements allow agencies other than Commerce to also take advantage of this unique Federal resource for testing and research that requires radio quiet. In FY 2013, ITS participated in nine CRADAs involving use of the Table Mountain Field site, six of which were with small businesses.

AdHoc UAV Ground Network (AUGNet) Test Bed

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

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 for Degraded Visual Environments

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

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 radio frequency 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.

National Weather Radio (NWR) Testing

La Crosse Technology Ltd., Musical Electronics Ltd., and MZ Berger & Co. entered into CRADAs with ITS to test new weather radio receiver models under development to ensure that they meet the required Consumer Electronics Association (CEA) performance specifications to bear the NWR logo. The tests use simulated broadcasts and a series of repeatable measurement methods developed in collaboration with the National Weather Service, for whom ITS serves as an independent CEA-2009-B surveillance test lab.

Adaptive Tactical Laser System (ATLAS) Testing

Nutronics, Inc. develops solutions for laser propagation through turbulence. The Adaptive Tactical Laser System (ATLAS) is an innovative variation of a compensated beacon adaptive optics (CBAO) system that provides improved focusing of the beam on the target in high temporal and spatial bandwidth operation. This CRADA allowed Nutronics to use the Table Mountain Field Site as a field location to safely test the functionality of the ATLAS beam control system during product development.

Areté LADAR equipment under development being tested at Table Mountain. Photo courtesy Areté Associates.

For more information about Table Mountain contact: Wayde Allen, (303) 497-5871, wallen@its.bldrdoc.gov

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 around 100 years of uninterrupted experience in radio research, ITS represents a unique Federal resource for agencies that have short- or long-term radio research or telecommunications planning needs that cannot be met effectively by existing in-house resources.

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

In FY 2013, ITS entered into over 30 interagency agreements with 13 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 public safety communications research projects were funded by the First Responder Network Authority (FirstNet), the National Institute of Standards and Technology Law Enforcement Standards Office, and different offices of the Department of Homeland Security. ITS tasks 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 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.

For more information about individual agreements see "Government Projects" on page 85.

Interagency Agreements for the Use of Table Mountain

Other Federal agencies enter into interagency agreements with NTIA to use the Table Mountain site for research activities to be conducted either by their own or ITS researchers. NOAA and NIST laboratories collocated with ITS on the DoC Boulder Laboratories campus are the most frequent other agency users of Table Mountain.

NOAA's National Geodetic Survey (NGS) Geosciences Research Division operates the Table Mountain Gravity Observatory (TMGO) on the site. In addition to having only a low uniform slope and relatively homogeneous underlying ground, Table Mountain is also seismically quiet, making it an ideal location for TMGO to conduct the absolute gravity observing program for the NOAA Climate and Global Change Program, and for other NOAA research and monitoring activities. The observatory has become a major center for intercomparisons of gravity meters, with space for up to nine instruments operating simultaneously on separate and isolated observing piers. NGS also has a Continuously Operating Reference Station (CORS) on Table Mountain, one of over 1900 stations that provide Global Navigation Satellite System (GNSS) data to support three-dimensional positioning, meteorology, space weather, and geophysical applications throughout the U.S.

The Central UV Calibration Facility (CUCF), a joint project between NOAA and NIST, provides highly accurate and long-term repeatable calibrations and characterizations of UV monitoring instruments. CUCF's Table Mountain Test Facility has several UV instruments and provides a useful test bed for intercomparisons, including annual spectroradiometer comparisons.

NOAA's Earth System Research Laboratory Global Monitoring Division maintains a SURFRAD (Surface Radiation) Network monitoring station on Table Mountain. SURFRAD stations perform ground-based measurements of upwelling and downwelling solar and infrared radiation; ancillary observations include direct and diffuse solar, photosynthetically active radiation, UVB, spectral solar, and meteorological parameters. Data are near real time by anonymous FTP and over the Internet. Observations from SURFRAD have been used for evaluating satellite-based estimates of surface radiation, and for validating hydrologic, weather prediction, and climate models.

USGS Table Mountain magnetic observatory. Variations and Proton Sensor buildings at the lower right. Photo courtesy USGS.

The National Geomagnetism Program of the U.S. Geological Survey (USGS) of the U.S. Department of the Interior operates a Magnetic Observatory on Table Mountain. In addition to serving as a site for routine collection of magnetometer data, the Table Mountain observatory also functions as the Program's test bed for on-going operational developments. USGS data are used to model and map the global magnetic field in cooperation with the international community of geomagnetism and various satellite programs. Regionally, USGS data are used to support aeromagnetic surveys and directional drilling programs for the oil and gas extraction industry. USGS data are also used by the pipeline and electrical power grid industries and for academic studies across a broad range of geophysical sciences.

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 or conferences. Many of these publications—both NTIA reports and monographs and peer-reviewed articles in external venues—have become standard references in several telecommunications areas. For example, the most frequently downloaded publication in 2013 was "A Guide to the Use of the ITS Irregular Terrain Model [ITM] in the Area Prediction Mode." This 1982 report describes a radio propagation model for frequencies between 20 MHz and 20 GHz (the Longley–Rice model) developed, validated, and computerized at ITS. The ITM continues to be widely used to plan wireless networks and is a recommended method under international standards such as ITU-R P.526 and ITU-R P.1546.

Topic Distribution of FY 2013 Publication Downloads

Propagation Modeling	25%
Spectrum Measurements	18%
Video Quality Metrics	17%
Interference Analysis	10%
Audio Quality Metrics	7%
Other	23%

Technical publication remains a principal means of ITS technology transfer. Increasingly, these publications are read over the Internet rather than in hard copy. All NTIA publications released since 1978 have been made available through the ITS public Web site as downloadable PDF files. Publication files are tagged with standardized metadata to assist Internet searches, and the ITS Web site offers advanced search capabilities to locate relevant publications by keyword. ITS publication PDFs were downloaded over 7,000 times in FY 2013.

An internal peer review process managed by the ITS Editorial Review Board (ERB) ensures the quality of new publications. In FY 2013, ITS authors published nine NTIA Technical Reports and Memoranda that were peer-reviewed through the ERB process and 15 journal articles or 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 2013 publications and presentations, with citations and abstracts, begins on page 76.

Conferences, Workshops and Symposia

Public Safety 700 MHz Demonstration Network Stakeholder Meeting

ITS hosted the Public Safety 700 MHz Demonstration Network Summer 2013 Stakeholder Meeting in Broomfield, CO, June 4–6, 2013. This was the fourth face-to-face stakeholders' meeting for the Demonstration Network, with over 500 attendees from public safety, Federal agencies, industry, and academia. Dereck Orr of NIST and Jeff Bratcher of ITS, co-managers of the Public Safety Communications Research program, opened the workshop alongside Acting Department of Commerce Deputy Secretary Dr. Patrick Gallagher. Keynote speakers were Sam Ginn, former Chairman of the First Responder Network Authority (FirstNet) Board, former FirstNet General Manager Bill D'Agostino and Board Member Craig Farrill.

Participants were briefed about Demonstration Network testing progress. The culmination of Phase 3 testing produced much-anticipated results from EPC and RAN interoperability testing (IOT), advanced drive testing, and LTE-LMR interference testing. Other briefings covered nationwide network and traffic flow modeling and simulation efforts and results, and public safety broadband standards development, including a panel on global standardization with participants from the German Federal Agency for Digital Radio of Security Authorities and Organisations (BDBOS) and the Association of Public-Safety Communications Officials Australia New Zealand. Many of the participants took part in two very productive *ad hoc* working lunch sessions on network architecture.





Speakers

Clockwise from top left: former Dept. of Commerce Deputy Secretary Dr. Patrick Gallagher, former FirstNet Board Chairman Sam Ginn, PSCR Operations Manager Jeff Bratcher (ITS), PSCR Program Manager Dereck Orr (NIST), Dr. Barbara Held, Federal Agency for Digital Radio of Security Authorities and Organisations (BDBOS), Federal Republic of Germany.

PSCR

2013 Public Safety Broadband Stakeholder Conference

June 4-6, 2013

10600 Westminster Blvd.
Westminster, CO 80020

Working lunches and product demos


Expert panels


Photos by Ken Tilley.

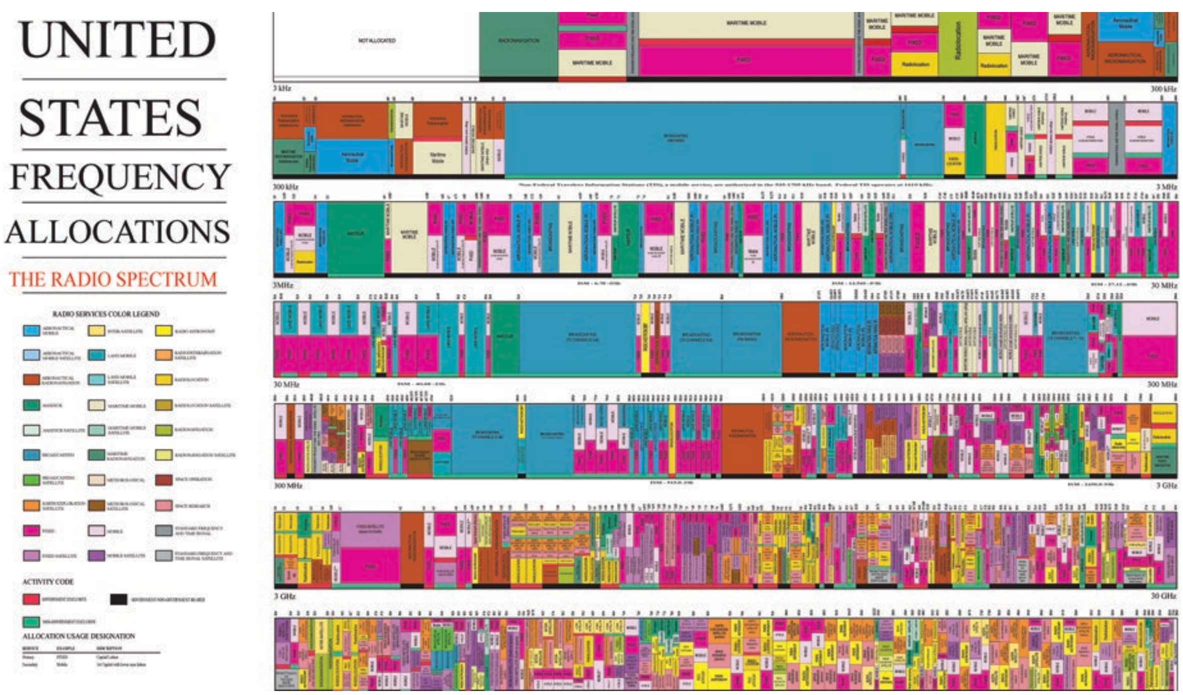
> *“America’s future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum.”*[1]

Enhancing Spectrum Utilization

Spectrum is a physically limited asset. To make more spectrum available, current users need to share spectrum with new users, find innovative ways to shrink the footprint of the spectrum reserved for their exclusive use in time or space, or do both. Enhancing spectrum utilization means finding ways to increase the number of users who can effectively operate in each band. Research to enable the fullest spectrum utilization encompasses interference analysis and mitigation, spectrum measurements, and national and international standards development. These provide the technical foundations necessary to “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.”[1]

Interference Analysis and Mitigation

Interference analysis and mitigation studies provide the data needed to continuously improve the technologies that allow users to gracefully share the same radio space or operate in adjacent bands. Electromagnetic compatibility (EMC) studies characterize the emissions of different radio devices and develop algorithms for detection and avoidance based on those characteristics, so that equipment in shared bands can be programmed to limit interference by recognizing and avoiding the emissions of other devices. Ideally, these studies are carried out prospectively, while new equipment or new sharing regulations are still under development. Sometimes, however, they are needed to trace to its root cause interference experienced in situations that were previously thought to be safe for sharing and to devise mitigation strategies.



The Radio Spectrum Chart is a visual display of the U.S. Table of Frequency Allocations. For information about obtaining a physical or electronic copy, visit http://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart.

1. The White House, Presidential Memorandum: Unleashing the Wireless Broadband Revolution, June 28, 2010. Accessed http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution January 9, 2014.

Spectrum Measurements

While EMC studies characterize the emissions of different devices, spectrum measurements characterize the radio space in which they operate. Spectrum measurements do not identify individual transmitters, but catalog the amount and nature of the electromagnetic radiation present in the radio spectrum over a specified period of time in a specified geographic location. This description of the existing radio spectrum environment is used to identify opportunities for increased utilization as well as to describe the background radio noise against which intentional transmissions will have to be made secure and resilient.

Radio waves are made to carry information by varying the wave's amplitude, frequency, and phase within a frequency band. They range from hundreds of meters to about one millimeter in length, corresponding to about 300 GHz to 3 kHz in frequency, and there are significant variations in the behavior of waves of different frequencies. This is why certain frequencies are more desirable "real estate" for certain purposes. To discover innovative ways to cram more information streams into each segment of the spectrum, and to make those streams resilient and robust no matter what frequency they travel on, we must continuously deepen our understanding of the behavior of radio waves and the radio environment.

Spectrum measurements also describe the current occupancy of different bands. This allows regulators to plan realistic strategies for increasing utilization, and it allows product designers to plan strategies to protect desired transmissions from other traffic in the neighborhood. While the behavior of radio waves is a physical constant that can be measured almost anywhere, occupancy varies geographically. Not only is the spectrum predictably more crowded in urban than in rural areas, but the frequencies and amplitudes of the traffic vary with proximity to airports, littoral areas, centers of research, etc.

National and International Standards Development

Data from ITS research is also used to support the development of national and international standards for radio devices. Strong and unbiased standards support fair competition in the information and communications technology sector. Technical standards establish common norms for technical systems—uniform engineering criteria, methods, processes, and practices that promote competition and interoperability. Standards define the parameters of permissible emissions from different transmitters to reduce the probability that unwanted radiation interferes with other users. Standards define the characteristics of transmission envelopes so that devices from different manufacturers can interoperate predictably. Participation in standards development organizations (SDOs) helps influence domestic and international telecommunications standards and policies to support U.S. industry and the Administration's spectrum sharing initiatives and needs.

In cooperation with other interested U.S. government agencies and industry groups, ITS participates in national and international telecommunication standards development. ITS submits, and coordinates the formal review and approval of, recommendations on emerging mobile radio technologies, broadband network performance, radio propagation prediction, and radar systems. Under agency reimbursable agreements, ITS staff also continue to support other Federal agencies with development of telecommunication specifications, standards, proof of concept and demonstration measurements, interoperability analyses, technical and economic impact assessments, and prototype development.

In FY 2013, 12 ITS employees participated in 50 committees or working groups in seven different SDOs and held 14 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 82.

> *"When necessary, repurposing of federal spectrum will be subject to conditions to ensure that there is no harmful interference with public safety needs or other critical public uses of the spectrum."*[1]

Interference Analysis and Mitigation

The Pew Research Center reports[2] that 91% of U.S. adults now use a cell phone, and 61% of those—56% of all American adults—use a smartphone. Exploding demand for wireless broadband for smart devices of all kinds led the President to propose an initiative to make 500 MHz of Federal and non-federal spectrum available for wireless broadband use by 2020.[3]

Since spectrum is a physically limited resource, there are only two ways to do this: open bands to shared use, or relocate incumbent users to underutilized, less desirable bands. But many Federal users who operate in the most desirable spectrum bands have complex and expensive systems that cannot be easily relocated within the time frame allowed. Thus, NTIA proposed sharing as a "fast track" solution in certain bands.[4]

Spectrum sharing proposals look to emerging technologies to enable interference-free sharing between commercial wireless broadband and incumbent Federal users. Smart wireless devices have enjoyed a very rapid development cycle,[5] making it feasible to imagine that by the time sharing has been codified, commercial devices entering a particular bandwidth will have the technology required to share gracefully with incumbents. However, incumbent devices are frequently of an entirely different nature, often with a refresh cycle of 50 years or more, and may be either difficult or impossible to update with new technologies due to their complexity or location (for example, radar and satellite systems).

Many of these are safety-of-life systems used by the Federal Aviation Administration, the U.S. Coast Guard, the National Weather Service, and similar agencies. While opening bands to shared use is the fastest way to accommodate more users, it is critical that these safety-of-life systems be fully protected. At the same time, entrants into bands where such devices operate must be able to devise technology that can reliably operate around these systems in order to be able to fully exploit the bandwidth that is being made available to them.

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.

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

1. The White House, Council of Economic Advisors, "The Economic Benefits of New Spectrum for Wireless Broadband," Feb. 2012. Accessed http://www.whitehouse.gov/sites/default/files/cea_spectrum_report_2-21-2012.pdf March 31, 2014.

2. Lee Rainie, "Cell phone ownership hits 91% of adults," *FactTank,* Pew Research Center, June 6, 2013. Accessed http://www.pewresearch.org/fact-tank/2013/06/06/cell-phone-ownership-hits-91-of-adults/ March 31, 2014.

3. The White House, Presidential Memorandum: "Unleashing the Wireless Broadband Revolution," June 28, 2010. Accessed http://www.whitehouse.gov/the-press-office/presidential-memorandum-unleashing-wireless-broadband-revolution March 31, 2014.

4 U.S. Department of Commerce, National Telecommunications and Information Administration, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands," October 2010. Accessed http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf March 31, 2014.

5. The U.S. General Services Administration (GSA) uses a two-year technology refreshment cycle for mobile communication devices to estimate telework costs for Government employees. See the Cost Analysis in the Telework/AWA Library at http://www.gsa.gov/portal/content/102447?utm_source=OGP&utm_medium=print-radio&utm_term=teleworklibrary&utm_campaign=shortcuts

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.

ITS is a recognized leader in radio frequency measurements and analysis for interference diagnosis and mitigation. Particular areas of expertise range from accurate measurement and characterization of emissions from transmitters of all kinds to complex simulation and modeling of proposed communications scenarios. Interference analysis and mitigation requires skilled application of these and other areas of expertise. From root cause analysis that traces experienced interference to its source, to developing complex mathematical models capable of driving multi-parameter simulations to prevent interference in systems under development, other Government agencies and private sector entities look to ITS for assistance to make sharing work.

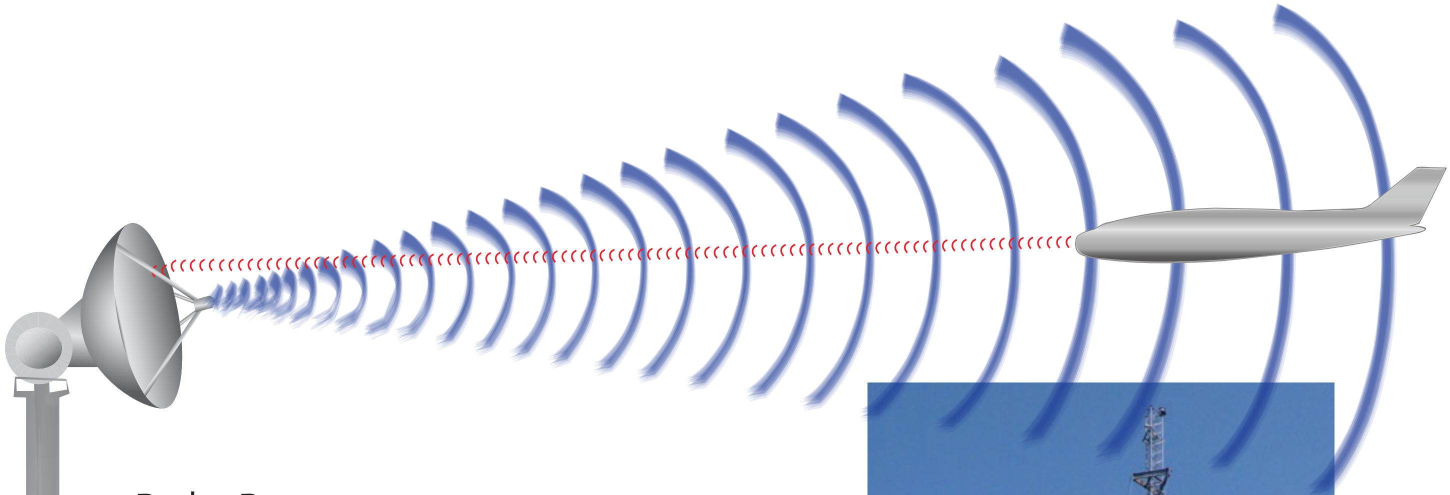
ITS performs measurements, analyses, and simulations for interference prevention and mitigation for other Government agencies via Interagency Agreements (IA) and for private entities via Cooperative Research and Development Agreements (CRADAs). These agreements provide benefits for both the Government and the private-sector partners. In addition to performing measurements and analyses on request, ITS engineers transfer knowledge to other agencies and the private sector through training in spectrum measurement, analysis, and modeling techniques developed over more than half a century of research.

Studies for interference analysis and mitigation performed in FY 2013 are described in the following pages. Some were performed as part of the basic telecommunications research mission of ITS, others in support of Government or private research partners under IAs and CRADAs.

ITS Spectrum and Propagation Measurements Engineers Geoff Sanders (foreground) and John Carroll in the RSMS mobile measurement laboratory taking measurements for use in a spectrum sharing study. Photo by Frank Sanders.

AN/TPQ-53 radar at the Yuma Proving Grounds. Photo by Frank Sanders.

The RSMS mobile measurement laboratory performing radar emission measurements at Wallops Island. Photo by Frank Sanders.



Radar Program

Radar systems consist of powerful transmitters that emit high-powered pulsed broadband signals and sensitive receivers to capture the returning low-powered echoes. Characterizing radio frequency (RF) emissions from radar transmitters presents particular challenges due to the nature of radar signals. Many federally operated radar stations emit peak effective isotropic radiated power (EIRP) levels that are among the highest of all radio transmitter systems. Even theoretically perfect radar transmitters cannot confine their electromagnetic emissions entirely to their assigned operating frequencies, or for that matter even to allocated radar spectrum bands, due to the inherent pulse modulation characteristics of these systems. While measuring radar emissions requires equipment that is capable of fast-response wideband measurements at high power levels, analyzing interference to radar reception requires a measurement system that can capture signals at very low power levels and distinguish them clearly from background noise.

The RSMS mobile measurement laboratory deployed in the field to take radar emission measurements. Photo by Frank Sanders.

The Institute's Radio Spectrum Measurement Science (RSMS) program has developed special expertise and custom-built capabilities particularly suited to measurements of high-dynamic-range radar emissions, general measurements involving radar technologies, and electromagnetic compatibility (EMC) involving radar systems. In addition to measuring RF emissions, the RSMS program has comprehensive resources and tools to synthesize radar signals and inject them into all types of radio systems to examine receiver performance in the presence of interference.

Radar Emissions Measurements

All U.S. radar systems must meet emission limits imposed by the NTIA Radar Spectrum Engineering Criteria (RSEC) as described in the NTIA "Redbook" "to ensure an acceptable degree of electromagnetic compatibility among radar systems, and between such systems and those of other radio services sharing the frequency spectrum."[1] Many foreign customers who purchase radar system from U.S. industry also require that the radars comply with the RSEC. The Institute has developed highly specialized capabilities for performing RSEC compliance measurements on radar transmitters using RSMS resources. Procedures

1. U.S. Department of Commerce, National Telecommunications and Information Administration, "Manual of Regulations and Procedures for Federal Radio Frequency Management (Redbook)," May 2013 Edition, p. 5-23. Accessed http://www.ntia.doc.gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook, March 21, 2014.

for RSEC measurements are provided in available literature, but building measurement systems that can perform these measurements can be prohibitively difficult and expensive for individual organizations, as compared to working directly with ITS to perform the measurement. ITS performs RSEC measurements for OSM, other agencies, and private sector companies. RSEC measurements for other agencies and private industry are performed under IA and CRADA funding, respectively. ITS performed the following RSEC compliance measurements during FY 2013:

- AN/TPQ-53: ITS performed emission measurements on this new radar at the Yuma Proving Grounds in Arizona using the RSMS mobile laboratory. The work was performed for an industry sponsor via a CRADA. The AN/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 to attain spectrum certification for the radar under the NTIA RSEC. These measurements and the resulting analysis helped to move this important new system forward to deployment with U.S. and allied forces worldwide.
- AN/APY-10: ITS performed emission measurements on this new radar at the ITS Table Mountain field site using a portable RSMS system. The work was performed for an industry sponsor via a CRADA. The AN/APY-10 airborne radar is currently being deployed in P-8 maritime surveillance aircraft with the U.S. Navy and foreign customers. ITS engineers analyzed the data and provided results to the sponsor. These measurements and the resulting analysis showed RSEC compliance, helping to move this new system forward to deployment with U.S. forces and foreign customers worldwide.
- AN/SPY-1(B/D): ITS performed emission measurements on this radar at the Navy's Wallops Island Test Range in Virginia using the RSMS mobile laboratory. The work was performed for OSM and the Naval Research Laboratory. This AN/SPY-1 variant is deployed on a variety of naval vessels. These measurements and the resulting analysis are being used in spectrum sharing studies for the U.S. Administration, domestically and internationally.
- AN/SPN-43: ITS performed emission measurements on this radar at the Naval Electronic Systems Engineering Activity (NESEA) test range in Maryland using the RSMS mobile laboratory. The work was performed for OSM and the Naval Research Laboratory. The AN/SPN-43 is the U.S. Navy's air marshalling radar, deployed on a variety of aircraft carriers. These measurements and the resulting analysis are being used in 3.6 GHz spectrum sharing studies for the U.S. Administration, domestically and internationally.
- ASR-11: ITS performed emission measurements on the FAA's Airport Surveillance Radar, model 11 (ASR-11) units in Colorado using the RSMS mobile laboratory. The work was performed for OSM and in support of an EMC study conducted jointly with the National Weather Service (NWS). The ASR-11 is the latest radar deployed by the FAA in and around smaller airports for air traffic control. These measurements and the resulting analysis have been used in 2.7–2.9 GHz spectrum repacking studies for the U.S. Administration, domestically and internationally.

Electromagnetic Compatibility Studies

In support of domestic and international initiatives to more efficiently use spectrum below 6 GHz, ITS undertook several studies with OSM on effects of radar interference on radio receivers. ITS synthesized radar interference and injected it into victim receivers at field sites in Virginia and Oklahoma. Quantifying the effects of radar interference on other radio systems, under controlled conditions, is critically important to moving spectrum sharing forward in a number of radio frequency bands.

For more information on Radar Programs and Electromagnetic Compatibility Studies contact: Frank Sanders, (303) 497-7600, fsanders@its.bldrdoc.gov; John Carroll, (303) 497-3367, jcarroll@its.bldrdoc.gov; or Geoff Sanders, (303) 497-6736, gsanders@its.bldrdoc.gov

- 3.6 GHz LTE Spectrum Sharing Study: In support of spectrum sharing initiatives between incumbent radar systems and proposed new terrestrial broadband LTE networks at 3.6 GHz, ITS injected a wide variety of radar waveforms into LTE base station receivers and measured interference effects on those receivers under controlled conditions. The radar waveform parameters spanned the range of all existing and future planned Federal radar systems at 3.6 GHz. Interference power levels were varied while LTE receiver performance was recorded. The results of this extensive study were published in NTIA Technical Report TR-13-499 and were used as part of NTIA's response to an FCC Notice of Proposed Rulemaking (NPRM).
- 2.7–2.9 GHz Band Repacking Study: In support of domestic and international studies for more efficient spectrum use, ITS, in collaboration with the NWS, investigated radar-to-radar spectrum sharing criteria in the 2.7–2.9 GHz band. ITS engineers used a portable interference test bed to inject synthesized radar signal into an NWS NEXRAD weather radar in Oklahoma.

  The NEXRAD is used by the NWS to monitor local weather conditions and generate severe-weather warnings. Criteria need to be established for minimum separations in both distance and frequency from one NEXRAD to the next and between NEXRADs and FAA ASRs that utilize the same band. Both NEXRAD and ASR signals were injected into an engineering test-and-development NEXRAD receiver under controlled conditions and the effects of the interference were recorded by NWS. NWS personnel are evaluating those data to develop radar-to-radar sharing criteria in the band. The results are being incorporated into studies for repacking of radars in the 2.7–2.9 GHz band.

FAA NEXRAD radar. Photo by F. Sanders.

Related Report: *Frank H. Sanders, John E. Carroll, Geoffrey A. Sanders, Robert L. Sole, Effects of Radar Interference on LTE Base Station Receiver Performance, NTIA Technical Report TR-14-499, December 2013. Available http://www.its.bldrdoc.gov/publications/2742.aspx.*

Analyses for Spectrum Sharing in Federal Bands

To support the President's Spectrum Initiative, ITS is examining the potential interference between various Federal communication systems that have been identified for sharing their assigned spectrum. One proposal involves the spectrum relocation of Federal broadband systems (entrants) to bands that are already in use by existing Federal systems (incumbents). In FY 2013, ITS began studying two systems affected by this relocation to determine the interference potential between the incumbents and the proposed entrants. 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 potentially shared band.

ITS engineers use the techniques of simulation and testing to address the feasibility of successful spectrum sharing. These techniques are interrelated and each one reveals complementary information about the interference potential between systems. The comprehensive and detailed analytical evaluation that ITS provides forms a strong basis for simulating and testing interference interactions.

Initially, an engineering analysis of the potential interference environment requires that the characteristics of the incumbent and entrant systems in the shared band be adequately defined. The characteristics

To reduce the complex interference environment to a judicious number of parameters so that cooperation can be forged between two users being asked to share spectrum, the techniques of simulation, analysis, and testing are performed iteratively. Decisions based on these standard engineering practices can help assure that Federal systems meet the communications needs and requirements of their users, while freeing precious spectrum for innovative future uses.

consist of the important parameters that define a given communication system. Parameters such as antenna patterns, modulation, transmit powers, and receiver sensitivity are used to accurately describe how the systems are deployed in, and react with, the interference environment. During the discovery phase, laboratory and field testing are performed to fully verify the range of operations of each receiver and transmitter in an interference-free environment, 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.). Operational scenarios of the systems under study are also parameterized to further refine the analysis.

It is important that the specific spectral characteristics of the transmitted signal, the electromagnetic limitations of the receiver, and an adequate description of the radio propagation environment be taken into account during the interference analysis. The radio propagation environment is typically represented by a mathematical model that describes dominant physical mechanisms that allow end-to-end communication. Years of expertise in the design and implementation of propagation models at ITS, and ITS's unique knowledge base, support fast and accurate predictions of the interference potential of a given scenario.

Applying an inappropriate propagation model for a given interference scenario could lead to inaccurate predictions. Decisions based on misapplied propagation predictions could result in efforts to reduce interference when none is present or to unexpected spectrum sharing conflicts because the field strength of the interfering signal is underestimated. ITS has an extensive catalog of publicly available, and internationally adopted, frequency-dependent propagation models. Because the propagation models were developed in-house, ITS can assure project sponsors that the appropriate propagation model will be used for each scenario. These propagation models were used to characterize the shared propagation environment for the two systems under study in this case—satellite base stations and small portable devices—but they can also be used for many other communications scenarios.

Accurate characterization of communications systems will lead to more accurate determination of the interference threshold. This is accomplished through the calculation of specific signal-to-interference and interference-to-noise ratios based on the receiver's energy per bit to noise power spectral density ratio.

ITS engineers use simulations of the propagation channel, the communications systems, and usage patterns to help illuminate the complexities of an interference environment. Since the degree to which a system can be characterized analytically may be limited, simulation is used to supplement this information. Simulation can 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 are 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 the

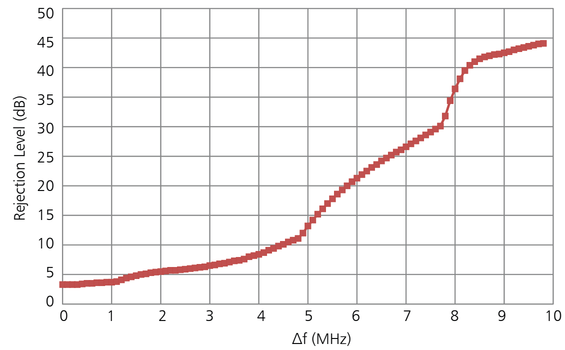
The black satellite base station receiver antenna in the foreground was mounted on the roof of the ITS laboratory for validation testing. Photo by Tim Riley.

performance degradation is evident to all of those involved so appropriate error-correction methods can be applied. Simulation can also be used to simplify or replace very resource intensive measurements. Testing is used to verify and validate the conclusions and the inevitable assumptions that are required to analyze and simulate systems with limited time and resources. Testing is also invaluable to assure the users of the shared spectrum that critical communication functions will not be interfered with and to identify the limitations in sharing a frequency band.

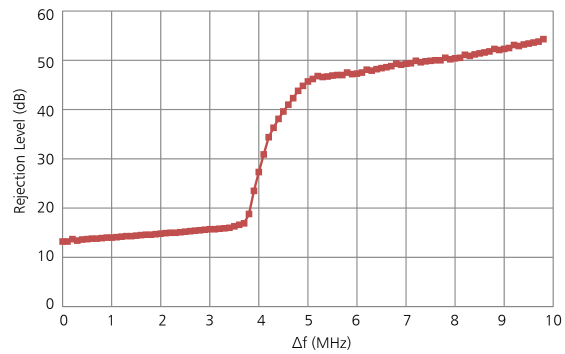
Figure 1 shows the performance of the target receiver for frequency offset versus receiver frequency dependent rejection. The figure represents scenarios where a wide bandwidth mobile Federal entrant system is interfering with a stationary Federal incumbent system. The incumbent system in Figure 1a) is a narrow bandwidth service while that in Figure 1b) is a medium bandwidth service. These types of plots graphically aid Federal spectrum managers in developing channel plans and/or establishing geographic protection zones. Specifically, Figure 1 indicates that the receiver will have less difficulty with interferers at spectral separations greater than 4 MHz. Figure 2 shows a graph of frequency separation versus separation distance between a wide bandwidth entrant and a narrow bandwidth incumbent. This graph shows that, given a fixed frequency separation of 4 MHz, a 20 to 34 km protection zone is needed to assure acceptable performance of the incumbent system.

ITS generalized the methods developed for this project and published the interference analysis in a conference paper delivered at the 2013 IEEE International Symposium on Electromagnetic Compatibility (EMC). This fulfills the important ITS mission objective of transferring technology to the public sector.

Related Publication: *N. DeMinco, T.J. Riley and C.J. Behm, "Electromagnetic Compatibility (EMC) Analysis Approach for Band Migration to Provide Spectrum for the President's Spectrum Initiative," IEEE International Symposium on Electromagnetic Compatibility (EMC), 2013, pp. 101–106, Aug. 2013. Available http://www.its.bldrdoc.gov/publications/2746.aspx.*



a) Wide bandwidth entrant, medium bandwidth incumbent



b) Wide bandwidth entrant, narrow bandwidth incumbent

Figure 1. Frequency-dependent rejection versus frequency separation for a wide bandwidth entrant system and two types of incumbents.

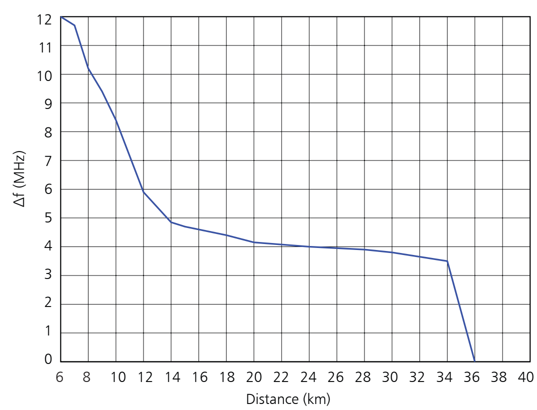


Figure 2. Frequency separation versus separation distance for a wide bandwidth entrant and a narrow bandwidth incumbent.

For more information about analyses for spectrum sharing contact Christopher Behm, (303) 497-3640, cbehm@its.bldrdoc.gov

Coast Guard Spectrum Reallocation Study

Objectives

- *Determine interference protection criteria*
- *Develop interference testing methodologies*

Background

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 base stations 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. Figure 2 shows the spectral relationships between the BRS signal and radar filters which can lead to interference in the radar system. Interference caused by overload can occur when the BRS signal is within the radar front end bandwidth. Interference caused by unwanted emissions can occur when the unwanted emissions are within the radar detection bandwidth.

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

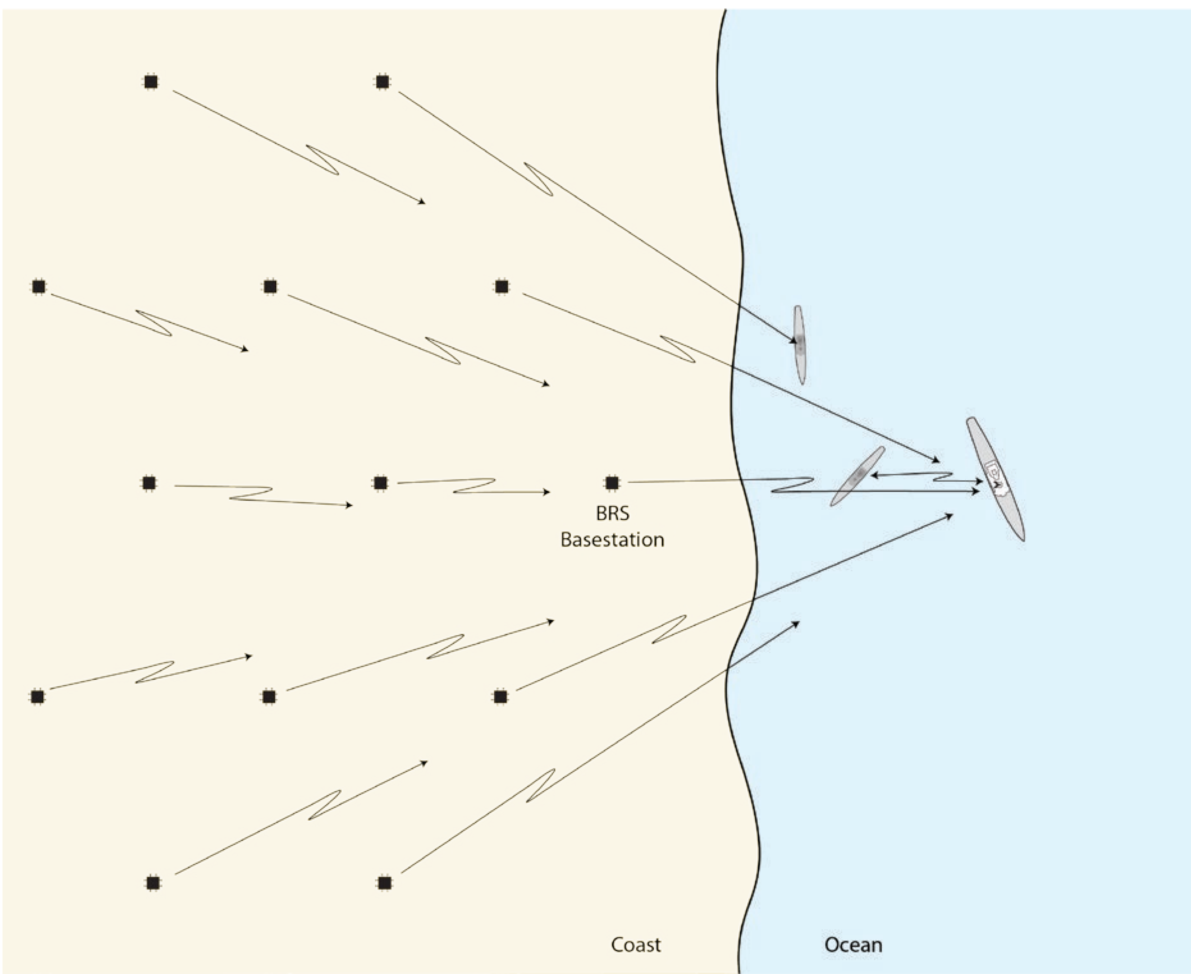


Figure 1. Interference scenario.

and minimum separation distances. Regulatory agencies of interest are the International Telecommunication Union (ITU), National Telecommunications and NTIA, and Federal Communications Commission (FCC). Second, the marine radar community needs to know how to test whether a marine radar can perform in the presence of other radio systems which satisfy the IPC. The testing methodology must be approved by test standards groups such as the United Nations/International Electrotechnical Council (UN/IEC).

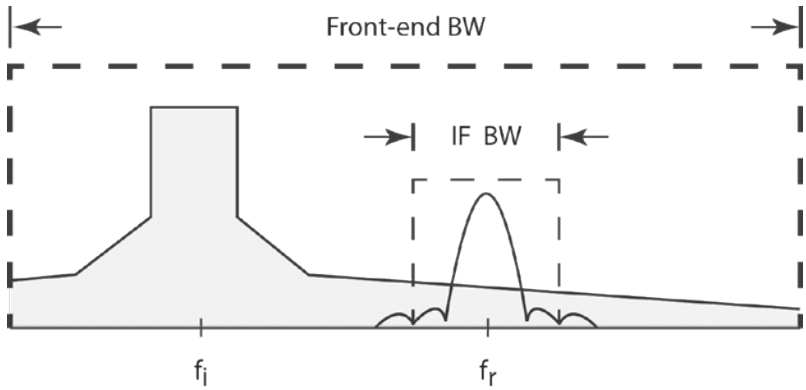


Figure 2. Spectral relationships between BRS signal and radar filters.

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. In FY 2012 we investigated the second potential threat—radar front end overload due to strong signals outside its detection bandwidth.

Current Work

In FY 2013 we focused on refining previous work and preparing final publications. The first technical challenge we undertook presented itself in FY 2012 when we used radar-to-target links in the IEC 62388 ship borne radar standard and a propagation model to derive realistic signal-to-noise ratio (SNR) distributions for interference tests. This approach is different than that more commonly used, which sets the SNR to a constant value corresponding to a baseline performance level. Results showed that the mean of the SNR distribution increased relative to the baseline SNR with radar to target distance.

In FY 2013 our investigations led us to conclude that significant portions of this power margin are necessary to accommodate changes in radar cross section due to target aspect, shape, and materials. As an example, a long cargo ship's radar cross section can decrease by two or three orders of magnitude when viewed "bow-on" as compared to "broadside". To avoid using the margin for interference mitigation, we removed enough to insure 99% radar to target link reliability. After this removal we found that more interfering power could be tolerated than with the constant SNR at longer radar to target distances. At shorter radar to target distances the difference was negligible.

The second technical challenge was demonstrating that BRS base station signals could be reliably emulated with Gaussian noise. This is important because all previous analysis was based on a Gaussian interference signal. We demonstrated this by performing statistical analysis on BRS base station signals collected by ITS engineers. The results showed that the signal had Gaussian amplitude statistics in the necessary bandwidth spectral region where the modulated signal resides and the spurious spectral region where unintended emissions created by transmission are. The out-of-band region between the necessary bandwidth and spurious regions is difficult to measure due to dynamic range considerations. However, since it is composed of modulated and spurious signals we can reasonably conclude that it is also Gaussian amplitude distributed. Hence the BRS base station signal can be reliably emulated as Gaussian noise.

The report series describing this work is in its final stages of publication. Currently it consists of three reports entitled "Effect of Broadband Radio Service Reallocation on S-Band Marine Radars" and subtitled "Background," "Base Station Unwanted Emissions," and "Front End Overload." All three reports focus on magnetron radar technology. A subsequent report will expand our analysis to solid-state radars.

For more information contact Robert J. Achatz, (303) 497-3498, rachatz@its.bldrdoc.gov

Spectrum Sharing Innovation Test Bed Pilot Program

Objectives

- *Determine the viability of DSA-based spectrum sharing in the 406-420 MHz band by:*
  - *Defining key performance indicators for DSA devices that might permit a rulemaking and allow spectrum sharing without harmful interference to incumbent land mobile radio (LMR) systems*
  - *Assessing the effect of co-channel dynamic spectrum access device operations on the intelligibility of voice communications over government LMR systems.*
  - *Confirming estimates of the interference range of DSA systems derived from Phase I laboratory tests.*

Background

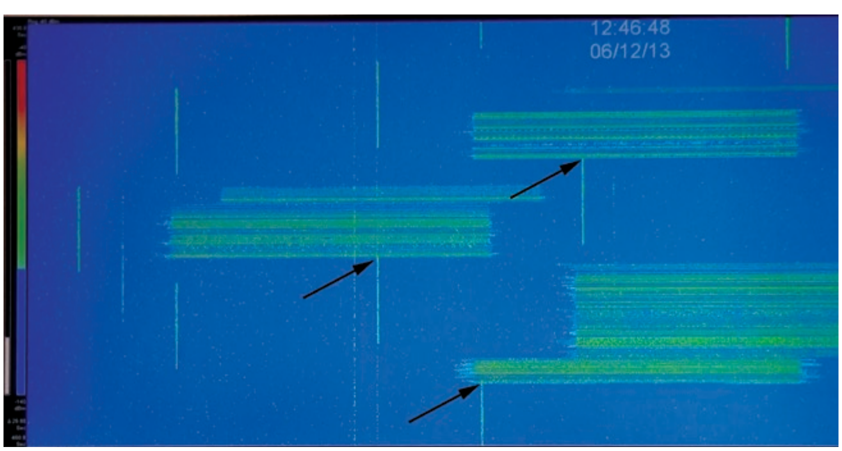
NTIA, in coordination with the FCC and other Federal agencies, established a Spectrum Sharing Innovation Test Bed pilot program to examine the feasibility of dynamic spectrum sharing between Federal and non-federal users as a means of improving spectrum efficiency and providing increased spectrum for commercial applications. This 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 (DSA) may permit new radios to share spectrum with land mobile radio (LMR) systems in the same band. But questions remain as to whether this technology is mature enough to ensure availability and preclude interference to mission critical public safety systems.

To begin resolving these questions, 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. Two devices submitted for evaluation in previous years remained in the program and progressed to Phase III field testing in FY 2013. An additional receiver system was delivered to ITS and began the testing cycle in FY 2013.

Phase I testing involves bench-top laboratory measurements of DSA radio characteristics such as transmitter emissions, sensor performance, and policy-based radio etiquettes 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. Phases II and III test the assumptions developed in Phase I through system level field tests of DSA radios in live LMR environments.



This screen capture shows a spectrogram plot of signals from the DSA devices under test and typical LMR signals (indicated by the black arrows) in the same bandwidth.

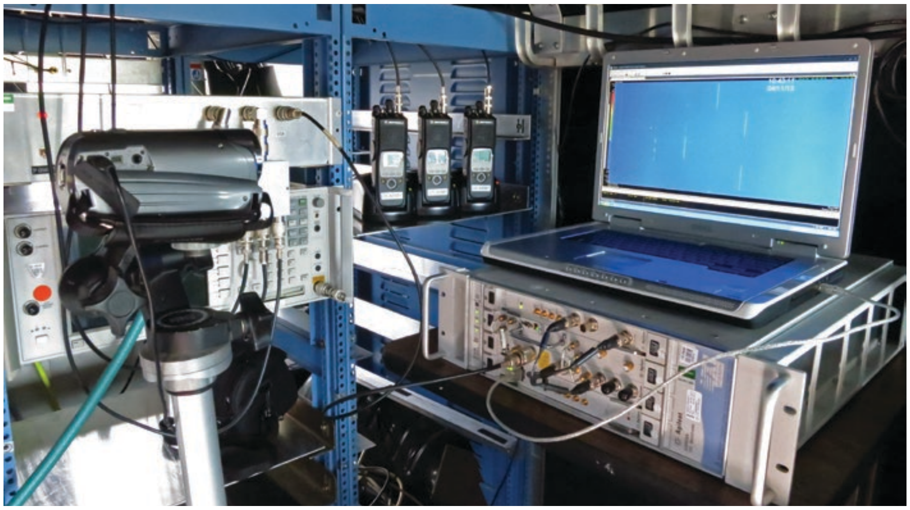
Phase III Testing Completed

In FY 2013, Phase III field testing was completed on the two devices that remained in the program. Phase III testing examined the DSA devices' spectrum sensing and detect-and-avoid capabilities in a live LMR environment under a variety of controlled LMR operating scenarios. We examined their behavior using a spectrum monitoring system while monitoring voice communications for harmful interference on a set of LMR receivers. The LMR messages were carefully constructed in the lab to permit repeatable over the air transmissions.

The DSA devices were installed in mobile platforms, which permitted an examination of various separation distances from LMR receivers. Three test cases were examined: fixed LMR receivers and transmitters for both uplink and downlink transmissions, fixed LMR transmitters with mobile LMR subscriber unit receivers, and mobile LMR transmitters with fixed LMR base station receivers. GPS logging of the DSA device locations were used to calculate separation distances. Video recordings of spectrum monitoring and land mobile radio receiver systems deployed in the test vehicle permitted determinations of co-channel operations. Time stamped audio samples were scored for intelligibility and correlated to separation distances. This permitted an assessment of the interference range of the DSA systems for the test cases.

Test results showed that the interference ranges were comparable to those predicted using the findings of the Phase I lab tests. The effect on mobile LMR receivers that require greater fade margins was less pronounced than the effect on stationary receivers. Documentation of the test results will be completed in FY 2014.

Test van with elevated land mobile radio base station antenna for Phase III field tests of DSA transceivers. Photo by Eric Nelson.



Spectrum monitoring and land mobile radio receiver systems deployed in a test van during Phase III field measurements. Photo by Eric Nelson.

For more information contact Eric D. Nelson, (303) 497-7410, enelson@its.bldrdoc.gov

“... good spectrum management can only satisfactorily proceed if the spectrum managers are adequately informed on the current usage of the spectrum ...”[1]

Radio Spectrum Measurements

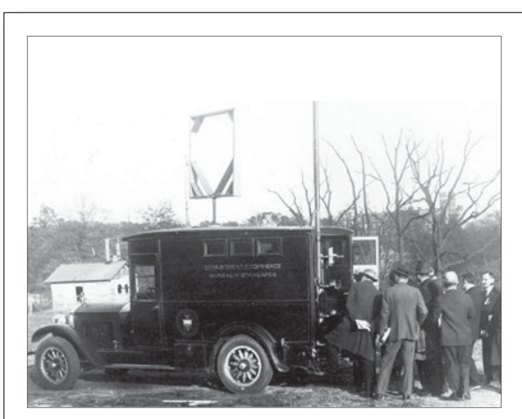
The Table of Frequency Allocations tells what uses particular radio spectrum bands are reserved for. It does not say anything about real usage of those bands. Frequency regulators need information about how the different frequency bands are actually being used—whether some bands are too crowded or some underused—in order to manage spectrum more effectively and increase usage efficiency. Spectrum occupancy measurements provide information about the electromagnetic radiation actually present in a certain band: how many signals, how strong they are, how often they occur, and on what wavelengths.

It is simple to say that we need this information, but not simple to effect. Unless the spectrum measurement effort is carefully crafted on the basis of a sound understanding of the science, it may easily produce false spectrum occupancy results. An entire band may look occupied just because the detection threshold is not adapted to the requirements of the sub-band. On the other hand, bands that are used by low duty cycle or frequency hopping systems may look completely free because the scanning speed is too low or not enough samples are taken on each frequency.

Today’s ITS Spectrum Measurement program builds on a hundred-year legacy of theoretical and applied research into the measurement of radio waves. The radio measurements section of the electrical division of the National Bureau of Standards (NBS) was established in 1911, and its work continued through reorganization as first the Interservice Radio Propagation Laboratory, then the Central Radio Propagation Laboratory, and finally the Institute for Telecommunication Sciences in 1967. A 1966 NBS report on spectrum utilization pointed out “the need for careful dimensioning of spectrum utilization, and the need for a vast amount of data to describe actual usages in a useful way.”[2] Like much early research at NBS, the first radio research programs were focused on the basics of developing instruments and methods for accurate and meaningful measurement. As methods for radio frequency (RF) measurement were perfected using the then current technology, ITS took measurements at locations all over the world and the U.S. whose results were freely published and highly regarded. This methods and measurements cycle continues today.

1. ITU-R Recommendation SM.1880: Spectrum occupancy measurement SM.1880-0 (02/11)

2 U.S. Department of Commerce, Commerce Technical Advisory Board, Telecommunication Science Panel, *Electromagnetic Spectrum Utilization—The Silent Crisis*, October 18, 1966, p. 32.



RSMS mobile measurement laboratories through the years. Left, the 1927 Bureau of Standards RF truck; center, RSMS-1 on the Boulder labs grounds in 1970; right, RSMS-3 taking measurements at Fort Irwin, c. 1998 (photo by Frank Sanders).

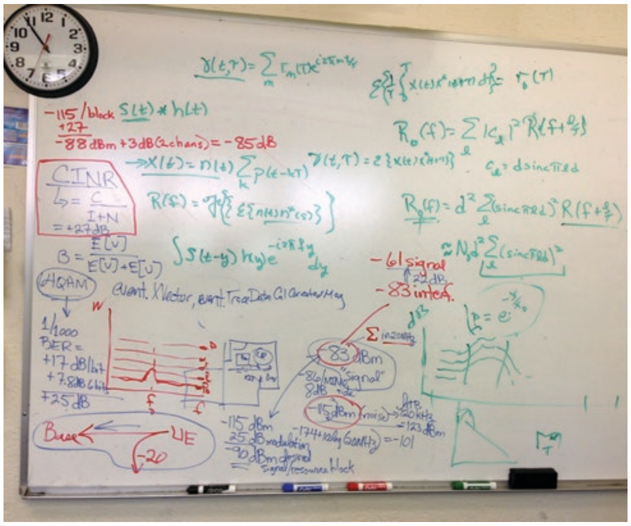
Radio Spectrum Measurement Science

Interest in reliably characterizing radio signals and measuring radio spectrum occupancy is as intense today as it was in 1966. The Radio Spectrum Measurement Science (RSMS) program at ITS continues to address both the development of advanced methods for "careful dimensioning" and the collection of "vast amounts of data" to facilitate Federal spectrum allocation decisions, policy making, and spectrum sharing. The RSMS program supports many types of critically needed and time-sensitive RF measurements, including spectrum surveys and channel usage as well as measurements for equipment characterization and compliance, interference resolution and electromagnetic compatibility, and signal coverage and quality. RSMS expertise and capabilities are used to resolve existing interference problems involving Federal systems and proactively prevent interference to and from Federal systems. The program continues to evolve through both intense theoretical analysis and continuous engineering improvements to methods and instruments.

Theoretical Analyses for Improved Spectrum Measurement

In FY 2013 Theory Division engineers provided three important analytic results in support of the spectrum measurement effort.

The first result was the derivation of the distribution of "median of 5 detected" average power measurements for Gaussian receiver noise. Median of 5 detection is used to suppress impulsive noise during spectrum measurements. Knowledge of the distribution allows us to create median of 5 amplitude probability distribution graphs where Gaussian noise is represented by a straight line. Measurements that do not plot as a straight line are indicative of signals in the radio spectrum.



A small core of highly qualified expert scientists provides key theoretical support for applied engineering projects at ITS. Here, the fruits of a discussion among ITS staff about a particular calculation. Photo by Frank Sanders.

The second analytic result was a derivation of a reasonable spectrum occupancy power threshold for peak detected power measurements. Spectrum occupancy analysis requires that a power threshold be set. Signal powers above the threshold indicate that the spectrum is occupied. Setting the threshold too high or too low introduces errors into the spectrum occupancy estimate. Typically the threshold is set to a fixed level above Gaussian receiver noise power. Spectrum occupancy in bands with pulsed radars with rotating antennas is measured with a peak detector. This analysis determined a reasonable power threshold value for peak detected Gaussian receiver noise.

The third effort was an analysis of the underlying statistical assumptions of spectrum occupancy metrics. Spectrum occupancy measurements are usually acquired over a large frequency range. When measuring pulsed radars with rotating antennas, the power is measured one frequency at a time once every antenna rotation period. This introduces long delays between measurements at the same frequency and limits sampling speed. The analysis of the underlying random processes in the spectrum occupancy measurement process and statistical assumptions of spectrum occupancy metrics showed that spectrum occupancy could be reliably estimated in a reasonable amount of time if certain assumptions about the underlying random process are met.

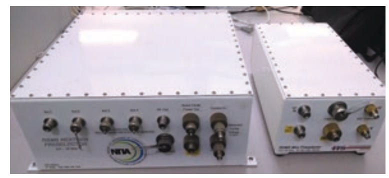
For information on Spectrum Measurements contact Eric D. Nelson, (303) 497-7410, enelson@its.bldrdoc.gov

Radio Spectrum Measurement System

The RSMS measurement system encompasses a comprehensive suite of test equipment, custom-built hardware and software, specialized measurement and analysis techniques, and the extensive expertise of engineers with years of radio frequency (RF) research experience. The objective of the program is to ensure that the Institute has access to the most advanced software and hardware so that it can perform accurate and complete RF measurements between 10 MHz and 40 GHz. The RSMS system and related ITS engineering expertise are available for use by industry and other government agencies on a cost-reimbursable basis under CRADAs and IAs, respectively.

Hardware

While not defined by any single hardware configuration, the system uses state-of-the-art spectrum analyzers, digital oscilloscopes, vector signal analyzers, vector signal generators, and signal intercept and collection systems. This equipment is often fused with RF preselectors, custom built by ITS engineers using state-of-the-art microwave components, to allow measurement of high-dynamic-range signals such as those from radars and communication systems. Overall measurement dynamic range of up 140 dB can be achieved by RSMS systems, extending the nominal 80 dB of instantaneous dynamic range available with precision test equipment. The modular design of the RSMS measurement platforms allows mobile or stationary measurements, both in laboratory settings and at field sites. Deployments of RSMS assets can use the RSMS-4 mobile laboratory or be constructed at field sites from individually-shipped modules.



Customized preselectors built by ITS. Photo by John Carroll.

ITS engineers inside the RSMS-4 mobile spectrum measurement laboratory performing and documenting a measurement. Photo by J.R. Hoffman.

RSMS-4 Mobile Laboratory

An integral part of the system is a measurement vehicle, now in its 4th generation. The vehicle has a highly-shielded enclosure (60 dB isolation from the ambient environment) with three full-size equipment racks, three 10 meter telescoping masts, and a 20 kW diesel generator with power conditioning, as well as internet connections and a climate control system. The RSMS-4 mobile laboratory can be deployed to remote field sites where many operational systems are located and can operate independently from systems under test.

RSMS-5G Software

The RSMS software package is now in its 5th generation (RSMS-5G) of development. It is dynamic and flexible, incorporating automated, semi-automated, and manual techniques for radio emission measurement and analysis. ITS used modern software tools to develop this version, simplifying the design and implementation of new measurement algorithms. The resulting decreased dependency on third party software and compatibility with multiple operating systems has extended the application life-cycle, reduced overall costs, and provided flexibility to continue to keep pace with rapid advances in RF technology.

For more information contact John Carroll, (303) 497-3367, jcarroll@its.bldrdoc.gov or Geoff Sanders, (303) 497-6736, gsanders@its.bldrdoc.gov

FY 2013 Radio Spectrum Measurement Efforts

The ultimate purpose of the Radio Spectrum Measurement Science program and systems is to gather trustworthy empirical data about the behavior of radio waves and the current electromagnetic environment. Propagation measurements collect information about the behavior of specific radio signals; occupancy measurements collect information about signal traffic within a specific radio environment. Data about both propagation and occupancy is a critical prerequisite for developing accurate propagation simulation and modeling tools used to evaluate spectrum sharing scenarios, agile and efficient technologies for spectrum sharing, and effective spectrum sharing policies. In FY 2013, ITS performed three important series of measurements to collect empirical data about both radio wave propagation and radio spectrum occupancy.

Clutter Measurements

Merriam-Webster's Unabridged Dictionary defines clutter as "a mass of disorderly or distracting objects or details." In radio science, "clutter" refers to vegetation and structures that may disrupt, divert, or block a radio signal.

Objectives:

- *Determine path loss values for various clutter areas*
- *Predict clutter attenuation based on statistical properties of measured propagation data*
- *Compare measured values to current models*
- *Incorporate models based on ITS measurements into existing modelling software*

Background

ITS-developed propagation models are widely used as communication planning tools. Geographic information and antenna patterns are two primary inputs to these models. Recently, it became increasingly apparent that more parameters must be included to improve modeling accuracy. Two parameters that will greatly improve accuracy are the attenuation values due to vegetation and buildings—clutter. Although attempts have been made to incorporate the effect of clutter into models, the results have been mixed and not highly satisfactory. To address this issue, ITS engineers are using a recently-developed mobile measurement technique to perform a series of measurements in various environments in the vicinity of Boulder, CO. The objective is to build up a large data base of actual mobile channel measurements and use this to improve the ability of models to estimate clutter effects.

Mobile Propagation Measurements

ITS engineers have developed both mobile and static propagation measurement systems that address a number of wireless propagation scenarios and are ideal for precision propagation measurements and model development/validation. The current systems cover a frequency range from 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, a signal generator, a power amplifier, and precision rubidium frequency references. The receiver van contains an antenna mounted on a large aluminum ground plane, equipment racks, spectrum analyzers, and an on-board generator. GPS measurements are taken using a recording module placed on the outside of the van.

The system is currently operated in a narrowband channel probe mode. A continuous-wave (CW) signal is transmitted and received using a spectrum analyzer in the vector-signal analyzer mode. In-phase (I) and quadrature (Q) data are saved to a file. The received data contain path loss, a slow-fading profile, and fast-fading components. The narrowband mode has high dynamic range, sensitivity, excellent immunity to interference, and low interference potential to existing wireless and land-mobile services, making it suitable for measurements in RF-congested urban environments. The data obtained are highly accurate.

ITS RSMS transmitter truck (background) and receiver van (foreground). Photo by R. Johnk.

A CW signal is transmitted from the transmitting vehicle to a mobile receiver van. The van is driven through various clutter areas such as housing subdivisions, shopping centers, and down a highway where line-of-sight propagation paths are interspersed with areas of blocking terrain and vegetation. One of the spectrum analyzers in the receiving van monitors the received signal level and the other spectrum analyzer digitizes the signal and down-converts it to a discrete time series of baseband I & Q components.

Processing Collected Data

Post-processing of the measured data is carried out in two distinct phases. In the first phase, the data is averaged over selected time intervals. In addition, global positioning system (GPS) tracker data provide precise geolocation information. This data is transferred into a mapping program where areas are selected depending on the expected types of clutter (i.e., neighborhoods, shopping centers) to perform an in-depth study of the propagation characteristics. During the second phase, data from selected areas are analyzed in depth to obtain the following channel parameters:

- Probability density function (PDF) of the signal envelope
- Auto-covariance function of the signal envelope
- Power spectral density of the signal envelope
- Auto-covariances of the I & Q components
- Power spectral densities of the I & Q components

Previous analyses of the system in a mobile measurement environment have shown that differences between line-of-sight (LOS) and non-line-of-sight (NLOS) components can provide insight as to whether the channel is Rayleigh- or Rician-distributed. Rician distributions contain LOS components. A statistical analysis of measured data is used to estimate fast-fading distributions and power spectra; understanding which distribution to apply in the statistical model leads to more accurate assessment of the amount of clutter in a given region and its potential impact on transmissions.

The high precision propagation measurement system in the receiver van was developed by ITS using commercial-off-the-shelf components. Photo by R. Johnk.

For more information on clutter measurements contact Dr. Robert Johnk, (303) 497-3737, bjohnk@its.bldrdoc.gov; Chriss Hammerschmidt, (303) 497-5958, chammerschmidt@its.bldrdoc.gov; or Mark McFarland, (303) 497-4132, mark@its.bldrdoc.gov

Spectrum Occupancy Measurements in the 1755-1780 MHz Band

Objectives:

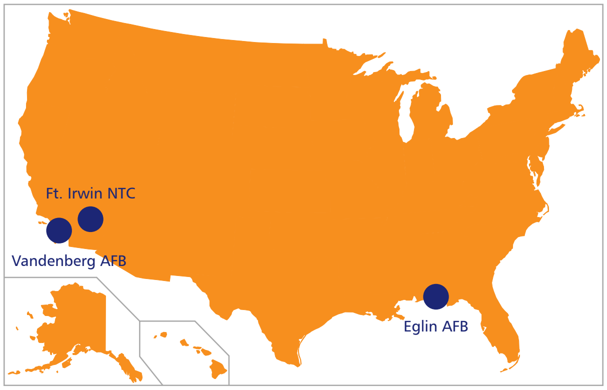
- *Collect data to help stakeholders understand RF activity at various Government ranges and to feed into sharing scenarios between Government and commercial entities*
- *Feed spectrum monitoring data into ITS propagation models to further validate models*
- *Assist in the analysis for a spectrum sharing collaboration between the DoD and the wireless industry*

Background

In July 2012, the Commerce Spectrum Management Advisory Committee (CSMAC) began working with the commercial wireless industry to recommend possible sharing scenarios via various working groups. In conjunction with these meetings, the Department of Defense (DoD) and the commercial wireless industry began collaborating in three research areas: (1) spectrum monitoring, (2) modeling of propagation and aggregate effects, and (3) laboratory measurements of interference effects for various systems. A commercial entity entered into a CRADA with ITS under which ITS conducted spectrum monitoring (spectrum occupancy measurements) in the 1755–1780 MHz band at three DoD locations.

Measurement Locations

The locations chosen for spectrum monitoring were Eglin Air Force Base (AFB), FL; Ft. Irwin National Training Center (NTC), CA; and Vandenberg AFB, CA. At each of these locations specific government systems were identified for monitoring. Three main systems were monitored at Eglin AFB: Aeronautical Mobile Telemetry (AMT), the Air Combat Training System (ACTS), and the Small Unmanned Aircraft System (SUAS). Monitoring at Ft. Irwin NTC measured RF emissions from SUAS, and monitoring at Vandenberg focused on the RF emissions from the Satellite Ground Link System (SGLS).



Measurements at Ft. Irwin were conducted from January 14, 2013 to February 3, 2013. This time frame encompassed one complete rotation of equipment through the base. We started monitoring RF activity on the range before actual systems were deployed and then retrieved equipment when RF activity had concluded. We set up the monitoring equipment in two locations on the range. The first location was in a valley where many training battles occur. The second location was on a mountaintop overlooking the range. A low and a high location were chosen to monitor the emissions from SUAS typically flying at altitudes of 150 m.

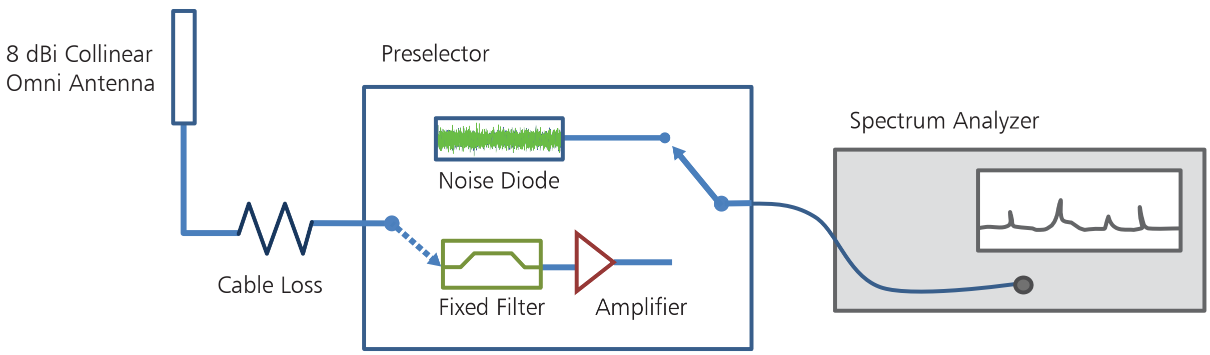
Measurements at Eglin AFB were conducted from January 15, 2013 to February 14, 2013. The monitoring equipment was placed in a laboratory on top of a 100 m tall tower. This site was selected because it provided the necessary infrastructure (such as power and an antenna mast), offered exceptional visibility of nearby test range activities, and, as the tallest structure in the area, maximized the observable range of airborne emissions.

Measurements at Vandenberg AFB were conducted from February 6, 2013 to February 22, 2013. The chosen measurement location had access to a base-station shelter. The shelter was used to house equipment and provide power. The shelter also had line-of-sight visibility to the SGLS station.

Measurement Methods

System calibrations and swept measurements were performed on an hourly basis. Calibrations were performed at the beginning of each hour using the Y-factor calibration method using a noise diode incorporated into the preselector. To compare power levels measured with different receivers, all received powers were converted to power received at the input of an isotropic antenna. The system gain and noise figure, both in dB, were used to correct the measured data from the spectrum analyzer to the output of the preselector. The cable loss, in dB, was added to this number, which moves the reference point to the input of the antenna. The antenna gain was subtracted to move the reference point from the input of the antenna to the output of the antenna. This power can then be referenced to power at the input of an isotropic antenna. Data was reduced to the following formats:

- Daily Maximum, Median, Minimum and Mean (M4) signal level statistics
- Daily Time vs. Frequency Spectrograms
- Daily Band Occupancy



This schematic describes the NTIA/ITS measurement system used for measurements in the 1755-1850 MHz band. The fixed filter is used to avoid strong out-of-band signals that might cause the amplifier to operate in its non-linear region. The amplifier improves system sensitivity by overdriving the relatively high noise figure of the spectrum analyzer.

Spectrum Occupancy Measurements in the 3.6 GHz Maritime Radar Band

Objectives

- *Implement an optimal measurement scheme for detecting maritime radar signals*
- *Determine the range of detection of the radar occupancy measurement system*
- *Obtain measured data of the 3.6 GHz maritime radar band in a high-usage environment*
- *Establish a theoretical framework for spectrum occupancy measurements*
- *Provide channel occupancy estimates with quantified uncertainties*

Background

NTIA's 2010 Fast Track Evaluation Report[1] identified the 3.6 GHz maritime radar band as a candidate to accommodate wireless broadband systems, and the 2012 report on "Realizing the Full Potential of Government-held Spectrum to Spur Economic Growth"[2] by the President's Council of Advisors on Science

1. U.S. Department of Commerce, National Telecommunications and Information Administration, "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands," October 2010. Accessed http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf March 31, 2014.

2 Executive Office of the President, President's Council of Advisors on Science and Technology, "Report to the President: Realizing the Full Potential of Government-held Spectrum to Spur Economic Growth," July 2012, p. 82. Accessed http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf March 14, 2014.

and Technology recommended that the FCC "immediately start the process to modify its rules to allow "general authorized access" devices to operate in" that band. To provide data to support well-engineered spectrum rules and decisions in this regard, ITS researchers investigated spectrum occupancy of the 3.6 GHz maritime radar band in a high-usage environment.

Related Report: *Michael Cotton and Roger Dalke, "Spectrum Occupancy Measurements of the 3550-3650 MHz Maritime Radar Band Near San Diego, California," NTIA Technical Report TR-14-500, January 2014. Available http://www.its.bldrdoc.gov/publications/2747.aspx.*

Measurements

In this effort, ITS provided information and measurement results to characterize how the military uses the 3.6 GHz band near San Diego, CA. First, ITS designed and built a measurement system optimized to detect the maritime SPN-43 radar signals assigned to this band. The measurement system could detect circularly-polarized transmission from the shipborne radar systems operating as close as 72 km and as far as 206 km from the coastline. Figure 1 illustrates measured signals over the two-week measurement duration.

A theoretical framework was established to reduce this data to a meaningful set of statistics and estimates with quantified uncertainties. More specifically, ITS researchers defined channel occupancy in the context of renewal theory, where occupancy is indicated by received signal power in exceedance of some predetermined threshold. This set up reduces channel occupancy estimation to counting the number of successes in N Bernoulli trials, for which many theoretical results are available. Figure 2 illustrates measured weekday and weekend channel occupancy statistics with confidence limits calculated from developed analytic expressions.

Results of this effort were published in an NTIA Technical Report. Daily signal-level and band occupancy plots are presented in this report, as well as summary tables and plots that show what was observed over the two-week measurement. Statistical considerations (e.g., channel occupancy definition, estimation, and uncertainty) that arise when measured data are used to characterize spectrum occupancy are also discussed.

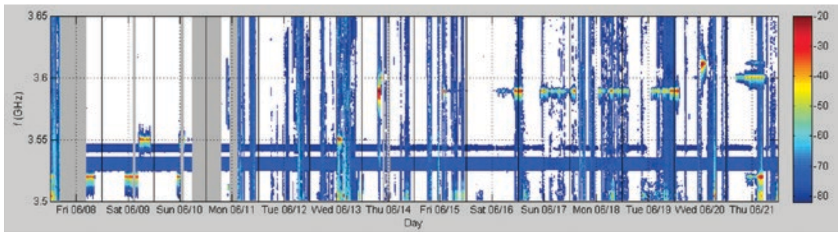


Figure 1. Measured signals in the 3.6 GHz band near San Diego in June 2012.

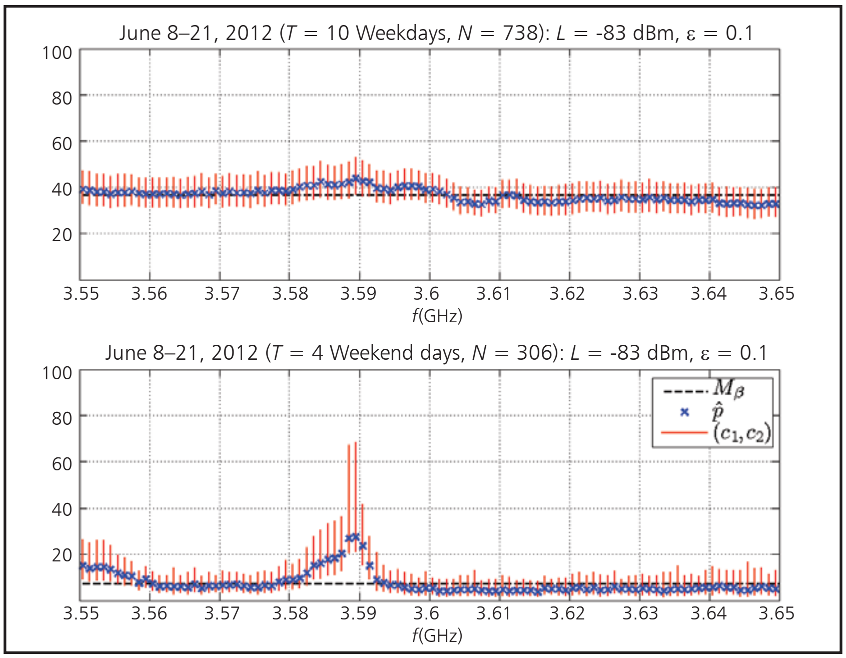


Figure 2. Channel occupancy estimates (for a threshold of -83 dBm) with 90% confidence intervals.

For more information on measurements in the 1755-1850 MHz band contact Chriss Hammerschmidt, (303) 497-5958, chammerschmidt@its.bldrdoc.gov. For more information on measurements in the 3.6 GHz band contact Michael Cotton, 303-497-7346, mcotton@its.bldrdoc.gov

National and International Standards Development

Radio waves respect no international borders. The International Telecommunication Union (ITU) is a treaty organization that provides a neutral platform for shaping global consensus on the standards that enable a seamless robust, and reliable, global communications system. ITU standards (called Recommendations) act as defining elements in the global infrastructure of information and communication technologies and play a critical role in advancing global interoperability and creating a level playing field in which companies can compete internationally. These are developed by consensus in Study Groups of public and private sector experts who provide input in the form of technical contributions.

Working with the U.S. ITU National Committees, ITS provides technical contributions and leadership to ITU-R (Radiocommunication Sector) and ITU-T (Telecommunication Standardization Sector) committees that develop technical standards of importance to U.S. industry and government. ITS also develops and coordinates approval of related U.S. voluntary consensus standards where appropriate. ITS recommendations are, and for decades have been, highly valued both nationally and internationally: a plurality of the technical recommendations of the ITU are based on research conducted at ITS, and key national quality-of-service standards developed under the American National Standards Institute (ANSI) accredited Committee T1 for video, audio, and digital data incorporate research results obtained at ITS. ITS staff chair 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.

ITU-R Standards Activities

Objectives

- *Develop and maintain internationally standardized radio propagation models for studies being conducted by the ITU-R*
- *Provide US and international users of ITU-R Propagation Recommendations with expert advice on the contents and bases for these Recommendations.*
- *Update the IF-77 propagation model to reflect advances in measuring propagation components*
- *Contribute to domestic and international working groups studying Earth-to-space communication links*

Background

Success in world-wide 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), a technical agency within the United Nations.

ITS conducts technology transfer via technical contributions and expert leadership to support U.S. interests in the ITU-R. Entities such as government agencies, businesses, and academia use Recommendations developed by the ITU-R to study, plan, and develop radiocommunication systems. Within the ITU-R, Study Groups develop the technical bases for decisions taken at World Radiocommunication Conferences (WRC) and develop Recommendations, Reports, and Handbooks on radiocommunication matters.

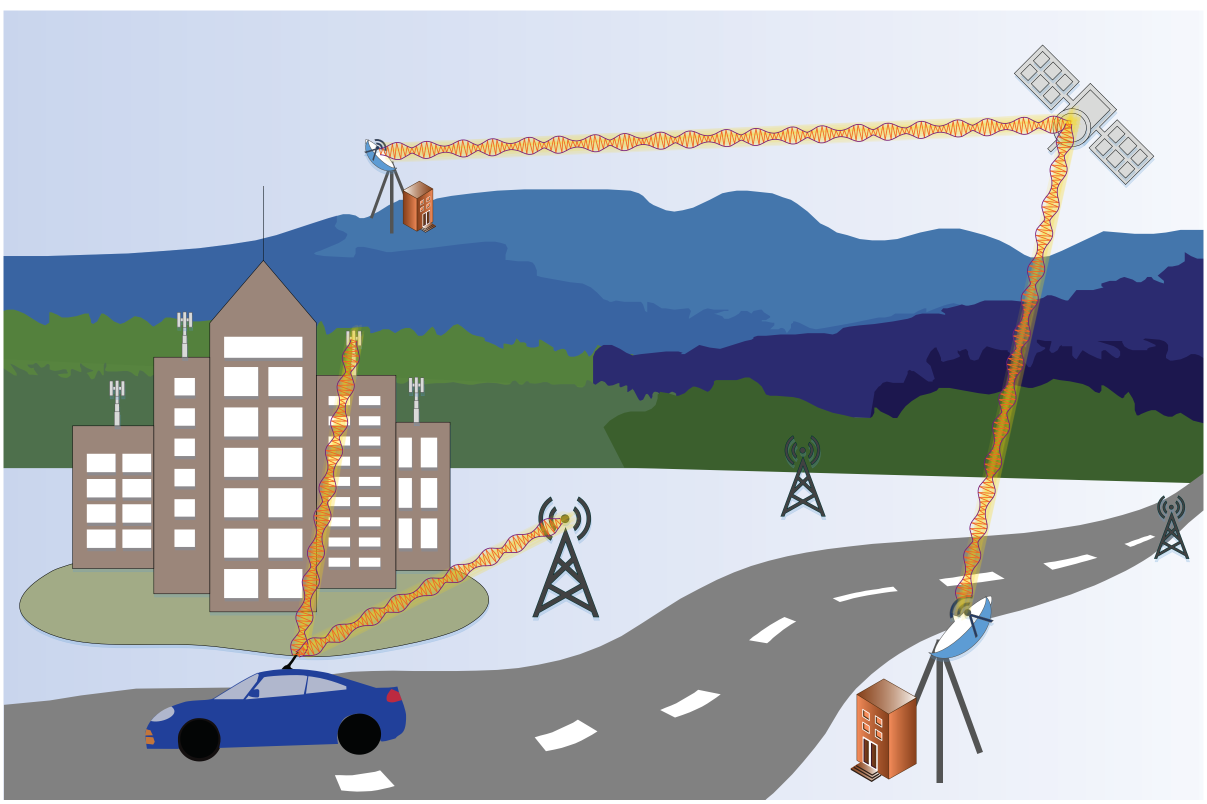
Study Group 3 of the ITU-R is responsible for Recommendations in the P-series, which pertain to propagation issues. ITS, with its long technical history in propagation modeling, is well suited to support SG 3 work. Other areas in which ITS contributes internationally recognized technical leadership are Spectrum Management (Study Group 1), Terrestrial Services (Study Group 5) and Integrated broadband cable networks and television and sound transmission (Study Group 9). ITS staff join over 4 000 specialists, from administrations, the telecommunications industry as a whole, and academic organizations throughout the world, to participate in the work of these Study Groups through smaller, specialist groups called Working Parties.

In FY 2012, NTIA joined other Federal agencies participating in the 2012 World Radiocommunication Conference (WRC-12) to successfully secure 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.

A Joint Task Group of experts from four of the seven standing Study Groups (JTG 4-5-6-7) was established within the ITU-R as the responsible group for these two WRC-15 Agenda Items, to conduct the necessary sharing studies and to develop the necessary preparatory text. This ensures the opportunity for all stakeholders to participate during the sharing study work, and sets the international framework in motion to advance the U.S. Administration's 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 its completion, Working Party (WP) 3K has continued its work inter-sessionally via correspondence. In particular, in FY 2013 ITS engineers participated in Correspondence Groups 3K3M-9 (Ground-Air-Satellite Links) and 3K-4 (Rec. ITU-R P.1546 and aggregation of low time percentage signals).

Propagation Modeling for Spectrum Sharing

Successful spectrum sharing requires careful planning to avoid interference between different users. To meet the objectives of spectrum flexibility and harmonization for the joint studies being 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. Radio



This schematic shows a possible scenario for cellular and satellite services potentially sharing the same frequency bands.

propagation prediction models are powerful tools for building international consensus around the introduction of these new services.

Some international standards for propagation modeling are based on models developed by ITS from our extensive background in radio propagation. ITS continues to update models to reflect contemporary conditions and equipment, and to present those updates as contributions towards revised standards. Our work in this area also includes ensuring that the best methods for accurate and realistic planning are available to both Federal and civilian users in the U.S. via IAs and CRADAs, respectively.

When properly applied, propagation models 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 ITU Recommendations, they are generally perceived as technically neutral and unbiased bases for multilateral coordination, regulation, and harmonization of spectrum.

FY 2013 Technical Contributions

During FY 2013, ITS produced several technical contributions to advance the work of JTG 4-5-6-7 through its participating Working Parties. Two U.S. technical contributions to WP 3K were produced: an editorial modification of Recommendation ITU-R P.528 (Doc. 3K/48) and a report of the work of Correspondence Group 3K3M-9 (Doc. 3K/47). In addition, during the meetings of Working Party 3K, several Liaison Statements concerning propagation advice and measurement data were drafted to Working Party 5B (Doc. 5B/320), Working Party 6A (Doc. 6A/283) and JTG 4-5-6-7 (Doc. JTG4567/141). At the conclusion of the meetings, the Chairman's Report on the Meeting of Working Party 3K (Doc. 3K/76) was also drafted.

After the meetings of Working Party 3K, two additional Liaison Statements to JTG 4-5-6-7 (Docs. 3K/80 and 3K/81) were drafted inter-sessionally. These documents provided further advice on propagation models for various sharing studies being conducted by the Joint Task Group.

Earth-to-Air-to-Space Propagation Models

Different propagation models have been developed and standardized for different types of radio links under different conditions. For example, to accurately model transmission links for Earth to air, Earth to space, and air to space, the special conditions required to predict the transmission losses and interference levels from these specific applications must be included in the model. One candidate for sharing that falls into this category is the 1695 MHz band, which has both national and international allocations for space to Earth satellite transmission. Satellite systems can be vulnerable candidates for spectrum sharing: mistakes are costly to correct and might even be unfixable. Unfortunately, there are only a few appropriate propagation models available for aeronautical and satellite wireless links. One of these is Recommendation ITU-R P.528.

Recommendation ITU-R P.528

Recommendation ITU-R P.528, "Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF band," gives a method for predicting basic transmission loss for aeronautical and satellite services. This Recommendation, which was developed from the ITS model IF-77, has been of particular interest in recent years because of 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.

Aeronautical and Satellite Systems

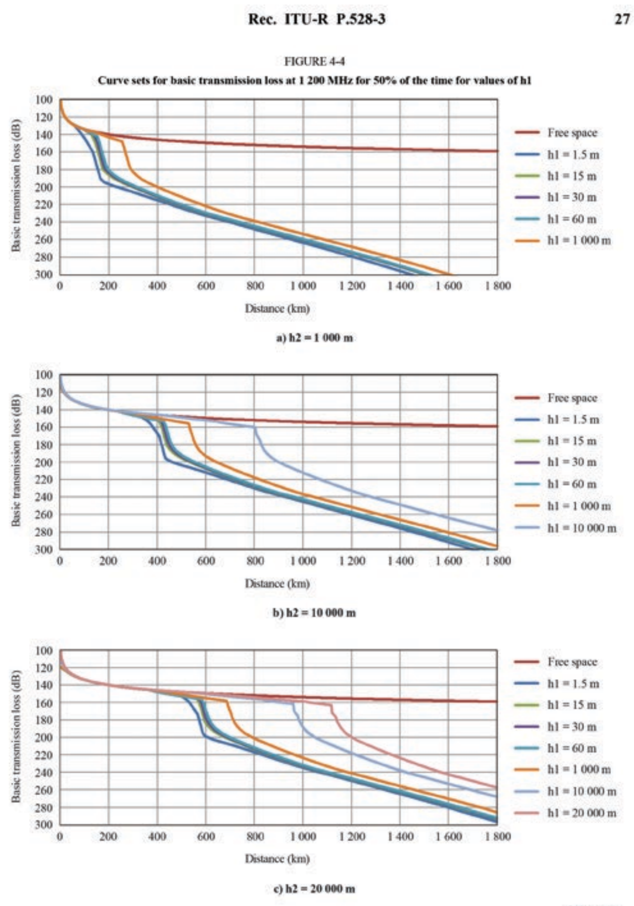
In the 2010 SG 3 Working Party meetings, the study group received questions about two separate issues. One issue concerned frequency sharing studies between the Earth stations of mobile satellite services (MSS) and satellite remote sensing (SRS) services. The other concerned frequency sharing studies between terrestrial mobile systems and aeronautical radionavigation systems (ARNS). In both cases, the appropriate Recommendation to use is ITU-R P.528. ITS led the correspondence group effort to expand version 2 of the recommendation to add frequencies, antenna heights and time percentages that were badly needed. Although version 3, adopted in 2012 with significant contributions by ITS, delivered important improvements, work continues to provide additional updates to respond to rapidly changing needs. To supplement the expanded graphs, the correspondence group plans to include a step-by-step method for calculating the transmission loss for user defined parameters using the same inputs as were used to produce the graphs.

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. ITS has again been chosen to lead 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. Two methods are presently being considered, and one is based on updating the ITS IF-77 model.

System Planning

The ITS-led correspondence group for the revision of Recommendation P.528 is presently developing a computational method for this 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. ITS's work in both aeronautical and unmanned airborne systems is essential to studies to evaluate frequency sharing proposals, and provides important contributions to the expanded ITU SG 3 investigations into all airborne platforms (Question ITU-R 233/3). The calculations based on the future computational method for P.528 and prediction method(s) likely to come out of the SG 3 investigations for airborne platforms will also be important in planning both satellite and aeronautical systems.



A page from ITU-R Recommendation P.528-3, which gives a method for predicting radio propagation loss. These curve sets show the predicted basic transmission loss at 1200 MHz for 50% of the time for antenna heights from 1.5 to 20,000 m (ground station and aircraft heights).

For more information about the work of JTG 4-5-6-7 contact Paul M. McKenna, (303) 497-3474, pmckenna@its.bldrdoc.gov. For more information about Rec. P.528 and IF-77 contact Teresa L. Rusyn, (303) 497-3411, trusyn@its.bldrdoc.gov.

ITU-T and Related Standards Activities

Objectives

- *Promote QoS/QoE standards through leadership roles in ITU-T Study Group 9 and the Video Quality Experts Group*
- *Develop and present technical contributions with U.S. standards proposals and ITS research results*
- *Work within the ITU-T to improve working methods by helping to revise key Recommendations and Resolutions*

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. In addition to the ITU-T, ITS experts provide input to the Alliance for Telecommunications Industry Solutions (ATIS) and the Society of Cable Telecommunications Engineers (SCTE), both North American partners for international SDOs.

The Institute's long-term goal in ITU-T, ATIS, and SCTE is to motivate the standardization of user-oriented, technology-independent measures of telecommunication service quality (QoS/QoE), 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. This facilitates the optimization and efficient use of spectrum and bandwidth resources.

ITU-T Study Group 9

ITU-T SG 9 (Broadband cable and TV) 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 SG 9 are those defining video and multimedia quality assessment and those supporting emergency telecommunications over broadband cable networks. SG 9 also develops Recommendations on digital transmission systems, digital rights management, and program insertion specifications, all for cable television systems.

In FY 2013, ITS staff members held several prestigious leadership roles in the ITU-T, including International Chair of SG 9, Head of the U.S. Delegation to SG 9, and Co-chair of the ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). ITS staff also served as SG 9 representative for Audiovisual Media Accessibility (AVA), Associate Rapporteur for Questions 2/9 (Measurement and control of the end-to-end quality of service (QoS) for advanced television technologies) and 12/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9), and SG 9 contact for Electronic Working Methods.

VQEG

An ITS staff member founded the Video Quality Experts Group (VQEG) 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 2013, the number of participants subscribed to the main reflector reached over 500. 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 SG 9, SG 12 (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 2013. Margaret Pinson co-chaired VQEG's audiovisual high-definition television (AVHD) and Independent Laboratory Group (ILG) groups and is now spearheading the final analyses and documentation for the hybrid 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 several 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 SG 9.

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.

JRG-MMQA

In related work, ITS leads the ITU-T's Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). This is a cross-cutting ITU-T standards body that unites the video quality expertise of SG 9 with the audio and network quality expertise of SG 12 in an effort to develop objective, perception-based metrics for combined audio and video signals in mobile and PC environments. The JRG-MMQA meets concurrently with VQEG. The JRG-MMQA provides an official mechanism for coordinating VQEG activities with ITU-T SG 9 and ITU-T SG 12. At the 2012 Telecommunications Standardization Assembly (WTSA-12), a new mechanism for facilitating technical work across the ITU-T and ITU-R Sectors was approved. In early FY 2014, the JRG-MMQA will be replaced by the Intersector Rapporteur Group on Audiovisual Quality Assessment (IRG-AVQA). This will expand both the scope and the reach of this joint ITU work by expanding the technical terms of reference and by including the ITU-R SG 6 in the first official Intersector Rapporteur Group in the history of the ITU.

Arthur Webster attended WTSA on the U.S. Delegation and presented his SG 9 Report to over 1000 delegates from 101 countries. Photo courtesy ITU.

Preparation for U.S. Participation in ITU World Conferences

In addition to direct participation in the technical committees discussed above, an ITS engineer 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). Arthur Webster attended WTSA-12 on the U.S. Delegation and presented his SG 9 Report to over 1000 delegates from 101 countries.

For more information contact Arthur A. Webster, (303) 497-3567, webster@its.bldrdoc.gov

1912

“From and after October first, nineteen hundred and twelve, it shall be unlawful for any steamer of the United States or of any foreign country navigating the ocean or the Great Lakes and licensed to carry, or carrying, fifty or more persons, including passengers or crew or both, to leave or attempt to leave any port of the United States unless such steamer shall be equipped with an efficient apparatus for radio communication, in good working order, capable of transmitting and receiving messages over a distance of at least one hundred miles, day or night.”[1]

1996

“The importance of radio communications to the Public Safety community cannot be overestimated. In a large-scale disaster such as an earthquake, forest fire, or flood, hundreds of agencies and thousands of individuals come together to provide emergency medical assistance, fire suppression, rescue operations, infrastructure repair, crowd control and security, food and shelter, and to begin the process of rebuilding. At a time when other means of communication are likely to be inoperable, Public Safety radio communication systems must provide the lifeline that connects each responder to his or her agency and to each other.”[2]

2010

“In a broadband world, there is a unique opportunity to achieve a comprehensive vision for enhancing the safety and security of the American people. Careful planning and strong commitment could create a cutting-edge public safety communications system to allow first responders anywhere in the nation to communicate with each other, sending and receiving critical voice, video and data to save lives, reduce injuries and prevent acts of crime and terror.”[3]

2012

“The First Responder Network Authority shall ensure the establishment of a nationwide, interoperable public safety broadband network. ... The nationwide public safety broadband network shall be based on a single, national network architecture that evolves with technological advancements ...”[4]

1. *Navigation Laws of the United States*, Government Printing Office: Washington, D.C., 1915, p. 424. Accessed https://archive.org/details/navigationlawsu00navigoog June 3, 2014.
2. Public Safety Wireless Advisory Committee, *Final Report to the Federal Communications Commission and the National Telecommunications and Information Administration*, September 11, 1996, p. 5. Accessed http://www.ntia.doc.gov/legacy/osmhome/pubsafe/PSWAC_AL.pdf June 3, 2014.
3. Federal Communications Commission, “Connecting America: The National Broadband Plan,” p. 313. http://www.broadband.gov.
4. 47 U.S.C. § 1422 - Public safety broadband network

Public Safety Communications Interoperability

The Government's interest in ensuring the availability of wireless communication for the safety of the public has been acknowledged since the earliest days of the 20th century. The first two-way transmission of wireless telegraphy across the Atlantic took place in 1906; three years later, a liner involved in a collision off Nantucket Island sent the first distress call, leading to the rescue of over a thousand people. After the sinking of the Titanic, when distress calls went unanswered for four hours because the closest radio operators were off-shift, the Wireless Ship Act of 1912 required that all large ships have 24 hour radio communication capability. That act also delegated to the Department of Commerce the authority to enforce wireless-communication laws, treaties, and conventions, and to regulate radio communication by issuing licenses to operate in order to prevent or minimize interference.

Since that time, the radio laboratories of the DoC have worked hand in hand with other government agencies at all levels to improve public safety communications—from radio signaling for military operations in World War I to the first radio beacons for airway safety in the 1920s to World War II and the birth of radar to the advent of digital radio in the 1970s and 1980s to the present-day work with the First Responders Network Authority (FirstNet)—the body mandated to establish a nationwide, interoperable public safety broadband network by legislation passed in 2012, 100 years after the Wireless Ship Act.

ITS has worked with the NIST Law Enforcement Standards Office (NIST/OLES) and its predecessors for decades to conduct research and contribute to standardization efforts to assist law enforcement and criminal justice agencies to select and procure communications equipment that meets their needs. Since FY 2003, this work has been carried out through the Public Safety Communications Research (PSCR) program (www.pscr.gov), a joint effort that leverages the capabilities of NIST/OLES and ITS through collaborative research projects.

PSCR 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), the DHS Office for Emergency Communications (OEC), and FirstNet. PSCR projects are planned and performed with coordination among local, state, tribal, and Federal practitioners. Technical thrusts within the program include public safety broadband requirements and standards, the PSCR Broadband Demonstration Network, and public safety broadband research.

Public Safety Broadband Requirements and Standards

Objectives

- *Identification of public safety broadband communications requirements*
- *Representation of the First Responder Network Authority in standards development*

Overview

In 2010 the FCC published the National Broadband Plan, which outlines how broadband spectrum will be utilized in the future. The Plan also proposed 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 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.

Activities

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 Telecommunications Industry Association (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.

- 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
- PSCR led the NPSTC Broadband Working Group in the creation and delivery of the Mission Critical Push To Talk over LTE Requirements to the FirstNet Board in 2013

In its standards development efforts, PSCR also represents FirstNet as a member of the organizations that are collectively responsible for developing the standards for the LTE technology selected by public safety for 700 MHz broadband—the 3rd Generation Partnership Project (3GPP, a collaboration among six telecommunications standards bodies to produce globally-applicable cellular system specifications); the Alliance for Telecommunications Industry Solutions (ATIS, the founding North American Organizational Partner of 3GPP); the Open Mobile Alliance (OMA, a standards body which develops open standards for the mobile phone industry); and the GSM Association (GSMA, an international association of mobile operators and related companies that supports GSM mobile telephone standardization).

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. Additionally, PSCR is representing FirstNet in 3GPP to ensure that Release 13 LTE products have a mission critical push to talk over LTE 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 standards 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)
- NPSTC Public Safety Broadband Push-to-Talk over Long Term Evolution Requirements A NPSTC Public Safety Communications Report (July 18, 2013)
- 3GPP TR22.803 Feasibility study for Proximity Services (ProSe) (Release 12) V12.2.0 (2013-06)
- 3GPP TS22.278 Service requirements for the Evolved Packet System (EPS) (Release 12) V12.4.0 (2013-09)
- 3GPP TS22.115 Service aspects; Charging and billing (Release 12) V12.2.0 (2013-09)
- 3GPP TR23.703 Study on architecture enhancements to support Proximity based services (ProSe); (Release 12) V12.0.0 (2014-02)
- 3GPP TS23.303 Proximity based services (ProSe); Stage 2 (Release 12) V12.0.0 (2014-02)
- 3GPP TS22.468 Group Communications System Enablers for LTE (GCSE_LTE) (Release 12) V12.0.0 (2013-06)
- 3GPP TS23.768 Study on architecture enhancements to support Group Communication System Enablers for LTE (GCSE_LTE) V12.0.0 (2014-02)
- 3GPP TS23.468 Group Communications System Enablers for LTE (GCSE_LTE); Stage 2 (Release 12) V12.0.0 (2014-02)
- 3GPP TR36.843 Study on LTE Device to Device Proximity Services; Radio Aspects (Release 12) V12.0.1 (2014-03)
- 3GPP TR36.868 Study on group communication for E-UTRA (Release 12) V12.0.0 (2014-03)
- 3GPP TR 33.833 Study on security issues to support Proximity Services (Release 12) V0.4.0 (2014-02)
- 3GPP TR 33.888 Study on security issues to support Group Communication System Enablers for LTE (GCSE_LTE) (Release 12) V0.2.0 (2014-01)

One of the two fixed LTE transmitters used for over-the-air testing in the Public Safety 700 MHz Broadband Demonstration Network. This one is located at the Table Mountain Field Site and Radio Quiet Zone. Photo by Ken Tilley.

PSCR Broadband Demonstration Network

Objectives

- *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

Public safety land mobile radio (LMR) networks have traditionally been built by individual localities or on a statewide basis. Stove-piped proprietary systems and non-contiguous spectrum assignments have long impeded effective cross agency/jurisdiction public safety 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 FCC and public safety leadership are working to develop baseline requirements for interoperability on this system.

PSCR leads this effort, tailoring it to the unique operational and technical requirements specific to broadband communications for public safety. Deploying new cellular technologies nationwide will be far more complex than building local or even regional networks, and require an unprecedented level of coordination. The PSCR Broadband Demonstration Network, established in FY 2010, facilitates accelerated development of testing for emerging LTE broadband equipment specific to public safety. It is an independent, vendor-neutral venue where public safety agencies can test equipment and identify interoperability issues prior to building or altering their networks.

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 3GPP.

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 Field Site and Radio Quiet Zone and the Green Mountain Mesa Test Site.

The Demonstration Network is made available through CRADAs for manufacturers and carriers to test the deployment of LTE 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 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.

Future Work

In FY 2014, 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 and will also begin to address National Security/Emergency Preparedness (NS/EP) Next Generation Network Priority Services (NGN-PS).

PSCR broadband research laboratory. Upper left: User equipment (UE) from multiple manufacturers in a variety of formats is tested for performance characteristics and interoperability; measurement instruments are on the middle shelf. In the secure area behind the door to the left are eNodeBs from multiple manufacturers for interoperability testing over the air. Above: A bidirectional radio channel emulator is used to develop repeatable air interface testing experiments with different simulation scenarios. Left: A test bench in a screen room for conducting tests in a shielded environment. Photos by Lilli Segre.

Public Safety Broadband Research

Objectives

- *Insight into special problems faced by a coverage-driven nationwide LTE network*
- *Possible mitigation techniques to enhance coverage, efficiency, and reliability*

Overview

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 LTE. The Public Safety Broadband Research program at ITS explores ways to optimize LTE within the constraints of a public safety network. 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.

Civilian broadband networks are primarily constrained by capacity—the need to serve a relatively well concentrated population of customers using cellular base stations with a finite user capacity. Since the networks are typically designed for population centers like cities or areas of high transient population density like highways, the proper design rule is to increase the number of base stations until the capacity demands are met, with the assurance that all of the users will contribute to the capital equipment and operational costs that result. Public safety networks, by contrast, typically serve a small number of highly mobile users (except during emergencies) but must provide service anywhere—incidents are obviously not constrained to occur only within areas of high population density. Thus, the public safety broadband network must be designed for coverage first, with capacity as a secondary consideration.

Another finite resource for the broadband public safety network is financial in nature. Although usage fees are contemplated for the NPSBN, the bulk of the cost for implementation of this network must be covered by money already furnished by Congress in the Middle Class Tax Relief Act of 2012. Given the greater size of the coverage area and the smaller number of fee paying users, the inevitable conclusion is that the public safety broadband network is highly likely to involve lower base station densities than current civilian LTE networks. Many of the FY 2013 Public Safety Research projects are designed to investigate or help mitigate the effects of this operational environment. Major efforts in FY 2013 included an investigation into cell edge behavior for various macrocell equipment vendors, a look at the properties of an extended coverage LTE “boomer cell,” and an investigation into the building penetration properties of our existing macrocellular demonstration network.

Cell Edge Behavior of LTE Public Safety Networks

The PSCR broadband public safety demonstration network encompasses two fixed site LTE base stations approximately 14.5 km apart along a north/south line, and one nomadic cell on wheels (COW) that can be transported to a chosen location for intervals of weeks or months and then relocated as necessary. In this investigation, the COW was located about 9 km east of the line between the two fixed site locations. A 20 km route that included both rural and suburban coverage near the center of the covered area was driven multiple times to determine the coverage characteristics of four different vendor radio access network systems.

This work resulted in a number of interesting observations. Even though the only major variable in this experiment was the vendor infrastructure being used, the average throughput results exhibited a considerable variability with vendor. The number of cellular handoffs was also quite different and the use of spatial multiplexing as opposed to diversity mode reception was a clear discriminator across vendors. In addition, some subtle ramifications of handoff parameter setup were uncovered. Some of the results of this work were presented in a public safety broadband stakeholders conference held in June 2013.

Investigations into Extended LTE Cells

Since ubiquitous rural coverage in areas of extremely low population density is required within the 2012 congressional mandate, the possibility of extended coverage LTE cells is of great interest. Typical LTE cells in the 700 MHz band encompass cell radii of 10 km or less, but 3GPP standards allow the possibility of cells with radii of 14, 30, 77, and 107 km depending on settings. In order to investigate this capability, a single sector LTE base station was mounted on a 305 m (1000 ft.) mast at 85 m above ground level.

Two different factors besides antenna height come into play in this experiment. The most obvious factor is signal strength—an LTE signal in the 700 MHz band experiences a path loss of approximately 130 dB over a distance of 100 km under perfect propagation conditions. To put this into perspective, the mobile device transmits a power level of about 23 dBm—approximately 200 milliwatts of RF power. This signal gets reduced by a factor of 10,000,000,000,000 (ten trillion) if conditions are perfect (and conditions are seldom perfect). As it turns out, empirical measurements suggest that this is not the controlling factor.

The 305 m "boomer" site mast. The test LTE base station antenna panel at 85 m above the ground is the white rectangle in the circle. Photo by Rob Stafford.

The second factor involves the timing of the signal. The signal travels about 300 kilometers in one millisecond. In order that signals from the far edge of the cell not interfere with signals from devices very close to the base station, a guard time, measured in fractions of a millisecond, is built into the LTE protocol. The length of the guard time appears to be the prime determinant of maximum cell size in our experimentation. The devices available for this investigation were restricted to a maximum cell size of 77 km, and we have been able to successfully connect at a distance of over 72 km using a directional antenna. With non-directional antennas, 50 km connections were successful. Present plans call for raising the antenna to 280 m above ground level, along with a software update to the base station to attempt to connect at over 100 km.

Indoor Propagation

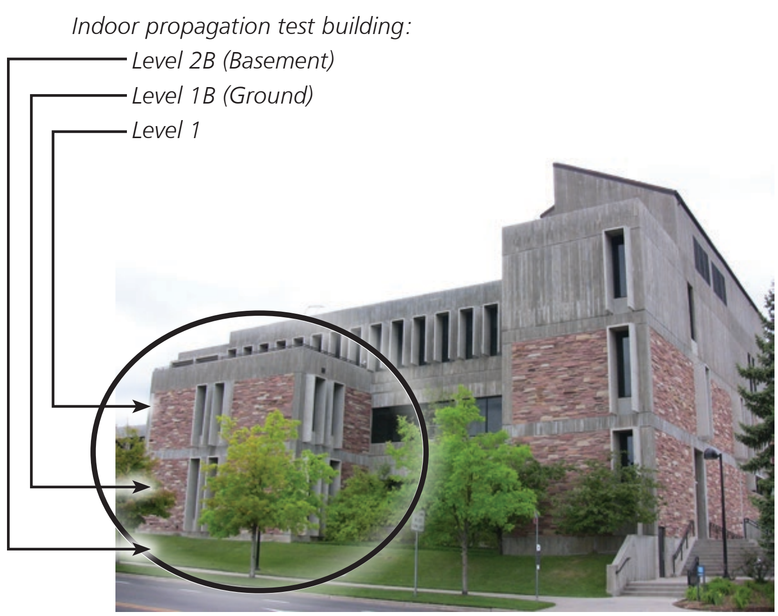
Assuming that public safety broadband base station density versus location may be low, signal power levels in the public safety spectrum are likely to be less at any given location than those of currently existing commercial LTE systems. Within buildings and other structures, losses through wall materials may be severely detrimental to public safety broadband communications. In order to investigate some aspects of this effect, a concrete structure approximately 2 km from one of our demonstration network field sites was selected as a test location. The test site for initial indoor propagation testing is shown below. Tests included a wide range of different signal propagation scenarios.

Initial testing involved reception inside the building of signals from our macrocellular site. We found that we could only achieve about 50% coverage on the two above-ground floors, with no coverage at all available in the two basement levels. Also, in areas where reception was possible the signal was very weak, roughly equivalent to the signal level expected at the edge of a normal LTE cell. The public safety mobile units increased their transmitted power output to combat the wall losses encountered, leading to reduced battery life.

A second test involved painting the building with a small cell/directional-antenna combination sited about 80 meters from the building. Although received signal strength increased, coverage was still somewhat intermittent, even when the small cell was broadcasting at a 40 W power level—the power that a macrocell normally transmits. Eventually the small cell was moved into the building, and this technique finally achieved acceptable coverage and service levels. Future work will concentrate on testing other buildings and learning more about potential mitigation measures.

Conclusions

Reliable rural and urban coverage will both be strict requirements of any public safety network. Current work suggests that both regimes offer challenges for public safety networks that may differ in significant ways from those faced by civilian systems. The broadband research conducted by this program offers experimental insight into these problems from a public safety point of view, and allows testing and evaluation of mitigation possibilities. Proper understanding of these issues is vital to the production of a Federal broadband public safety network that will effectively and efficiently meet the special needs of the nation's first responders.



Initial indoor propagation testing was performed in four levels of the building wing on the left; three are visible in this picture. Photo by R. Stafford.

For more information about Public Safety Broadband Requirements and Standards and the PSCR Demonstration Network contact Andrew Thiessen, (303) 497-4427, athiessen@its.bldrdoc.gov.
For more information about Public Safety Broadband Research contact Dr. Rob Stafford, (303) 497-7835, stafford@its.bldrdoc.gov.

Improving Telecommunications Network Performance

End-to-end performance of a telecommunications network is influenced by both the characteristics of the radio wave and the characteristics of the equipment used to transmit and receive it, including the software that controls the equipment. ITS performs research in both those areas, with the goal of transferring knowledge and technology that can be used to optimize performance.

As equipment and software become more sophisticated and complex, designers seek more and more detailed information about radio wave characteristics so that the network and its components can become "smarter" and deliver a more satisfactory user experience. In FY 2013, ITS performed research to develop improved methods for estimating fast fading of a radio signal and to investigate the possibility of using the extremely high frequency band, or the millimeter wave, for telecommunications.

The ultimate arbiter of the performance of a telecommunications network for inter-human communication is the end user, the listener or viewer of the audio or video signal transmitted over that network. The ITS Audio and Video Quality Research programs perform research to assist in developing and standardizing methods for assessing and improving the quality of delivered transmissions. This work provides important information for network and equipment designers as well as reliable technical input to standards bodies.

In FY 2013, the Audio Quality Research program developed, tested, and documented an improved objective metric of the intelligibility of speech transmitted over a wireless network. The Video Quality Research program began work to develop new methods of subjective testing to answer questions about video quality that currently have no methodological solution.

Radio Wave Research

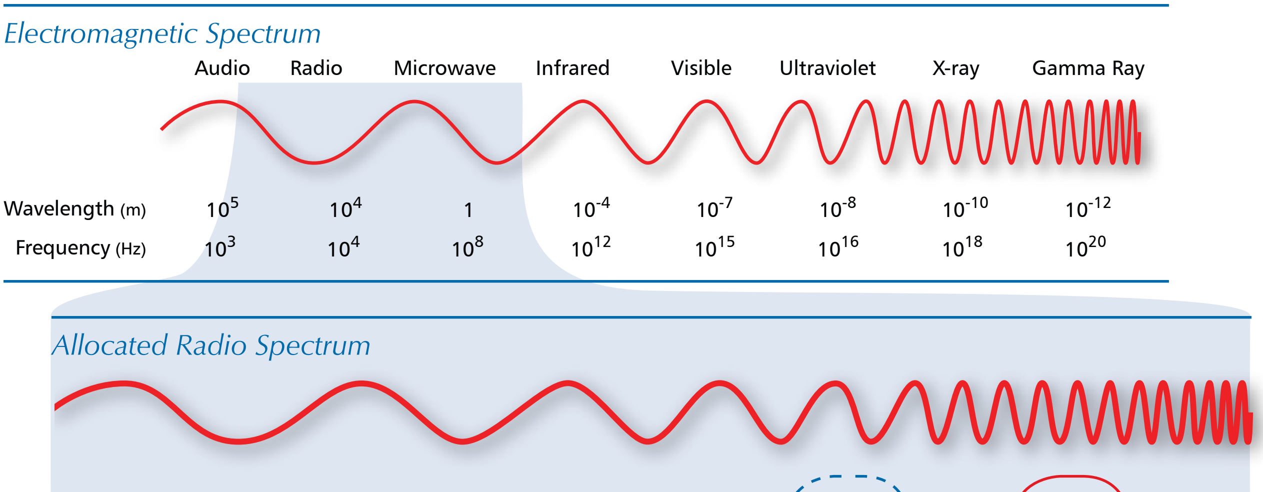
Correlations in Rayleigh Fading

A radio signal received by a mobile receiver exhibits fast and slow fading due to multipath propagation and shadowing, respectively. An important part of decision making in mobile radio systems (for example, handover decisions and dynamic power control) depend upon estimates of the average local power of the signal at various spatial locations, obtained by smoothing out the fast fading. It is therefore important that radio systems designers know the uncertainty of these estimates in order to incorporate appropriate margins in decision making processes.

The statistics of the fast fading in mobile radio channels are often well described by the so-called Rayleigh distribution. Discrete samples of the Rayleigh distribution exhibit some degree of correlation, depending on the spatial separation of the samples. These correlations lead to larger uncertainties in estimates of average power than would be obtained using uncorrelated samples. Moreover, estimates in the literature of the spatial separation required for uncorrelated samples are ad hoc and contradictory.

Rayleigh fading may be a reasonable model to use to predict propagation in "urban canyons" due to the variety of materials, angles, and shapes that can reflect or scatter radio waves. Photo of a Denver urban canyon by R. Johnk.

In order to resolve this confusion, in FY 2013 ITS researchers determined the effect of these correlations on estimates of average power by simulating fading radio signals using a Rayleigh channel simulator and calculating the uncertainties of average power estimates as a function of spatial separation of discrete samples. For example, we have found that to obtain an uncertainty no more than 1 dB greater than that for uncorrelated samples using 35 discrete samples requires a spatial separation greater than approximately 0.8 wavelengths.



ITU Band	4–VLF	5–LF	6–MF	7–HF	8–VHF	9–UHF	10–SHF	11–EHF	12–THF
Frequency	3 to 30 kHz	30 to 300 kHz	300 to 3000 kHz	3 to 30 MHz	30 to 300 MHz	300 to 3000 MHz	3 to 30 GHz	30 to 300 GHz	300 to 3000 GHz
Wavelength	10 to 100 km	1 to 10 km	100 to 1000 m	10 to 100 m	1 to 10 m	10 to 100 cm	1 to 10 cm	1 to 10 mm	0.1 to 1 mm

Current generation cell phone sweet spot

Millimeter band

Millimeter Wave Research

Objectives

- *Investigate and describe radio wave propagation in the frequency range 30-300 GHz*
- *Develop new technologies to facilitate expanded use of spectrum in the frequency range 30-300 GHz*

Background

The allocated radio spectrum encompasses frequencies from 3 kHz to 3000 GHz. Projects to enhance spectrum utilization largely focus on frequency bands that can best be exploited by current technology and are consequently both the most coveted and the most crowded—the so-called “sweet spot” for current cell phone technologies. While it is true that spectrum is a physically limited resource, it is also true that our ability to fully exploit that resource is limited by the capacities of current technologies. Another way to make more spectrum available for commercial use would be to develop new technologies capable of operating in frequency bands that cannot now easily or cost-effectively be used for cellular services. The extremely high frequency (EHF), or millimeter wave, is one such under-exploited band. The band includes frequencies from 30 to 300 GHz and with corresponding wavelengths of 10 to 1 mm—they are very fast and very short. This presents both advantages and challenges for commercial exploitation of the EHF band.

The Case for EHF

One advantage is that more data can be sent in a short period of time, since there are more wave cycles to which information bits can be attached. A signal at gigahertz frequencies (one billion cycles per second) can carry a thousand times more information than a signal at megahertz frequencies (one million cycles per second). Another advantage is that the shorter wave lengths require smaller antennas, with correspondingly higher directionality and efficiency. This would mean that more systems could operate in closer proximity to each other without causing interference to adjacent systems compared to what is possible in the UHF or even SHF band. These advantages are one reason why the international community is exploring the EHF band as a potential home for the future 5G (5th generation) mobile network.

Research Areas

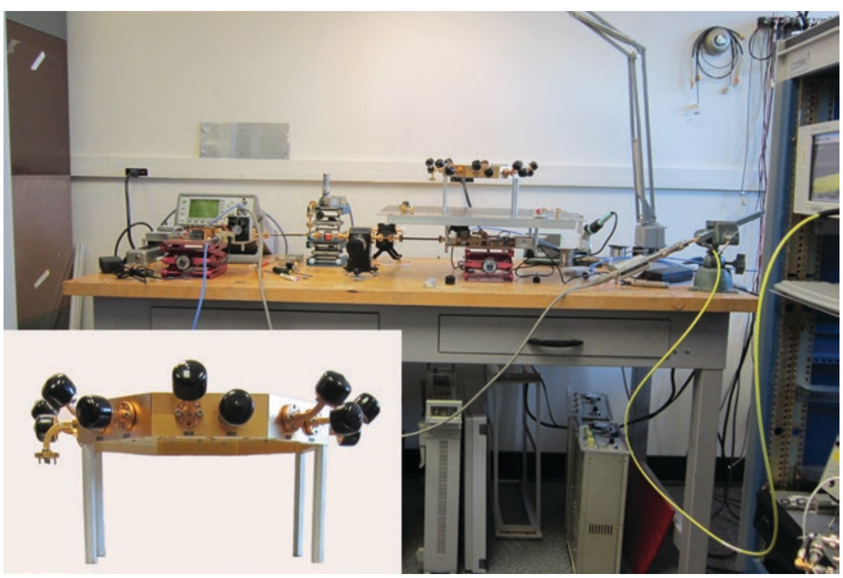
In FY 2012, a joint project of ITS and NIST was formed to perform preliminary research to investigate millimeter wave telecommunications. The project takes advantage of a century of ITS radio propagation research and NIST expertise in standards development and metrology to perform the basic research that will eventually lead to standards for the use of the EHF radio channel and standards for the equipment that will use it. The instruments being designed, prototyped, and tested by this project include:

- A millimeter wave channel sounder capable of measuring indoor and outdoor radio channels and propagation impairments in EHF frequencies with modulation bandwidths of up to 5 GHz
- A millimeter wave antenna array
- An 80 GHz transmitter and receiver
- A 10 GB/s code generator to integrate the receiver with the transmitter

Using a very short, fast wave to carry information has disadvantages. Current cellphone technologies are designed to use waves measured in centimeters, not millimeters. To exploit the millimeter band for cellular telecommunications, all the components of the network must be able to encode, transmit, receive, and decode very fast, short signals. Until recently, this was a significant challenge for the required transistor circuitry and commercially viable manufacture of such components was not deemed possible. Advances in semiconductor and materials science have now made realization of such advanced radiocommunication devices much more feasible. But faster speed generally equates to greater power consumption, so power consumption remains a challenge. Another challenge is that equipment must be very precisely machined—a receiving antenna for a 1 mm long wave, for example, must be manufactured to microscopic precision.

FY 2013 Millimeter Wave Research

Before commercial technologies for the use of the millimeter band can be developed, the instruments to characterize, calibrate, and test the devices that will operate in those bands must exist, and for those to exist, the propagation characteristics of the band must be well understood. In FY 2013, ITS researchers designed and constructed equipment to transmit and receive test signals in the EHF band. New semiconductor designs and manufacturing methods had to be devised to achieve the processing speeds and manufacturing precision required. The equipment was used to transmit signals emulating what might be sent over a 5G cellular network, and the signals were measured to begin the work of characterization necessary to update the existing ITS Millimeter-wave Propagation Model (MPM), developed in the 1980s and 1990s, to meet current and predicted future needs.



The millimeter wave research laboratory, an ITS/NIST collaboration project. Inset: close up of the prototype millimeter wave antenna array. Photo by L. Segre

For more information about Rayleigh fading contact Robert J. Achatz, (303) 497 3498, rachatz@its.bldrdoc.gov. For more information about millimeter wave research contact Peter Papazian, (303) 497-5369, ppazian@its.bldrdoc.gov.

Audio and Video Quality Research

The audio and video quality research programs at ITS are both long-standing and internationally renowned. These programs conduct research and development leading to publication, implementation, and standardization of perception-based tools for assessment and optimization of video and audio communication systems. The goal of these NTIA-funded programs is to develop tools to monitor and optimize the quality of audio and video information on communication channels, especially in light of bandwidth constraints and time-varying channel quality.

Great strides have been made in recent years towards developing automated tools for assessing audio and video quality, but subjective testing is still a very important tool for assessing the success of emerging audio and video encoding and transmission technologies. ITS continues to conduct subjective testing for validation of automated tools as well as for other purposes. In recent years, new research has been performed to develop methods for subjective testing involving a much broader variety of platforms and use case scenarios. Another area of investigation is subjective usability testing. This area includes speech intelligibility testing for public safety communications and testing the readability of video transmission of sign language.

Audio Quality Research

Objectives

- *Tools that accurately quantify speech quality and speech intelligibility*
- *Improved speech quality in wireless voice services*
- *Enhanced speech intelligibility when wireless voice services are used in noisy environments*
- *More consistent performance of voice services through greater robustness to transmission channel impairments*

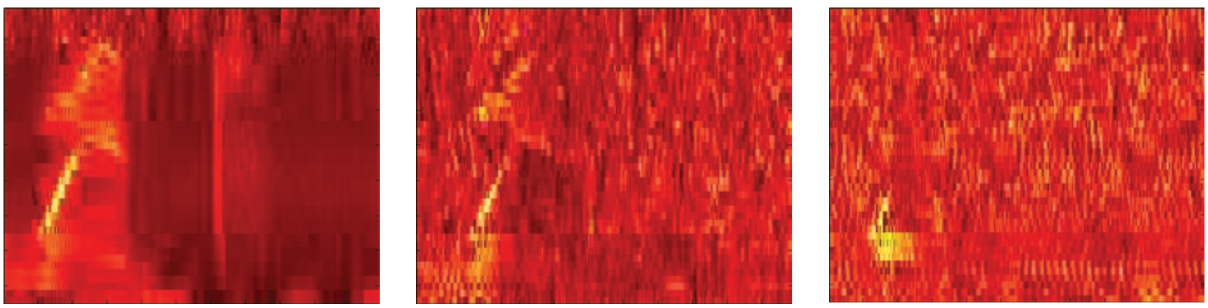
Background

Variations in transmission channels reduce speech quality, and can also reduce the intelligibility of speech. To mitigate these quality and intelligibility reductions, digital speech coding, transmission, and decoding algorithms must be maximally robust to channel variations. User experiences can be further enhanced if the algorithms are able to adapt with respect to different signal classes, background noise environments, speech bandwidths, quality levels, or coding rates. Such adaptive nature allows telecommunications speech transmission that is well-matched to channel conditions even though those conditions are continually evolving. This in turn maximizes the user experience associated with the telecommunications speech service. The ITS Audio Quality Research Program supports the industry-wide effort towards robustness and adaptability. The program identifies, develops, and characterizes algorithm innovations in the areas of robustness and adaptability. In addition, the program seeks to improve tools and techniques for characterizing speech quality and speech intelligibility, both through subjective testing and by means of signal processing algorithms.

Objective Estimation of Speech Intelligibility:

The most direct approach to evaluate speech intelligibility is based on human listening. One approach is rhyme testing, and a specific, popular test is the Modified Rhyme Test (MRT). In the MRT a trial consists of the presentation of one word in a carrier phrase—for example "Please select the word kit." The listener then uses a graphical interface to indicate which of six rhyming options was heard—in this case those options are "kit," "bit", "fit," "hit," "wit," and "sit." Thus the MRT asks listeners to perform a specific speech recognition task and the rate of correct word identification leads to a measure of speech intelligibility.

In FY 2013 Program staff conducted extensive research to determine if an automatic speech recognition (ASR) algorithm might be used to gather the same intelligibility information that the MRT does, but without the time, cost, and variability associated with human listeners. Normally ASR algorithms are designed to be as robust as possible to noise and distortion. But for this application program staff had to design an ASR algorithm with some unusual properties. A key property is that the ASR algorithm should have performance that drops just as human speech recognition performance drops. Staff accomplished this by forming novel time-frequency representations of speech signals and then performing temporal correlations in each individual Articulation-index Band. The new approach proved very successful, and was named Articulation-index Band Correlation MRT (ABC-MRT). The figure shows time-frequency representations for the word "went" under ideal conditions, and under mild and severe degradation cause by noise and distortion. As the degradation becomes more severe, the defining characteristics of the word "went" become more obscured and ABC-MRT has more difficultly selecting the proper word from the six choices. The success rate then forms a measure of speech intelligibility, just as in the MRT.



Time-frequency power distribution for the word "went." Left panel shows ideal, middle panel shows mild degradation, and right panel shows severe degradation. (Black, red, yellow indicate increasing power levels.)

ABC-MRT was designed to invoke some basic concepts that are thought to govern how humans identify words. As a consequence, it selects the correct word about as often as humans do in the MRT context. Thus, ABC-MRT serves as a powerful surrogate for true MRTs, and it requires a tiny fraction of the time and expense of the true MRT. Correlation values between MRT and ABC-MRT results range from 0.95 to 0.99.

The derivation, development, testing, and documentation of ABC-MRT were major FY 2013 accomplishments for the program. Industry, academic, and government users can now access ABC-MRT software, supporting speech files, and a descriptive refereed technical publication from the ITS website.

Additional FY 2013 Accomplishments

In FY 2013 program staff finalized their research on time-varying speech quality. This topic is highly relevant to the current telecommunications scenario since transmission channels vary continuously and this is reflected in the resulting speech quality. Staff also produced a final report on previously conducted research on ultra-low complexity lossless coding of toll-quality speech. Both projects resulted in refereed technical publications describing the work and the results.

Throughout FY 2013, 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 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.

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Video Quality Research

Objectives

- *Develop and disseminate knowledge, techniques and tools that will:*
  - *Allow academia and industry to start new lines of research into video algorithms*
  - *Allow industry to develop improved video systems*
  - *Let users measure the minimal encoding bandwidth that supplies the quality needed for their application*
  - *Encourage the development of international standards related to video quality issues*

Background

Video is a booming industry: content is embedded on many Web sites, delivered over the Internet, streamed to mobile devices, delivered on-demand, and used for real time monitoring in increasingly diverse applications. Cisco statistics indicate that video was 53% of total mobile traffic by the end of 2013, and predicts that over 69% of the world's mobile data traffic will be video by 2018.[1] The available video quality continues to be limited by constraints on the network bandwidth and receiver's speed and memory.

The work of the Video Quality Research program emphasizes international issues and technology transfer, because U.S. industry benefits from the availability of new algorithms and products. Program outputs include:

- 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

Measuring Video Quality

There are two ways to measure video quality:

- Ask a person's opinion of a video
- Use a computer algorithm

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 2013, ITS began evaluation of an immersive subjective testing technique developed privately by AT&T. If proven, this method will answer questions that currently have no methodological solution, such as the level of video quality needed to communicate using a visual language such as American Sign Language (ASL). This technique may also be better suited for answering quality/bandwidth trade-off questions, where the quality of experience interacts with the perceived video quality.

ITS led an effort within ITU-T Study Group 9 to produce a draft new Recommendation for audiovisual subjective testing. This document accommodates the needs of researchers and developers to test mobile

1. "Cisco visual networking index: global mobile data traffic forecast update, 2013-2018," Feb. 5, 2014. Accessed http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html April 2, 2014

video devices. The Recommendation is suitable for use in any environment, which will reduce the cost associated with subjective testing. This Recommendation is expected to be consented in FY 2014.

Reliable Objective Video Quality Models

ITS developed objective Video Quality Models (VQM) from 1988 to 2011. 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 FY 2013, 591 people downloaded the VQM software.

Since 2011, ITS ceased objective model development and now focuses its efforts on validating the performance of models developed by other organizations. Margaret Pinson is Co-chair of the Video Quality Experts Group (VQEG, www.vqeg.org) independent lab group (ILG). In that role, she has helped progress the validation of hybrid perceptual bit-stream models. These hybrid models examine both the network performance and the decoded video, to produce an accurate quality estimation that is suitable for real time deployment in most modern video systems. An important role taken by ITS was to provide secret video content (i.e., video that was not available to the model vendors).

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 Web site.

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 2013, 224 people downloaded video from CDVL. Also in FY 2013, ITS made available a particularly valuable dataset developed by ATIS in 1994. ITS has made over 3,000 video clips available on CDVL, including VQEG's high definition television (HDTV) datasets. The impact of CDVL can be seen in the research papers that reference this website.

Sample frames from the 1994 ATIS dataset of 25 source video sequences (SRC), all in the public domain, made available on CDVL. Original (top row) and impaired (bottom row) clips include content with high object/camera motion, graphics, more than one person, one person with graphics, and more. Stills courtesy CDVL.

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.videoservicesforum.org), ITU-T Study Group 9, and ITU-T Study Group 12. 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 publications.

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

Related Publications:

Margaret H. Pinson, Karen Sue Boyd, Jessica Hooker, and Kristina Muntean, "How To Choose Video Sequences For Video Quality Assessment," Proceedings of the Seventh International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM-2013), Scottsdale, AZ, January 30-February 1, 2013. Available http://www.its.bldrdoc.gov/publications/2694.aspx.

Margaret H. Pinson and Stephen Wolf, Fast Low Bandwidth Model: A Reduced Reference Video Quality Metric, NTIA Technical Memorandum TM-13-497, June 2013. Available http://www.its.bldrdoc.gov/publications/2731.aspx.

Margaret H. Pinson, Christian Schmidmer, Lucjan Janowski, Romuald Pépion, Quan Huynh-Thu, Phillip Corriveau, Audrey Younkin, Patrick Le Callet, Marcus Barkowsky, and William Ingram, "Subjective and objective evaluation of an audiovisual subjective dataset for research and development," Fifth International Workshop on Quality of Multimedia Experience (QoMEX 2013), Klagenfurt am Wörthersee, Austria, July 3-5, 2013. Available http://www.its.bldrdoc.gov/publications/2733.aspx.

Margaret Pinson, Marcus Barkowsky, Patrick Le Callet, "Selecting scenes for 2D and 3D subjective video quality tests," EURASIP Journal on Image and Video Processing 2013, 2013:50. Available http://www.its.bldrdoc.gov/publications/2734.aspx.

Margaret Pinson, Nicolas Staelens, and Arthur Webster, "The history of video quality model validation," 2013 IEEE 15th International Workshop on Multimedia Signal Processing (MMSP), Sept. 30 2013-Oct. 2 2013. Available http://www.its.bldrdoc.gov/publications/2743.aspx.

Margaret Pinson, "The Consumer Digital Video Library [Best of the Web]," IEEE Signal Processing Magazine, vol. 30, no. 4, pp. 172,174, July 2013. Available http://www.its.bldrdoc.gov/publications/2730.aspx.

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> *"I want us to ask ourselves every day, how are we using technology to make a real difference in people's lives."*[1]
>
> *President Barack Obama*

eGovernment Research and Engineering

Like many Federal laboratories, ITS was an early adopter of computerization, frequently developing both its own software and its own computers and computerized instruments. Radio wave propagation modeling depends on the processing of empirical data to validate theoretical models—the more data can be used to exercise a model, the more accurate it can be made. The DoC has been collecting spectrum measurement data since 1909 and continues to do so regularly. This provides a large pool of varied datasets that can be used for validation of individual models. From the earliest days of computing, it was immediately apparent to radio scientists that automation of propagation prediction models would greatly increase the ability to refine models for better accuracy and usability. Specialized research projects were created in the late 1950s to pursue automation solutions for both the collection of measurement data and the processing of measured data in propagation models. The laboratory used commercially available computing equipment as much as possible, but designed and constructed its own when necessary.

By FY 1961, CRPL (which later became ITS) had written several computer programs to automate different propagation models. On the measurement side, several projects supported the objective "to improve current methods of data handling and processing by the development of automatic data reduction and computation systems."[2] In addition to ensuring that the mathematical computations were correctly executed, early efforts to automate both modeling and data handling had to devise computationally economical methods of repetitively processing many sets of similar data. Later, as measurement equipment became more sophisticated, the number of data points collected during each measurement increased exponentially. Today it is not uncommon for ITS measurement instruments to collect six million data samples every 10 minutes. To extract meaningful information from such large data sets in a reasonable amount of time requires that the data be post-processed using appropriate statistical techniques. Even though the models can be exercised with post-processed data to improve speed, these are still very large data stores. The challenge of finding computationally economical methods of repetitively processing very large numbers of data points remains.

In FY 2013, ITS built on these five decades of expertise in the design of secure and robust systems for handling large volumes of records to continue research in two principal eGovernment areas: providing web-based access to accurate propagation models, and assisting Federal agencies to prototype cloud based solutions for secure storage, servicing, and management of large numbers of electronic records.

Web-based Propagation Analysis Services

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. Advanced propagation prediction models that can successfully integrate geographic data and display coverage predictions geographically are important tools for accurately predicting the performance of communication systems. Ideally, these models should be easy for non-specialists to access and use for operational and financial planning purposes. They should also be detailed and accurate enough for specialists to use in deployment.

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1. The White House, "Digital Government: Building a 21st Century Platform to Better Serve the American People," http://www.whitehouse.gov/sites/default/files/omb/egov/digital-government/digital-government.html

2. See U.S. Department of Commerce, National Bureau of Standards, "FY 1961: Seventh Summary of Research at Boulder Laboratories," January 1962, p. 172. Available http://www.its.bldrdoc.gov/publications/2723.aspx.

Web-based propagation analysis services team: from left, Julie Kub, Kristen Davis, Linh Vu, Teresa Rusyn, Billy Kozma, and George Engelbrecht. Photo by F. Sanders.

The earliest computer programs made available by ITS for propagation modeling by other, non-expert users were written in FORTRAN and freely distributed first on hard media and later over the Internet. Users had to have fairly sophisticated computing skills as well as a good understanding of radio science to be able to use these programs. At the turn of this century, many models were ported to new programs that would operate in a Windows® operating system environment and integrate with the proprietary Geographic Information System (GIS) program most used by our sponsor agencies. This implementation required all users to have licensed commercial software installed and some expertise in the use of that software.

Recently, ITS began work on new programs that reduce dependency on licensed software applications for end users, allowing them to access the models through a Web interface. These programs are consistent with the Federal Digital Government goals of making existing high-value data and content available through Web APIs and using a shared platform approach to developing and delivering digital services to lower costs and reduce duplication.

Propagation Modeling Website

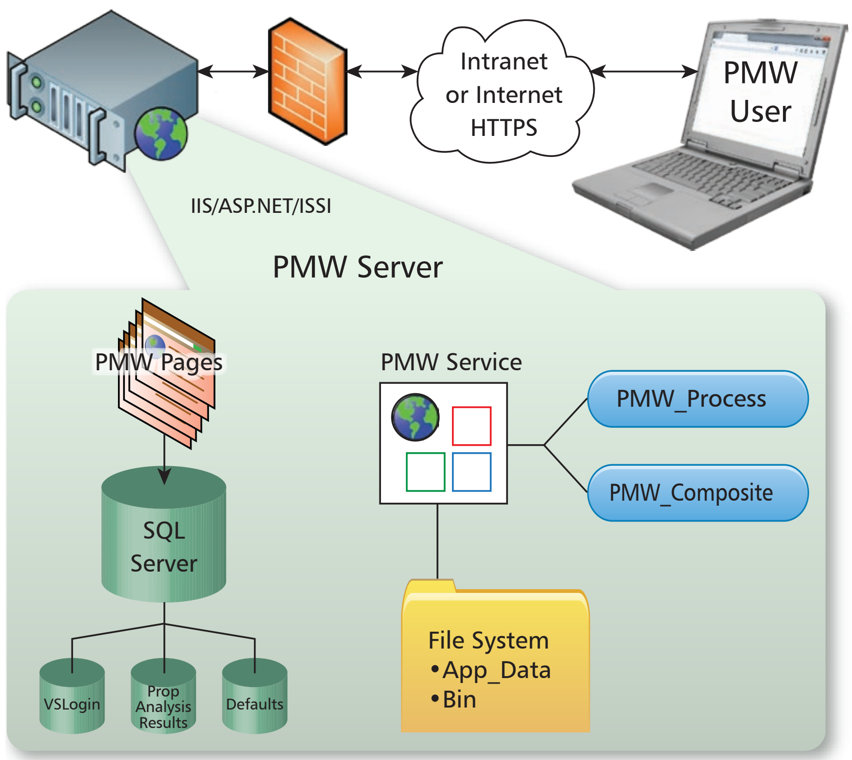
Objectives

- *Allow users to perform propagation prediction studies for High Frequency (HF) and Very High Frequency (VHF) applications using custom-tailored Propagation Modeling Website (PMW) software through a browser interface*
- *Enable compositing of thousands of transmitter analyses to predict regional wireless network coverage for system planning and interference detection for national security and public safety*

Overview

Accurate propagation modeling is an essential component of wireless communications planning, and accurate geographic information is a critical input for accurate modeling. To assist other agencies in the design of effective wireless systems, ITS has developed propagation modeling website tools that use commercial GIS to both acquire geographic data and display geographic coverage areas. The Propagation Modeling Website (PMW) is a web-based GIS propagation modeling tool, customized to meet the propagation prediction needs of the Department of Defense (DoD) and Department of Commerce (DoC)/National Weather Service (NWS) sponsors. PMW is presently available only to Federal government agencies. The PMW covers radio frequencies from 1 MHz to 20 GHz.

The PMW project builds on over 50 years of ITS expertise in evaluating and analyzing propagation models. Over the last six years, ITS has been developing the newest generation of propagation prediction tools, the PMW web-based GIS solutions. The PMW provides intranet users with web-accessible propagation models, a central imagery/data storage facility, and a central database location to store all propagation analyses, using just one set of licensed software, as illustrated in the diagram of the PMW architecture. The system



Overview diagram of the PMW architecture.

enjoys streamlined maintenance, operation, and upgrades for ease of deployment, and ITS has a support system in place to deliver end-user support, upgrades, and enhancements.

Work on the Propagation Modeling Website (PMW) software is sponsored by several DoD agencies and NOAA's National Weather Service (NWS).

PMW Capabilities

PMW presently includes the capacity to perform propagation analysis using any of the following propagation models: TIREM 3.15; Longley-Rice 1.22; COST 231 Extended Okumura-Hata; Undisturbed Field/Mobile-to-Mobile; and ICEPAC. Future development is planned to incorporate low frequency/medium frequency (LF/MF), ICEWave, and ITURHFProp models. Users can simultaneously run a batch of transmitters, specified in an Excel® transmitter file. Propagation analyses, using all five of the currently available models, can be performed in either single or batch-transmitter mode using a separate thread for each analysis.

Depending on the hardware capabilities, the software can use parallel threading to decrease propagation analysis time proportional to the number of computer cores. Users can export analyses for use with Esri's ArcGIS® Desktop application or any other GIS application that accepts GIS shape or Esri layer files. Because the PMW is modular in design, ITS engineers can enhance the PMW software to incorporate the specific needs of different sponsors.

For all but the ICEPAC model (which contains historical code that cannot easily run in parallel), the PMW incorporates a parallel-threaded design that offers speed improvements over a single-threaded model. For all but the ICEPAC model (which typically produces analyses that cover the globe), the PMW provides the ability to create analysis composites for thousands of transmitters and export data analyses to 3-D Google Earth® (KML/KMZ). For TIREM, Longley-Rice, and ICEPAC models, users can choose from antenna pattern data included with the software to run an analysis or upload their own files to the site. TIREM and Longley-Rice propagation models use SRTM1, SRTM2, DTED1, DTED2, GLOBE, or user-selected terrain files.

The PMW contains a Windows® "service" module, which reads XML propagation model files created by the Web site and runs each XML process according to priority and availability of system resources. This service monitors and communicates the status of all processes back to the PMW Web site for users to monitor system progress.

Over the next several years, as the PMW continues to mature, current and future sponsors may choose several software enhancements, including interference studies, an embedded interactive map display, 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 currently operates on our sponsors' internal, secure networks or on a secure site hosted by ITS, 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, ITS has aided Government agencies in efficiently managing their telecommunications infrastructure through sound system planning and interference detection for national security and public safety.

National Weather Service PMW

Under a multi-year interagency agreement, ITS is providing the National Weather Service (NWS) with web-based Propagation Analysis Services based on the PMW VHF service. NWS is mandated to provide the Nation with 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.

The goal of this system is 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 this broadcast coverage goal, NWS engages in ongoing expansion efforts that provide new or upgraded transmitters in many locations around the country. ITS provides NWS with customized web-based propagation analysis services used to plan the location and characteristics of new transmitters to optimize coverage.

NWS engineers log into the PMW, which is hosted on their customized server housed at ITS, to run propagation analyses. Using this system and its databases, planners of the national alert system can verify and improve coverage by their large, diverse radio transmission system. ITS is adding 2010 census data processed into smaller 90 square meter components to the PMW system in order to more accurately predict population coverage.

For more information on the locally-hosted PMW contact Julie Kub, (303) 497-4607, jkub@its.bldrdoc.gov or George Engelbrecht, (303) 497-4417, gengelbrecht@its.bldrdoc.gov. For more information on the NWS PMW contact Teresa Rusyn, (303) 497-3411, trusyn@its.bldrdoc.gov or Kristen Davis, (303) 497-4619, kristen@its.bldrdoc.gov

Cloud Prototyping Lab

Archival Records Management Portal Prototype

Objectives

- *Design, deploy, and test a prototype for a records management system that meets specific Federal security requirements and allows rapid and accurate remote search and retrieval with a capacity of millions of documents in various electronic formats*
- *Transfer to the sponsoring agency the knowledge and documentation needed to allow them to acquire, deploy, and maintain a production system based on the prototype architecture*
- *Automate the NARA records schedule.*

One of several banks of ITS IT equipment dedicated to securely storing, servicing, managing, and serving large volumes of electronic records, including the Archival Records Management Portal Prototype described in this article. Photo by Lilli Segre.

Overview

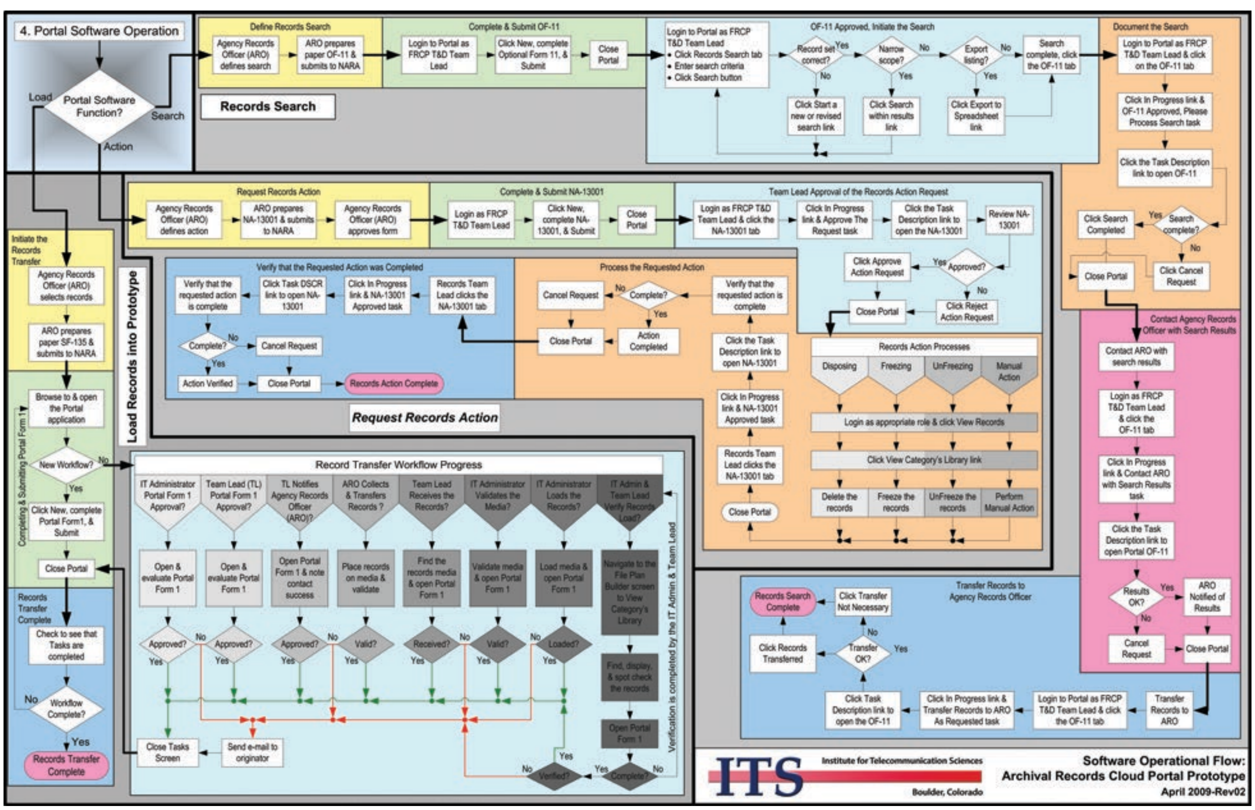
In keeping with Digital Government strategies, and based on decades of experience creating, managing, and using large data stores and migrating them to new technologies, ITS designed and built an open-ended, modular data store using commercial-off-the-shelf products to support another Federal agency. ITS was engaged through an interagency agreement to design and prototype a formal records management system to be used to transfer and archive highly sensitive archival records.

The opportunity to exercise a fully-functional prototypes greatly increases the probability of success when a complex information technology acquisition project goes to RFP. The acquiring agency has been able to test the business process impact of the system and document and validate critical requirements for levels of service and performance required. Exercising the prototype also provides the information needed to realistically and comprehensively calculate the cost of going to production and the return on investment (ROI).

To support the sponsor, ITS created three separate prototypes that were successfully tested first with dummy data and then with real records obtained through the sponsor. Prototype 1 won the National Archives and Records Administration (NARA) Archivist Achievement Award in 2010. In FY 2014, the prototyping phase of the project will conclude and Prototype 3 will be transferred to the sponsor for use in preparing a request for proposal (RFP) for a cloud system that duplicates the prototype functionality.

Requirements and Engineering Design

The system needed to automate and implement electronically all records management processes currently in use (i.e., those defined for paper records), to generally fit into the sponsoring agency's current business process framework, and to support records management, scheduling, and retrieval, as well as"end of life" and destruction processes. The system also needed to incorporate the workflow, formatting, tagging, and tracking requirements for Federal records governed by NARA records schedules. Finally, because the system might potentially hold DoD records, it needed to meet DoD requirements for handling records of the



Software operational workflow diagram for an archival records management system built in the ITS Cloud Prototyping Lab.

specified sensitivity. ITS obtained DoD 5015.02 Certification, as well as formal privacy impact analyses, security assessments, and authority to operate (ATO) from all stakeholders.

> *"We can use modern tools and technologies to seize the digital opportunity and fundamentally change how the Federal Government serves both its internal and external customers—building a 21st century platform to better serve the American People."[1]*

Architectural Choices

The ITS team met with multiple stakeholders convened by the sponsor to build a list of requirements for the system. These included functions to be performed, business roles, supported data formats, privacy/security requirements, a basic Service Level Agreement (SLA) for the service as a whole, and a testing matrix to cover requirements tracking. A Concept of Operations (CONOPS) document showed which requirements the first prototype would cover, which business processes it would support and the separation of tasks between the system and records management staff, by role.

Given the requirements, the stakeholder team chose to prototype the records management portal using Microsoft® SharePoint. Out of the box, SharePoint is a full featured web-based content management system with the ability to build in formal business processes and manage multiple file formats. ITS had been using this product for a number of our other projects and had experience in customizing it. As in the case of PMW, end users need nothing but a browser to upload or search and retrieve records.

Prototyping and Exercises

Prototype 1 was built to test basic functionality and processes: a load module ingested 10,000 dummy records; quality assurance staff and end users tested the workflows. Weekly stakeholder meetings were held to fine tune the processes, transfer knowledge to the sponsor, and make sure the SLA was being met. The sponsor also ran various data quality tests to verify that the records were indexed correctly and accessible.

For Prototype 2, a protocol was developed for the transfer of sample records into the new system that included specific formats and required metadata tags. The records were transferred and loaded into the database, the metadata was associated to the individual records, and the proper NARA records schedule was applied. Some records were also scanned and indexed for full text search. Prototype 2 successfully tested end to end transfer and ingestion of a realistic quantity of actual records and confirmed that all the business process changes made during the exercise of the first prototype were functional and appropriate.

Prototype 2 was engineered to be scalable in chunks of 50 terabytes (TB) or 250,000 records. In FY 2013, Prototype 3 was built to a capacity of 15 million records and exercised with a realistic simulation of production. New records arrived in 2–3 TB blocks and were ingested, indexed, and sampled for QA. Typical records searches were performed by remotely attached end users and the results returned. Audit trails were reviewed to determine that all actions taken in the system were recorded and the privileges and responsibilities of each role were not violated. Finally, the SLA components for the system, including accessibility, availability, accuracy, and operational characteristics, were validated. All tests were passed. Ultimately, Prototype 3 easily accepted both a doubling of the number of records and an increase to a realistic number of simultaneous users with no degradation in response time to loading and searching. At 100 TB and 500,000 records, the prototype had accomplished its purpose, demonstrating a cost-effective and fully scalable solution for the cloud storage of infrequently used but long-term scheduled records.

1. Executive Office of the President, "Digital Government: Building a 21st Century Platform to Better Serve the American People, May 23, 2012. (Accessed http://www.whitehouse.gov/sites/default/files/omb/egov/digital-government/digital-government.html January 14, 2014.)

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A unique combination of past experience, current knowledge, experimental facilities, and specialized tools enable ITS to perform advanced research and solve complex problems in telecommunications. These resources are shared through interagency agreements to solve telecommunications challenges for Federal, state, and local agencies and through cooperative research and development agreements 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. 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 and cable TV

- Video on demand
- Streaming Internet video
- Video teleconferencing
- Cell phone audio and video
- VoIP

Audio and Video Capabilities

The ITS audiovisual lab includes support for the following technologies:

- Standard definition (SD) television
- High definition television (HDTV)
- Three-dimensional television (3DTV)
- Monophonic, stereophonic, and 5.1-channel audio streams
- Studio quality analog and digital video recorders with 2 to 8 audio channels
- Digital audio recorders
- Analog audio mixing, filtering, and equalization
- Studio quality video monitors, monitor loudspeakers, and headphones
- Telephone handsets
- Subjective test chambers compliant with ITU-T Rec. P.800, ITU-R Rec. BT.500, and ITU-T Rec. P.900
- Various hardware and software encoders and decoders
- Internet protocol network error simulator compliant with ITU-T Rec. G.1050

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Audio Visual 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.

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 intermediate frequency (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 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 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.

A cluster of antennas of various types used for testing of different telecommunications technologies at the Green Mountain Mesa Field Site. Photo by Ken Tilley

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 multiple CPU cores. 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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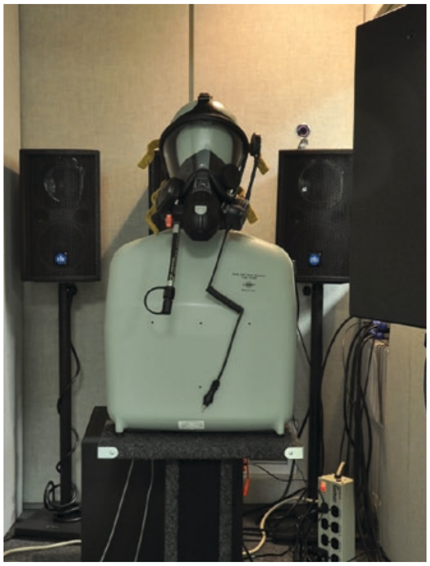
Public Safety Audio and Video Laboratories

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 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.



An ITU-Standard Head and Torso Simulator (HATS) set up in a sound-isolated booth for testing in the PSAL. Photo by Andrew Catellier.

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 suffer hearing loss when exposed to harsh noise environments for extended periods.

The PSAL system provides a reproducible acoustic path that enables emulation of the harsh noise environments encountered by public safety practitioners. The recorded output from the system can be used in a number of ways. For example, the recordings might be analyzed by an objective measurement technique such as that defined in ITU Recommendation P.862 (Perceptual evaluation of speech quality (PESQ): an objective method for end-to-end speech quality assessment for 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 research on video quality for public safety applications. To accomplish this mission, scenes that contain selected elements unique to or typical 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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Video sequences filmed during a simulated accident training exercise are used for public safety video quality research. Stills courtesy of www.cdvl.org.

Public Safety RF Laboratory

ITS's Public Safety RF Laboratory (PSRF Lab) hosts the PSCR Broadband Demonstration Network, a test bed that manufacturers may use 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 land mobile radio technologies currently in use. 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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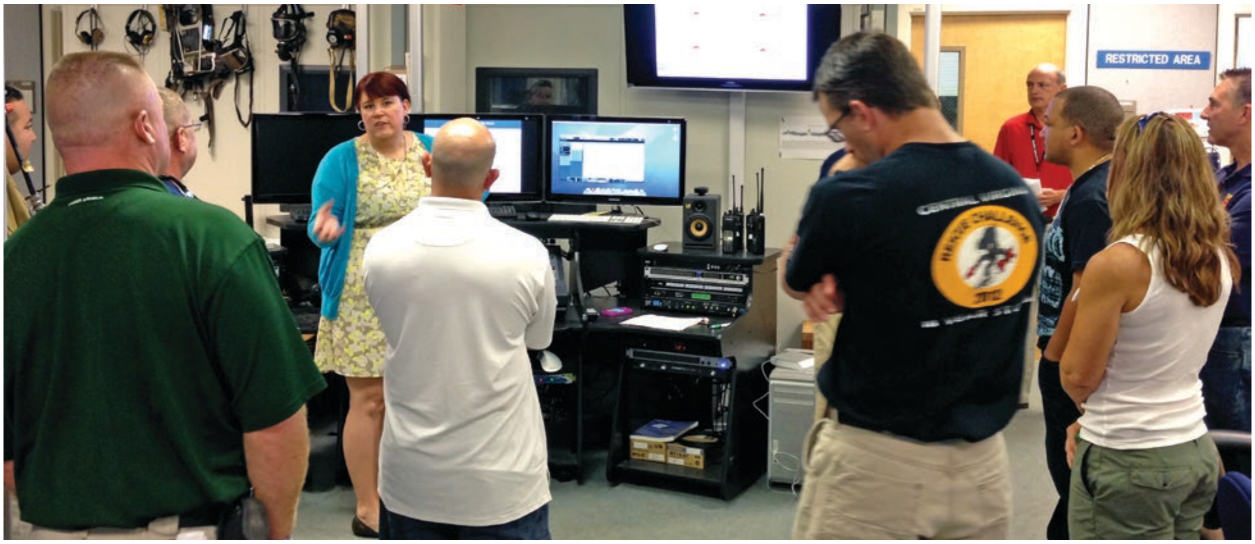

A group of 65 public safety practitioners took time out from the 2013 International Association of Fire Fighters (IAFF) Occupational Health & Hazards of the Fire Service and Emergency Medical Services Conference for a tour of the PSCR RF lab. Above, ITS engineer Anna Paulson describes audio intelligibility testing equipment and techniques. Photo by Ken Tilley.

Radio Propagation Measurement Capabilities

ITS designs, develops, and maintains a number of mobile and static RF measurement systems that address a very broad range of wireless scenarios in frequencies from 10 MHz to 300 GHz. All measurement systems are modular and easily configurable for specific measurement purposes. The RSMS system, fully described on page 31, allows mobile or stationary RF measurements from 10 MHz and 40 GHz, both in laboratory settings and at field sites, attended or unattended. The mobile propagation measurement system described on page 33 covers a frequency range from 20 MHz to 30 GHz. An extremely high frequency (EHF) measurement system for frequencies from 30 to 300 GHz is currently under development as part of the “Millimeter Wave Research” program described on page 55. For the 3.6 GHz maritime radar band occupancy measurements described on page 36, ITS designed and configured a unique measurement system optimized to detect specific signal types.

The mobile propagation measurement system has two operational modes: 1) narrowband channel probe 2) broadband channel probe. The narrowband mode has high accuracy, dynamic range, and sensitivity, and excellent immunity to interference. 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 system is 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 five 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 S_{21} 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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Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older ones can result in electromagnetic compatibility (EMC) problems. Although theoretical models and simulations provide useful information in guiding design decisions, the complexity of modern systems and the existing spectral environment often require real-world measurements of a proposed system's effects within its operating environment to determine its impact on other spectrum users.

Another problem is to adequately produce controlled interfering signals with known characteristics in environments where suspected interferers may be unavailable for tests and measurements. This includes situations such as laboratory investigations of possible interference from ship- or aircraft-mounted radars or terrestrial or space-based communications systems. In these sorts of situations, a system is needed that simulates the spectral emissions of other devices with high fidelity. An example of these needs is the requirement to determine the thresholds at which various types of interference from communication transmitters are manifested as observable interference effects in radar receivers. Another example would be to determine the source(s) of interference from terrestrial services to space-based communication links.

To meet these needs, ITS engineers have developed capabilities to generate interference signals. These signals can be coupled directly into a system under test or they can be transmitted through space into a target system's receiver to more accurately gauge its response to a real interference situation.

ITS engineers generate interference by first using high-speed digitizers (vector signal analyzers (VSAs)) 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

The Table Mountain Field Site and Radio Quiet Zone is located north of Boulder and extends about 4 kilometers (2.5 miles) north-south by 2.4 kilometers (1.5 miles) east-west, 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. Site power distribution is by means of buried line to avoid interference. Partnerships and cooperative research activities with other entities are encouraged at the site—see the articles on "CRADAs for the Use of Table

Mountain" on page 10 and "Interagency Agreements for the Use of Table Mountain" on page 13. Facilities at the site include:

One of the two 18.3 meter (60 foot) parabolic dish antennas at the Table Mountain Field Site..

- 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—As a flat-topped butte with uniform 2% slope, Table Mountain 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 open space just south of the Spectrum Research Laboratory is available for testing radar systems.

Learn more online at: http://www.its.bldrdoc.gov/resources/table_mountain.

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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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ITS Activities in FY 2013

ITS Publications and Presentations in FY 2013

NTIA Publications

Frank H. Sanders, Robert L. Sole, John E. Carroll, Glenn S. Secrest, T. Lynn Allmon, "Analysis and Resolution of RF Interference to Radars from Adjacent-Band Transmitters," NTIA Report TR-13-490, October 2012. http://www.its.bldrdoc.gov/publications/2684.aspx

This report describes the methodology and results of an investigation into the source, mechanism, and solutions for radio frequency (RF) interference to WSR-88D Next-Generation Weather Radars (NEXRADs). It shows that the interference source is nearby base stations transmitters in the Broadband Radio Service (BRS) and the Educational Broadband Service (EBS) and that their out-of-band emissions (OOBE) can cause interference on NEXRAD receiver frequencies. The methodology for determining interference power levels and mitigation solutions is described. Several technical solutions that can mitigate the problem are shown to be effective. Trade-offs between effectiveness, difficulty, and costs of various solutions are described, but it is shown that there is always at least one effective technical solution. The report shows that careful planning and coordination between communication system service providers and Federal agencies operating nearby radars is important in the implementation of these interference-mitigation techniques. A number of the report's interference mitigation options have already been implemented in several United States cities served by a BRS/EBS licensee, at licensee WiMAX stations where NEXRAD radar operations are located nearby. As of the date of this report's release, interference from the licensee's WiMAX links to NEXRAD receivers in those markets has been successfully mitigated using the techniques described herein.

"Scientific progress relies on the broad and open dissemination of research results."[1]

Robert T. Johnk, Frank H. Sanders, Kristen Davis, Geoff Sanders, John D. Ewan, Ronald L. Carey, Steven Gunderson, "Conducted and Radiated Emissions Measurements of an Ultrawideband Surveillance Radar," NTIA Report TR-13-491, November 2012. http://www.its.bldrdoc.gov/publications/2692.aspx

We provide detailed descriptions of recent measurements conducted by the National Telecommunications and Information Administration Institute for Telecommunication Sciences in Boulder, Colorado. ITS engineers performed a comprehensive series of both conducted and radiated emission measurements of the Shore-Line-intrusion-Monitoring System (SLiMS). The SLiMS system is currently being developed by Time Domain® under the sponsorship of the Naval Facilities Engineering Command.

Frank Sanders, "Antenna Selection for Monitoring of Airborne Radio Systems," NTIA Technical Memorandum TM-13-492, November 2012. http://www.its.bldrdoc.gov/publications/2691.aspx

This Technical Memorandum describes a process for selecting an appropriate antenna for monitoring radio signals from airborne transmitters. A mathematical formula for the optimal receiver antenna gain is presented. This formula takes into account the factors of minimal required signal-to-noise ratio of signals in a monitoring receiver, airborne radio transmitted power and antenna gain, airborne radio height and resulting maximal line-of-sight coverage, free-space propagation loss, airborne radio signal bandwidth, monitoring system bandwidth, and the sensitivity of the monitoring system's receiver. The optimal monitoring antenna gain is calculated as a function of elevation angle above the local horizon. That function is used to select an antenna type that will receive signals from as many airborne radios as possible. A worked example of the selection process is presented. Although it is assumed that a terrestrial system will be used for monitoring, the process can be applied to antennas for marine and airborne monitoring systems as well.

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

David J. Atkinson, Stephen D. Voran, Andrew A. Catellier, "Intelligibility of the Adaptive Multi-Rate Speech Coder in Emergency-Response Environments," NTIA Report TR 13-493, December 2012. http://www.its.bldrdoc.gov/publications/2693.aspx

This report describes speech intelligibility testing conducted on the Adaptive Multi-Rate (AMR) speech coder in several different environments simulating emergency response conditions and especially fireground conditions. The intelligibility testing protocol was the Modified Rhyme Test (MRT). Conditions included background noises of various types, as well as a mask associated with a self-contained breathing apparatus. Analog FM radio transmission and Project 25 digital radio transmission were also included in the test as reference points. Test participants were persons employed as first responders in public safety fields. Through statistical analysis of 26,900 MRT trials we are able to draw conclusions on speech intelligibility for AMR speech coding relative to analog and digital radio reference points for five different operating environments.

Nicholas DeMinco, Paul M. McKenna, Robert T. Johnk, Chriss A. Hammerschmidt, J. Wayde Allen, Linh P. Vu, "Free-Field Measurements of the Electrical Properties of Soil Using the Measured Reflection Coefficient at Normal Incidence and Multilayer Analysis," NTIA Report TR 13-494, February 2013. http://www.its.bldrdoc.gov/publications/2695.aspx

This report describes a free-field radio frequency (RF) measurement system that is 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 system is deployed. This measurement system uses reflection coefficient measurements at normal incidence over ground using a dual-ridged horn antenna placed close to and radiating directly down at the ground at specific antenna heights. Soil properties are extracted by comparing measured data with known analytical models for single and multilayer scenarios using optimization.

David J. Atkinson, Andrew A. Catellier, "Intelligibility of Analog FM and Updated P25 Radio Systems in the Presence of Fireground Noise: Test Plan and Results," NTIA Report TR-13-495, May 2013. http://www.its.bldrdoc.gov/publications/2720.aspx

This report describes a modified rhyme test (MRT) conducted to characterize the behavior of digital and analog communication in the presence of background noise and moderate RF channel degradation. This is done through the use of reference systems to provide a manufacturer-independent perspective on this issue.

C. Hammerschmidt, H. Ottke, R. Hoffman, "Broadband Spectrum Survey in the Denver Area," NTIA Report TR-13-496, August 2013. http://www.its.bldrdoc.gov/publications/2735.aspx

NTIA is responsible for managing the Federal Government's use of the radio spectrum. In discharging this responsibility, NTIA uses the Radio Spectrum Measurement Sciences system to collect spectrum occupancy data for radio frequency assessments. This report shows measured frequency data spanning spectrum from 108 MHz to 10 GHz in the vicinity of Denver, Colorado, during the month of June 2011.

Margaret Pinson and Stephen Wolf, "Fast Low Bandwidth Model: A Reduced Reference Video Quality Metric," NTIA Technical Memorandum TM-13-497, June 2013. http://www.its.bldrdoc.gov/publications/2731.aspx

This memorandum describes the Fast Low Bandwidth model. This summary is intended to help the reader understand the model from an algorithmic standpoint. Some knowledge of prior NTIA objective video quality models is necessary for the understanding of this document. The Fast Low Bandwidth was designed to be operated in-service using the reduced reference (RR) methodology. The model requires access to the original video at one location, the processed video at another location, and low bandwidth data link between the two locations. That link is used to communicate RR features between the two locations. The Fast Low Bandwidth model is included in ITU-T Rec. J.249

Outside Publications

M.H. Pinson, L. Janowski, R. Pépion, Q. Huynh-Thu, C. Schmidmer, P. Corriveau, A. Younkin, P. Le Callet, M. Barkowsky, and W. 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, pp. 640–651, October 2012. http://www.its.bldrdoc.gov/publications/2682.aspx

Traditionally, audio quality and video quality are evaluated separately in subjective tests. Best practices within the quality assessment community were developed before many modern mobile audiovisual devices and services came into use, such as internet video, smart phones, tablets and connected televisions. These devices and services raise unique questions that require jointly evaluating both the audio and the video within a subjective test. However, audiovisual subjective testing is a relatively under-explored field. In this paper, we address the question of determining the most suitable way to conduct audiovisual subjective testing on a wide range of audiovisual quality. Six laboratories from four countries conducted a systematic study of audiovisual subjective testing. The stimuli and scale were held constant across experiments and labs; only the environment of the subjective test was varied. Some subjective tests were conducted in controlled environments and some in public environments (a cafeteria, patio or hallway). The audiovisual stimuli spanned a wide range of quality. Results show that these audiovisual subjective tests were highly repeatable from one laboratory and environment to the next. The number of subjects was the most important factor. Based on this experiment, 24 or more subjects are recommended for Absolute Category Rating (ACR) tests. In public environments, 35 subjects were required to obtain the same Student's t-test sensitivity. The second most important variable was individual differences between subjects. Other environmental factors had minimal impact, such as language, country, lighting, background noise, wall color, and monitor calibration. Analyses indicate that Mean Opinion Scores (MOS) are relative rather than absolute. Our analyses show that the results of experiments done in pristine, laboratory environments are highly representative of those devices in actual use, in a typical user environment.

N. DeMinco, "The undisturbed-field model: A propagation model for close-in distances and very low antenna heights," *2013 US National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, pp.1–6, 9–12 January 2013.

When communication systems operating in one band must be moved to another band occupied by existing (incumbent) systems, an electromagnetic compatibility (EMC) analysis is used to evaluate the viability of spectrum sharing and frequency reassignments. The analysis starts with gathering all of the transmitter and receiver parameters of both systems. The correct propagation model for different geometric scenarios is then used to accurately estimate the signal strength of the interfering signal and determine the noise level of the victim receiver. If the separation distance is not adequate to reduce the interfering signal to an acceptable level, then the necessary frequency dependent rejection (FDR) must be determined. Finally, the interference-to-noise ratio (I/N) can be calculated which will allow a determination of frequency separation versus separation distance from the FDR curves.

Margaret H. Pinson, Karen Sue Boyd, Jessica Hooker, and Kristina Muntean, "How To Choose Video Sequences For Video Quality Assessment," *Proceedings of the Seventh International Workshop on Video Processing and Quality Metrics for Consumer Electronics (VPQM-2013)*, Scottsdale, AZ, January 30-February 1, 2013. http://www.its.bldrdoc.gov/publications/2694.aspx

This paper presents recommended techniques for choosing video sequences for subjective experiments. Subjective video quality assessment is a well understood field, yet scene selection is often limited by content availability. The Consumer Digital Video Library (www.cdvl.org) is a solution. Task oriented subjective testing is a newer field than entertainment oriented testing that may require a different approach to scene selection. We describe three different task-based investigations currently underway: performance requirements for public safety equipment, how quality affects comprehension of sign language over a video link, and how video affects oral comprehension over an audiovisual link. Recommendations for scene selection for two types of testing are given. The impact of experiment design will be considered. An example 1080i 29.97fps video sequence set is presented.

Joel Dumke, "Visual acuity and task-based video quality in public safety applications," *Proceedings of the SPIE Image Quality and System Performance X*, 865306, February 4, 2013. http://www.its.bldrdoc.gov/publications/2749.aspx

This paper explores the utility of visual acuity as a video quality metric for public safety applications. An experiment has been conducted to track the relationship between visual acuity and the ability to perform a forced-choice object recognition task with digital video of varying quality. Visual acuity is measured according to the smallest letters reliably recognized on a reduced LogMAR chart.

Stephen D. Voran, "Lossless Compression of G.711 Speech Using Only Look-Up Tables," *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing*, May 2013, pp. 8179–8183. http://www.its.bldrdoc.gov/publications/2728.aspx

The lossless compression algorithm specified in ITU-T Recommendation G.711.0 provides bit-exact G.711 speech coding at reduced bit-rates. We introduce two Look-Up Coders (LUCs) that also offer bit-exact G.711 speech coding at reduced rates but the LUCs do not use arithmetic operations and hence eliminate the need for a processor. Instead they read in eight G.711 symbols, reinterpret those 64 bits to form eight new symbols that carry temporal information, then look up Huffman codes for those new symbols. When compared to G.711.0, LUC rates are 9% to 40% higher and they require 2 to 8 kB additional ROM, but LUCs eliminate about one million weighted arithmetic operations per second. LUCs reduce the 8 b/smpl G.711 rate to 3.8 to 6.7 b/smpl, depending on speech and noise levels.

Stephen D. Voran and Andrew A. Catellier, "When Should a Speech Coding Quality Increase be Allowed Within a Talk-Spurt?" *Proc. IEEE International Conference on Acoustics, Speech, and Signal Processing*, May 2013, pp. 8149–8153. http://www.its.bldrdoc.gov/publications/2729.aspx

The value or harm associated with an increase in speech coding quality depends on the type of the increase as well as the temporal location of the increase in an utterance. For example, some increases in speech coding bandwidth can be perceived as impairments. The higher quality associated with the wider bandwidth can offset the impairment, but only if the increase happens early enough in an utterance. We present a subjective speech-quality experiment that qualifies these relationships at the talk-spurt time-scale for six different combinations of AMR and SILK speech coders. If a quality increase does not include a bandwidth increase, then, on average, it is beneficial only if it occurs in the first 2.8 seconds of a talk-spurt. If a quality increase includes a bandwidth increase, then it is beneficial only if it occurs in the first 1.8 seconds of a talk-spurt.

M. H. Pinson, C. Schmidmer, L. Janowski, R. Pépion, Q. Huynh-Thu, P. Corriveau, A. Younkin, P. Le Callet, M. Barkowsky, W. Ingram, "Subjective and Objective Evaluation of an Audiovisual Subjective Dataset for Research and Development," *Fifth International Workshop on Quality of Multimedia Experience (QoMEX 2013)*, Klagenfurt am Wörthersee, Austria, July 3-5, 2013. http://www.its.bldrdoc.gov/publications/2733.aspx

In 2011, the Video Quality Experts Group (VQEG) ran subjects through the same audiovisual subjective test at six different international laboratories. That small dataset is now publicly available for research and development purposes.

Margaret H. Pinson, "The Consumer Digital Video Library [Best of the Web]," *IEEE Signal Processing Magazine,* vol. 30, no. 4, pp. 172,174, July 2013. http://www.its.bldrdoc.gov/publications/2730.aspx

The difficulty of finding and getting rights to use the high quality video sequences needed for video quality research has hampered research in this area for many years. This article describes the Consumer Digital Video Library (CDVL) website (www.cdvl.org), which attempts to address this obstacle by making high-quality, uncompressed video clips available for use by the education, research, and product development communities.

C. Hammerschmidt and H. Ottke, "Spectrum occupancy results from several surveys," *2013 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, pp. 76–81, 5-9 Aug. 2013. http://www.its.bldrdoc.gov/publications/2745.aspx

This paper presents spectrum occupancy results from spectrum surveys conducted at three locations: Denver, CO; Table Mountain near Boulder, CO; and Point Loma, near San Diego, CA. Equipment setups are described along with the measurement algorithms used to measure various emission types. Various statistical graphs, M4 statistics plots and FS-CCDF plots, as well as time vs. frequency or waterfall plots give different representations of the data. Results are shown for a land-mobile radio band and a radar band. Five bands in total will be shown during the presentation.

R.T. Johnk, F.H. Sanders, K.E. Davis, G.A. Sanders, J.D. Ewan, R.L. Carey, and S.J. Gunderson, "Radiated measurements of an ultrawideband surveillance radar," *2013 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, pp. 87–92, 5-9 Aug. 2013. http://www.its.bldrdoc.gov/publications/2744.aspx

We provide detailed descriptions of recent radiated emissions measurements conducted by the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (NTIA/ITS) in Boulder, Colorado. ITS engineers performed a comprehensive series of radiated emission measurements on the Shore-Line Monitoring System (SLiMS). The SLiMS system is currently being developed by Time-Domain Acquisition Holdings® (TDC) under the sponsorship of the Naval Facilities Engineering Command (NAVFAC). The measurement results demonstrate both low emission levels, consistent with existing U.S. electromagnetic compatibility requirements and a low potential for causing interference to incumbent systems. A high level of precision is required to perform the characterization.

N. DeMinco, C.J. Behm, and T.J. Riley, "Electromagnetic compatibility (EMC) analysis approach for band migration to provide spectrum for the President's Spectrum Initiative," *2013 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, pp. 101–106, 5-9 Aug. 2013. http://www.its.bldrdoc.gov/publications/2746.aspx

When communication systems operating in one band must be moved to another band occupied by existing (incumbent) systems, an electromagnetic compatibility (EMC) analysis is used to evaluate the viability of spectrum sharing and frequency reassignments. The analysis starts with gathering all of the transmitter and receiver parameters of both systems. The correct propagation model for different geometric scenarios is then used to accurately estimate the signal strength of the interfering signal and determine the noise level of the victim receiver. If the separation distance is not adequate to reduce the interfering signal to an acceptable level, then the necessary frequency dependent rejection (FDR) must be determined. Finally, the interference-to-noise ratio (I/N) can be calculated which will allow a determination of frequency separation versus separation distance from the FDR curves.

Margaret H. Pinson, Marcus Barkowsky, and Patrick Le Callet, "Selecting scenes for 2D and 3D subjective video quality tests," *EURASIP Journal on Image and Video Processing 2013*, 2013:50 28 Aug. 2013. http://www.its.bldrdoc.gov/publications/2734.aspx

This paper presents recommended techniques for choosing video sequences for subjective experiments. Subjective video quality assessment is a well-understood field, yet scene selection is often driven by convenience or content availability. Three-dimensional testing is a newer field that requires new considerations for scene selection. The impact of experiment design on best practices for scene selection will also be considered. A semi-automatic selection process for content sets for subjective experiments will be proposed.

M.H. Pinson, N. Staelens, and A. Webster, "The history of video quality model validation," *2013 IEEE 15th International Workshop on Multimedia Signal Processing (MMSP)*, pp. 458-463, Sept. 30-Oct. 2 2013. http://www.its.bldrdoc.gov/publications/2743.aspx

This paper describes objective video quality validation efforts conducted in the past two decades. Validation efforts to be examined include a validation test performed by the T1A1 committee in the early 1990's; five rounds of validation testing performed by the Video Quality Experts Group; and validation tests performed by ITU-T Study Group 12. Useful products that resulted from those efforts will be identified, including standards, datasets, and model validation techniques.

Presentations

- Jeff Bratcher, "PSCR Updates," Utilities Telecom Council 2012 Region 10 Fall Technical Meeting, Phoenix, AZ, October 2-4, 2012
- Jeff Bratcher, with Emil Olbrich of NIST, "PSCR Updates," LTE North America Dallas, Texas, November 14-15, 2012.
- Jeff Bratcher, with Dereck Orr of NIST, "700 MHz Broadband for Mission Critical Public Safety Data – A Technical Discussion," Sixth Canadian Public Safety Interoperability Workshop, Toronto, Canada, December 3, 2012.
- Jeff Bratcher, with Dereck Orr of NIST, "P25 Updates," Sixth Canadian Public Safety Interoperability Workshop, Toronto, Canada, December 3, 2012.
- Rob Stafford, "Applications and Opportunities for LTE in Public Safety," Wireless Innovation Forum, Washington, DC, January 9-11, 2013.
- Nick DeMinco, "The undisturbed-field model: A propagation model for close-in distances and very low antenna heights," National Radio Science Meeting (USNC-URSI) 2013, Boulder, CO, January 10, 2013.
- Teresa Rusyn and Julie Kub, "Resolving discontinuities in the COST 231 Extended Okumura-Hata model in the Propagation Modeling Website (PMW) software," National Radio Science Meeting (USNC-URSI) 2013, Boulder, CO, January 10, 2013.
- Linh P. Vu and Robert B. Stafford, "A MATLAB based test tool for LTE signal analysis," National Radio Science Meeting (USNC-URSI) 2013, Boulder, CO, January 11, 2013.
- Jeff Bratcher, with Dereck Orr of NIST, "PSCR Updates," Association of Public-Safety Communications Officials – International (APCO) Emerging Technology Forum. Anaheim, CA, January 31, 2013.
- Joel Dumke, "Visual Acuity and Task-Based Video Quality in Public Safety Applications," SPIE Electronic Imaging 2013 Conference, San Francisco, CA, February 6, 2013.
- Jeff Bratcher, with Emil Olbrich of NIST, "FirstNet: The Technology Discussion," International Wireless Communications Exposition 2013 (ICWE 2013), Las Vegas, NV, March 13, 2013.
- Andrew Thiessen, "FirstNet Standards," International Wireless Communications Exposition 2013 (ICWE 2013), Las Vegas, NV, March 13, 2013.
- Dr. Bob Johnk, "A Fast-Fading Mobile Channel Measurement System," Antenna Measurement Techniques Association (AMTA) Emerging Antenna and Co-Existence Technologies for Wireless Applications Conference, San Diego, CA, April 22, 2013.
- Andy Thiessen, "FirstNet Standards Development Work for Public Safety Broadband," Paris, France, May 23, 2013.
- Nick DeMinco, Chris Behm and Tim Riley, "Electromagnetic Compatibility (EMC) Analysis Approach for Band Migration to Provide Spectrum for the President's Spectrum Initiative," 2013 IEEE International Symposium on Electromagnetic Compatibility (EMC 2013), Denver, CO, August 6, 2013.
- Bob Johnk, "Radiated Measurements of an Ultrawideband Surveillance Radar," 2013 IEEE International Symposium on Electromagnetic Compatibility (EMC 2013), Denver, CO, August 6, 2013.
- Chriss Hammerschmidt, "Spectrum Occupancy Results from Several Surveys," 2013 IEEE International Symposium on Electromagnetic Compatibility (EMC 2013), Denver, CO, August 6, 2013.
- Jeff Bratcher, with Dereck Orr of NIST, "PSCR Current Efforts," Association of Public Safety Communications Officials – International 79th Annual Conference & Expo, Anaheim, CA, August 20, 2013.
- Jeff Bratcher, with Dereck Orr of NIST, "PSCR Current Efforts," International Association of Fire Fighters (IAFF) Occupational Health & Hazards of the Fire Service Emergency Medical Services Conference, Denver, CO, August 23, 2013.
- Anna Paulson, "Audio Quality and Voice Over LTE (VoLTE), International Association of Fire Fighters (IAFF) Occupational Health & Hazards of the Fire Service Emergency Medical Services Conference, Denver, CO, August 23, 2013.

ITS Standards Leadership Roles in FY 2013

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 Positions Held by ITS Staff in FY 2013

- **Christopher J. Behm:** U.S. Chair of International Telecommunication Union Radiocommunication Sector (ITU-R) Study Group 3 (SG 3, Radiowave Propagation). Head of Delegation for Working Party (WP) 3L. Delegate to Working Parties 3L and 3K. Subgroup Chair in WP 3L.
- **Randall S. Bloomfield:** U.S. Department of Commerce Delegate to 3GPP SA (Service and System Aspects) Working Group 2 (Architecture).
- **John E. Carroll:** Delegate to ITU-R Study Group 5 (SG 5, Terrestrial Services) WP 5B (Radiodetermination service) and Study Group 1 (SG 1, Spectrum Management) WP 1A (Spectrum engineering techniques).
- **Paul M. McKenna:** International Chair of ITU-R SG 3 WP 3K. U.S. Chair of WP 3K.
- **Margaret H. Pinson:** Head of U.S. Delegation to ITU-T Study Group 9 (SG 9, Broadband cable and TV). Associate Rapporteur for Questions 2/9 (Measurement and control of the end-to-end quality of service (QoS) for advanced television technologies) and 12/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9) in SG 9. SG 9 contact for Electronic Working Methods. Co-chair of the Video Quality Experts Group's (VQEG) Independent Lab Group (ILG), AVHD Group, and IRG-AVQA Group.
- **Patricia J. Raush:** U.S. Co-chair and Head of Delegation of ITU-R SG 3 WP 3J. Delegate to Working Parties 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 SG 3 Correspondence Group 3K3. Member of SG 3 Working Parties 3K and 3M. Subgroup Chair in WP 3L.
- **Frank H. Sanders:** Chair of ITU-R Radar Correspondence Group (radar technical spectrum issues). Delegate to ITU-R SG 5 WP 5B (radar spectrum allocation and sharing) and Joint Rapporteur Group 1A-1C-5B (radar spectrum efficiency issues).
- **Andrew P. Thiessen:** U.S. Department of Commerce Delegate to 3GPP Technical Study Group Radio Access Network (TSG RAN) and to Technical Study Group Service and System Aspects (TSG SA) and to Working Groups SA1 (Services) and SA2 (Architecture).Vice-Chair of the Technology Committee and Chair of the Broadband Working Group, National Public Safety Telecommunications Council. Member, Global System for Mobile Communications Association (GSMA) Operators Group
- **Bruce R. Ward:** Member, Technical Specification Group for Service and System Aspects Working Group 1 (TSG SA WG1), 3rd Generation Partnership Project (3GPP)
- **Arthur A. Webster:** International Chair of ITU-T SG 9. SG 9 representative for Telecommunications for Disaster Relief and to several ITU-T Joint Coordination Activities such as those on the Internet of Things (JCA-IoT) and Child Online Protection (JCA-COP). Co-chair of VQEG. Co-chair of ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). Member of U.S. Delegations to the ITU World Telecommunication Standardization Assembly (WTSA), ITU-T Study Groups 9 and 16, and to the Telecommunication Standardization Advisory Group (TSAG). 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).

Mr. Arthur Webster received a certificate of appreciation for his service as International Chair of ITU-T Study Group 9 for the Study Period 2009-2012 from Mr. Malcolm Johnson, Director of the Telecommunication Standardization Bureau, during a Plenary Session of WTSA-12 in Dubai, UAE. The following week, Mr. Webster was re-elected International Chair of SG 9 for the current study period. Photo courtesy ITU.

ITS Projects in FY 2013

Cooperative Research and Development Agreements

Public Safety 700 MHz Broadband Demonstration Agreements

Operate various elements of an LTE network in a laboratory test bed and over-the-air (OTA) network to test interoperability of public safety communications equipment under simulated field conditions. Sixty-eight equipment manufacturers/resellers and wireless carriers who intend to supply 700 MHz LTE equipment and service to public safety organizations had CRADAs in place under this program in FY 2013.

CRADAs for the Use of Table Mountain

New Product Research and Development

Areté Associates

Use the Table Mountain Field Site as a field location to safely test and demonstrate LADAR technologies under development in atmospheric conditions and at distances relevant to potential applications.

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

FIRST RF Corporation

Use the Table Mountain Field Site as a field location to fully test the functionality of new antenna designs during product development.

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

Lockheed Martin Coherent Technologies

Use the Table Mountain Field Site for field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar

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

Nutronics, Inc.

Use the Table Mountain Field Site as a field location to safely and accurately test the Adaptive Tactical Laser System (ATLAS) compensated beacon adaptive optics (CBAO) system Under development.

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

University of Colorado Research and Education Center for Unmanned Vehicles

Use the Table Mountain Field Site as a field location to safely and accurately test collective and autonomous sensing and communication technologies for small unmanned aircraft.

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

Compliance Testing

Raytheon

Perform 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.

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

La Crosse Technology Ltd.

Test new weather radio receiver models under development to ensure that they meet the Consumer Electronics Association (CEA) performance specifications to required bear the NWR logo.

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

Musical Electronics Ltd

Test new weather radio receiver models under development to ensure that they meet the Consumer Electronics Association (CEA) performance specifications to required bear the NWR logo.

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

MZ Berger & Co.

Test new weather radio receiver models under development to ensure that they meet the Consumer Electronics Association (CEA) performance specifications to required bear the NWR logo.

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

Sangean Electronics, Inc.

Test new weather radio receiver models under development to ensure that they meet the Consumer Electronics Association (CEA) performance specifications to required bear the NWR logo.

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

Spectrum Measurement CRADAs

Spectrum Measurements

CTIA-The Wireless Association®

Address technical assumptions, parameters, and approaches to evaluating the compatibility of commercial broadband and incumbent government systems in the 1755-1780 MHz segment of the 1755-1850 MHz band. Measure spectrum occupancy to provide data showing the percentages of time and time durations the incumbent systems are received above predetermined power threshold, model propagation and aggregate effects to facilitate determination of separation that ensures interference avoidance, and perform laboratory measurements of interference effects on individual systems.

Project Leader: Chriss Hammerschmidt, (303) 497 5958, chammerschmidt@its.bldrdoc.gov

Radar Measurements

Lockheed Martin

Perform the NTIA RSEC emission measurements on a new tactical radar that determines points of origin and impact for artillery, rocket and mortar rounds, analyze data, and provide a final report.

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

Government Projects

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 Standards

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

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

Effects of the Channel on Radio Systems

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

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

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/Quality of Experience (QoS/QoE), and resource management standards.

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

RSMS Development

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

Project Leader: Geoffrey A. Sanders, (303) 497 6736, gsanders@its.bldrdoc.gov

RSMS Enhancements

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

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

RSMS 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

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 HDTV 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

5 GHz Dynamic Frequency Selection (DFS) Expansion

Perform measurements and analysis of electromagnetic compatibility (EMC) issues between incumbent radar systems in the 5 GHz spectrum band and unlicensed systems operating in the same spectrum and using Dynamic Frequency Selection (DFS) to avoid interfering.

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

Digital Receiver Compatibility with Radar Signals

This project supports the U.S. Administration's spectrum sharing initiatives by studying electromagnetic compatibility between incumbent radar systems and digital receivers. The emphasis is on radars and digital receivers that will operate together in spectrum around 3500 MHz. The effects of radar signals on digital (primarily LTE) receivers will be determined so as to provide spectrum managers and engineers with the information that they need to know for spectrum sharing at 3500 MHz to move forward.

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

Interference to Noise Criteria for Radars

As a prerequisite to evaluation of sharing options in the 2700-2900 MHz band, collect data on how much pulsed interference ASR radars used for short range ATC control/monitoring and NEXRAD radars used for weather prediction, monitoring, and severe weather alerts can tolerate. Program a Vector Signal Generator with the representative waveforms of radars operating in the band, and inject these waveforms into the FAA radars to see what level of interference-to-noise ratio (I/N) degrades their performance. Provide data collected from these measurements to be used to perform a more detailed EMC analysis of the assignment methodologies and develop more precise radar frequency assignment procedures, possibly making spectrum available for commercial systems.

Project Leader: John E. Carroll, (303) 497 3367, jcarroll@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 Engineering Support

Support USWP5B, USJRG, and the U.S. Administration's positions in ITU-R WP 5B 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

Other Agency Projects

Department of Commerce / NIST / Communications Technology Laboratory

Development of Millimeter Wave Radio Channel Measurement Systems

Perform research to provide industry and standards bodies with the information and technology needed for development of next generation mobile communication systems in the extremely high frequency (EHF) band (30–300 GHz),

Project Leader: Peter Papazian, (303) 497-5369, ppazian@its.bldrdoc.gov

Department of Commerce / NIST / Law Enforcement Standards Office

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

Department of Commerce / NOAA / National Weather Service

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

Department of Commerce / NOAA / Office of Habitat Conservation

Electronic Collaboration Systems Research

Develop, test, and refine an electronic collaboration tool as a platform for improved communication, productivity, and quality of service in support of the BP oil spill injury assessment and subsequent restoration. Provide training, system maintenance, and ongoing support as needed.

Project Leader: Amanda C. Alsafi, (303) 497-4201, aalsafi@its.bldrdoc.gov

Department of Defense (DoD)

Propagation Modeling Web site (PMW)

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

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

Propagation Modeling Web site (PMW) HF 2.0 Functionality

Create, validate, and verify a new ICEWave model. Implement the new ICEWave model within the PMW HF environment using a modern programming architecture.

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

DoD / U.S. Air Force

FPS-117 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-117. 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-117 emission spectrum, a determination of transmitter bandwidths, calculated spurious and harmonic emission levels, and, if possible, a plot of the azimuthal antenna pattern.

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

Department of Homeland Security (DHS) / Office for Interoperability and Compatibility

Public Safety Communications Research

Provide applied science and engineering expertise 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

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

National Security or Emergency Preparedness Telecommunications Development

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 the applicable broadband committees and meetings. Coordinate analysis of new and emerging technologies relating to the implementation of the Nationwide Public Safety Broadband Network with the public safety community.

Project Leader: Andrew P. Thiessen, (303) 497-4427, andrew@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 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: Robert J. Achatz, (303) 497 3498, rachatz@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' Wireless Communications Committee.

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

First Responder Network Authority (FirstNet)

Public Safety Broadband Standards

Provide engineering support, scientific analysis, technical liaison, and standards body participation to advance the development of standards for public safety communication system products and services intended to operate over the nationwide first responder broadband network under development.

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

FirstNet Test Bed

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: Andrew P. Thiessen, (303) 497-4427, andrew@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: Amanda C. Alsafi, (303) 497-4201, aalsafi@its.bldrdoc.gov

Abbreviations/Acronyms

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

A
ABC-MRT Articulation-Index Band Correlation MRT
AC alternating current
ACTS air combat training system
AFB Air Force Base
AMR Adaptive Multi-Rate
AMT aeronautical mobile telemetry
ANSI American National Standards Institute
ARNS aeronautical radionavigation system
ASL American Sign Language
ASR automatic speech recognition/air surveillance radar
ATIS Alliance for Telecommunications Industry Solutions
AUGNet Ad Hoc UAV Ground Network
AVA audiovisual media accessibility
AVHD audiovisual high-definition television

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

C
CDA Code Domain Analyzer
CDVL Consumer Digital Video Library
CEA Consumer Electronics Association
COTS commercial-off-the-shelf
COW cell on wheels
CRADA cooperative research and development agreement
CSMAC Commerce Spectrum Management Advisory Committee
CW continuous wave

D
DAT digital audio tape
dB decibel
DFS dynamic frequency selection
DHS Department of Homeland Security
DoC Department of Commerce
DoD Department of Defense
DSA dynamic spectrum access

E
EHF extremely high frequency
EIRP effective isotropic radiated power
EMC electromagnetic compatibility
ERB Editorial Review Board
ERP effective radiated power

F
FAA Federal Aviation Administration
FCC Federal Communications Commission
FirstNet First Responders Network Authority
FLC Federal Laboratory Consortium
FM frequency modulation
FTTA Federal Technology Transfer Act
FY fiscal year

G
GHz gigahertz
GIS geographic information system
GLOBE Global Land One-km Base Elevation
GPS global positioning system
GSM Global System for Mobile Communications
GSMA GSM Association

H
HATS head and torso simulator
HD high definition
HDTV high definition television
HF high frequency
HRTe high-resolution terrain elevation

I
IA interagency agreement
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
IP Internet protocol
IPC interference protection criteria
IRG-AVQA Intersector Rapporteur Group on Audiovisual Quality Assessment
I/Q in-phase/quadrature
IT Information Technology
ITM Irregular Terrain Model
ITS Institute for Telecommunication Sciences
ITU International Telecommunication Union
ITU-R ITU Radiocommunication Sector

ITU-T	ITU Telecommunication Standardization Sector

J

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

MD	multimedia definition
MF	medium frequency
MHz	megahertz
MOS	mean opinion score
MPM	millimeter-wave propagation model
MRT	Modified Rhyme Test
MSS	mobile satellite services

N

NARA	National Archives and Records Administration
NAVFAC	Naval Facilities Engineering Command
NF	noise figure
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPSBN	Nationwide Public Safety Broadband Network
NPSTC	National Public Safety Telecommunications Council
NTIA	National Telecommunications and Information Administration
NTC	National Training Center
NWR	NOAA Weather Radio
NWS	National Weather Service

O

OEC	Office for Emergency Communications
OIC	Office of Interoperability and Compatibility
OLES	Law Enforcement Standards Office
OOBE	out-of-band emission
OSM	Office of Spectrum Management
OTA	over-the-air

P

P25	Project 25
PCS	personal communications service
PDF	probability density function
PESQ	perceptual evaluation of speech quality
PMW	Propagation Modeling Website
PN	pseudorandom number
PRQC	Network Performance, Reliability and Quality of Service Committee
PSCR	Public Safety Communications Research
PSAL	Public Safety Audio Laboratory
PSRF	Public Safety RF Laboratory
PSVL	Public Safety Video Laboratory
PTSC	Packet Technologies and Systems Committee

Q

QoE	quality of experience
QoS	quality of service

R

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
SG	Study Group
SGLS	Satellite Ground Link System
SHF	super high frequency
SLA	service level agreement
SLiMS	Shore Line Intrusion Monitoring System
SNR	signal-to-noise ratio
SoR	Statement of Requirements

SRS satellite remote sensing
SUAS small unmanned aircraft system

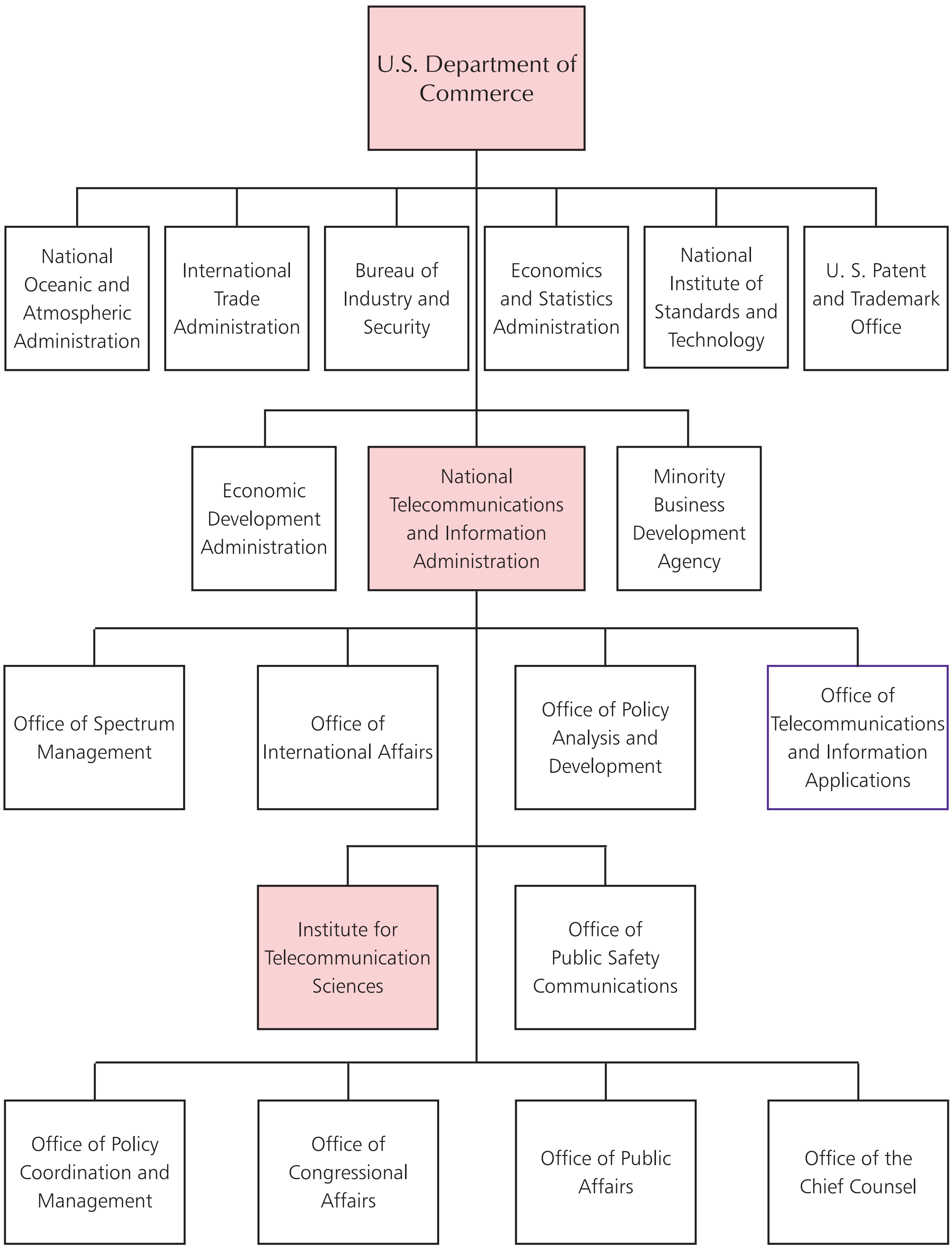
T
THF tremendously high frequency
TIA Telecommunications Industry Association
TIREM Terrain Integrated Rough Earth Model
TR technical report
TSAG Telecommunication Standardization Advisory Group
TSG Technical Specification Group
TV television

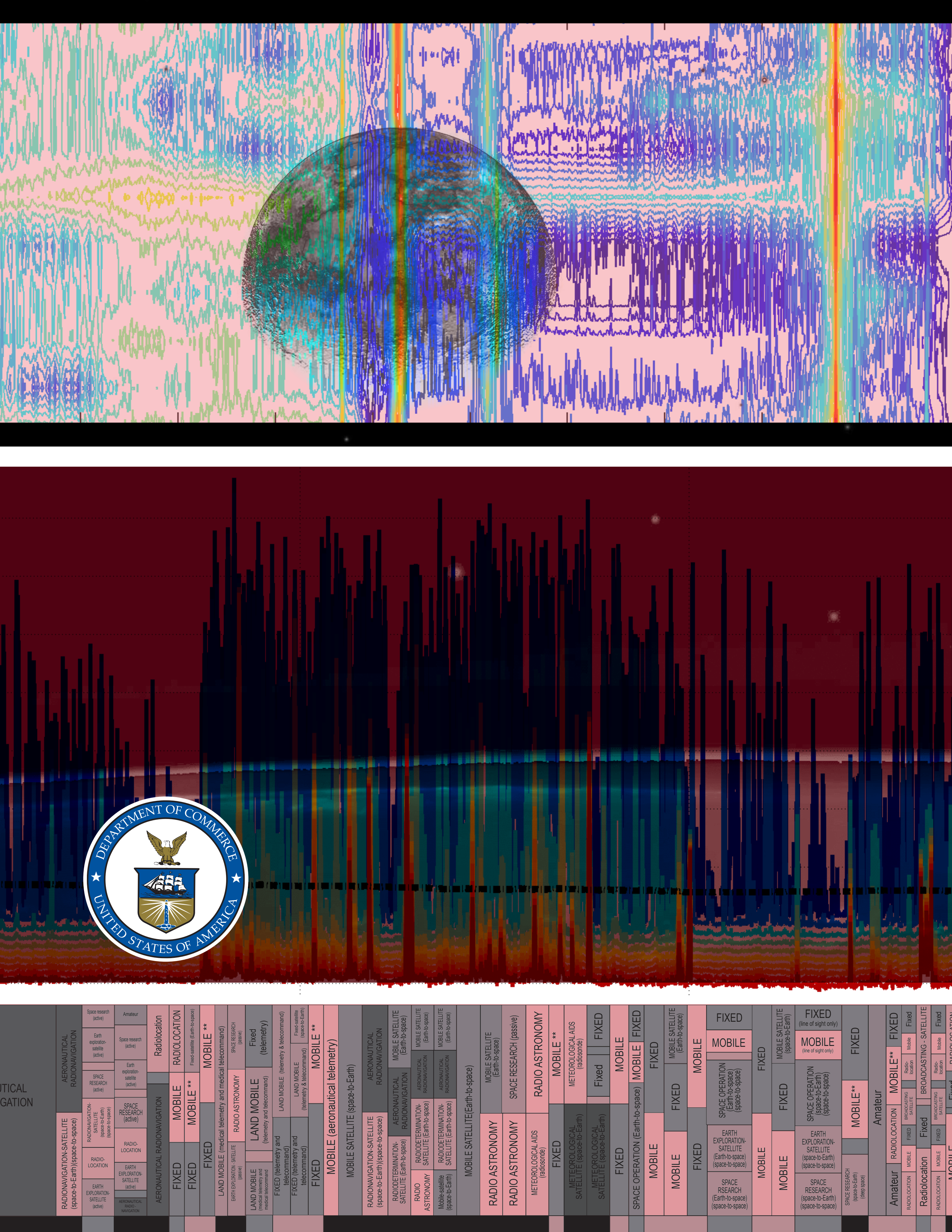
U
U.S. United States
UA unmanned aircraft
UAS unmanned aircraft system
UAV unmanned aerial vehicle
UE user equipment
UHF ultra high frequency
UN United Nations
URSI International Union of Radio Science
USGS U.S. Geological Survey
USNC United States National Committee
UWB ultrawideband

V
VHF very high frequency
VLF very low frequency
VNA vector network analyzer
VoIP voice over Internet protocol
VoLTE voice over Long Term Evolution
VQEG Video Quality Experts Group
VQM Video Quality Model
VSA vector signal analyzer
VSG vector signal generator

W
W watt
WCIT World Conference on International Telecommunications
WG Working Group
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




DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA
AERONAUTICAL RADIONAVIGATION
RADIONAVIGATION-SATELLITE (space-to-Earth)(space-to-space)
Amateur
Radiolocation
RADIOLOCATION
MOBILE **
FIXED
LAND MOBILE
MOBILE (aeronautical telemetry)
MOBILE SATELLITE (space-to-Earth)
MOBILE SATELLITE(Earth-to-space)
SPACE RESEARCH (passive)
RADIO ASTRONOMY
METEOROLOGICAL AIDS (radiosonde)
SPACE OPERATION (Earth-to-space)
MOBILE
FIXED (line of sight only)
MOBILE (line of sight only)
MOBILE**
BROADCASTING - SATELLITE