Institute for Telecommunication Sciences

FY 2008 Technical Progress Report

U.S. Department of Commerce

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An ITS engineer performing tests of NOAA Weather Radios at the Table Mountain Field Site (photograph by J.W. Allen).

The ITS Mission

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

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

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

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

Two ITS engineers prepare an antenna on the laboratory rooftop prior to a set of spectrum occupancy measurements (photograph by F.H. Sanders).

Overview

The Institute for Telecommunication Sciences (ITS), located in Boulder, Colorado, is the research and engineering arm of the National Telecommunications and Information Administration (NTIA), of the U.S. Department of Commerce (DOC). The Institute's staff of Federal employees provides strong engineering and scientific skills and experience to our technical programs. The majority of employees are electronics engineers, but the staff also includes mathematicians, physicists, computer scientists, and specialists in other fields. ITS' support during Fiscal Year 2008 consisted of $6 million of direct funding from the DOC and approximately $8 million for work sponsored by other Federal agencies and U.S. industry.

History

ITS began in the 1940s as the Interservice Radio Propagation Laboratory, which after the war became the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards, U.S. Department of Commerce. A new facility was built for CRPL in Boulder, Colorado, and dedicated by President Eisenhower in September 1954. In 1965, CRPL joined the Environmental Science Services Administration (ESSA) and was renamed the Institute for Telecommunication Sciences and Aeronomy (ITSA). In 1967, ITSA split into four laboratories: Aeronomy, Space Research, Wave Propagation, and the Institute for Telecommunication Sciences (ITS). In 1970, Executive Order 11556 established the Office of Telecommunications (OT) within the Department of Commerce and the Office of Telecommunications Policy (OTP) in the Executive Office of the President; at the same time, ITS was transferred to OT. Under the President's Reorganization Act #1 of 1977, OT and OTP merged to form NTIA.

Since 1978, ITS has performed telecommunications research and provided engineering support to NTIA, while continuing to assist other Federal agencies on a reimbursable basis. Over the last two decades, ITS has pursued cooperative research with U.S. industry and universities under the provisions of the Federal Technology Transfer Act of 1986.

Our Expertise

- **Radio Research Fundamentals and Spectrum Measurement:** ITS measures emission characteristics of Federal transmitter systems, and identifies and resolves radio frequency interference. We incorporate remote sensing data into our signal propagation models, and explore advanced antenna designs.
- **Communication Systems and Networks:** ITS plans, implements, and evaluates telecommunication systems and networks.
- **Public Safety Interoperability:** ITS facilitates interconnectivity and interoperability between services and technologies.
- **Standards Development:** ITS has a long record of leadership and technical contributions to telecommunication standards committees.
- **Wireless Voice/Data Systems and Emerging Technologies:** ITS assesses telecommunications system components, evaluates network survivability, and assesses system effectiveness in national security/emergency preparedness, military, and commercial environments. We test emerging technologies, e.g., Voice over IP and ultrawideband.
- **Audio and Video Quality Research:** For over 15 years, ITS has conducted research on digital audio and video quality, grounded in signal processing theory and models of perception.
- **Electromagnetic Modeling & Analysis:** ITS maintains ongoing investigations in broadband wireless systems performance, propagation model development, advanced antenna designs, and noise as a limiting factor for advanced communication systems.

Our Facilities

The Institute's world-class facilities include:

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

The Benefits Created by ITS

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

- **Spectrum Utilization:** Optimization of Federal spectrum allocation methods, identification of unused frequencies and potential interference through field measurements, and promotion of technology advances to aid in efficient use of the spectrum.

- **Telecommunications Negotiations:** Expert technical leadership at international conferences and development of negotiation support tools such as interference prediction programs.

- **Public Safety:** Systems engineering, planning, and testing of interoperable radio systems (e.g., voice, video, and data) for the use of "first responders" at the Federal, State, local, and tribal levels.

- **National Defense:** Improvement of network operation and management, enhancement of survivability, expansion of network interconnections and interoperation, and improvement of emergency communications that contribute to the strength and cost-effectiveness of the U.S. Armed Forces.

- **Domestic Competition:** Development of user-oriented, technology-independent methods of measuring telecommunications performance to give users a practical way of comparing competing equipment and services.

- **International Trade:** Promulgation of international telecommunications standards to remove technical barriers to U.S. export of telecommunications equipment and services.

- **Technology Transfer:** Direct transfer of research results and measurements to U.S. industry and Government to support national and international competitiveness, bring new technology to users, and expand the capabilities of national and global telecommunications infrastructures.

Our Organization

The Institute's technical activities are organized into four program areas:

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

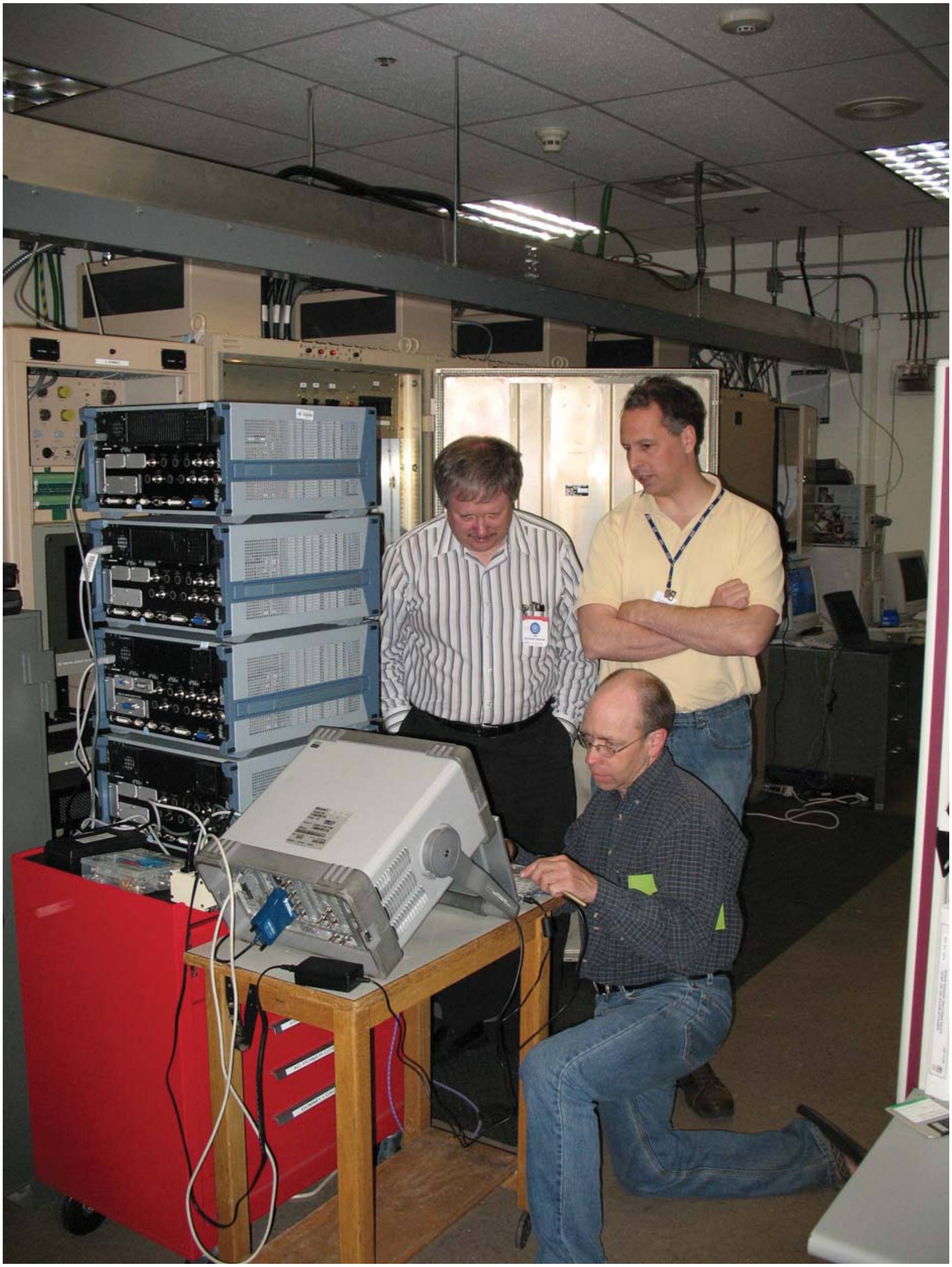
ITS's research and engineering work is supported by the Director's Office, which provides support to the program, budget, and administrative functions of the Institute. ITS also maintains an NTIA liaison function to provide assistance to NTIA on participation in national and international conferences and negotiations. The liaison also coordinates the laboratory's technical research with other Federal agencies.

Our Sponsors

Activities at the Institute are undertaken through a combination of programs sponsored by the Department of Commerce and other Federal agencies, and through cooperative research agreements with the private sector. The Institute's policy stipulates that research sponsored by other agencies must contribute to and reinforce NTIA's overall program and must be directed toward supporting the goals of the Department of Commerce. Other agency sponsors that provide significant support include the National Institute of Standards and Technology's Office of Law Enforcement Standards, the Department of Homeland Security, the Department of Transportation, the Department of Defense, the National Archives, and the National Weather Service.

Cooperative research and development agreements (CRADAs) with telecommunication-operating companies and manufacturers support technology transfer and commercialization of telecommunications products and services, which are major goals of the Department of Commerce. ITS has had CRADAs with large established companies as well as small start-ups. Partnerships such as these enhance synergies between entrepreneurial ventures and broad national goals.

Because of its centralized Federal role, ITS can provide a cost-effective, expert resource that supports many Federal agencies and industry organizations. ITS provides research and engineering that is critical to continued U.S. leadership in providing telecommunications and information equipment and services. This Progress Report summarizes technical contributions made by ITS during Fiscal Year 2008 to both the public and private sectors.



ITS engineers confer with an engineer from NTIA's Office of Spectrum Management during measurements conducted at an ARSR-4 radar installation (photograph by J.E. Carroll).

Spectrum and Propagation Measurements

The radio spectrum is an inexhaustible yet finite resource which is in ever-increasing demand by users. Accommodating this demand necessitates greater efficiencies through technological advancement and improved spectrum management.

Historically spectrum has been allocated and managed by assigning channels to users and regulating transmitter emissions within certain limits. Working within these constraints, engineers have developed modulation and coding schemes that have dramatically improved efficiencies — and increased system complexity. Similarly, improvements in spectrum management require a more complex spectrum management process.

The engineers of the Spectrum and Propagation Measurements Division draw upon decades of institutional knowledge to perform radio frequency measurements of telecommunications systems and the radio channel environment. Their advanced measurement techniques and sophisticated custom-built test fixtures allow them to fully exploit test equipment capabilities.

In November 2007, one member of the division, Jeffery Wepman, was part of a team from NTIA awarded the Department of Commerce Silver Medal, the second highest honor given by the Department (see p. 89 for more information). The team was recognized for outstanding work in designing the rules for the Digital Television Coupon Program.

The following areas of emphasis are indicative of the work done recently in this Division to support NTIA, other Federal agencies, academia, and private industry.

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Areas of Emphasis

Radio Spectrum Measurement Science (RSMS) Program The RSMS program encompasses the equipment and operational expertise employed in sophisticated radio frequency measurements. The program supports continuous improvements in measurement system capabilities and performance in both the near and long term. This culminates in enhanced engineering expertise and development and deployment of a sophisticated toolbox of laboratory equipment, analysis tools, and mobile facilities to assess spectrum occupancy and usage, electromagnetic compatibility, and to resolve interference problems. Two RSMS projects are funded by NTIA:

RSMS Operations

RSMS 4th Generation System Development

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

Antenna Polarization Mismatch Loss Measurements Working closely with NTIA's Office of Spectrum Management (OSM) to develop best practices for frequency planning tools, ITS engineers measured antenna polarization mismatch for a variety of combinations of field and antenna polarizations. The project is funded by NTIA/OSM.

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

Radio Spectrum Measurement Science (RSMS) Operations

Outputs

- Measurements to validate compatibility between off-the-shelf 5-GHz dynamic frequency selection (DFS) devices and a 5-GHz radar.
- Measurements of broadcast TV harmonic interference into a Federal Earth station receiver.
- Measurements of WiMAX device emissions.

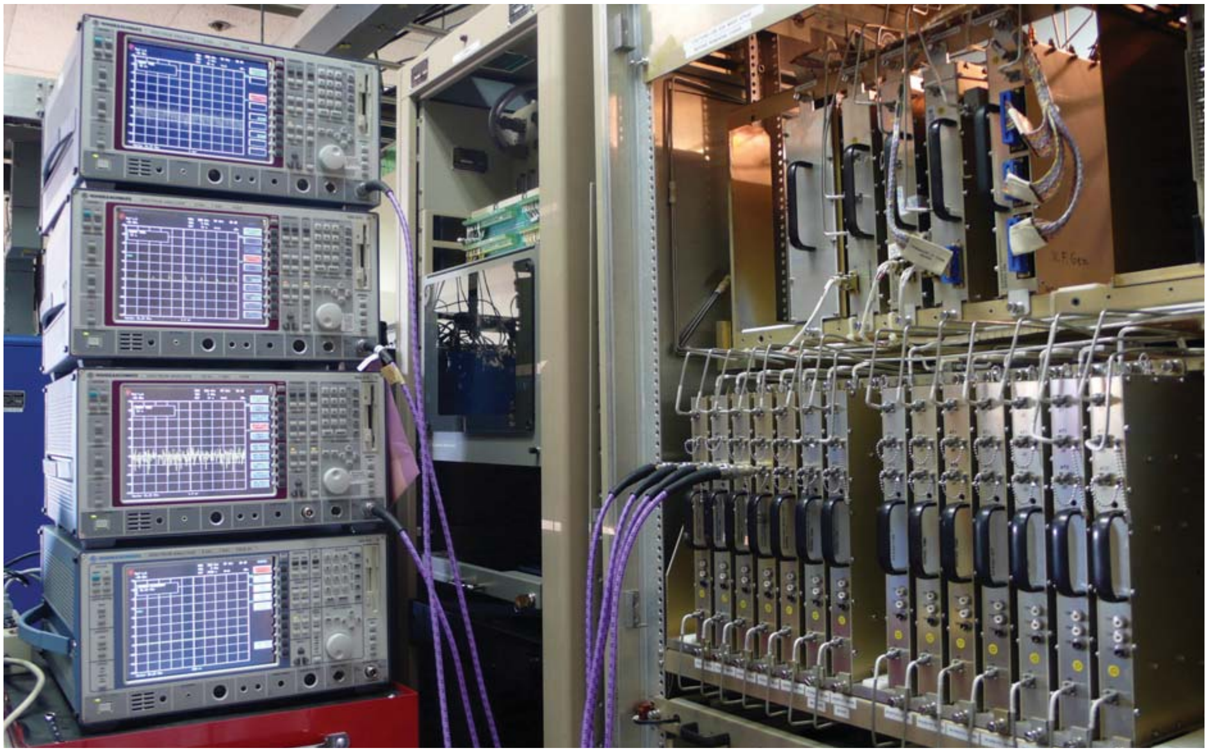
The Radio Spectrum Measurement Science (RSMS) program has the task of performing critically needed radio signal measurements necessary for making decisions regarding Federal Government spectrum allocations. As stated under Departmental Organization Order 25-7, issued 5 October 1992, and amended December 1993, the NTIA Office of Spectrum Management (OSM) is responsible for identifying and making arrangements for measurements necessary to provide NTIA and various Federal agencies with information to ensure effective and efficient use of the spectrum. The RSMS team is based in Boulder, Colorado, and performs measurements in support of OSM as required to fulfill this mission.

ITS, through the RSMS Operations Project, provides OSM and the executive branch with critically needed radio spectrum data, data analyses, reports, and summaries. The four basic areas of RSMS are measurements of 1) spectrum surveys and channel usage, 2) equipment characteristics and compliance, 3) interference resolution and electromagnetic compatibility, and 4) signal coverage and quality. In FY 2008, several different measurements were performed in support of the RSMS mission.

In the summer of 2008, field measurements were conducted to determine compatibility between off-the-shelf 5-GHz dynamic frequency selection (DFS) devices and 5-GHz radars. DFS is a method whereby Unlicensed National Information Infrastructure (U-NII) devices, which use the 5-GHz band for unlicensed operations, must detect the operations of radars and promptly vacate the channel if local radar signals are present. U-NII devices are defined as devices that provide short-range, high-speed, wireless digital communications. The FCC adopted compliance rules and procedures for U-NII devices in FY 2006. In order to monitor the performance of the devices that are currently on the market, NTIA purchased four 5-GHz U-NII devices "off the shelf" and tested them to the published compliance standards. The results obtained to date have been reported to the FCC, and more of this type of testing is expected to occur in FY 2009.

In January of 2008, measurements were conducted to resolve interference between a Federal Earth station and a harmonic spectrum emission from a broadcast television (TV) station in New Hampshire. An initial NTIA study of the problem had found that a harmonic from the TV station was interfering with the Earth station operations. After installation of an emission filter on the TV station transmitter failed to solve the problem, NTIA was asked to re-assess the problem with the intent of identifying the harmonic-generation mechanism and potential solutions. After careful examination of the TV station emissions for local oscillator (LO) leakage and intermodulation (IM) products with other signals, it was determined that the TV station transmitter was not emitting the harmonic, nor was the signal an IM emission. Rather, the harmonic was due to the re-radiation of energy from a non-linear interaction with either the TV station's broadcast tower or one of the nearby transmitter towers, an example of the so-called rusty-bolt effect. Direction-finding by the ITS team on the source of the energy confirmed the rusty-bolt hypothesis. The problem should resolve itself when the digital television transition takes place on February 17, 2009 and the existing analog TV signal goes off the air.

In early FY 2008, ITS examined and recorded the emission spectra of two Worldwide Interoperability for Microwave Access (WiMAX) devices supplied by two manufacturers. WiMAX is a telecommunications technology that provides for the wireless



Examining the electromagnetic compatibility of a radar and a Radionavigation Satellite Services (RNSS) signal (photograph by F.H. Sanders).

transmission of data, from point-to-point links to full mobile cellular-type access, at rates of up to 70 Mbps. Wide-scale deployment of this technology is expected to occur in the near future. The measurements performed by ITS on the devices were part of a larger effort to examine the electromagnetic compatibility of WiMAX devices and radars operating in the same band.

Later in 2008, ITS provided support for three separate measurements to determine interference potential to radars in the 1215-1400 MHz band (L Band) from new Radionavigation Satellite Services (RNSS) now sharing that band. The Department of Defense, the Federal Aviation Administration, NTIA, and other Federal agencies have expressed concerns about the operations of the RNSS devices. Specifically, NTIA measurements and analyses show that RNSS signals coupling into L-Band radars could cause interference which could result in loss of targets and/or reduced detection range. Within the International Telecommunication Union — Radiocommunication Sector (ITU-R), work has continued on a study of the issues, and the results of the NTIA studies have been submitted to ITU-R Working Party 5B. The so-called L-Band Group in the United States has been formed to perform a unified and comprehensive review of the issues and determine how to resolve them domestically and at the ITU-R.

Recent Publication

J.E. Carroll, J.R. Hoffman, and R.J. Matheson, "Measurements to characterize land mobile channel occupancy for Federal bands 162-174 MHz and 406-420 MHz in the Denver, CO area," NTIA Report TR-08-455, Sep. 2008.

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RSMS 4th Generation System Development

Outputs

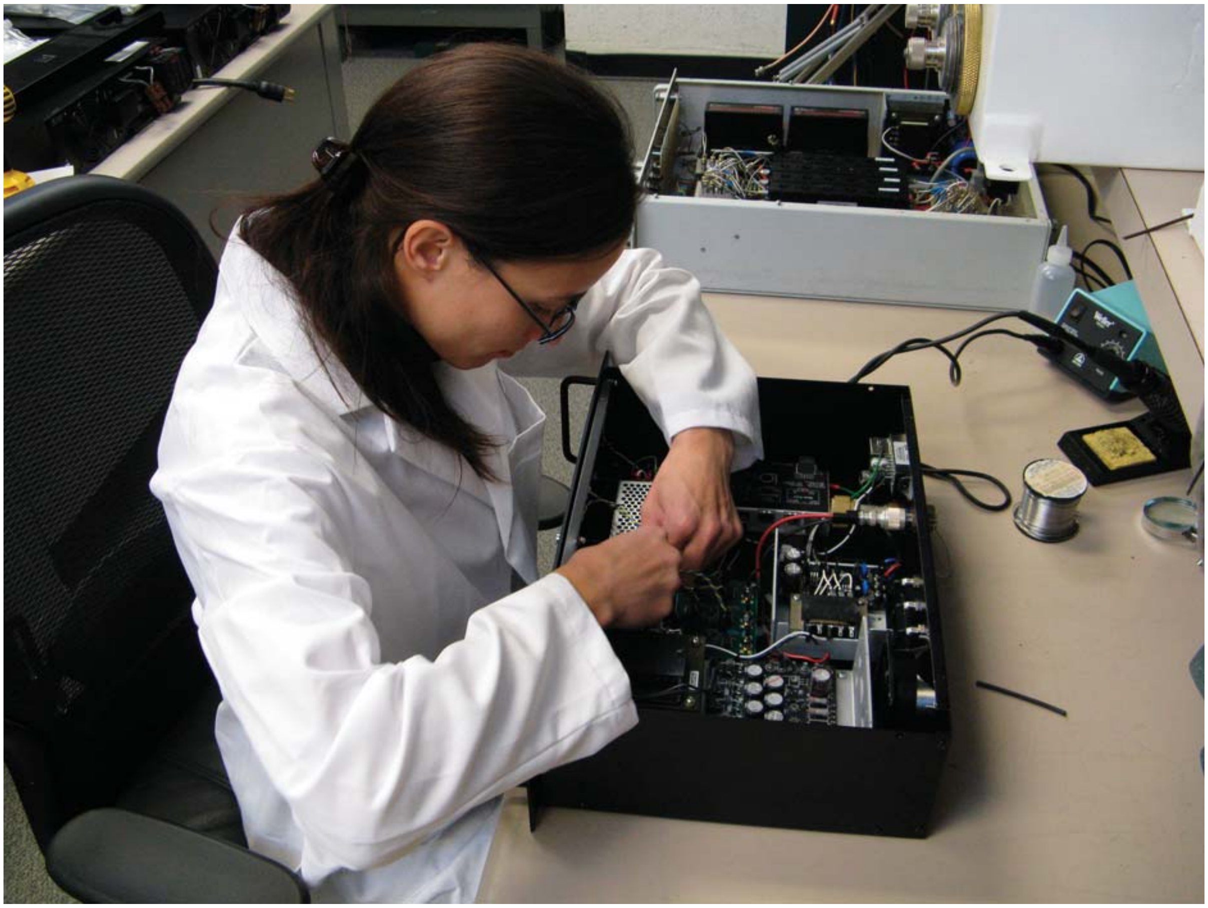
- Development of low-frequency preselectors and duplication of high-frequency preselectors.
- Several new ITS custom designed software modules for instrument control and measurement.
- Maintenance of normal operations through repairs, lab improvements, and calibrations.
- Specialized training for new entry-level hires.

The 4th generation system for Radio Spectrum Measurement Science (RSMS) consists of state-of-the-art tools (vehicle, software, and hardware) necessary for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of the 4th generation system originated out of the recognized need to upgrade to the latest technology used in RSMS operations. RSMS operations, in turn, directly supports NTIA by providing critical measurements for determining policies affecting both the public and private sectors. To this end, several new capabilities and improvements were added to the system in FY 2008.

Integral to the RSMS measurement system has been the development of customized preselector units that filter out unwanted signals and amplify the input to increase system sensitivity. Over the last few years, two new computer-controlled 4th generation preselectors have been designed and constructed — one for frequencies between 0.5–18.0 GHz and the other for frequencies between 18.0–26.5 GHz. To provide redundancy in case of failure or dual system requirements, a second set of each preselector is currently under construction. Both types of preselectors are protected against strong signals by highly shielded enclosures and are controlled via fiberoptic connections to prevent signals from coupling into control lines. In addition to these higher frequency preselectors, a 4th generation low-frequency preselector (1.5–1000 MHz) was designed, parts were purchased, and construction is nearly complete. Under the development of the 4th generation software, computer automated control of each of the units — new and old — has been integrated into the larger software package. Modularized instrument software units have made it possible to seamlessly swap out units for different applications of the same measurement capabilities.

During FY 2008, several improvements were made to existing tunable YIG filter systems frequently used for radar measurement. Specialized gain-offset circuits were developed for voltage conversion in situations where frequency tracking voltages are provided by spectrum analyzers. For spectrum analyzers that do not provide frequency tracking voltages, a YIG tracking system incorporating an arbitrary waveform generator was developed for the purpose of sweeping a YIG control voltage to coincide with the frequency sweeps of the spectrum analyzer.

Several new additions and improvements were also made to software measurement routines, as well as instrument control modules. These include the advent of a new automated bandwidth progression measurement, and an instrument module for an HP8566 spectrum analyzer. The bandwidth progression measurement determines signal power contained in different bandwidths and is useful for determining the optimal bandwidth for performing radar emission characterization measurements. The HP8566 is an older spectrum analyzer in the RSMS inventory that, while not used as extensively as the newer instruments, is still a useful instrument. Improvements were also made to the “stepped” measurement and the amplitude probability distribution (APD) measurement. The “stepped” measurement is an automated routine used frequently to characterize the emission characteristics of radars. Improvements to this routine include an event table that provides multiple automated measurement without interruption and a data viewer that allows examination of data and the ability to re-measure designated sections of the spectrum. The APD measurement is an automated routine used for statistical analysis of signal and noise power levels. Improvements to this routine also include the addition of an event table and a data viewer. Modifications were also made to



ITS engineer building a preselector control module (photograph by J.R. Hoffman).

the “swept” and “swept calibration” measurements to accommodate use of the new YIG tracking system.

Every year, approximately 20% of RSMS 4G project resources are reserved for maintaining equipment readiness. This includes repairs and maintenance to the measurement vehicle, as well as various instruments. It also includes periodic equipment calibrations, upgrades to the labs, characterization and record keeping for discrete components such as amplifiers, filters, and cables, and the purchase of components required to complete specified measurements.

Funds were also reserved this year for additional training of two new entry-level employees. In an effort to expedite the knowledge and skill base of these employees, additional on-the-job experience was provided that would not normally be available under other tightly budgeted projects. Because measurements frequently have time and monetary constraints that prevent adequate training in the field, this allocation of funds provided financing for duplicate personnel in the field who are still learning and may not be able to provide the necessary skills to accomplish the task at hand without working with other more senior engineers. This allows the work to be accomplished in a timely manner within budget and still provide training of new employees.

Further developments expected in FY 2009 include enhanced data file management, a scheduler for automated control of multiple measurements, improvements to the swept and stepped APD programs, work on an FPGA re-programmable instrument module, and the completion of the second set of preselectors.

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Table Mountain Research Program

Outputs

- NOAA Weather Radio receiver performance testing and validation.
- Antenna characterization.
- Geospatial data representation and visualization.
- Lidar system testing and evaluation.

The Table Mountain Field Site and Radio Quiet Zone (see p. 73) supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. Activities this year have included:

Studies in Geospatial Data Representation
Radio spectrum measurements are typically associated with location, time, bandwidth, and antenna characteristics. However, such a sample does not give a complete representation of the distribution of electromagnetic energy in three dimensions (3D). In FY 2008, ITS explored the use of geographic information system (GIS) technology to research radio spectrum measurements and preserve the geospatial relationship between spectrum measurements. ITS created the first phase of a Table Mountain Frequency Coordination Website (TMFCW) to store and analyze two-dimensional (2D) frequency propagation data originating from transmitters that are within 80 miles of the Table Mountain Research radio quiet zone. Modeling 2D radio propagation data at Table Mountain is the first step in utilizing GIS technology to provide a more complete picture of the radio environment. As GIS technology improves, ITS plans to perform more sophisticated radio analyses in 3D.

Laser Research
The Table Mountain field site provides a large, open, unobstructed area that is ideal for the study of laser systems. Researchers from the National Oceanic and Atmospheric Administration (NOAA) and private research partners perform tests that include: atmospheric effects on laser light, imaging and ranging using laser based systems, and even laser based systems for counting the fish in the ocean.

NOAA Weather Radio Testing
NOAA Weather Radio (NWR) is an information broadcasting service operated by NOAA to provide continuous information on the latest weather conditions. Per a 1975 White House Policy statement, NWR was designated as the sole government-operated radio system to provide warnings regarding natural and other disasters and hazards directly to the public. ITS operates a laboratory at the Table Mountain Field Site for the purpose of measuring the performance of these radios. This test facility provides NOAA with performance data based on tests outlined by the Consumer Electronics Association standard CEA-2009.

NOAA Weather Radio research at Table Mountain (photograph by J.W. Allen).

Antenna Performance and Evaluation Testing
The controlled radio environment at the Table Mountain Field Site is an ideal place to study the radiation pattern, gain, and polarization of radio antenna systems. Experiments have included: testing the effects of vehicles on mobile antenna systems, evaluating the performance of new antenna designs, and studying the polarization of antenna side-lobe emissions.

FY 2008 Cooperative Research and Development Agreement (CRADA) Partners at Table Mountain

- Arete Associates
- Lockheed Martin/Coherent Technologies
- First RF Corporation
- University of Colorado, Ad hoc UAV Ground Network (AUGNet)
- Deep Space Exploration Society (DSES)

Laser research at Table Mountain (photograph courtesy Lockheed Martin/Coherent Technologies).

Recent Publications

J. Carroll, R. Hoffman, and R. Matheson, "Measurements to characterize land mobile channel occupancy for Federal bands 162–174 MHz and 406–420 MHz in the Denver, CO area," NTIA Report TR-08-455, Sep. 2008

T. Brown, B. Argrow, E. Frew, C. Dixon, D. Henkel, J. Elston, and H. Gates, "Experiments using small unmanned aircraft to augment a mobile ad hoc network," in B. Bing, ed., *Emerging Technologies in Wireless LANs: Theory, Design, and Deployment*, pp. 695-718, 2008.

E.W. Frew, C. Dixon, J. Elston, B. Argrow, and T.X Brown. "Networked communication, command, and control of an unmanned aircraft system," *AIAA Journal of Aerospace Computing, Information, and Communication*, vol. 5, no. 4, Apr. 2008, pp. 84-107.

D. Henkel and T.X Brown, "Delay-tolerant communication using mobile robotic helper nodes," in *Proc. The First Workshop on Wireless Multihop Communications in Networked Robotics*, Berlin, Germany, Apr. 2008.

E.W. Frew, D.A. Lawrence, and S. Morris, "Coordinated standoff tracking of moving targets using Lyapunov guidance vector fields," *AIAA Journal of Guidance, Control, and Dynamics*, vol. 31, no. 2, Mar.–Apr. 2008.

C. Dixon and E.W. Frew. "Maintaining optimal communication chains in robotic sensor networks using mobility control," in *Proc. of the First International Conference on Robot Communication and Coordination (Robocomm)*, Athens, Greece, Oct. 2007.

T.X Brown. "The role of communication in UAS in the next 10 years," *First Community Symposium dedicated to Civilian Applications of Unmanned Aircraft Systems (CAUAS)*, Boulder, CO, Oct. 2007.

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Antenna Polarization Mismatch Loss Measurements

Outputs

- Co- and cross-polarized azimuthal antenna patterns.
- Antenna polarization mismatch loss plots.

Radio waves have a property called polarization, which is defined as the orientation of the electric field vector. The three polarization types are linear (which has common subdivisions of vertical, horizontal, and slant), circular, and elliptical. An antenna's polarization is the same as the polarization of a radio wave that would be produced if the antenna was energized by a transmitter. For example, an antenna that transmits a vertically polarized radio wave would have a vertical antenna polarization.

Generally, in a communication system involving a transmitting antenna and a receiving antenna, the maximum radio wave energy is transferred when both antennas have the same polarization.

For an electromagnetic compatibility (EMC) analysis, there can be an effect on the received level of an interfering signal caused by differences in antenna polarization between a potentially interfering transmitter and a victim receiver. The polarization of an antenna remains relatively constant throughout the main lobe of the antenna pattern, but can vary considerably in the minor lobes. This variation can create a significant additional loss to be considered when doing an EMC link analysis. The loss due to differences between transmit and receive antenna polarizations is called antenna polarization mismatch loss.

Figure 1. Physical setup used for antenna polarization mismatch loss measurements (photo by B. Bedford).

In FY 2008, ITS performed measurements of antenna polarization mismatch loss between many combinations of an electromagnetic field's polarization and the polarization of an antenna under test (AUT). The measurements were performed using two AUTs, a linearly polarized double ridged guide horn and a right hand circularly polarized cavity backed planar spiral. Both linear and circularly polarized electromagnetic fields were generated to measure the mismatch loss with various combinations of field polarizations and antenna polarizations.

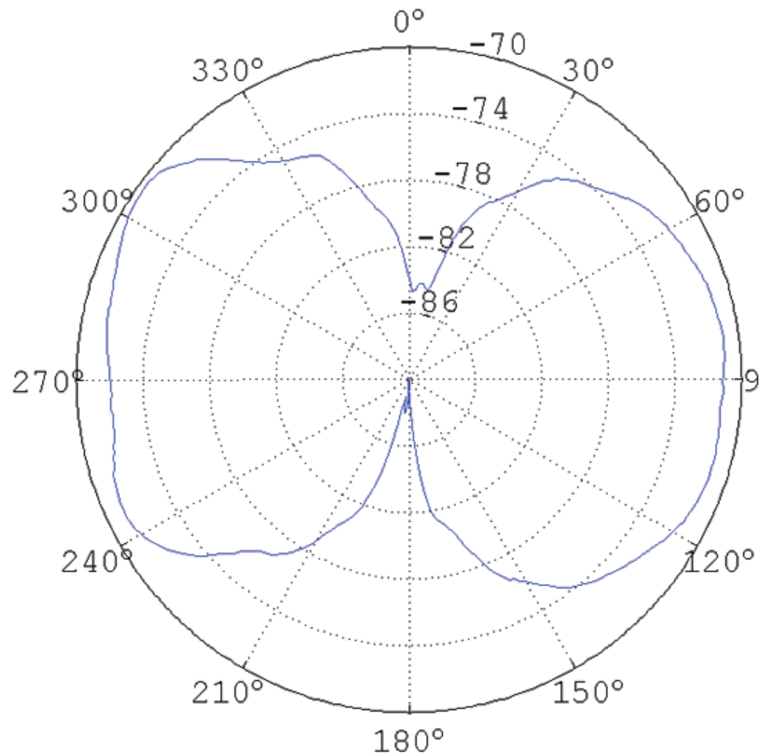

Figure 2. A polarization mismatch loss pattern for a lobe on a double ridged guide horn antenna at 311 degrees in the cross-polarized azimuthal antenna pattern.

First, points in the AUT antenna pattern had to be identified where the polarization mismatch loss measurements would be made. Since many EMC analyses involve terrestrial links, terrestrial azimuthal antenna patterns were measured for each AUT. Polar plots of the patterns were created for co- and cross-polarized field cases. The cross-polarized cases were defined as vertical vs. horizontal and right hand circular vs. left hand circular. Lobes in these patterns were selected for further measurements.

For each selected lobe, the lobe was immersed in a vertically polarized field and the lobe was rotated through 360 degrees of polarization angles. A polar plot was made of the received signal level vs. the lobe polarization angle, illustrating any polarization mismatch loss that may exist. An example plot is shown in Figure 2. In this plot, a lobe on a double ridged guide horn antenna at 311 degrees in the cross-polarized azimuthal antenna pattern was selected for measurement. At a polarization angle of 3 degrees, the lobe is cross-polarized with the field, yielding a maximum mismatch loss. As the angle increases, the mismatch loss mostly decreases to a minimum at around 85 degrees. Further angular progression results in an increase in the mismatch loss up to 179 degrees. For a theoretical model of this antenna in free space, this pattern would be expected to exhibit symmetry about the 5 degree axis but the measurement shows that for a real antenna with a coaxial cable attached to it, there is some deviation from perfect symmetry.

The co- and cross-polarized azimuthal antenna patterns show the degree of isolation that can be achieved with real antennas including the effects from coax cable. The polarization mismatch loss patterns provide information about how real antennas, with effects from coax cable, deviate from theoretical predictions. This new information may potentially be used to improve electromagnetic compatibility link analyses in the future.

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Radio Noise and Spectrum Occupancy Measurement Research

Outputs

- Design and development of an automated wideband noise measurement system.
- Characterization measurements of the noise measurement system.

The proper design of a radio communication system requires, among other considerations, knowledge of the noise and interference environment at the receiving location. While distinguishing between what is considered noise and what is considered interference is subject to interpretation, one interpretation is that interference arises from intentionally radiated signals whereas noise arises from either natural sources or from unintentionally radiated signals from man-made sources. Noise can be further categorized as being internal to the receiving system or external to the receiving antenna. External man-made noise was studied extensively at ITS in the 1960's and 1970's and culminated in the development of a man-made noise model that is still in use today (see Recommendation ITU-R P.372-9). However, the proliferation of computers, cellular telephones, and other electronic devices as well as increases in spectrum crowding, use of RF overlay technologies, aging of the power distribution infrastructure, and improvements in auto ignition systems suggest that the man-made radio noise environment may have changed since the 1970's. Thus, there has been a renewed, worldwide interest in measuring, quantifying, and modeling man-made radio noise.

To respond to this interest, ITS designed and developed a new, automated wideband noise measurement system. Unlike previous noise measurement systems at ITS, this new system uses a vector signal analyzer (VSA). The VSA-based system permits wideband noise measurements in up to 36 MHz of bandwidth and permits the recording of digitized in-phase/quadrature (I/Q) samples of the entire noise signal. Previous noise measurement systems at ITS were limited to much narrower bandwidths and only recorded amplitude values of the measured noise. Measurements in the wider bandwidth and recording the actual I and Q signal data provide many more options in how the data can be processed and further utilized.

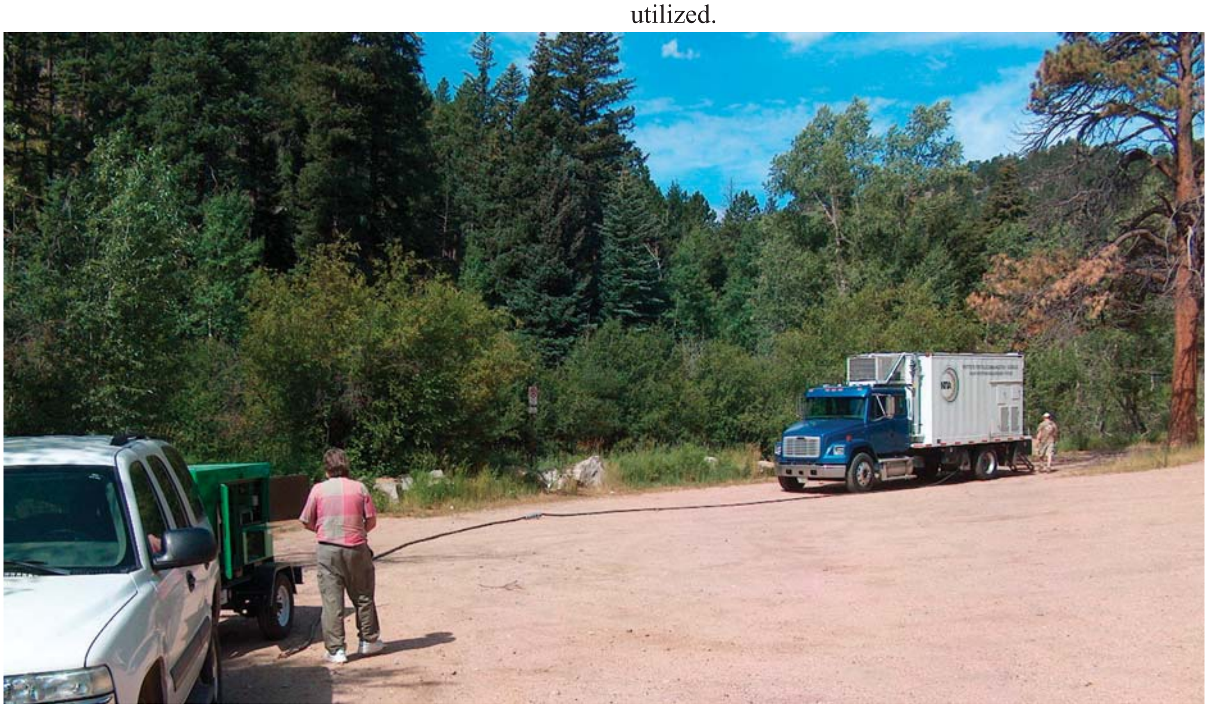

Figure 1. Characterization measurements of the noise measurement system in a radio quiet area in Boulder Canyon (photograph by R.F. Kaiser).

The measurement system consists of an antenna, ITS custom-built RF preselector, VSA, and personal computer. Due to their omnidirectional pattern and gain predictability when mounted on a measurement vehicle and to provide better comparison with historical noise measurement results, quarter-wave monopole antennas tuned to the desired measurement center frequency and mounted on a circular ground plane are used.

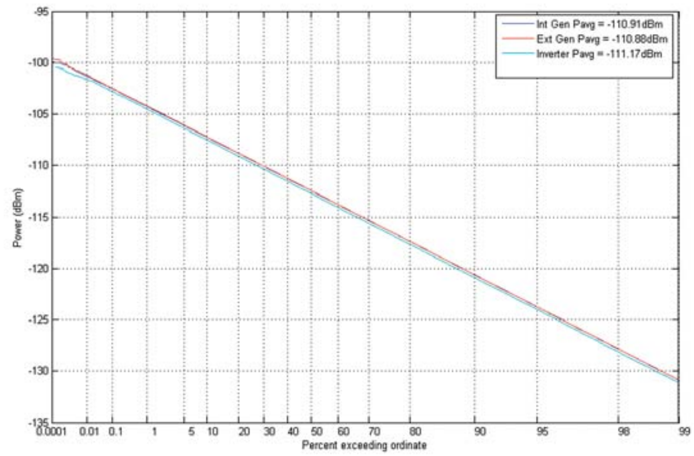

Figure 2. Comparison of the amplitude probability distributions of measured noise power at 761 MHz for different AC power sources.

The preselector is able to switch between three different filter paths, which currently are configured as manually tunable bandpass filters but can be replaced with fixed bandpass filters to achieve narrower bandwidths for better interfering signal rejection. Switching of the filter paths is accomplished with coaxial RF switches under automated software control using ethernet-based electro-mechanical relays. After filtering, an ultra low-noise amplifier is used to minimize the overall system noise figure.

The VSA downconverts the preselected signal from RF to IF, digitizes the signal, performs a digital downconversion to produce baseband I and Q samples, digitally filters and decimates this data, and saves the data to a file. A key benefit in using the VSA is the capability of capturing and storing a very large number of I and Q noise data samples.

The noise measurement system is controlled by custom software developed by ITS that runs on a personal computer. The software allows the user to select measurement parameters such as the time between data recordings and the total duration of the measurements. The software also allows the user to select a center frequency, VSA span, and the number of points to save to a file. The capability to perform and display results of noise diode calibrations, spectrum captures, and single, manual noise measurement data captures is included in the software.

Currently the noise measurement system is housed in the RSMS-4G measurement vehicle (see pp. 8-9), which provides AC power, temperature control, and shelter for the equipment. Even more importantly, the vehicle provides a high degree of shielding between any electromagnetic interference (EMI) generated by the equipment housed inside and the receive antenna mounted on the roof of the vehicle. Since it is critical in a noise measurement system to ensure that the system does not receive EMI from its own equipment, extra precautions are taken. High shielding, low-loss RF cabling is used between the antenna, the preselector, and the VSA. In addition, the preselector was constructed within an RF shielded enclosure.

The noise measurement system software is able to prevent the air conditioning and heating system from turning on during data acquisition. This eliminates any possibility that EMI generated by the air conditioning and heating system will be measured.

Characterization measurements of the noise measurement system were made using the RSMS-4G vehicle in a radio quiet area in Boulder Canyon (see Figure 1) to test the system and to determine (1) the susceptibility of the system to self-generated EMI and (2) the effects of using different AC power sources. Figure 2 shows a comparison of the amplitude probability distributions of measured noise power at 761 MHz during system characterization for different AC power sources. No difference in noise power levels was seen between the internal and external generators; the noise power level is only slightly lower for the inverter (located completely inside the shielded area of the vehicle).

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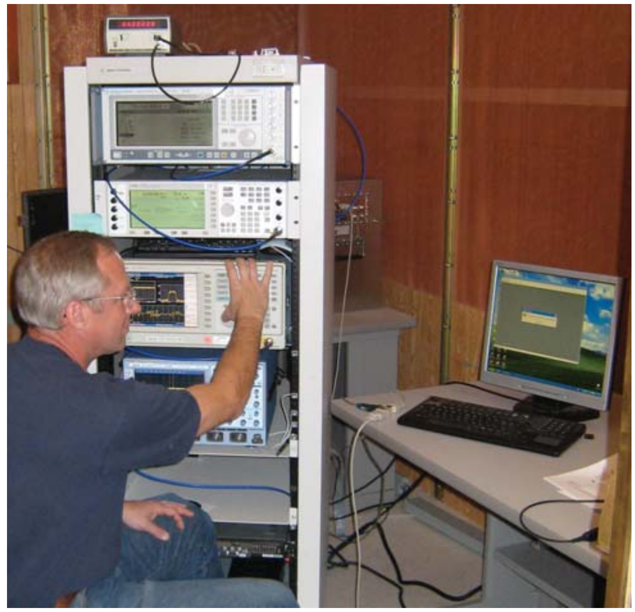
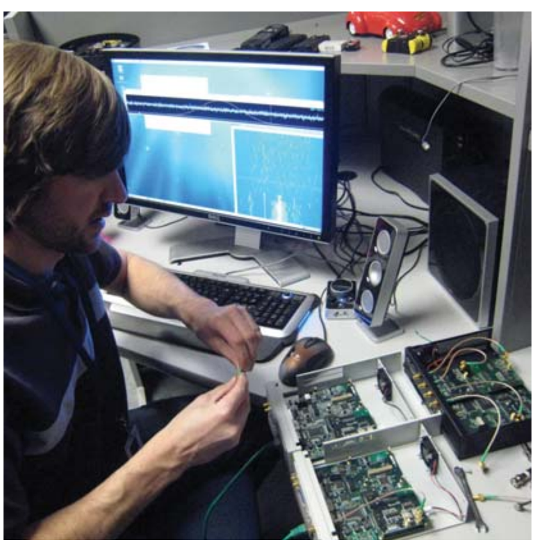
At ITS' Public Safety audio labs, an ITU-Standard Head and Torso Simulator "speaks" through a fireman's self-contained breathing apparatus (SCBA) mask into a radio.



Working in the RF screen room of ITS' Public Safety RF lab, an ITS staff member adjusts an RF signal generator before launching public safety land mobile (LMR) radio test software.



An ITS staff member configures the boards of three software-defined radio devices. A captured radio signal displays on the monitor.

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

Telecommunications and Information Technology Planning

The telecommunications and information technology planning function represents the highest-level system or network perspective of the Institute. This work includes planning and analyzing existing, new, and proposed telecommunications and information technology systems, especially networks, to improve efficiency and enhance performance and reliability. ITS performs this work for both wireline and wireless applications. This encompasses work frequently referred to in industry as “systems engineering.”

All phases of strategic and tactical planning are conducted under this work area, as well as problem solving and actual implementation engineering. ITS engineers identify users’ functional requirements and translate them into technical specifications. Telecommunication system designs, network services, and access technologies are analyzed, as well as information technologies (including Internet and Internet-related schemes).

Following is a summary of significant activities that occurred in the area of telecommunications and IT planning during FY 2008. Telecommunications interoperability relating to Public Safety communications remains the largest program area.

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Areas of Emphasis

Public Safety Communications Interoperability One of the largest programs at the Institute conducts broad-based technical efforts aimed at facilitating communications interoperability and information-sharing among wireless and IT systems within the public safety community. These activities are funded by the National Institute of Standards and Technology’s Office of Law Enforcement Standards Program and the Department of Homeland Security, and are planned and performed with coordination among local, State, tribal, and Federal practitioners. Technical thrusts within the program, described in separate sections on the following pages, include:

- **Project 25 Standards Development**
- **Project 25 Compliance Assessment Program**
- **Public Safety Audio Quality**
- **Public Safety Interoperability Test Tools**

Emergency Telecommunications Service (ETS) Standards Development The Institute develops and verifies ETS Recommendations for ITU-T Study Group 9. The project is funded by the Department of Homeland Security’s National Communications System.

Railroad Telecommunication Study The Institute assists the Association of American Railroads’ frequency management office in developing their narrowband VHF channel plan and wideband-to-narrowband migration strategy for the U.S. railroads. The study is funded by the Federal Railroad Administration.

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

Wireless Network Measurement Methods The Institute studies the performance characteristics of wireless networks and attempts to standardize measurement methods in order to better understand the applicability of different types of wireless networks to specific user requirements. The project is funded by NTIA.

Project 25 Standards Development

Outputs

- Technical requirements upon which Project 25 digital radio and system standards are developed.
- Technical standards contributions for conformance, performance, and interoperability testing of Project 25 radios and systems.
- Formal participation in the groups responsible for Project 25 standards development.

Project 25 (P25) is a partnership between the public safety communications community and industry manufacturers whose goal is the publication of standards for commercial interoperable land mobile radio (LMR) equipment (i.e., digital radios and infrastructure) that satisfies the complex and evolving needs of Federal, State, local, and tribal public safety communication users. Project 25 has been recognized through recent legislative and related actions as the preferred equipment and systems solution for LMR public safety users. The use of competitively offered P25 equipment continues to grow, with broad adoption by the more than 50,000 public safety organizations in the U.S. and by public safety organizations in over 54 countries. An example of a Federal user of P25 equipment and systems is the U.S. Department of the Interior, which owns and operates over 63,000 P25 radios.

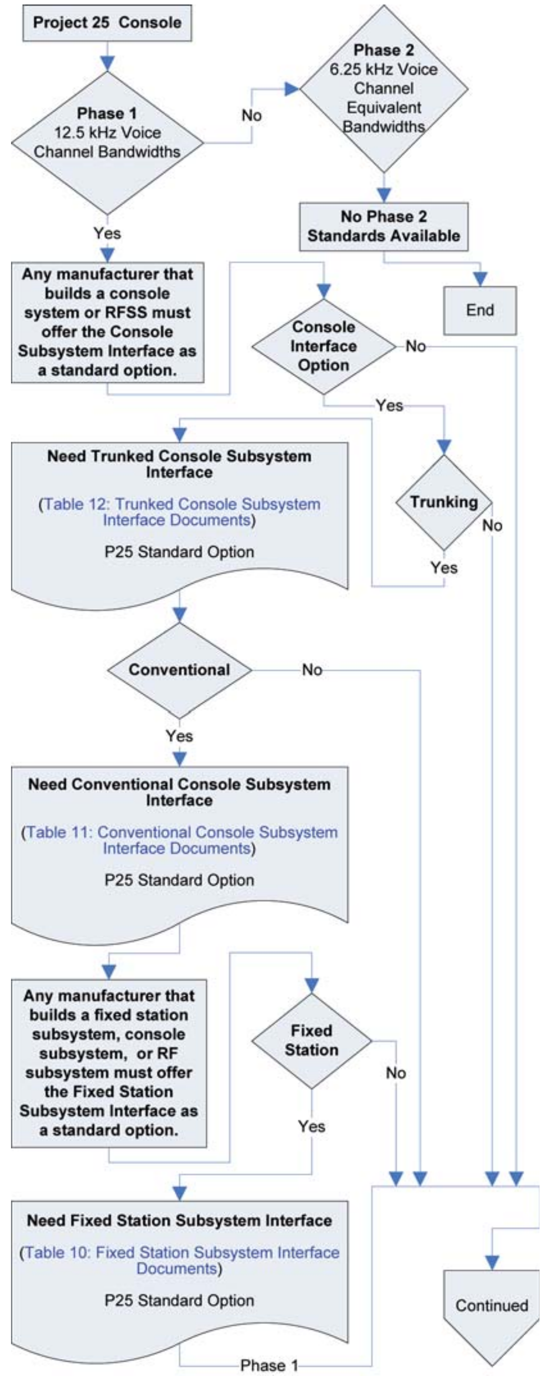
ITS began advancing the development of P25 standards, which are approved and published by the ANSI-accredited Telecommunications Industry Association (TIA), shortly after the establishment of Project 25 approximately 20 years ago. Over the last five years ITS has supported the accelerated development of P25 standards to meet increasing user needs for functionally enhanced P25 equipment and systems, and to satisfy Congressional mandates concerning allocation of Federal funding for P25-compliant equipment and systems. In FY 2008, ITS continued its efforts to (1) assist the development of technical requirements for P25 standards; (2) propose technical approaches for the standardized testing of the conformance, performance, and interoperability of equipment implementing P25 interfaces; and (3) formally participate as user representatives in the P25 standards development process through focused technical, leadership, and organizational involvement.

Of particular importance during FY 2008 was ITS involvement that directly assisted the approval of new P25 standards for the Inter-RF Subsystem Interface (ISSI) and other P25 interfaces recognized by Congress as critical to complete in the near-term. ITS efforts over several fiscal years contributed directly to the approval of a precedent-setting approach that defines P25 standardized tests used to assess the conformance of equipment that implements trunked voice services using the ISSI. ITS has implemented these tests as part of its ISSI Test Tool (ITT). ITS involvement also directly contributed to the approval of a new ISSI standard that specifies the test procedures and performance specification of equipment that implements trunked voice services using the Console Subsystem Interface (CSSI). The CSSI standards development support effort built upon the essential technical leadership role ITS played in the development of ISSI measurement methods and performance recommendations standards published in early 2007.

Building on its FY 2007 efforts, in FY 2008 ITS submitted several significant technical contributions proposing practical approaches for assessing interoperability of equipment implementing the ISSI. The ISSI is the most important interface in supporting multi-agency use of P25 radios across different jurisdictions on a wide-area basis. ITS' technical approaches have been generally adopted, with the result that the ISSI interoperability test procedures standard is being rapidly advanced and is planned for completion in 2009. The publication of ISSI conformance, performance, and interoperability test standards will enable the subsequent completion of ISSI compliance test procedures in 2009. These compliance documents will enable ISSI equipment to be offered and procured in accordance with the P25 Compliance Assessment Program (P25 CAP).

During FY 2008, ITS leadership in the P25 User Needs Subcommittee (P25 UNS) continued to support the drafting of an updated P25 Statement of Requirements (P25 SoR), which is expected for approval in October 2008. Other examples of ITS' technical involvement in P25 during FY 2008 include several contributions supporting the development of the next generation P25 Common Air Interface (CAI), the Two-Slot Time Division Multiple Access (TDMA) standard, which is urgently needed to satisfy public safety and impending regulatory requirements for more efficient use of limited radio spectrum. Integral to all ITS activities supporting the development of P25 standards is the conduct of formal P25 voting activities on behalf of ITS and its sponsors, which requires extensive committee involvement and associated coordination activities. During FY 2008, numerous letter ballot comments were submitted that enabled resolutions to be accomplished consistent with ITS and sponsor objectives. A significant number of P25 standards were completed, including 19 standards associated with the ISSI and other critical P25 interfaces.

ITS continues its outreach efforts to promote development and use of P25 standards, and to increase participation in the P25 standards process. For example, ITS was invited to organize a panel discussion on P25 standards at a major conference on radio communications held by the U.S. Department of the Interior and the U.S. Department of Agriculture. At this joint DOI/USDA radio workshop, held in February 2008, ITS conducted a session that summarized the status of the critical P25 interfaces, and presented a talk titled "Project 25 Standards Overview." Other outreach efforts included hosting a meeting at the request of representatives of public safety practitioners in the San Francisco Bay Area to assist their ongoing ISSI design and procurement efforts for the purpose of achieving multi-agency P25 system interoperability. Since 2006, ITS has maintained the *P25 Document Suite Reference* (P25 DSR) to track the current state of P25 standards documents (http://www.its.bldrdoc.gov/resources/p25/P25DocSelection.pdf). Understanding the status of specific P25 interface, equipment, and service standards helps public safety LMR system managers make planning and procurement decisions. The P25 DSR serves to describe the organization and relationships of the standards (see figure) necessary to build components of a P25 LMR system. The P25 DSR provides users, manufacturers, and government agencies a roadmap for charting progress and prioritizing standards development. The P25 DSR is also playing an increasingly important role in identifying the documents used for P25 compliance assessment purposes.



P25 DSR console decision chart example with references to tables listing applicable P25 standards.

The inter-related ITS public safety projects, which assist the development of high-priority P25 and other standards, are sponsored by several Federal organizations with a vital interest in advancing interoperable public safety communications. ITS activities focusing on P25 standards development continue to be sponsored by the National Institute of Standards and Technology Office of Law Enforcement Standards. In FY 2009, ITS will continue to support the accelerated development of Project 25 standards to further realize the commercial offering, procurement, and operation of interoperable LMR radios and systems that meet the mission-critical communication needs of the public safety community.

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Project 25 Compliance Assessment Program

Outputs

- Development of technical materials for DHS P25 CAP Governing Board.
- Grant guidance language for Federal Project 25 equipment grant programs.
- Laboratory assessment program management and subject matter expertise.
- Compliance assessment related Project 25 standards.

"... Testing was something that for a long time public safety assumed occurred, but then they realized that their toasters were tested to a higher degree than their radio systems." – Dereck Orr, NIST/OLES Communications Program Manager

For several decades, public safety agencies have been purchasing and using equipment made by disparate manufacturers and operating on disparate spectrum. As a result, this equipment often cannot interoperate, preventing many public safety agencies from communicating when responding to critical incidents that threaten lives and property. Public safety and industry have partnered through Project 25 (P25) on developing standards that allow radios and other components to interoperate regardless of manufacturer – enabling emergency responders to exchange critical communications. The goal of Project 25 is to specify formal standards for interfaces between the various components of a land mobile radio (LMR) system – commonly used by emergency responders.

After many years of effort, industry is incorporating standards into the radio and communications equipment used by public safety, but there is currently no independent method for purchasers to verify that the equipment is actually compliant with those standards. In fact, preliminary test data indicates that some radios currently sold under the Project 25 label do not meet all of the standards' requirements. To address this issue, ITS, in conjunction with the National Institute of Standards and Technology's Office of Law Enforcement Standards (NIST/OLES) and the Department of Homeland Security's Office of Interoperability and Compatibility (DHS OIC), built a coalition of public safety users and communications equipment manufacturers to create an independent compliance assessment program that will test the equipment for standards compliance.

The Project 25 Compliance Assessment Program (P25 CAP) is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the P25 suite of standards. The purpose of the program is to provide emergency response agencies with evidence that the communications equipment they are purchasing meets P25 standards for performance, conformance, and interoperability.

The program requires test laboratories to demonstrate their competence through a rigorous and objective assessment process. Such a process promotes the user community's confidence in, and acceptance of, test results from recognized laboratories. All equipment suppliers that participate in the P25 CAP must use recognized laboratories to conduct performance, conformance, and interoperability tests on their products. P25 equipment suppliers will release summary test reports from recognized labs along with declarations of compliance. This documentation will serve to increase the public's confidence in the performance, conformance, and interoperability of P25 equipment.

Performance, conformance, and interoperability issues are likely to occur in all communications technologies and especially in those like P25 with protocols that constantly adapt to changing user requirements. Such problems should be resolved within the P25 CAP, and notably, before product launch and deployment. Further, the declaration of compliance-related documents developed by program participants will provide useful technical information about the equipment.

P25 CAP will provide more than 50,000 emergency response agencies nationwide with a consistent and tractable perspective of P25 product compliance. It will also provide a means of verifying that billions of Federal grant dollars are being invested in standardized solutions and equipment that promotes interoperability.

A number of important milestones were reached in FY 2008:

- The P25 CAP Governing Board was created, and several critical requirements documents have been released, including the Testing Requirements, Supplier's Declaration of Compliance Requirements, and Summary Test Report Requirements. ITS drafted all of the Compliance Assessment Bulletins currently approved.

- The laboratory assessment process was begun in 2008, where ITS provides subject matter experts for the process, as well as leadership in the form of the P25 CAP Deputy Laboratory Program Manager.

- ITS continues to work within the standards development process of TIA to ensure timely release of standards that directly impact the P25 CAP, namely test standards for the Common Air Interface and the Inter-RF Sub-System Interface.

- ITS assisted in developing Federal grant guidance language for DHS that affects how Federal grant money is used by state and local public safety in the purchase of communications equipment.

Cover of the NIST Handbook drafted by NIST/OLES and ITS.

In short, the P25 Compliance Assessment Program:

- Was mandated by Congress in legislation.[1]

- Is a cost effective solution. ITS is supporting OLES/DHS in their effort to recognize existing independent laboratories to conduct the testing rather than building a large centralized facility.

- Is a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements.

- Is a partnership of ITS, DHS OIC, NIST/OLES, industry, and the emergency response community.

- Was launched in 2008, with the assessments of labs to begin in late 2008.

- Is an example of government making a minimal investment that catalyzes industry and the community it serves to develop a solution that will affect billions of dollars in purchases.

1 House Report 109-241 – "Making Appropriations for the Department of Homeland Security for the Fiscal Year Ending September 30, 2006, and for Other Purposes."

Senate Report 109-088 – "Department of Commerce and Justice, Science, and Related Agencies Appropriations Bill, 2006"

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Public Safety Audio Quality

Outputs

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

When a public safety practitioner's life is in danger, the ability to call for help, to warn others, to communicate, is essential. However, some background noises encountered in the public safety environment, such as sirens, chainsaws, and personal alert safety systems (PASS), can interfere with digital communication. Sometimes this interference is so severe that it can prevent a practitioner and the person talking with him or her from understanding each other at the most critical moments. To understand how background noise affects voice communications and to determine what technology improvements are needed to overcome any background noise issues, ITS and its program sponsors (the National Institute of Standards and Technology/Office of Law Enforcement Standards, the Department of Homeland Security/Office of Interoperability and Compatibility and the Office of Emergency Communications) have worked with practitioners to develop and implement tests that measure how digital radios operate in the presence of loud background noise.

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

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

The high-quality digital recordings are used to reproduce real-life sound levels inside a sound-attenuated chamber which contains an ITU-Standard Head and Torso Simulator (HATS) (Figure 1). The HATS has a calibrated speaker representing the mouth and calibrated microphones representing each ear. Using these capabilities, the HATS can be used to simulate a conversation in any noise environment for which a recording exists. Utilizing a pair of these chambers containing HATS enables both halves of a conversation to be simulated and recorded for later analysis or playback to a subjective listener panel.

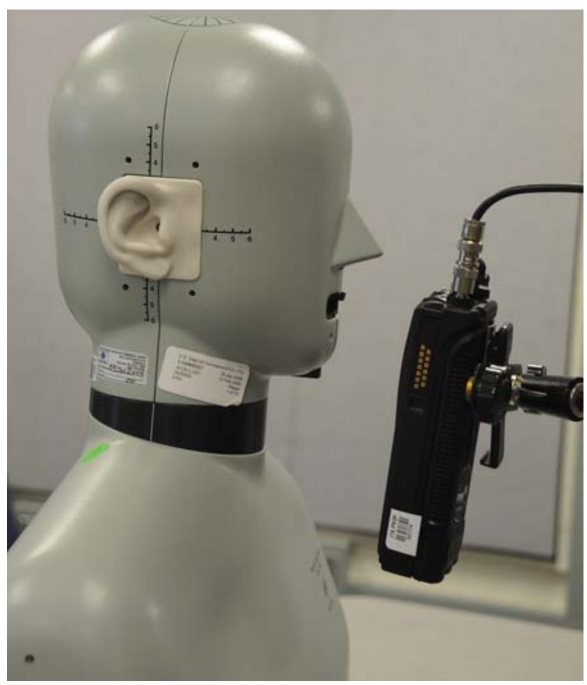

Figure 1. A Head and Torso Simulator (HATS) "talks" to a digital radio. The signal is transmitted to a companion HATS that "listens," enabling recording for later analysis or playback to a subjective listening panel.

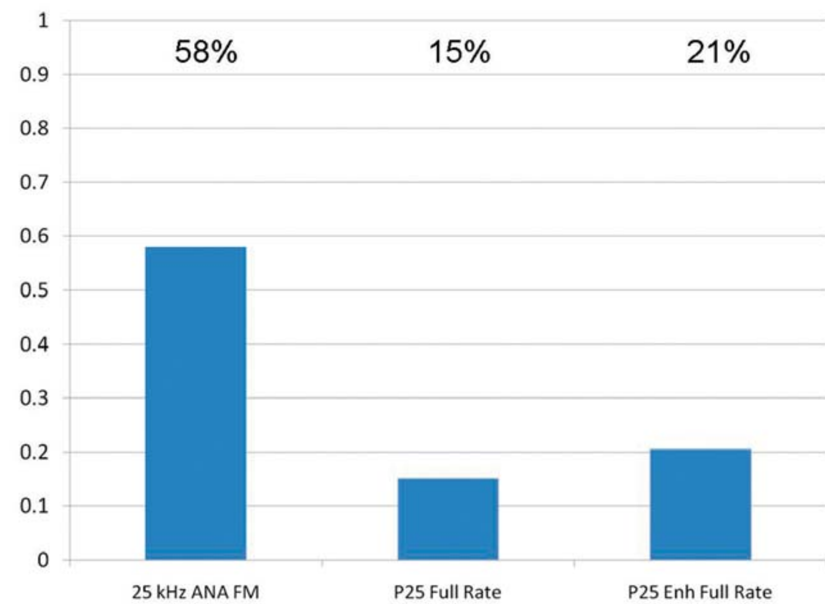

Figure 2. The biggest observed difference in intelligibility scores for radio systems (25 kHz analog (ANA) FM, Project 25 Full Rate, and Project 25 Enhanced Full Rate) was in the presence of PASS noise.

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

The results showed that there were some conditions where analog radios performed significantly better than digital radios. Some of the IAFC recommended best practices included:

- Train all personnel to properly use the assigned radio equipment in conjunction with all components of the protective ensemble.
- Fire departments should be actively involved in the design and development of requirements for any communication-system implementation from the beginning.
- Incident commanders should evaluate background noise in the environment as a safety consideration in task assignments. Additional personnel may need to be assigned to a task to ensure communication capability when there are high levels of background noise in the environment.
- System managers and users should work with their vendors to ensure that their radios and accessories are compatible and configured with the optimal system settings to maximize audio intelligibility in high-noise environments.

In FY 2009 the project will focus on identification of strategies and technologies that can improve the intelligibility of digital radio systems in the presence of loud background noises (Figure 2). The work will continue to involve the IAFC and the Project 25 communities.

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1 Atkinson, D. and A. Catellier, "Intelligibility of selected radio systems in the presence of fireground noise: Test plan and results," NTIA Technical Report TR-08-453, Jun. 2008. http://www.its.bldrdoc.gov/pub/ntia-rpt/08-453/

2 IAFC Digital Problem Working Group, Interim Report and Recommendations: Fireground Noise and Digital Radio Transmissions, International Association of Fire Chiefs, Jun. 2008. http://www.iafc.org/digitalproject/

Public Safety Interoperability Test Tools

Outputs

- An ISSI reference implementation.
- Software capable of conformance testing the ISSI protocol.

The importance of the Project 25 (P25) suite of standards has been conveyed by Congress through several pieces of recent legislation. With Congress providing grants to local, State, and Federal government for the acquisition of public safety telecommunications equipment, the suite of P25 standards is necessary to ensure interoperability among different levels of government. The Inter-RF Sub-System Interface (ISSI), one of seven P25 interfaces, has top priority for completion. ISSI can be thought of as a network protocol that can utilize a standard network interface card. The intent is for this interface to be present in future deployments of P25 Radio Frequency Sub-Systems (RFSS). When the ISSIs of various RFSSs are interconnected, IP packets that contain encoded voice can be transmitted and received. The ISSI is important to public safety agencies because it will foster competition among RFSS manufacturers. Over time, this increased competition should drive down costs. An ISSI interface also promotes interoperability between RFSS manufacturers, allowing a consumer to implement a P25 network of RFSSs from multiple vendors.

Testing the ISSI Interface

A balloted scope one version of the P25 ISSI Messages and Procedures for Voice Services (TIA-102.BACA) specification was released in August 2006. A formal published version of the ISSI conformance test document is expected in late 2008. These tests will verify that the vendor implementation under test conforms at a message level to what has been specified in TIA-102.BACA.

To verify objectively that a vendor conforms to TIA-102.BACA, a reference implementation of the ISSI protocol stack has been developed, the ISSI Test Tools (ITT). ITS developed this software in conjunction with the National Institute of Standards and Technology (NIST). Since ITT is implemented in Java, the software can be loaded on a desktop PC with a Linux or Windows operating system. A single instance of ITT can emulate one of four different roles in a P25 ISSI-based network: (1) calling serving RFSS, (2) calling home RFSS, (3) called home RFSS, and (4) called serving RFSS. ITT will be placed in a test configuration, as defined in the conformance test document, which will fulfill one of the four roles depending on the test case under consideration. The number of vendor RFSSs and roles may vary depending on the test case requirements.

When attempting to determine a particular vendor's conformance, the preferred configuration is to test in isolation the ISSI of the vendor's RFSS. This scenario implies that there is only one vendor RFSS with a real ISSI and the rest of the ISSI interfaces are emulated by ITT. An example of this test architecture is shown in Figure 1. The number of emulated ISSIs and the role of the emulated interfaces will vary depending on the test case under consideration.

Since ITT cannot emulate the P25 common air interface, the behaviors of (or events generated by) subscriber units are emulated in the ITT software. From the ITT graphical user interface (GUI), the user selects a conformance test case to execute. Figure 2 shows the layout of the ITT GUI. After the test case has been executed, the user can view the session initiation protocol (SIP) and real-time transport protocol (RTP) Push-to-Talk (PTT) messages exchanged between ISSIs in a graphical message sequence chart (MSC). Upon completion of test case execution,

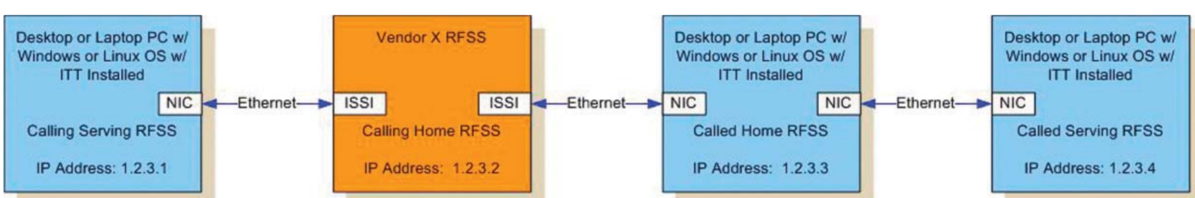

Figure 1: Test architecture with three instances of ITT. Note that IP addresses are for example purposes only.

ITT declares either pass or fail. Figure 3 illustrates the SIP MSC generated as a result of executing test case 9.1.1 — Unconfirmed Group Call Successful. Raw IP packet data can be rendered by clicking on the message of interest in the MSC. ITT has a packet processing capability that will render an MSC based on the Ethereal packet capture (PCAP) file that is fed in for processing. Wireshark (formerly Ethereal) is used to capture packets off the wire and save the captured packets in the PCAP file.

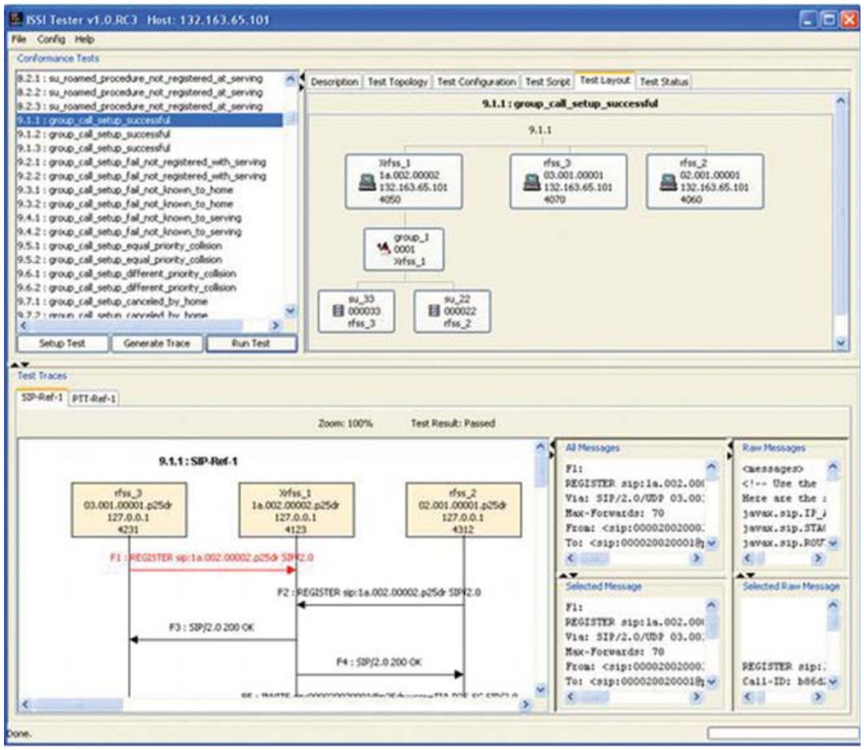

Figure 2. ITT conformance test tool GUI.

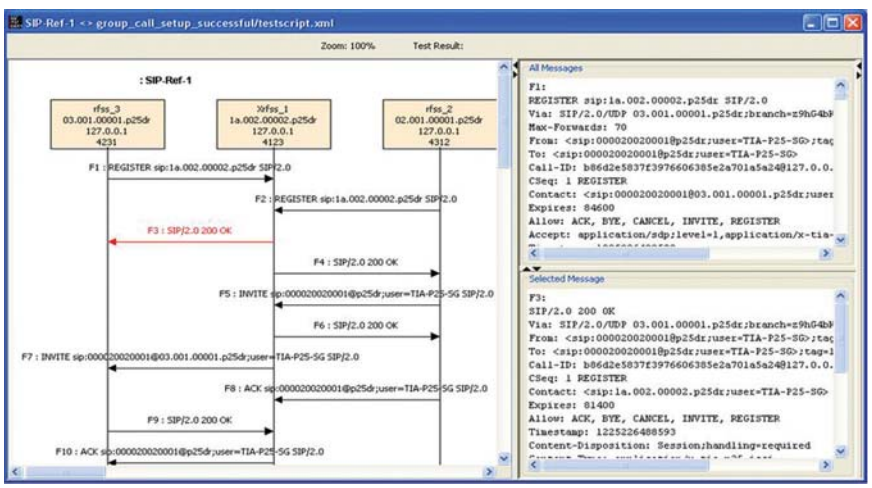

Figure 3. SIP MSC for Unconfirmed Group Call Successful.

Other Project 25 Wireline Test Tools

ITT is being expanded to test two other wireline interfaces: the Fixed Station Interface (FSI) and the P25 Trunked Console Sub-System Interface (CSSI). The FSI standard, TIA-102. BAHA, was published in 2006. The CSSI was published in April 2007 and is an addendum to TIA-102. BACA.

The purpose of the FSI is to enable connectivity of a fixed station (i.e., base station) to an RFSS. It can be thought of as a protocol stack. The intent of the FSI is to allow interoperability between conventional fixed stations and RFSSs. The purpose of the CSSI is to enable the connectivity of a dispatcher's console to an RFSS. The CSSI is very similar to the ISSI. The conformance test document TIA-102.CADA for the FSI has been published. The conformance test case development for the CSSI may begin at the end of 2008.

In addition to expanding ITT's capability to test additional P25 interfaces, ITT is also being expanded to test the performance of the ISSI according to the Project 25 ISSI Measurement Methods for Voice Services standard. This is scheduled for completion by early 2009.

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Emergency Telecommunications Service (ETS) Standards Development

Outputs

- Technical contributions to ATIS Technical Committee PRQC.
- Technical contributions to ITU-T Study Group 9.

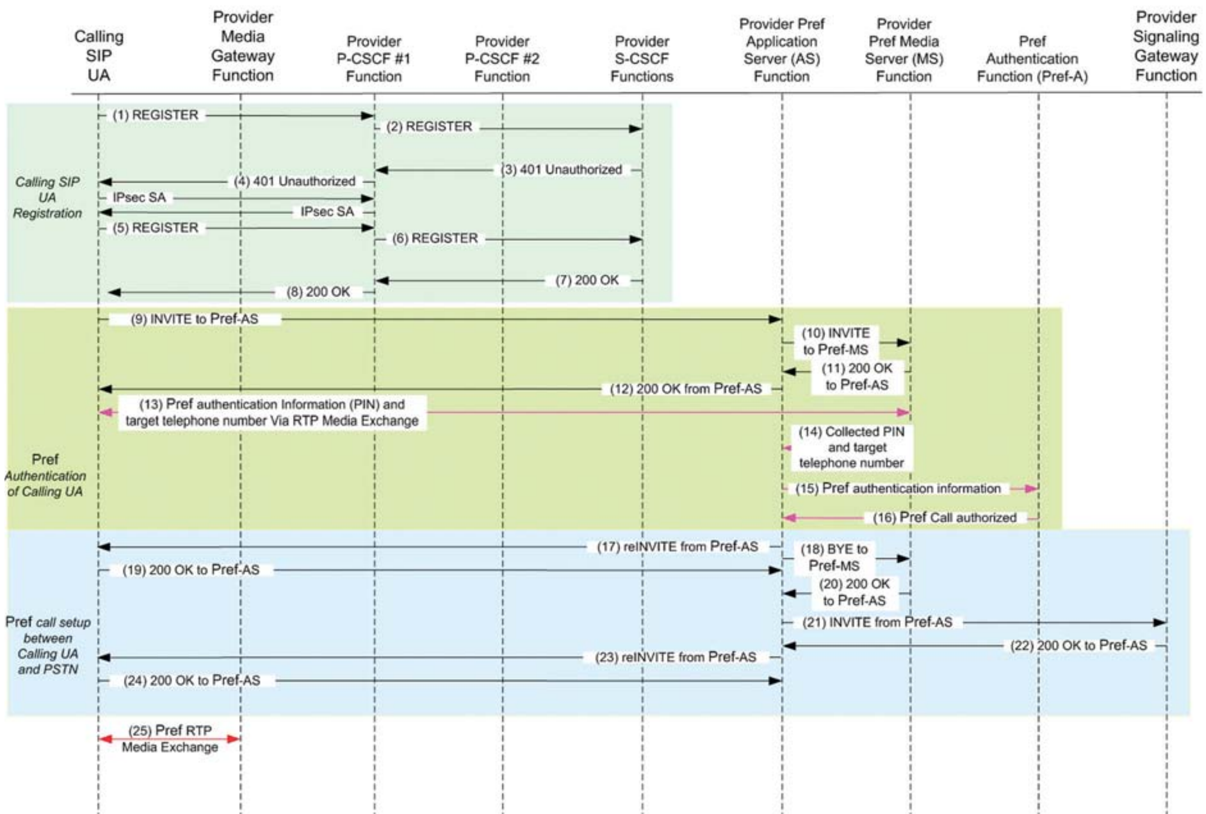
In the aftermath of the 2001 terrorist attacks, the Federal Government has become very interested in priority treatment for emergency communications. While the Government Emergency Telecommunications Service (GETS) has served emergency workers well for many years, it has been limited to the Public Switched Telephone Network (PSTN) in the United States. The Emergency Telecommunications Service (ETS) is envisioned as a GETS-like service that will be available internationally and encompass virtually all wireless and wireline communications networks. Types of traffic to be carried include voice, video, database access, text messaging, e-mail, FTP, and web-based services.

The ETS Standards Development project conducts laboratory studies, requirements and specification development, and security analyses to further the approval of standards supporting National Security/Emergency Preparedness (NS/EP) and Critical Infrastructure Protection (CIP) initiatives. This project is funded by the National Communications System (NCS) — a part of the Department of Homeland Security (DHS). The work supports NCS in its mission to protect the national security telecommunications infrastructure, and to ensure the responsiveness and availability of essential telecommunications during a crisis.

The ETS Standards Development project provides contributions to three standards development organizations. These are the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) Study Group (SG) 9 and two American National Standards Institute (ANSI)-accredited groups: the Alliance for Telecommunications Industry Solutions (ATIS)'s Performance, Reliability, and Quality of Service Committee (PRQC), and the Society of Cable Telecommunications Engineers (SCTE). ITU-T SG 9 is the Lead Study Group, internationally, on integrated broadband cable and television networks and the SCTE produces North American Standards for the cable industry. PRQC works in the areas of Quality of Service (QoS), Reliability, and User-Plane Security, and produces North American Standards. In SG 9, ITS develops and verifies Recommendations to support preferential telecommunications services and user authentication. One major goal of this project is to ensure that future ETS mechanisms and the current GETS service will interoperate over broadband cable television networks in their delivery of voice, data, and multimedia communications.

In PRQC, ITS provides ETS expertise relating to priority support and network security. During FY 2008, an ITS engineer served as co-editor of several ANSI and ATIS Standards and Technical Reports. These provide guidelines, specifications, and requirements for aspects of ETS communications and network and computer security. An ITS engineer served as the Chair of PRQC's Security Task Force where he leads security standardization for the Network User Plane.

The standardization work in ITU-T SG 9 is focused on the IPCablecom and IPCablecom2 families of Recommendations. These Recommendations define the protocols and signaling to be used on broadband cable television networks to support telephony, multimedia, and Internet access. The IPCablecom Recommendations have been standardized in ITU-T SG 9, and equipment implementing them is currently in production worldwide. IPCablecom2 has recently been approved and equipment will be deployed in the coming years. One goal of this project is to identify where additions or changes might be needed to support GETS-like capabilities. This effort also involves work with the Internet Engineering Task Force (IETF), since many of the underlying protocols used in IPCablecom2 (as well as some of the ETS mechanisms) are under development in the IETF. An ITS engineer served as editor and principal author of ITU-T Recommendation J.260, "Requirements for preferential telecommunications over IPCablecom networks," in SG 9. An ITS engineer also serves as the editor of three Draft new ITU-T Recommendations:



VoIP preferential treatment using PIN authentication message flow.

- J.preffr, "Framework for implementing preferential telecommunications in IPCablecom networks,"
- J.prefa2, "Specifications for authentication in preferential telecommunications over IPCablecom2 networks," and
- J.prefp2, "Specifications for priority in preferential telecommunications over IPCablecom2 networks."

J.preffr will provide a framework for standardizing preferential services and priority user-authentication in cable networks. J.prefa2 and J.prefp2 will provide specifications for IPCablecom2 networks that satisfy the requirements set forth in J.260.

The figure, from J.prefa2, shows a call flow diagram indicating how a VoIP Preferential Call (e.g., an ETS call) would be established on an IPCablecom2 network connecting to a PSTN gateway using a PIN for authentication.

In FY 2009, ITS will continue to work on the development and standardization of ETS in ATIS PRQC, SCTE, and ITU-T SG 9. The project will address technologies in the NGN and interactions with the IPCablecom and IPCablecom2 networks. This work on ETS must of necessity be conducted with the help of representatives from network providers and cable television equipment manufacturers, as well as NCS. The work in FY 2009 will focus on priority and security in the NGN ETS as well as GETS and ETS specifications in the IPCablecom and IPCablecom2 networks.

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Railroad Telecommunication Study

Outputs

- Assistance to the Association of American Railroads' frequency management office in developing a narrowband VHF channel plan and wideband-to-narrowband migration strategy for U.S. railroads.

The Federal Communications Commission's (FCC) Third Report and Order[1] mandated that all private land mobile radio (PLMR) users shall use narrowband radio transmissions by January 1, 2013. The U.S. railroad industry had already begun implementing fleet-wide migration strategies to transition all of their 25-kHz bandwidth radio equipment to 12.5-kHz bandwidth-capable equipment.

A subsequently issued FCC communiqué[2] urged the PLMR community to consider directly migrating from 25-kHz bandwidth wideband (WB) architectures to 6.25-kHz bandwidth "very narrowband" ("VNB") architectures, and bypass migration to 12.5 kHz bandwidth narrowband (NB) architectures altogether. Migration to VNB equipment offers opportunities to deploy technically superior solutions and creates additional spectral capacity. However, 6.25-kHz bandwidths mandate a digital radio implementation, as analog FM is just not feasible at such very narrow bandwidths. This presented unique challenges in devising a plan that would accommodate a direct migration to VNB in tandem with a two-step migration policy, from WB to NB to VNB, as had already been embarked upon by some railroads.

Since the Federal Railroad Administration (FRA) oversees railroad safety in the United States, and since PLMR communications is an integral element of ensuring railroad safety, the FRA asked ITS to monitor the activities of the Association of American Railroads (AAR) and to provide technical guidance where and when appropriate, as the AAR implemented the FCC's mandates.

The AAR, familiar with ITS' earlier work related to the analysis of a 1999 railroad channel plan realignment proposal,[3] asked ITS to collaborate with their railroad frequency management office to develop a new VHF channel plan. This jointly developed plan exhibits the following characteristics:

- Complies with current FCC direction to migrate to 12.5-kHz bandwidth equipment.
- Facilitates eventual migration to 6.25-kHz bandwidth equipment.
- Includes 24-kbps data channels.[4]
- Encourages the use of trunking technology.
- Facilitates mixed use of conventional repeaters or simplex usage as secondary users on trunked channel allocations.
- Facilitates mixed use of simplex (peer-to-peer) voice channels as secondary users on data channel allocations.
- Retains frequency sharing agreements with Canadian Railroads along the northern US border.

The figure shows a diagram of the band plan. Channel numbers use different numbering format schema to differentiate between the types of modulation and bandwidths (example: channel 008 is a narrowband analog channel at 160.23 MHz, while channel 08 is a wideband analog channel at 160.23 MHz).

For non-trunked repeater or trunking system use, "like" channels are grouped for use within a geographic region or trunking system. For example, the set of yellow color-coded paired frequencies in the figure could belong to a single trunking system or to a regional collection of non-trunked stand-alone repeaters (for example, 160.215 MHz paired with 161.055 MHz plus 160.305 MHz paired with 161.145 MHz, and so on). These color-coded frequencies (yellow, orange, green, etc.), although

1 Federal Communications Commission Third Report and Order in Docket No. WT 99-87, FCC 07-39, released March 26, 2007.

2 Federal Communications Commission Fourth Memorandum Opinion and Order in Docket No. WT-99-87, FCC 08-127, released May 13, 2008.

3 J.M. Vanderau and E.J. Haakinson, "An evaluation of the proposed railroad VHF band channel plan," NTIA Report 99-370, Sep. 1999.

4 The AAR has awarded a research and development contract to private industry to develop an integrated voice plus data radio to support their anticipated data needs for train control and mobile office applications and interoperate with VNB digital voice.

Channel Plan with 25 kHz, 12.5 kHz and 6.25 kHz Numbering Schemes

Base Transmit / Mobile Receive

Channel Number 25 kHz	12.5 kHz	6.25 kHz	Freq.
	104	302	160.1775
05	005	303	160.1850
	105	304	160.1925
06	006	305	160.2000
	106	306	160.2075
07	007	307	160.2150
	107	308	160.2225
08	008	309	160.2300
	108	310	160.2375
09	009	311	160.2450
	109	312	160.2525
10	010	313	160.2600
	110	314	160.2675
11	011	315	160.2750
	111	316	160.2825
12	012	317	160.2900
	112	318	160.2975
13	013	319	160.3050
	113	320	160.3125
14	014	321	160.3200
	114	322	160.3275
15	015	323	160.3350
	115	324	160.3425
16	016	325	160.3500
	116	326	160.3575
17	017	327	160.3650
	117	328	160.3725
18	018	329	160.3800
	118	330	160.3875
19	019	331	160.3950
	119	332	160.4025
20	020	333	160.4100
	120	334	160.4175
21	021	335	160.4250
	121	336	160.4325
22	022	337	160.4400
	122	338	160.4475
23	023	339	160.4550
	123	340	160.4625
24	024	341	160.4700
	124	342	160.4775
25	025	343	160.4850
	125	344	160.4925
26	026	345	160.5000
	126	346	160.5075
27	027	347	160.5150
	127	348	160.5225
28	028	349	160.5300
	128	350	160.5375
29	029	351	160.5450
	129	352	160.5525
30	030	353	160.5600
	130	354	160.5675
31	031	355	160.5750
	131	356	160.5825
32	032	357	160.5900
	132	358	160.5975
33	033	359	160.6050
	133	360	160.6125
34	034	361	160.6200
	134	362	160.6275
35	035	363	160.6350
	135	364	160.6425
36	036	365	160.6500
	136	366	160.6575
37	037	367	160.6650
	137	368	160.6725
38	038	369	160.6800
	138	370	160.6875
39	039	371	160.6950
	139	372	160.7025
40	040	373	160.7100
	140	374	160.7175
41	041	375	160.7250
	141	376	160.7325

Integrated Voice plus Data Radio

Channel Number 25 kHz	12.5 kHz	6.25 kHz	Freq.
42	042	377	160.7400
	142	378	160.7475
43	043	379	160.7550
	143	380	160.7625
44	044	381	160.7700
	144	382	160.7775
45	045	383	160.7850
	145	384	160.7925
46	046	385	160.8000
	146	386	160.8075
47	047	387	160.8150
	147	388	160.8225
48	048	389	160.8300
	148	390	160.8375
49	049	391	160.8450
	149	392	160.8525
50	050	393	160.8600
	150	394	160.8675
51	051	395	160.8750
	151	396	160.8825
52	052	397	160.8900
	152	398	160.8975
53	053	399	160.9050
	153	400	160.9125
54	054	401	160.9200
	154	402	160.9275
55	055	403	160.9350
	155	404	160.9425
56	056	405	160.9500
	156	406	160.9575
57	057	407	160.9650
	157	408	160.9725
58	058	409	160.9800
	158	410	160.9875
59	059	411	160.9950
	159	412	161.0025
60	060	413	161.0100
	160	414	161.0175
61	061	415	161.0250
	161	416	161.0325
62	062	417	161.0400
	162	418	161.0475

Mobile Transmit / Base Receive

Channel Number 25 kHz	12.5 kHz	6.25 kHz	Freq.
63	063	419	161.0550
	163	420	161.0625
64	064	421	161.0700
	164	422	161.0775
65	065	423	161.0850
	165	424	161.0925
66	066	425	161.1000
	166	426	161.1075
67	067	427	161.1150
	167	428	161.1225
68	068	429	161.1300
	168	430	161.1375
69	069	431	161.1450
	169	432	161.1525
70	070	433	161.1600
	170	434	161.1675
71	071	435	161.1750
	171	436	161.1825
72	072	437	161.1900
	172	438	161.1975
73	073	439	161.2050
	173	440	161.2125
74	074	441	161.2200
	174	442	161.2275
75	075	443	161.2350
	175	444	161.2425
76	076	445	161.2500
	176	446	161.2575
77	077	447	161.2650
	177	448	161.2725
78	078	449	161.2800
	178	450	161.2875
79	079	451	161.2950
	179	452	161.3025
80	080	453	161.3100
	180	454	161.3175
81	081	455	161.3250
	181	456	161.3325
82	082	457	161.3400
	182	458	161.3475
83	083	459	161.3550
	183	460	161.3625
84	084	461	161.3700
	184	462	161.3775
85	085	463	161.3850
	185	464	161.3925
86	086	465	161.4000
	186	466	161.4075
87	087	467	161.4150
	187	468	161.4225
88	088	469	161.4300
	188	470	161.4375
89	089	471	161.4450
	189	472	161.4525
90	090	473	161.4600
	190	474	161.4675
91	091	475	161.4750
	191	476	161.4825
92	092	477	161.4900
	192	478	161.4975
93	093	479	161.5050
	193	480	161.5125
94	094	481	161.5200
	194	482	161.5275
95	095	483	161.5350
	195	484	161.5425
96	096	485	161.5500
	196	486	161.5575
97	097	487	161.5650
	197	488	161.5725

Railroad VHF channel plan, 2008.

allocated as primary usage for trunking systems, could be used for conventional repeaters as secondary users, or as simplex channels as tertiary users. White color-coded frequency pairs, such as 160.47 MHz paired with 161.31 MHz, would be reserved for non-trunked repeater use as primary, and simplex channels as secondary.

The frequency range from 160.74 MHz to 161.475 MHz would be reserved for eight 25-kHz wide data channels and two narrowband simplex voice channels.

In the American/Canadian border areas, the turquoise color-coded assignments depicted in the "Freq" columns of the figure (and their corresponding channel numbers) are reserved for use on the United States side of the border, while the pink color-coded assignments are reserved for use on the Canadian side of the border, per an earlier 1960 agreement between the governments of the United States and Canada. The red color-coded assignments (encompassing 160.1775-160.2075 and 161.5725 MHz) are only authorized for railroad use in Canada, not the United States.

This plan is quite flexible in that it promotes an orderly migration to a structured channel plan. Should a geographic region require trunking to alleviate radio traffic congestion, it could implement one or more of the eight 6-channel trunking groups (i.e., the yellow or orange or green, etc., channel groups in the figure). A trunking system, if instituted, would not have to use all six channels allocated to it. Conventional repeaters could be assigned these channels, but as secondary users. If a region implemented trunking or expanded its use of allocated but unused trunking channels, incumbents on those channels would need to either relocate to new channels, or join the trunking system.

A similar methodology would apply to simplex voice users on trunked, repeated, or data channels. As replacement technology would be deployed in a region, incumbents would have to relocate to different channels, or adopt the same technology as used by the primary users on those channels.

This plan supports a direct migration from WB equipment to VNB digital equipment in tandem with a two-step migration path with an intermediate migration to NB equipment.

The AAR adopted this channel plan in August 2008. Its adoption preceded its September 2008 policy statement urging railroads to replace outdated legacy equipment with "tri-mode" (WB, NB, and VNB) capable radio equipment. These tri-mode radios are now available in the commercial marketplace.

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Multimedia Quality Research

Outputs

- Technical contributions to VQEG.
- Technical contributions to ITU-T Study Group 9.

The transmission of audio/video (multimedia) signals over wireline and wireless channels has increased exponentially in the past decade. In particular, the distribution of multimedia signals over wireless links to devices such as laptops, personal digital assistants (PDAs), and cellphones is widespread and the need for quality measurements is great. The widespread use of digital technology for the transmission of audio and video signals has led to the need for new objective quality assessment methods based on human perception. ITS has a long history of successful research in the areas of voice and video quality assessment. Until recently, however, the development of an objective measure of overall multimedia quality has not been adequately addressed.

Multimedia is defined here as the combination of audio and video in the communication of information. The objective of the ITS Multimedia Quality Research project is to characterize and analyze the fundamental aspects of multimedia quality assessment. A primary goal of this research is to develop an algorithmic system to objectively assess multimedia quality by combining audio quality, video quality, and audiovisual synchronization information.

In FY 2008, ITS conducted two subjective experiments to advance this work. The first experiment utilized video at CIF resolution (Common Intermediate Format: 352 by 288, square pixels) compressed at several bit rates and accompanying audio also compressed at several bit rates. These audiovisual signals were combined in a full matrix design to facilitate data analysis. Figure 1 shows the average quality of the multimedia sequence for a given condition. In this test the data indicate that the video quality was more important to the viewer than the audio quality. Further tests with different levels of quality will need to be undertaken before we can know how to fully interpret these results.

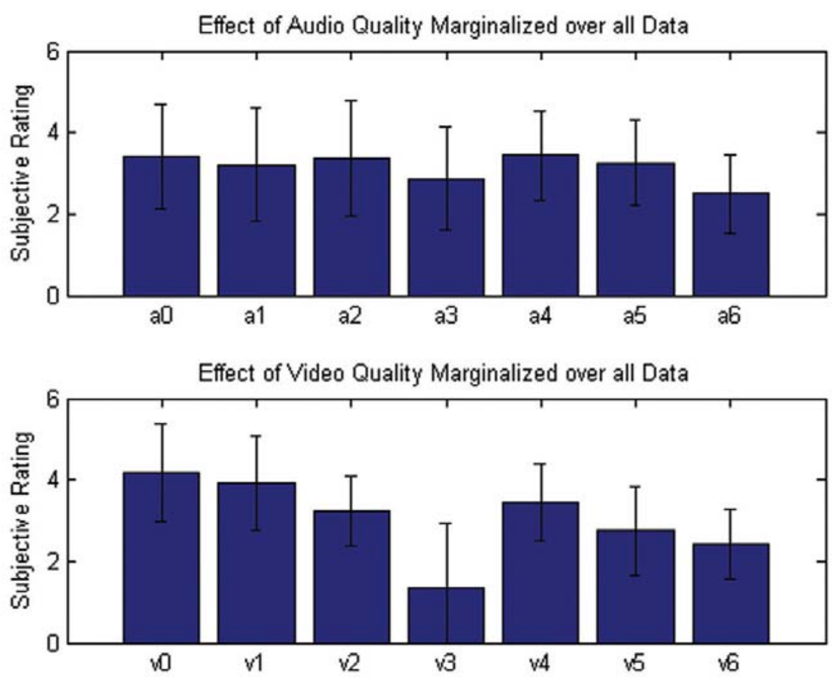

Figure 1. Effect of audio and video quality on overall multimedia quality.

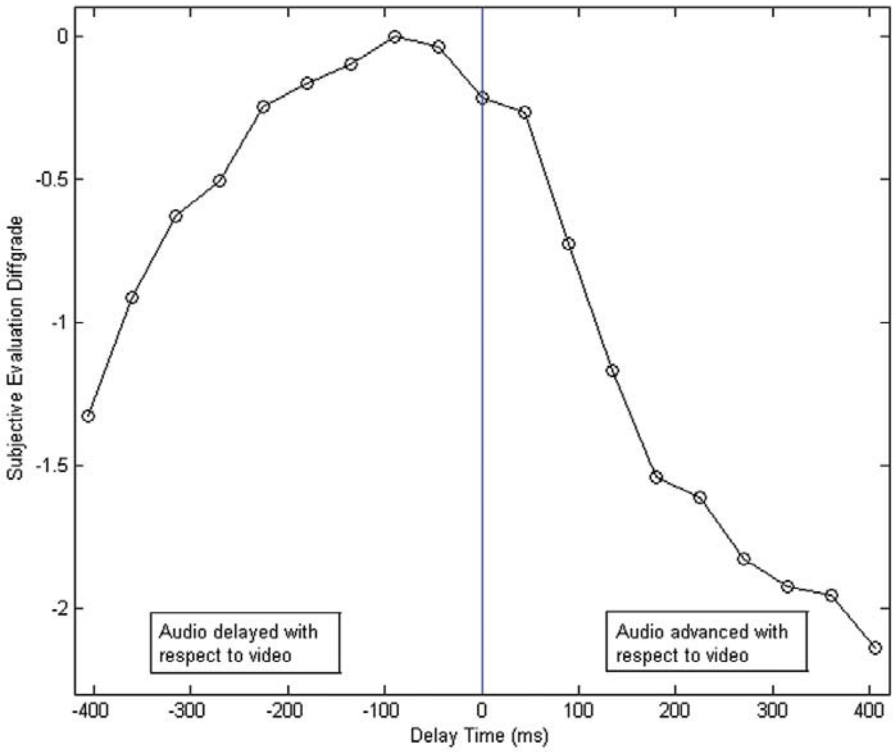

Figure 2. Effect of audio and video desynchronization on overall multimedia quality.

A second multimedia subjective test was begun to quantify the effect of audio and video desynchronization on the quality as perceived by the viewer/listener. Figure 2 shows a plot of the preliminary results of this second experiment — the subjective quality versus the amount of desynchronization between the audio and video signals. Note that the perceived quality degradation is not symmetric about zero desynchronization (delay time). These results are consistent with other tests conducted in the field.

Subjective testing plays an important part in ITS efforts to develop voice and video quality assessment methods. For multimedia research, subjective testing is no less important. Objective quality assessments are based on data derived from subjective quality experiments. A series of multimedia subjective tests will be executed to explore the relationships between the quality parameters for audio, video, and audiovisual synchronization. This will provide the data needed for the development of an integration function that will estimate the overall audiovisual quality from measurements of audio quality, video quality, and audiovisual synchronization.

This work is being done in conjunction with projects underway in the Video Quality Experts Group (VQEG) and the ITU-T Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA). The JRG-MMQA is an official body of the International Telecommunication Union and is formed from members of ITU-T Study Groups 9 and 12.

In FY 2009 this project will continue to develop tools and conduct research into the Hybrid Perceptual/Bitstream models in conjunction with projects in progress in VQEG and the JRG-MMQA. ITS will continue to work on the development of a multimedia quality assessment model. Additional tests measuring the effects of audio/video desynchronization will be completed in FY 2009. HDTV audiovisual tests will be performed to explore the effects high resolution video has on multimedia quality.

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Wireless Network Measurement Methods

Outputs

- SDR test instrument technologies.
- Wireless channel measurement techniques for high speed data networks.

Broadband wireless data systems incorporate significantly greater operational mode complexity than legacy voice systems. In analog voice radio systems, a continuous signal is transmitted, and reception often depends primarily upon the amount of signal power available to the receiving device and the noise power that the system must overcome at the receiving site. Relatively simple power-versus-frequency measurement methods suffice to determine the availability and quality of received signals.

By contrast, digitally modulated wireless data systems utilize higher system complexity to achieve higher capacity in the radio channel. The digital modulation itself is a case in point. Sampled digital RF modulation techniques quantize the signal in time as well as in some other parameter – frequency shift, phase, amplitude, etc. The time quantization leads to synchronicity issues. A receiver must ensure that it is synchronized at the RF level, often in both frequency and phase, as well as at the symbol level, i.e., the receiver carries precise information about the start and end time of a symbol. Loss of synchronicity at either level results in signal errors whose cause may be difficult to characterize.

Modern technologies like Wi-Fi, WiMAX, and LTE (Long Term Evolution) also embody a notion of rate-adaptive error correction and modulation. These devices change their error correction strength and modulation methods on the fly based on sensed information about the current conditions of the radio channel. In general, this includes the concept of closed loop control – messaging passing between mobile nodes and the base station that provides information about the local radio environment.

In turn, control messages imply control protocols. Systems of this type rely on proper adherence to well specified protocols for control and messaging. These systems are often said to be “stateful” — they have precisely defined states that respond only to certain messages. Messages that are correct in content but incorrectly sequenced will cause network failure, as will incorrect or incorrectly formatted messages.

All of these different mechanisms lead to a much broader error tree for current wireless networks than has been the case in the past. At the physical layer, historical concepts of signal power and signal to noise thresholds still apply. However, digital modulations create possible failure modes due to channel timing constraints that lead to intersymbol interference and excessive transmission retries, as well as errors in receive timing synchronization at either the RF carrier or the symbol level. The closed loop nature of current networks as well as their stateful nature means that errors may stem from confusion about modulation type or error correction level. Finally, protocol errors may cause system failure if messages are incorrectly formed or exceed timeout thresholds, or if optional proprietary parameters are included in messages meant for devices from the same manufacturer that are instead received by different manufacturers’ systems.

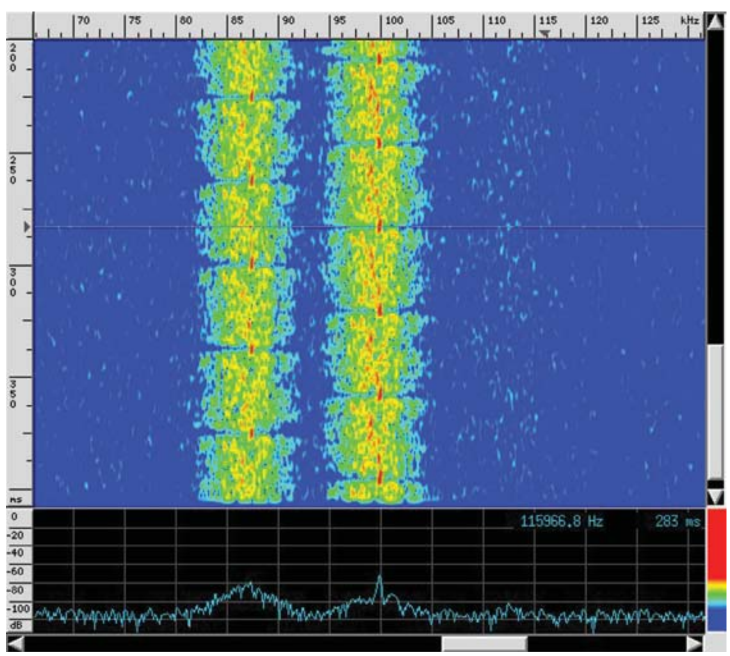

Figure 1. Spectrogram of SDR P-25 trunking control channel capture.

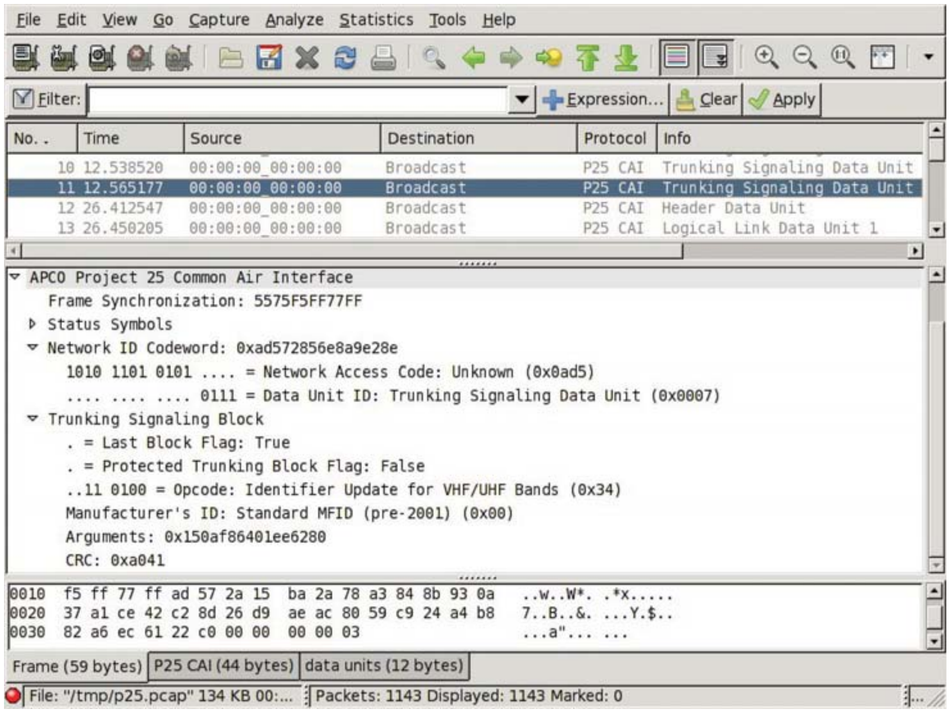

Figure 2. Network trace from P-25 trunking control channel.

This complex testing environment makes great demands on test instruments. In many cases the testing device can no longer be a passive receiver, but must respond with correct protocol and control information to bring the system under test into the desired state for the test to proceed. In other instances, the test instrument must intentionally provide incorrect responses to the target system, to determine if error sensing algorithms in the system under test are operating correctly.

Software defined radio (SDR) systems offer a possible solution to the demands of this complex testing regime. They typically allow a high degree of configuration flexibility, and some current development platforms include multiple receivers and transmitters on the same motherboard, allowing software control of transmission and reception on multiple frequencies simultaneously. ITS investigations into test instrumentation capabilities of this technology have demonstrated applicability in multiple tasks, from acting as an RF recorder/retransmitter and spectrum analyzer to potential use as an inexpensive sensor system for MIMO (multiple input multiple output) research. A spectrogram from one experiment using an inexpensive SDR platform is shown in Figure 1.

In this series of experiments, an SDR platform was configured as an APCO Project 25 trunked radio control channel receiver. A software plugin with the ability to decode the control message protocol was devised to enable the use of a standard digital network trace tool to evaluate the control messages being sensed by the SDR platform. A screenshot from this operation is shown in Figure 2.

As wireless data systems become more heavily used by multiple Federal and civilian agencies, the ability to rapidly configure specialized test instrumentation for unusual test cases becomes more important. The availability of low cost SDR development platforms that are easily programmed to respond to various radio protocols and offer a high degree of modulation flexibility may be crucial to future work on state of the art high speed data systems. Future systems promise to become even more complex than present technology — the use of low cost SDR based test instrumentation is an important tool to help ensure that Federal wireless systems remain on the cutting edge of the technology.

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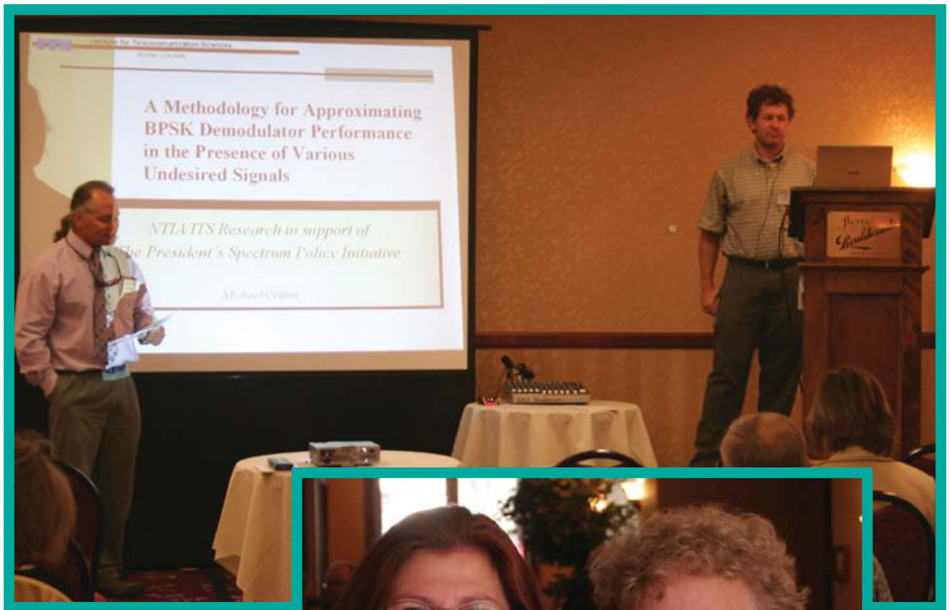

The 10th International Symposium on Advanced Radio Technologies (ISART), Chaired by Patricia Raush, was run in parallel with a meeting of ClimDiff, Co-Chaired by Carol Wilson of CSIRO, Australia, and Merhala Thurai of Colorado State University. ISART and ClimDiff had about 25 and 15 speakers respectively and were held June 2-4, 2008, at the Hotel Boulderado in Boulder, Colorado.

Telecommunications Engineering, Analysis, and Modeling

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

Engineering encompasses technical assessment of telecommunications systems, their components, and their performance, including impact of access, interoperability, timing and synchronization, and susceptibility to noise, jamming, and interfering signals on system effectiveness in national security/emergency preparedness (NS/EP), military, and commercial operational environments.

Analysis is often performed in association with the TA Services project, which offers analytical tools via an on-line cooperative research and development agreement. ITS can customize these tools and analyses for specialized applications. Propagation prediction models are being incorporated into GIS formats and web-based access.

Modeling is one of ITS's core strengths. Propagation models are incorporated with terrain databases and other data. Adaptations of historic models, and those for specialized situations have been developed, enhanced, and compared. ITS engineers contribute to international and national standards bodies, such as ITU-R SG3, 8F, and ATIS WTSC-RAN.

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Areas of Emphasis

ENGINEERING

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

Public Safety Video Quality (PSVQ) The PSVQ project is conducting a series of subjective tests illustrating different types of video compression and artifacts. These are shown to expert viewers and then the data are analyzed and correlated. From this analysis NTIA/ITS has made recommendations for a new video standard based on applications in the public safety arena, Rec. ITU-T P.912. This project is funded by NIST/OLES.

ANALYSIS

Telecommunications Analysis Services The Institute provides network-based access to research results, models, and databases supporting applications in wireless system design and evaluation. These services are available to government and non-government customers and are funded by fee-for-use and fee-for-development charges through an on-line CRADA. ITS is examining migration of TA Services to a web-based system.

Geographic Information System (GIS) Applications The Institute continues to develop a suite of GIS-based applications for propagation modeling and performance prediction studies. This powerful GIS format complements ITS's propagation prediction capabilities nicely. The work is funded by the U.S. Department of Defense.

MODELING

Broadband Wireless Standards The Institute develops radio propagation algorithms and methods to improve spectrum usage of wireless systems. Technical standards are prepared that support U.S. interests in 3G broadband wireless systems and are fed into ITU-R SG 3, WPs 3J, 3K, 3L, 3M. ITS is active in path specific model development in WP 3K and its development of ITU-R Recommendation P.1812. Work is funded by NTIA.

Low and Medium Frequency Propagation Modeling The Institute has developed a unique software model for performance and interference analysis. ITS has integrated this model into a GIS-based application so that the analysis outputs can be be presented with more detailed and illustrative graphics.

Short-Range Mobile-to-Mobile Propagation Model Development and Measurements The Institute is developing a model for short-range (1 m to 2 km) propagation between mobile radios. The propagation work consists of both modeling and field measurements. With a new customized propagation measurement system, field measurements were performed in FY 2008. This project is funded by NTIA/OSM.

Interference Issues Affecting Land-Mobile Systems

Outputs

- Self-interference models for evaluating CMRS technologies and deployment of adjacent-channel systems.
- Technical contributions to industry-supported efforts for predicting, identifying, and mitigating interference related problems.
- Technical support for U.S. involvement in international and national standards development organizations.

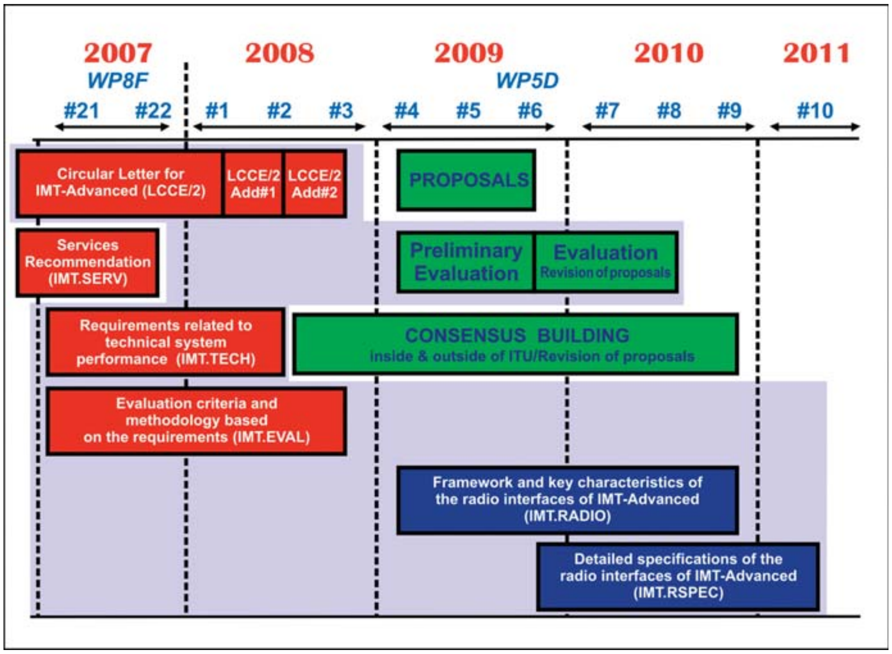
As next-generation commercial communication systems are deployed and future-generation technologies are developed, the demand for additional spectrum increases and the lack of available spectrum becomes an issue. The desire, and need, to implement true universal coverage (worldwide roaming) places different demands on spectrum allocations depending on the geographic and political location of the user and provider. Aside from the commercial uses of spectrum, the increasing needs of civil and Federal users place additional demands on the finite amount of spectrum. Spectrum dedicated to systems supporting emergency responders must be allocated from that already in use. Spectrum sharing by multiple users is necessary to accommodate all proposed and existing systems.

Until the planned, interoperable, communication systems for emergency services are deployed, Commercial Mobile Radio Services (CMRS) will remain an important asset in establishing emergency communications. As a result, wired and wireless communication services will experience usage rates significantly greater than average during emergency situations. This sudden influx of traffic by private, commercial, civil, and Federal users will result in system overloads, a decrease in signal quality, and further disruption of service in affected areas. Beyond the physical damage caused by events, additional factors will contribute to diminished channel capacity of wireless networks, such as co- and adjacent-channel interference and the operation of multiple, independent, non-interoperable systems servicing the same geographical area, often using the same frequency bands and infrastructure (base station sites and towers). One way of coping with damaged or destroyed infrastructure is to deploy temporary equipment to supplement the surviving system. To make efficient use of limited resources, responders need to know what equipment needs to be deployed in which locations. Knowledge of interference issues, system dynamics, and load patterns is key to effective, post-disaster support by national security/emergency preparedness (NS/EP) planners and network operators in an overloaded environment.

ITS is actively applying its expertise in propagation and interference areas through its participation in national and international standards development organizations. ITS contributed to the understanding of inter-PCS interference by participating in the Telecommunications Industry Association (TIA) committee TR46.2 (Mobile & Personal Communications 1800-Network Interfaces). As a member, ITS helped develop the Technical Service Bulletin “Licensed Band PCS Interference” (TSB-84A). This bulletin was a first step in characterizing the interfering environment caused by large numbers of active users and competing technologies. Since the completion of this work, coverage of interference issues concerning all mobile communication systems has been adopted by the Alliance for Telecommunications Industry Solutions (ATIS) subcommittee WTSC-RAN (Wireless/Mobile Standards – Radio Access Networks). Work on the successor to TSB-84A is currently underway as Issue P0017, “Proposed Joint ATIS/TIA Standard on Coexistence and Interference Issues in Land Mobile Systems.” ITS continues to be involved in these activities as issue champion and editor.

Work is being done in the international arena to coordinate worldwide development of future systems; the International Telecommunication Union (ITU) is the lead organization in this effort. ITU Working Party 5D (WP5D) is developing standards and recommending frequency allocations for the group of future technologies referred to as IMT-2000 and IMT-Advanced. Coordinating world-wide frequency allocations is a near-impossible task, given the disparity in the historical evolution of frequency use and requirements in each country. Interference and coexistence issues are a primary concern as more systems try to use the same limited quantity of spectrum on a worldwide basis. ITS supplies technical support involving interference and propagation issues for the U.S. delegation to WP5D.

The increase in the demand for mobile communications capacity requires that limited spectrum



Detailed schedule for the development of the IMT-Advanced process. The shaded area indicates the areas where ITS has been involved in the past and will continue to be involved in the future. (Adapted from the Working Party 5D Chairman's Report, R07-WP5D-C-0327!H02!MSW-E).

resources be shared by different users and utilized as efficiently as possible. Spread spectrum technologies, which make efficient use of allocated spectrum and are relatively unaffected by noise, are used in current cellular systems and will become even more prevalent in next-generation systems. The capacity of these technologies, such as code division multiple access (CDMA), is limited primarily by the number of other users occupying the same frequency band. These legitimate users appear to each other as an increase in the noise floor and are referred to as co-channel interferers. Most automatic power control schemes in spread spectrum systems increase power levels when the level of interference/noise is unacceptable. This increases the interference level for all users of a common frequency band and can cause an exponential effect where all users of the spectrum are operating at maximum power levels and experiencing a diminished Quality of Service (QoS). With the increasing dependence on spread spectrum technology, a clear understanding of the effects of interference is essential to increase the efficiency of spectrum use.

Work in detecting, identifying, and mitigating co-channel interference requires tools to characterize the interference experienced by air-interface signals. An interference model is a tool that can be used to predict levels of interference and identify sources of interference. To improve our understanding of how well spread spectrum systems can tolerate congested environments and how well multiple systems can coexist in the same environment, ITS has developed an interference model capable of implementing two CDMA-based systems: the TIA/EIA-95B standard and W-CDMA (Wideband CDMA). The model produces a representation of an instantaneous air interface signal; this signal contains outputs of multiple base stations with variable numbers of mobile users for each base station and can assign relative power levels for each individual mobile user. Both forward and reverse link processes are included in the model.

This system-specific interference model is used to determine the level of co-channel interference from both immediate and adjacent cells. The model calculates each channel's sampled QPSK or OQPSK signal contribution separately, then sums all signals identified in a specified scenario together to form a composite output signal. The power level for a single channel is a gain factor of the baseband filter and is set separately for each channel. There is no error correction added to the input sequence; only spreading codes and modulation processes are used. Software- and hardware-based simulations can use the sampled signal from the model to evaluate system designs. These simulations can characterize one-on-one, one-on-many, and many-on-one interference. As a result, potential solutions to congestion can be proposed to solve existing problems or to anticipate and avoid potential problems.

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Public Safety Video Quality

Outputs

- Test results from six phases of testing.
- Technical contributions to standards bodies to establish video quality measurements and standards for the public safety community.
- Technical contributions on video quality standards to the sponsor.

Police and fire agencies often purchase radios, cameras, and other communications equipment based on their local needs. Unfortunately, this equipment may not be of high enough quality for certain applications or be able to communicate with other agencies with specific needs. Until recently, there were no technical standards for emergency communications equipment. ITS is conducting audio and video quality research to determine standard parameters for levels of quality of communication systems based on the specific needs of public safety practitioners and their applications. ITS is working on behalf of the Department of Homeland Security (DHS) and the National Institute of Standards and Technology's Office of Law Enforcement Standards (NIST/OLES) to ensure that first-responder video systems communicate clearly and accurately with each other.

The PSVQ project started with a single video quality study, conducted at ITS in December 2005. This test focused on the application of tactical video with a narrow field of view (i.e., the area of video frame of interest, the "target," was relatively large). Over the next two years ITS expanded testing to include four additional study phases:

- Tactical, small target (wide field of view)
- Observed (live) surveillance, large target (narrow field of view)
- Observed (live) surveillance, small target (wide field of view)
- Recorded surveillance, large target (narrow field of view)
- Recorded surveillance, small target (wide field of view)

The resulting recommendations from the studies of these applications are given in Section 4 of the Public Safety Statement of Requirements (PS SoR) Volume II, Versions 1.1 and 1.2.[1,2]

In order to develop useful standards for video quality parameters, accurate measurements for video quality assessment must be employed, usually through subjective data collected from human subject testing. The ITU-T has a series of Recommendations that address methodology for performing subjective tests in a rigorous manner.[3,4] These Recommendations prescribe tests in which subjective viewers are asked to watch video that has been impaired to various degrees. The viewers are then asked to report their perceived quality of the video using a given rating system, usually consisting of a scale (e.g., Excellent, Good, Fair, Poor, Bad). These standard methods are generally targeted at the entertainment application of video, such as broadcast television. However, public safety agencies utilize video to help them perform their jobs, such as security, surveillance, remote command and control, and forensic evidence analysis. These applications fall into the class of video that is used to perform a specific task. The methods developed to assess a person's perceptual opinion of entertainment quality are not appropriate for task-based video. Task-based video is used to recognize objects, people or events. Methods that rely on a viewer's rating of quality may not capture the answer to the underlying question — that is, at what level of impairment does video data become unable to carry the information necessary to make decisions regarding the task at hand.

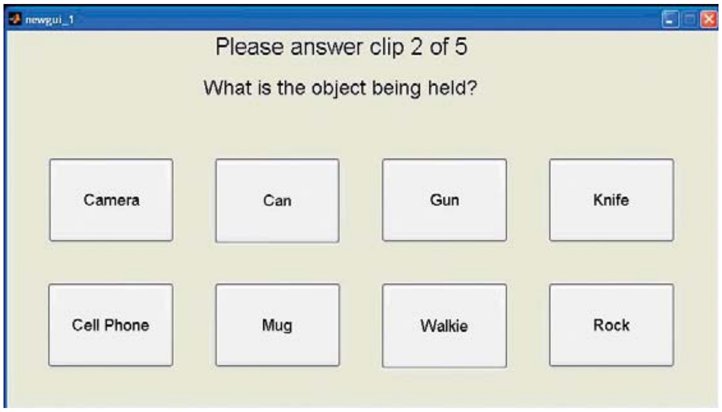
The first series of tests in FY 2007 highlighted a need to develop new quality assessment methods for video used to perform tasks for specific applications.

1 *Public Safety Statement of Requirements for Communications & Interoperability*, Volume II: Quantitative, Version 1.1, Nov. 2007.

2 *Public Safety Statement of Requirements for Communications & Interoperability*, Volume II: Quantitative, Version 1.2, Sep. 2008.

3 ITU-R, 2002. Recommendation BT.500-11. Methodology for subjective assessment of the quality of television pictures. Recommendations of the ITU, Radiocommunication Sector.

4 ITU-T. 1999 September. Recommendation P.910. Subjective video quality assessment methods for multimedia applications. Recommendations of the ITU, Telecommunication Standardization Sector.



An example of a task-based video quality assessment method.

Research was conducted in the area of military target recognition, computer object recognition, and human facial recognition. The results were adapted for development of video quality tests for public safety applications. A new standard was developed for video quality assessment for recognition tasks, and has been adopted by ITU-T Study Group 9 as Recommendation ITU-T P.912.[5]

Two task-based tests were designed for the PSVQ project using this new assessment method. These tests focused on two different application areas — forensic video analysis and live surveillance. Instead of being asked to report an opinion of quality, subjects were asked to perform specific recognition tasks, such as identify an object or read an alpha-numeric sequence. For example, practitioners were asked to watch a video clip and identify the object being held or used by a person, recognize if a certain object appeared in the video, read a license plate, or a read a hazmat sign. The subjective test viewers were experts in their fields of forensics or law enforcement. For the forensic test, the subjects were allowed to pause and replay the video, as they would during the performance of their jobs. The live surveillance test subjects were required to perform recognition tasks in real time. The results of this testing determined the percentage of experts (first responders) able to perform the desired task at a certain video impairment level. The results were categorized by the size of the target (object or alpha-numeric character) of interest. The two task-based tests were the first tests to employ the methods in P.912, and allowed for an evaluation of these methods for future studies.

In February 2009, ITS will host the first annual conference on Video Quality in Public Safety (VQiPS). VQiPS aims to bring together all users of video in the public safety community. The goal is to coordinate efforts in establishing quality requirements for video used in public safety applications.

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5 ITU-T. 2008 August. Recommendation P.912. Subjective video quality assessment methods for recognition tasks. Recommendations of the ITU, Telecommunications Standardization Sector.

Telecommunications Analysis Services

Outputs

- Internet access on a cost reimbursable basis for U.S. industry and Government agencies to the latest ITS engineering models and databases.
- Contributions to the design and evaluation of broadcast, mobile, and radar systems, personal communications services (PCS), and local multipoint distribution systems (LMDS).
- Standardized models and methods of system analysis for comparing competing designs for proposed telecommunication services.
- On-line CRADAs that allow users to task ITS to develop special models or perform special analysis tasks.

Telecommunications Analysis Services (TA Services) gives industry and Government agencies access to the latest ITS research and engineering outputs on a cost reimbursable basis. It uses a series of computer programs designed for users with minimal computer expertise or in-depth knowledge of radio propagation. The services are updated as new data and methodologies are developed by the Institute's engineering and research programs.

TA Services also allows users to work closely with ITS engineering staff to develop small-scale research and development models and programs via the on-line Cooperative Research and Development Agreement (CRADA) options. Users can create task items for a cost of up to $25,000 per CRADA. As new tasks are needed, new CRADAs can be quickly created on the TA Services website.

Some currently available databases and services are: on-line terrain data with 1-arc-second (30m) for CONUS and 3-arc-second (90m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; the U.S. Census data for 2000, and 1990; Federal Communications Commission (FCC) databases; and geographic information systems (GIS) databases (ArcInfo). For more information on available programs, see p. 74 of the Tools and Facilities section or call one of the contacts listed below.

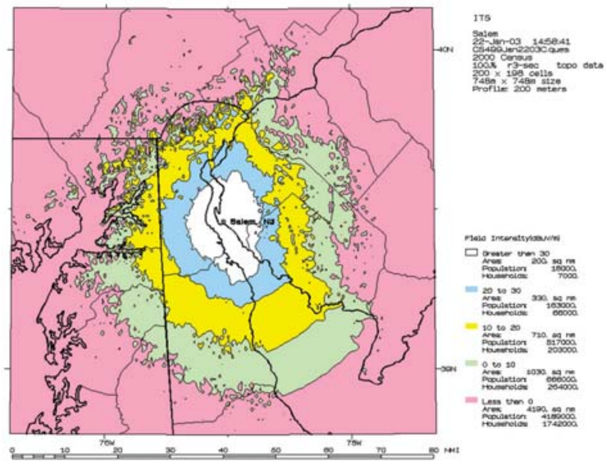

Figure 1. Sample output of the CSPM model of a broadcast transmitter in New Jersey.

Over the past 20 years, TA Services has developed both generic propagation models for a wide variety of applications in many frequency bands and application specific models used for a particular type of analysis such as High Definition Television (HDTV). These models are placed on the TA Services Web access system for use by customers with active accounts on the system. These customers can activate models, enter information about their broadcast equipment and produce a generic transmitter coverage such as that shown in Figure 1 for a typical broadcast application using the Communications System Performance Model

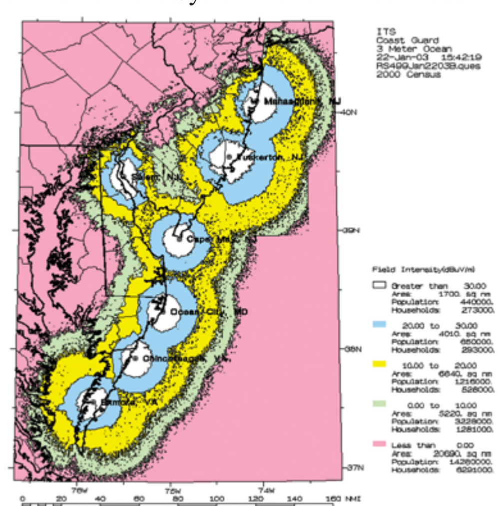

Figure 2. Composite coverage of several Coast Guard Stations located along the east coast.

(CSPM) application program. These coverages follow FCC guidelines and requirements in order to show both the signal coverage and the population that resides within the various analysis contours. Users can also combine many individual transmitter coverages into a composite coverage such as that shown in Figure 2. This allows the user to determine both single transmitter performance and integrated system performance.

TA Services has assisted the broadcast television providers of the U.S. with their transition to digital television (DTV) by providing an application specific model for use in advanced television analysis (high-definition television, advanced television, and digital television). This model allows the user to create scenarios of desired and undesired station mixes. The model maintains a catalog of television stations and advanced television stations from the FCC from which these analyses are made. The results of these studies show those areas of new interference and the population and number of households within those areas so that designers can mitigate possible interference situations before they become a problem. The model can also determine the amount of interference a selected station gives to other stations. This allows the engineer to make modifications to the station and then determine the effect those modifications have on the interference that station gives other surrounding stations. In addition to creating graphical plots of signal levels, the program creates tabular output which shows the distance and bearing from the selected station to each potential interfering station as well as a breakdown of the amount of interference each station in the study contributes to the total interference.

TA Services has also assisted the Public Broadcasting System of the U.S. and the National Weather Service in the determination of their system coverage and public outreach. These two major public providers ensure that more than 95% of all Americans have access to potentially life-saving information in the event of a national crisis of any kind. With the use of the TA Services system and databases, these two national systems were able to improve and verify the coverage of their large diverse systems.

The National Public Radio Laboratories used the CRADA capabilities to develop an In-Band On-Channel (IBOC) interference model and plans to do similar development for HDTV.

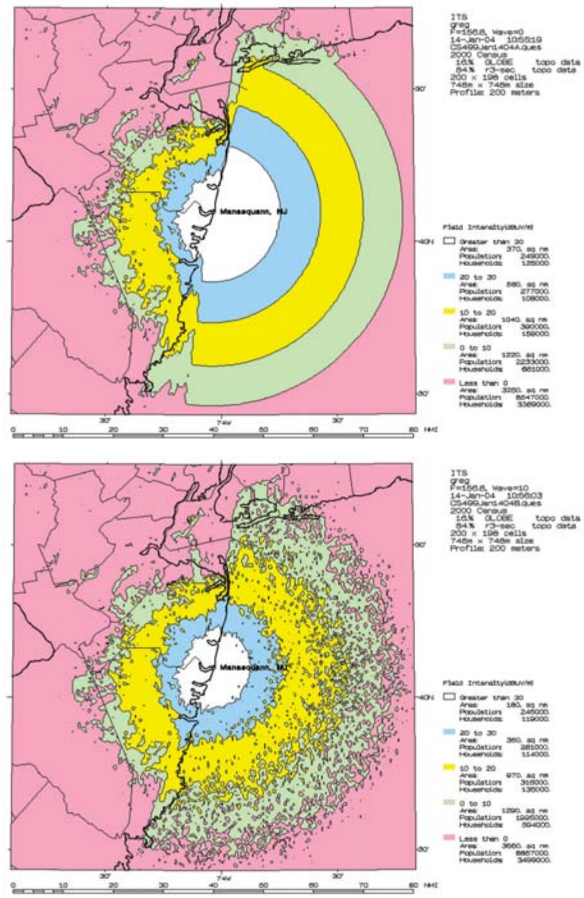

Figure 3. Coverage studies without (top) and with (bottom) an ocean clutter loss addition to CSPM.

An example of a simple model change that can be quickly accomplished through this CRADA capability is shown in Figure 3 which shows the effect of adding an ocean wave-clutter attenuation factor to CSPM.

ITS has begun the effort to upgrade the TA Services System to a new Geographic Information System (GIS) Web-based interface that will place the power of state of the art GIS functions and features in the hands of TA Services customers.

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Geographic Information System (GIS) Applications

Outputs

- Propagation coverages (LFMF, HF, and VHF) for one or more transmitters draped over surfaces.
- Composite, interference, overlap, point-to-point, and coupled outdoor/indoor coverages (VHF).
- 2D and 3D visualization environments.
- FCC database downloads.
- Fly-through visualization capabilities.
- Web-based propagation models and frequency coordination in development.

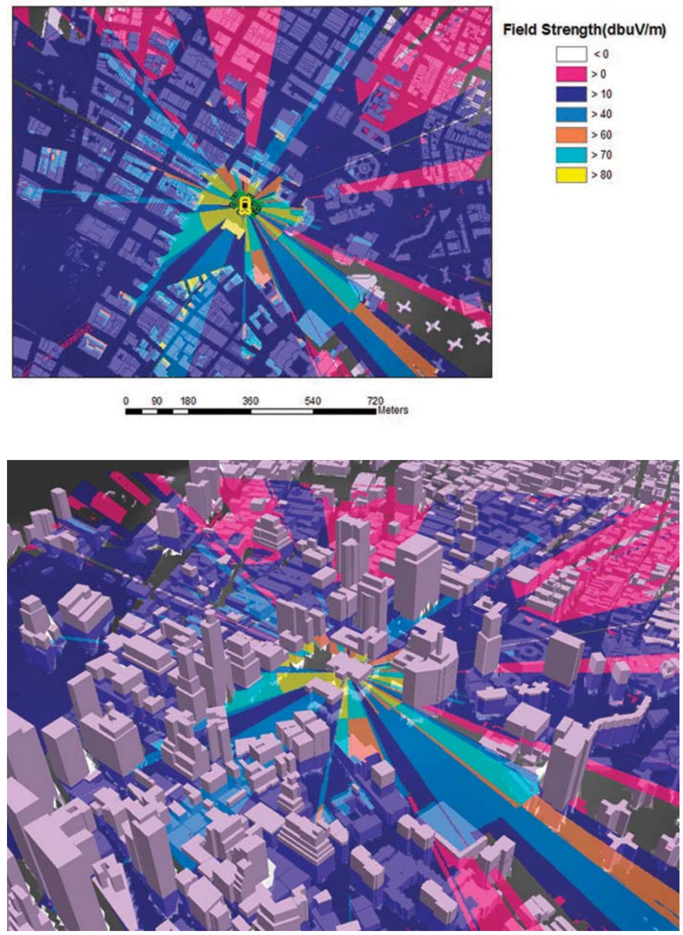

Figure 1. A CSPT-VHF study for New York showing both 2D (top) and 3D (bottom) results.

ITS has developed and enhanced a suite of Geographic Information System (GIS) based propagation model applications for outdoor and indoor analyses. Databases for GIS use, including terrain, satellite and aircraft imagery, roads and other transportation infrastructure layers, building data, and population, are becoming more available and affordable. These databases can be easily incorporated into GIS systems and can be shared among users in web-based or standalone GIS applications. The Institute has developed generic and application-specific GIS programs that aid Government agencies, private cellular companies, public and private radio and television stations, transportation companies and consultants in the performance of their missions to efficiently manage the telecommunications infrastructure of the United States.

The primary GIS-based tool developed by ITS is the Communication Systems Planning Tool (CSPT). CSPT is a menu-driven propagation tool suite developed for frequencies from 150 kHz to 20 GHz that allows the user to select models and use a variety of image catalogs and terrain libraries that cover most of the world. Users can create specific analysis areas using this data and can perform propagation scenarios for their specific application. Applications can range from worldwide outdoor coverage studies to indoor propagation studies of one building in an urban environment. Figure 1 shows a sample transmitter coverage for a small portion of New York City in both 2D and 3D. The CSPT tool also allows the user to create a simple rendition of a building, including windows, doors, and interior walls so that the tool can create coupled indoor/outdoor (shown in Figure 2) or outdoor/indoor coverages.

Two other extensions of CSPT allow the user to incorporate the ITS HF ICEPAC model, which provides sky-wave analysis capabilities from 2 to 30 MHz, and the ITS LFMF System 3 model, which provides analysis capabilities from 150 kHz to 2

MHz for areas as large as the entire world. The CSPT tools can download FCC FM and TV databases, perform overlap, composite, and interference studies and can report demographic information from the 1990, 2000, and 2007 (estimated) Census Population databases.

Over the last year, the Institute has been upgrading the CSPT stand-alone software into a cutting-edge web-based GIS solution. Two products are simultaneously being developed: 1) the TMFCW (Table Mountain Frequency Coordination Website) and the PMW (propagation modeling website) — shown in Figure 3. The TMFCW uses Longley-Rice propagation analysis to identify potential interference from organizations transmitting within an 80-mile radius of the Table Mountain Radio Quiet Zone. The PMW allows users to perform TIREM and Longley-Rice analysis via the web in either single or batch transmitter mode. Both GIS websites allow users to log into one center server site and use one central database server for data storage, retrieval, and analysis. The solution integrates COTS (commercial off the shelf) GIS, database, and web-development products in a fully-customizable software programming environment that can be tailored to meet individual customer needs. Both the TMFCW and the PMW display 2D propagation analyses; these displays will become 3D as customizable GIS web technology becomes available.

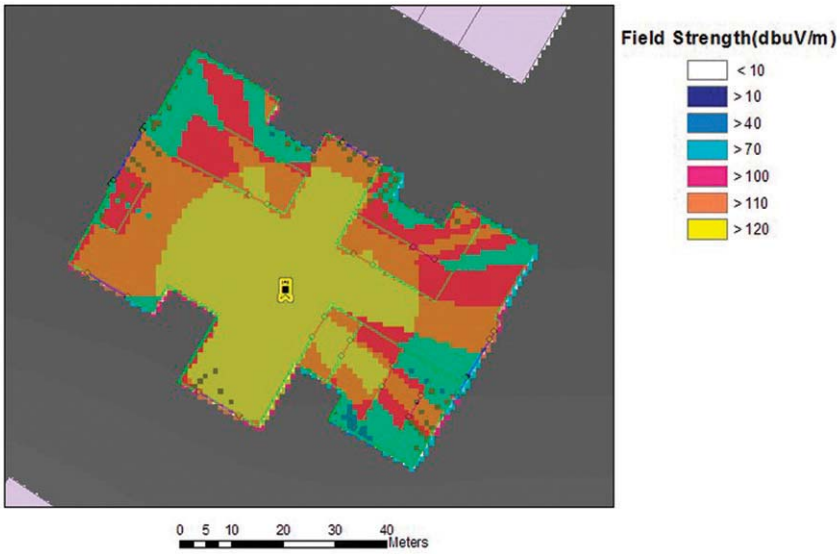

Figure 2. A CSPT-VHF indoor/outdoor study in New York.

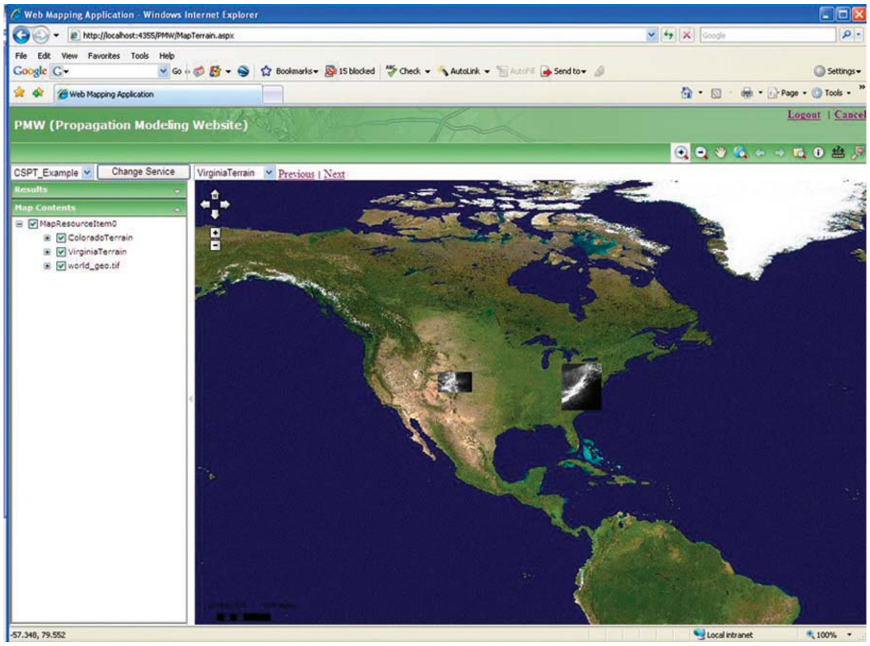

Figure 3. The PMW with user-selectable Virginia or Colorado terrain imagery.

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Broadband Wireless Standards

Outputs

- Hosting/Supporting the 2008 Block Meetings of ITU-R Working Parties 3J, 3K, 3L, and 3M, ISART 2008, and ClimDiff 2008.
- Support of ongoing efforts in various Correspondence Groups, formal and informal, conducting studies between meetings of the Working Parties.

Much of the work on the Broadband Wireless Standards project in FY 2008 centered on hosting and supporting the Block Meetings of the ITU-R Working Parties 3J (propagation fundamentals), 3K (point-to-area propagation), 3L (ionospheric propagation) and 3M (point-to-point and earth-space propagation), which were held at the Hotel Boulderado in Boulder, Colorado, in June 2008. The Block Meetings are held outside Geneva, Switzerland, on a biennial basis, typically in years when a subsequent meeting of ITU-R Study Group 3 is not required. Although the meetings are held outside of Geneva, a great deal of the preparatory work involved in formulating draft new Recommendations and revising existing Recommendations, Handbooks and Reports is accomplished at these venues. The Boulder meetings were no exception to this rule.

In addition to hosting the Block Meetings of the Working Parties, ITS sponsored two concurrent conferences, the International Symposium on Advanced Radio Technologies (ISART) 2008 and ClimDiff 2008, just prior to the Block Meetings at the same venue in Boulder. ISART provides a forum that brings together technical researchers, business leaders, government policy makers, and regulators for the purpose of forecasting the development and application of radio frequency technologies. ISART 2008 had five half-day sessions: Topics in Spectrum Management; Communications in Various Noise Environments; Propagation Prediction Models; Wireless in Mobile Environments; and Emerging Wireless Technologies. The ClimDiff 2008 conference covers topics in radio-climatological and diffraction effects on radio propagation. ClimDiff 2008 had three half-day sessions: Measurement and Modelling of Climatic Effects; Measurement and Synthesis of Rain Parameters; and Effects Due to Buildings and Terrain.

In addition to these activities, ITS personnel were heavily involved in supporting ongoing studies being carried out in the Subgroup 3K-1 Correspondence Group (3K-1 CG). Subsequent to the adoption of Recommendation ITU-R P.1812, the Rapporteur convened a third Special Workshop for this 3K-1 CG at Ofcom, London, UK in March 2008. This Special Workshop provided an opportunity for members of the 3K-1 CG to present and discuss, in detail, various alternative methods for combining single knife-edge diffraction results to approximate multiple knife-edge diffraction and, in particular, to consider the

Figure 1. As part of the U.S. Delegation, NTIA/ITS hosted the working party meetings this year for ITU-R Study Group 3 in Boulder, Colorado, June 5-13, 2008. Here, in a joint plenary session, the Working Party Chairs and Counselor discuss the input documents with the various delegations from all over the world.

implications of these methods for the real-world problem of radio signal propagation by diffraction over irregular terrain, relative to other propagation mechanisms. To this end, ITS re-engineered, implemented, and validated the Fresnel-Kirchhoff based approach to numerical solution of the multiple knife-diffraction problem outlined in NTIA Reports 81-86 and 83-124 by L.E. Vogler.

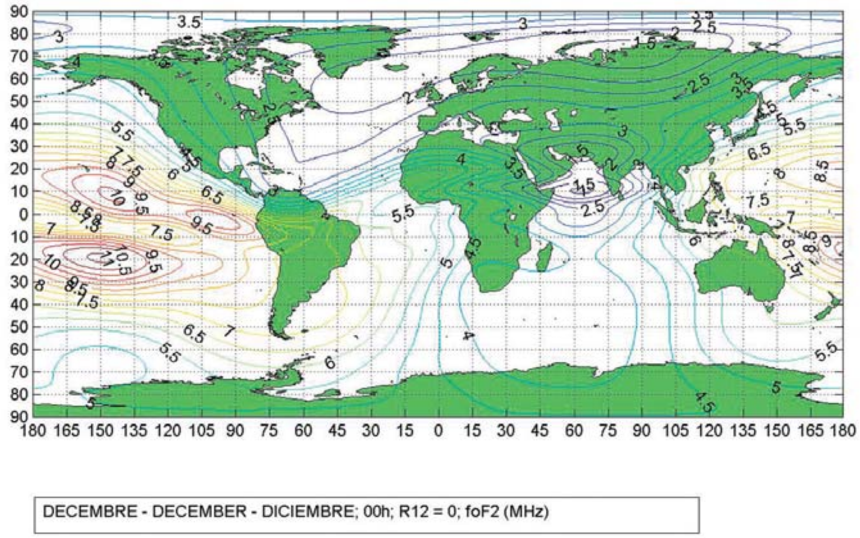

Figure 2. An example of an ionospheric map discussed in ITU-R Working Party 3L.

ITS has supported the correspondence group which produced the vocabulary list from the ITU-R recommendations maintained by Study Group 3. The ITU-R Coordination Committee for Vocabulary (CCV) has accepted the vocabulary list into the web-based ITU Terms and Definitions page.

ITS is also giving support to handbook publications from the ITU that are based on Study Group 3 recommendations. ITS participated in the final review of a new edition of the ITU "Handbook on Radiometeorology." The last edition of this handbook was published in 1996. In addition, ITS is corresponding with NASA to begin work on a new handbook on interference of radiowave transmission which will cover the information from Recommendations ITU-R P.452 (Prediction Procedure for the Evaluation of Microwave Interference Between Stations on the Surface of the Earth at Frequencies Above About 0.7 GHz) and ITU-R P.620 (Propagation Data Required for the Evaluation of Coordination Distances in the Frequency Range 100 MHz to 105 GHz).

In support of Working Party 3L, ITS is implementing revisions of the Recommendations ITU-R P.533 (Method for the Prediction of Performance on HF Circuits) and P.1239 (Ionospheric Characteristics). The latter Recommendation is based on methods developed at ITS and ITS' predecessor organizations after the 1958 International Geophysical Year. The longstanding models of the F2 layer penetration frequency, foF2, and M Factor at 3000 km, M(3000)F2 are based on measurements that are now over 40 years old. Many administrations have been collecting data from that time to the present and need a way to augment foF2 and M(3000)F2. ITS is working within ITU-R Working Party 3L to find a way to enhance ionospheric maps to take into account the wealth of contemporary measurements. ITS is working with other members of WP 3L to coordinate a new set of coefficient files that are used to generate these maps. Through the work of the German delegation and others, a new set of coefficients based on several implementations of ionospheric mapping software will soon be available through the ITU. ITS has been instrumental in this effort since these coefficient sets and models were developed here in Boulder. ITS has made every effort to assure the HF community that this effort is both accurate and true to the original models.

A new version of ITU-R Recommendation P.533 is available that takes into account digital modulation, equatorial scattering, and circuit reliability. With the advent of Digital Radio Mondiale (DRM) and a variety of digital modulation techniques it had become apparent that a new method to determine the reliability of HF digital communications needed to be developed. ITS has been working with other international HF experts to devise such a method. After several years of work the new algorithm is now available in the HF propagation software suite that ITS maintains.

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Low and Medium Frequency Propagation Modeling

Outputs

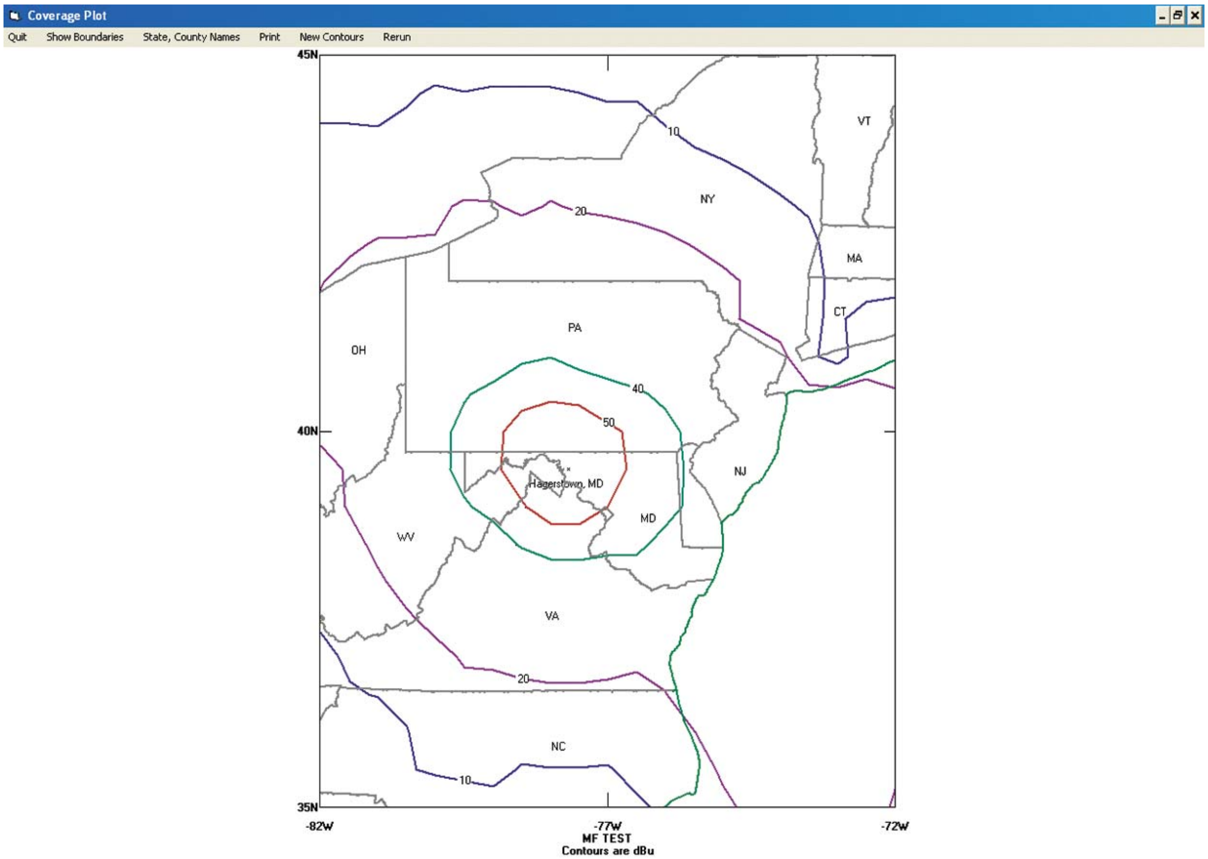
- Unique low and medium frequency ground-wave and sky-wave propagation models.
- Antenna models specific to LF/MF frequencies incorporated into analyses.
- Interference analysis used to allocate frequencies for DGPS station sites and AM broadcast stations.

The Institute has developed and continues to improve a propagation model to be used for analysis of coverage and interference in the medium frequency (MF) and low frequency (LF) bands. This is a Windows®-based communication/broadcasting system performance model designed for a PC that includes three ground-wave and three sky-wave propagation loss prediction methods. The models perform radio-wave propagation and antenna analysis in addition to interference prediction analysis. The sky-wave propagation models are valid from 150 to 1705 kHz, and the ground-wave models are valid from 10 kHz to 30 MHz. This model has been used for interference and coverage analysis for two versions of the Nationwide Differential Global Positioning System (NDGPS) in the two bands of frequencies from 285 to 325 kHz and 435 to 495 kHz, and for coverage and interference analysis of the AM broadcast band of 150 to 1705 kHz.

For the frequency band of 150 to 1705 kHz, the propagation of radio waves at night includes both a ground wave and a sky wave. The expected sky-wave signal combined with the ground-wave signal may be compared with the expected radio noise environment (consisting of atmospheric, galactic, and man-made noise components) to predict the likelihood that the communication link will operate satisfactorily or whether interference will occur. The presence of the sky wave at night could create potential interference problems between distant stations on the same frequency or frequencies that are near each other. The sky-wave models provide some means of estimating the expected field strengths of signals to assist in frequency allocation and to avoid potential interference problems. At night the undesirable interference from the sky wave can manifest itself as adjacent and co-channel interference to stations that it would not normally reach in the daytime. The absence of the sky wave during the day precludes the use of systems in this band for reliable long distance communication, since the sky wave at frequencies from 150 to 1705 kHz is strongly attenuated by the electron density in the D region during the daytime. Long distance radio-wave propagation during the daytime is limited by how far the surface-wave component of the ground wave can diffract around the Earth and its terrain features.

Antenna modeling in this band is also quite unlike that in other bands, since the performance of an antenna on or near the surface of the Earth is very dependent on the interaction with the lossy Earth, so specific antenna models have been included that correctly launch the ground wave at the horizon angle and the sky wave at the appropriate elevation angle.

This model consists of three distinct analyses called System 1, System 2, and System 3. While the analyses are related in function, each is independent of the others. System 1 treats the broadcast circuit from a proposed transmitter to a particular receiver site as a point-to-point problem. The user selects transmitter characteristics, receiver characteristics, site characteristics, and a propagation model. System 2 continues to treat the desired transmitter and the desired receiver site as a point-to-point problem, but interference effects are included. All adjacent and co-channel transmitters (referred to as the interfering transmitters) within a user-defined search radius are used to compute signal-to-interference ratios at the receiver location. For each adjacent and co-channel transmitter, the model lists the computed signal-to-interference ratio as well as the amount that the ratio exceeds or fails to exceed the required signal-to-interference ratio for the adjacent or co-channel case. System 3 evolves from the System 2 analysis by treating the broadcast situation as an area problem. The System 3 output is a map of the user-selected area showing contours of signal coverage or signal-to-interference ratios.



NDGPS coverage plot for Hagerstown, Maryland, at 454 kHz.

ITS has integrated the low and medium frequency model into a Geographic Information System (GIS) based application, the Communication Systems Planning Tool Low and Medium Frequency (CSPT-LFMF) model which provides the user with a GIS input capability so that low and medium frequency analyses can be run and displayed with more detailed and illustrative graphics. The GIS-based model makes use of GIS databases that include terrain, satellite and aircraft imagery, roads and other transportation infrastructure layers, building data, and population data. Additional efforts in the planning stages for future modifications to the low and medium frequency model include extending the frequency capability below 150 kHz by adding additional propagation models.

The figure shown above is an actual output of the low and medium frequency propagation model developed by ITS. It shows the coverage for an NDGPS site in Hagerstown, Maryland, at 454 kHz using the System 3 analysis of the low and medium frequency model. The contours are electric field strength in dB micro-volts per meter.

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Short-Range Mobile-to-Mobile Propagation Model Development and Measurements

Outputs

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

With the tremendous growth in demand for mobile wireless devices, it is necessary to address the problems of interference between existing and new radio spectrum users. The evolution of our communications infrastructure depends on these communication devices, and the successful operation of these devices in a crowded electromagnetic spectrum has a profound impact on our economy. An accurate and flexible radio propagation model is essential to meet the needs of the spectrum management and electromagnetic compatibility (EMC) analysis processes.

In an Executive Memorandum from the President dated November 30, 2004, the Department of Commerce was asked to submit a plan to implement recommendations to ensure that our spectrum management policies are capable of harnessing the potential of rapidly changing technologies. The recommendations included (1) providing a modernized and improved spectrum management system; (2) developing engineering analysis tools to facilitate the deployment of new and expanded services and technologies; (3) preserving national security and public safety; and (4) encouraging scientific research and development of new technologies. To implement these recommendations, it is necessary to determine the best practices in engineering for spectrum management, and address the EMC analysis process.

ITS was tasked by NTIA/OSM to review and evaluate the current propagation models and ITU-R Recommendations to determine which could be used to perform propagation analyses to facilitate EMC analyses of mobile wireless devices. After performing an exhaustive review of current models, ITS determined that none was entirely suitable for use in analyzing mobile-to-mobile (MTOM) interference interactions. Although the models had their own regions of validity with respect to frequency, separation distance, and antenna heights, they were all inadequate for the short-range MTOM model requirements of: 1 m to 2 km separation distances, 1–3 m antenna heights, and a frequency range of 150–3000 MHz. Existing radio-wave propagation models are valid only for much higher antenna heights (4 m or greater) and larger separation distances (greater than 1 km). It was therefore necessary to initiate an analysis and measurement effort to develop and validate models in this parameter range.

In FY 2008, ITS conducted a measurement campaign in and around the Denver-Boulder metroplex to provide an initial set of measurements in real-world environments ranging from the dense urban high-rise environment of downtown Denver to the open, rural environment to the east of Table Mountain along N. 63rd St. in Boulder County, CO. The measurements were conducted using pseudo-mobile-to-mobile protocol, with the transportable transmitter truck driven to fixed sites and the transmitting antennas deployed near the ground on tripod supports, and the receiver van was driven through the surrounding environment at normal traffic speeds. At certain sites, measurements were collected using both the wideband impulse response-based receiver system, described in the ITS FY 2007 Technical Progress Report, and a narrowband, spectrum analyzer based receiver system. When the receiver system was deployed in narrowband mode, the pseudo-noise code based modulation of the (wideband) transmitter system was turned off.

There are theoretical and practical advantages and disadvantages to both the wideband and narrowband receiver systems. The wideband system is able to obtain channel impulse response information over the bandwidth of the transmitted signal, with the disadvantage of limited dynamic range and ability to tolerate ambient interference, while the narrowband system cannot collect channel impulse responses, but has the advantages of increased dynamic range and tolerance to ambient interference when a sufficiently narrow resolution bandwidth is chosen.

An important issue is the extent to which the wideband and narrowband systems give comparable results. The fading/enhancement observed by the narrowband system is that which occurs for a very small frequency range (approximately ±1.5 kHz) about the carrier frequency, while the frequency

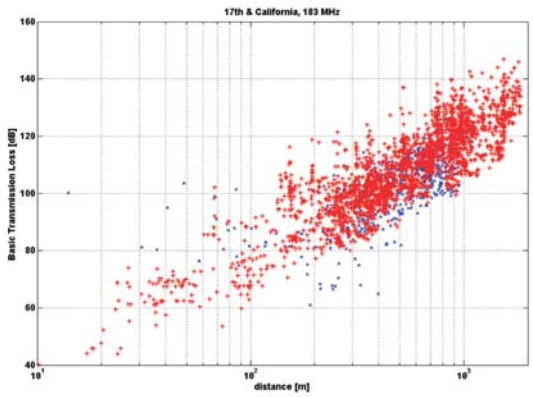

Figure 1. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, CO at 183 MHz.

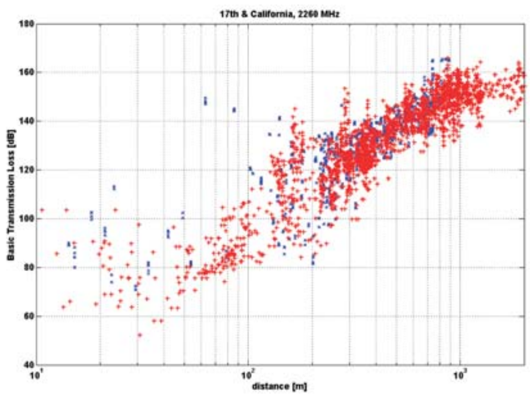

Figure 2. Comparison of wideband, x's, and narrowband, +'s, measured basic transmission losses in the dense urban high-rise region of downtown Denver, CO at 2260 MHz.

range about the carrier for the wideband system is as large as ±10 MHz and may include frequency selective effects. Figures 1 and 2 show comparisons of measurements taken with the two systems on drive routes in the dense urban high-rise environment in downtown Denver at 183 MHz and 2260 MHz, respectively. The wideband measurement results are represented by x's and the narrowband results are represented by +'s. In view of the fact that both datasets show comparable values of the basic transmission loss versus distance, it appears that frequency selective fading is not a dominant mechanism in the measurements obtained using the wideband system.

Simple slope-intercept models have been obtained using linear regression fits to the existing measurement data. The values obtained by the narrowband system are listed in Table 1.

Table 1. Results for All Measured Data

Slopes

	183	430	915	1350	1602	2260	5750
Rys	37.3	35.4	40.1	39.5	42.1	48.9	44.9
NCA	22.3	0.0	34.5	0.0	36.1	33.9	39.1
DTC	40.3	45.4	42.4	44.5	43.8	44.2	42.7
Fed	34.6	33.5	33.0	38.0	36.0	40.0	41.6
Bro	38.4	42.2	41.1	0.0	43.0	51.3	58.5
Aur	38.0	39.8	39.9	39.8	45.2	41.1	47.5
17t	39.1	43.3	46.1	43.0	45.7	48.0	50.1

Intercepts

	183	430	915	1350	1602	2260	5750
Rys	1.1	2.4	-6.6	-10.2	-15.2	-31.3	-3.8
NCA	48.4	0.0	28.4	0.0	24.8	37.0	33.9
DTC	0.8	-12.8	11.6	-1.1	5.5	7.2	41.0
Fed	9.2	12.0	26.9	5.1	32.8	6.3	16.7
Bro	12.7	3.2	22.6	0.0	15.8	-0.0	-6.6
Aur	4.6	-1.2	14.8	8.0	0.4	25.6	21.0
17t	2.0	-4.0	3.8	6.8	3.6	6.1	24.3

Standard Deviations

	183	430	915	1350	1602	2260	5750
Rys	5.4	5.8	7.0	7.7	7.4	7.8	9.2
NCA	7.9	0.0	8.9	0.0	9.9	9.6	9.1
DTC	7.4	8.2	7.4	8.1	7.6	7.6	8.4
Fed	7.5	7.4	9.2	9.9	10.6	9.5	9.7
Bro	8.0	8.2	8.8	0.0	8.7	10.0	10.6
Aur	6.6	7.5	7.5	7.1	7.5	7.4	7.9
17t	7.8	8.6	8.3	8.6	8.9	9.1	10.2

Number of Points

	183	430	915	1350	1602	2260	5750
Rys	563	547	547	555	482	311	509
NCA	260	0	254	0	258	271	312
DTC	1527	1616	1379	1401	1302	1665	1381
Fed	1441	1467	1334	1502	1269	1468	1430
Bro	2289	2600	3304	0	2728	2494	2835
Aur	2059	2656	1981	2514	2024	2314	1561
17t	3069	2379	2840	2248	3152	2243	2257

Rys=Ryssby Church ; NCA=NCAR ; DTC=Belleview Promenade, Denver Tech Center ; Fed= Denver Federal Center ; Bro=Broadway and Spruce, downtown Boulder ; Aur=Auraria Campus, downtown Denver ; 17t=17th and California, downtown Denver.

Work on this project in FY 2009 will focus on obtaining measurements for additional environments as well as further work on model development and refinements.

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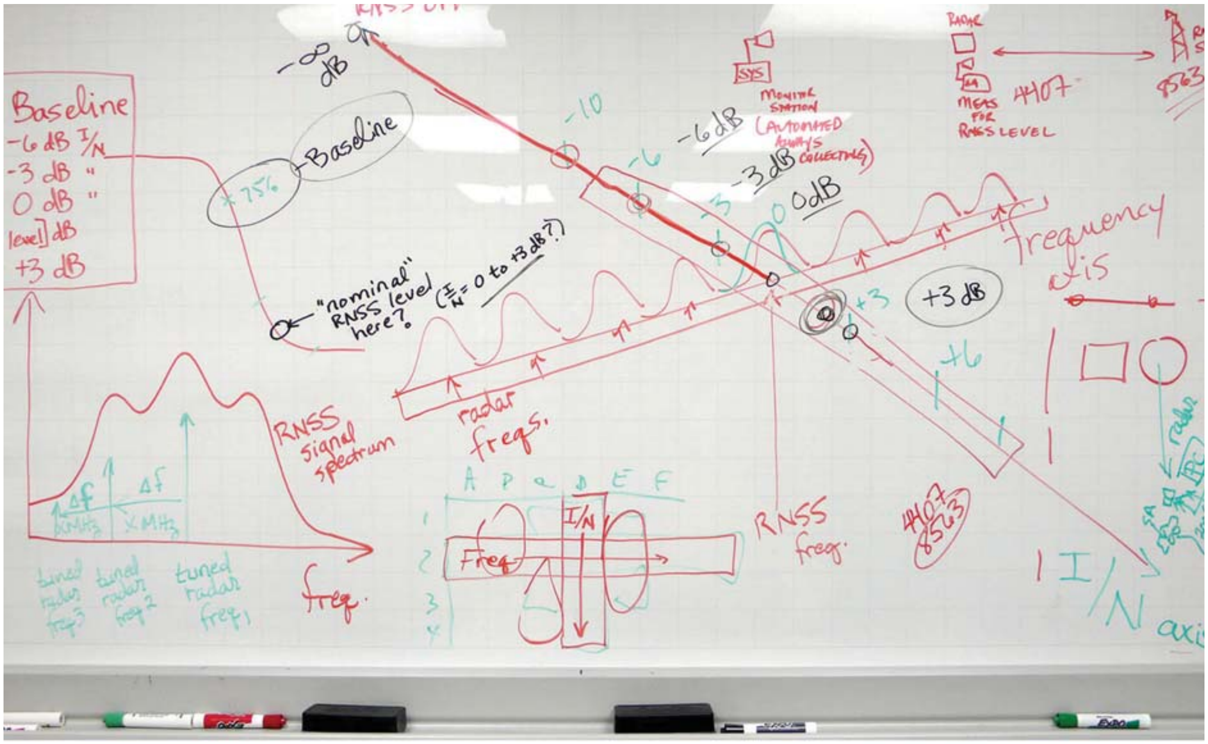

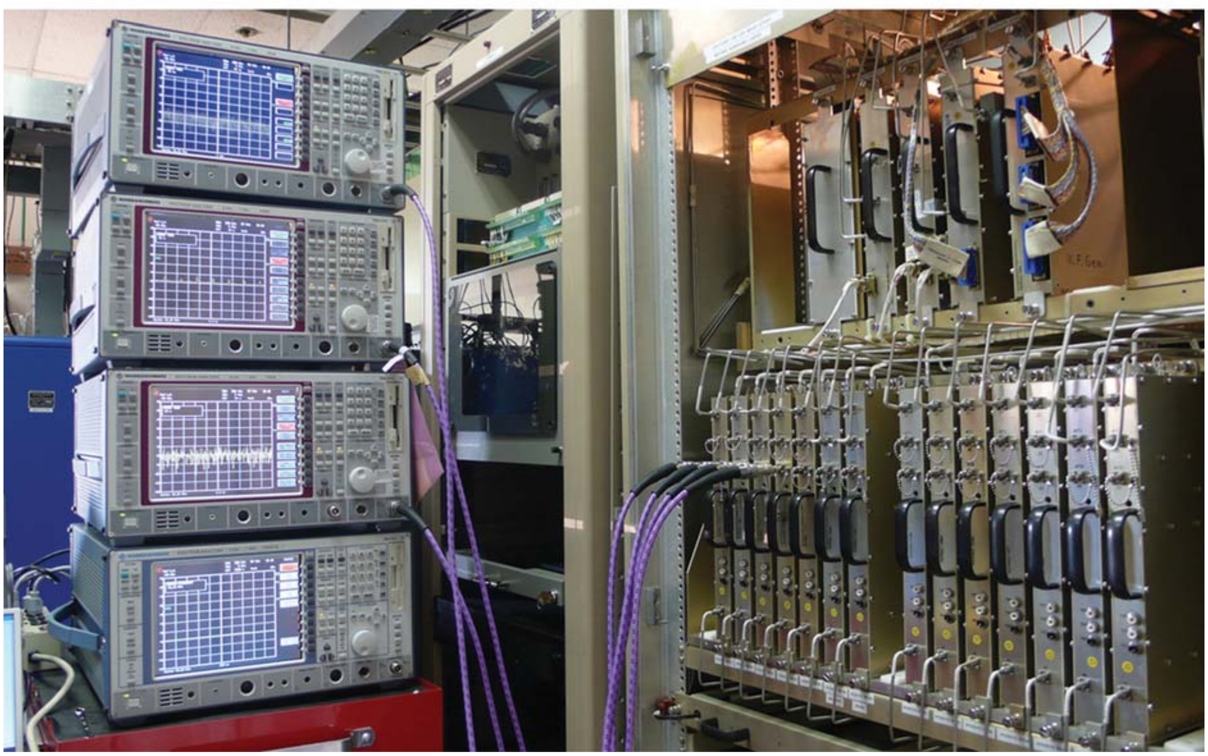

The ITS Telecommunications Theory Division fuses theory (top, a whiteboard created during a discussion of the predicted effects of interference on a radar system) with implementation of measurements to verify and expand theoretical models and predictions (bottom, a measurement system monitoring the IF stage outputs of a radar during an interference event) (photographs by F.H. Sanders).

Telecommunications Theory

The worldwide telecommunications network is undergoing explosive growth, in terms of both the build-out of hardware infrastructure and ever-increasing loading demands. Wireline and radio networks generally complement each other, but whereas wireline capacity can be expanded almost indefinitely, radio spectrum is a limited resource. Ever-increasing demands for radio spectrum are driving the development of new radio technologies that promise to use spectrum more efficiently and effectively. The basic paradigm of radio spectrum management is responding to these changes by moving away from traditional, top-down frequency-assignment methods and is migrating instead toward autonomous, interference-limited technologies. Historically rigid spectrum band allocations on a service-by-service basis (i.e., differentiation of band usage on service bases) are being supplanted by more sharing of radio bands by multiple services. The new sharing schemes emphasize the need for new capabilities in radio systems to recognize and avoid interference between each other.

To fulfill the promise of these interference-limited schemes, the effects of noise and interference on radio receiver performance must be thoroughly understood, and such knowledge must be focused on improvements in the performance of both new and existing networks. Tools to monitor the quality of audio and video information on communication channels also must be developed and used so that audio and video quality levels can be accurately adjusted in real-time to achieve maximal quality with minimal use of available bandwidth.

To achieve these goals for the U.S. Government as well as the private sector, the Institute's Telecommunications Theory Division performs research in both wireless and wireline telecommunications, seeking to understand and improve telecommunications at the most fundamental levels of physics and engineering. Strong ongoing investigations are being maintained in the major areas of broadband wireless systems performance in the presence of interference; the development of new propagation models for short-range mobile radio systems; the effects of noise and interference as critical limiting factors for advanced communication systems; automated tools for assessing audio and video quality; and the further development of advanced spectrum sharing concepts such as dynamic frequency selection.

Through technical publications, cooperative research and development agreements (CRADAs), and interagency agreements, ITS continuously transfers the results of its work in all these technology areas to both the public and private sector, where the knowledge is transformed into better telecommunications for the United States, new and better products for consumers and the Government, and new opportunities for economic development and growth for the economy.

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Areas of Emphasis

Audio Quality Research The Institute develops and evaluates new techniques for encoding, decoding, and analyzing speech and audio signals. Projects are funded by NTIA.

Effects of the Channel on Radio System Performance The Institute, a recognized leader in radio channel measurement and modeling, is researching the effects of interference and noise on the performance of radio receivers and networks. Current work is focused on the effects of noise and interference as limiting factors in system performance. The project is funded by NTIA.

Interference Effect Measurements in an Allocated Radar Band In response to interference problems resulting from non-radar signals in an allocated radar band, the Institute has performed an extensive set of analyses and measurements. This problem, which had originally been predicted by ITS engineers on a theoretical basis, is now a reality. It is being assessed and solutions are being sought. The project is funded by NTIA.

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

Audio Quality Research

Outputs

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

Digital encoding and transmission of speech signals enables many telecommunications services including voice over Internet protocol (VoIP) services, cellular telephone services, voice messaging services, and automatic voice recognition call processing systems. Similarly, general audio signals (including music, voices, environmental sounds, and sound effects) can be digitally encoded and transmitted and this has enabled satellite and terrestrial digital audio broadcasting services and Internet digital audio streaming services. Key to all of these services is the efficient and robust encoding of speech and audio signals at low bit-rates while maintaining good fidelity.

But digital encoding of speech and audio involves compromises and trade-offs among five basic factors: signal quality, transmission bit-rate, robustness to transmission errors and losses, coding and transmission delay, and coding and transmission algorithm complexity. More complex encoding schemes can generally encode a given signal into fewer bits. But when a signal is described by fewer bits, each bit is inherently more important to the description of the signal and the data stream is thus less robust to errors and losses. The trade-off between delay and robustness can be demonstrated by receive-side buffering of data packets delivered by a best-effort network. Increasing the size of a buffer can reduce the number of packets lost (desirable), but this will also increase the algorithm delay (undesirable). For a complete system of coding and transmission, all five factors will generally come into play. For any given application, joint optimization with respect to these five factors can be a very elusive goal.

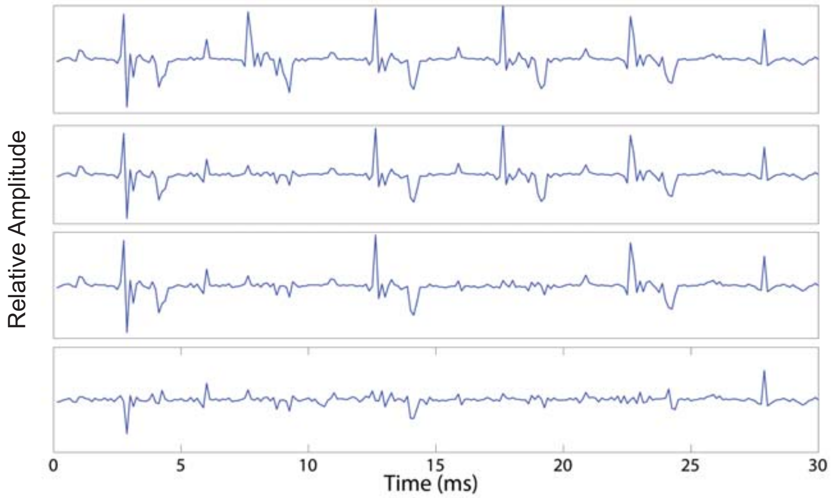
The ITS Audio Quality Research Program identifies, develops, and characterizes new techniques with potential to increase relative quality or robustness or reduce relative bit-rate, delay, or complexity of speech and audio coding and transmission algorithms. In addition, the Program seeks to develop techniques that aid in optimizing the trade-offs between these five factors. To optimize, one must be able to quantify. Quantification of speech and audio quality is a particularly difficult challenge. Thus a key component of our efforts is the development of more effective and efficient ways to characterize speech and audio quality. The ultimate goal for Program efforts is more reliable and efficient telecommunications and broadcasting services with improved speech and audio quality.

In FY 2008 Program staff performed significant work on the problem of high quality speech and audio coding at reduced bitrates. The extreme in high quality coding is lossless coding, where a bit-exact copy of the original signal is reproduced at the decoder output. Transform coding, predictive coding, and entropy coding techniques were studied, extended, and analyzed for applicability to several specific audio and speech applications.

Efficient coding requires that redundancy be eliminated from signals as part of the coding process. One novel technique to eliminate temporal redundancy in speech prediction residuals is demonstrated in the figure on the next page. The top panel shows a speech prediction residual signal that must be transmitted. It is clear that a basic pattern (related to the glottal pulse pattern and the pitch) approximately repeats at intervals of about 5 ms. Through an iterative shifting, scaling, and adding process, the signal can be replaced with the one shown in the second panel, then the third, etc., and this process is invertible. By iterating this process we ultimately arrive at the signal shown in the bottom panel. By reversing the process we can generate the top panel signal from the bottom panel signal.

The final signal, shown in the bottom panel, can be coded at a lower rate than the original signal shown in the top panel. In order to realize this rate-reduction benefit, it is necessary to transmit the side information that will allow for the inversion of the iterative reduction process described in the figure. Thus one must weigh these two factors against each other to determine if this technique could be advantageous in a given speech or audio encoding application.

In other FY 2008 work Program staff developed, implemented, and verified a new subjective testing protocol addressing speaker identification. This protocol quantifies the extent to which various speech communication links can convey or obscure the identifying characteristics of a specific talker's voice. Project staff selected a set of speech recordings from three female and three male speakers to conform with very specific criteria of content and quality. They then processed the recordings through various speech communication links and wrote a sophisticated subjective test controller that provided listeners with a set of task-specific graphical user interfaces. After the appropriate training process, listeners heard recordings and were asked to select which of the six talkers they had just heard. When combined with parallel results from earlier intelligibility tests, staff determined that the cues associated with speaker identification can be fairly robust. In fact, even when distortions are so severe that it is not possible to determine what is being said, it can still be possible to determine who is talking.



An example speech prediction residual signal (top panel) and the results of an invertible iterative process (second, third, and fourth panels) that reduces the bit rate necessary to encode the signal, at the cost of some additional side information. Vertical axis displays relative amplitude.

Throughout FY 2008, Program staff continued with additional speech and audio quality testing using both objective and subjective techniques. These tests support both this program and other ITS programs. Some laboratory upgrades were performed throughout the year. Staff continued to transfer program results to industry, Government, and academia by means of technical publications, lectures, laboratory demonstrations, and poster presentations. Staff also completed a significant number of peer reviews and associate editor functions for technical journals and conference proceedings. Program staff supported telecommunications standards development through research efforts and technical exchanges. Program publications, technical information, and other program results are available at http://www.its.bldrdoc.gov/audio.

Recent Publications

S.D. Voran, "Lossless audio coding with bandwidth extension layers," in *Proc. 2007 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, New Paltz, New York, Oct. 2007.

J.B. Allen, G. Chan, and S.D. Voran, "Perceptual models for speech, audio, and music processing," *EURASIP Journal on Audio Speech, and Music Processing*, Volume 2007, Nov. 2007.

S.D. Voran, "Listener detection of talker stress in low-rate coded speech," in *Proc. IEEE International Conference on Acoustics, Speech and Signal Processing,* Las Vegas, Nevada, Mar. 2008.

A.A. Catellier and S.D. Voran, "Speaker identification in low-rate coded speech," in *Proc. 7th International Measurement of Audio and Video Quality in Networks Conference*, Prague, Czech Republic, May 2008.

S.D. Voran, "Estimation of speech intelligibility and quality," Ch. 28 of *Handbook of Signal Processing in Acoustics*, D. Havelock, S. Kuwano, and M. Vorländer, Eds., Vol. I, Part V, Springer Science+Business Media, LLC, 2008, pp. 483-520.

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Effects of the Channel on Radio System Performance

Outputs

- Interference susceptibility analysis.
- Translations of channel measurements to receiver performance metrics.

Telecommunications play a vital role in providing services deemed essential for modern life. Many of these services use radio links composed of a transmitter and receiver, i.e., the *radio system* and the *channel* separating the two. The channel is often the primary impediment to fast and reliable radio system performance. Understanding the channel and the effects of the channel on radio system performance are crucial to the advancement and regulation of telecommunications.

The channel degrades radio system performance by introducing multipath and undesired signals. Multipath is due to reflection, diffraction, and scattering propagation phenomena supported by the channel media which can be as diverse as the earth's ionosphere or an urban landscape. Undesired signals include natural noise created by phenomena such as lightning, man-made noise created by electrical devices, and signals from other radio systems.

Multipath is, in essence, channel filtering which can potentially cause intersymbol interference and attenuation. Undesired signals, as well as multipath attenuation, reduce signal power margins. Intersymbol interference and reduced signal power margins cause increased numbers of bit errors and corresponding reductions in radio system performance.

Results from our work are useful to radio system designers and radio spectrum managers. Radio system designers often want channel characteristics reported in terms of their effect on radio system performance. Radio spectrum managers need to be able to evaluate the susceptibility of legacy receivers to signals from other radio systems. This need has become more pressing as spectrum managers seek to alleviate spectrum scarcity through novel spectrum sharing techniques.

Our approach towards evaluating the effects of the channel on radio system performance emphasizes our expertise in channel characterization and radio system signal processing. This expertise allows us to pare down complex problems to simple, verifiable models and experiments with those models.

In FY 2007 we developed a computer simulated radio link model, shown in Figure 1, to evaluate the effects of the radio channel on radio system signal processing algorithms. The model is built around a radio link core (RLC) which provides reliable modulation, channel degradation, and demodulation operations. Tethered to this core are the various combinations of channel and signal processing subsystems being tested. A transmitter premodulator subsystem impresses information on source bits needed by the receiver signal processing.

The model uses Monte Carlo techniques to generate bit error sequences. The bit error sequences are used to compute first order bit error rate (BER) and the second order error free interval (EFI) statistics. The first order BER statistic is used to evaluate how effectively the receiver rejects interference caused by the undesired signal. Briefly, a link operating at a 10^{-4} BER in the absence of the undesired signal is subjected to increasing levels of the undesired

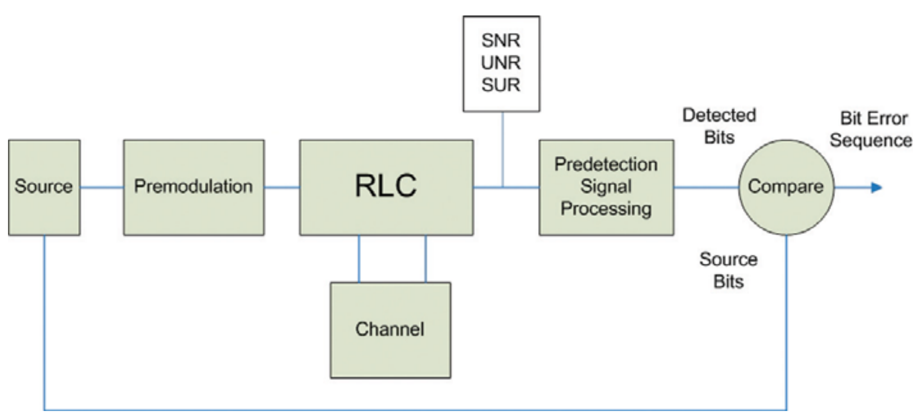

Figure 1. Block diagram of radio link model.

signal. Our performance metric is the undesired signal to noise ratio (UNR) needed to drive the link to 10^{-3} BER. Higher values of UNR correspond to greater effectiveness. In general, our interest is usually in whether or not it is greater than that of Gaussian noise.

The second order statistics are used to determine whether the bit errors are independent. If they are independent, rejection by subsequent block forward error correction can be quantified with analytic expressions much faster than they can with Monte Carlo simulation. This is extremely important at the low BER after block forward error correction (FEC) where the execution times of Monte Carlo simulation are much too long.

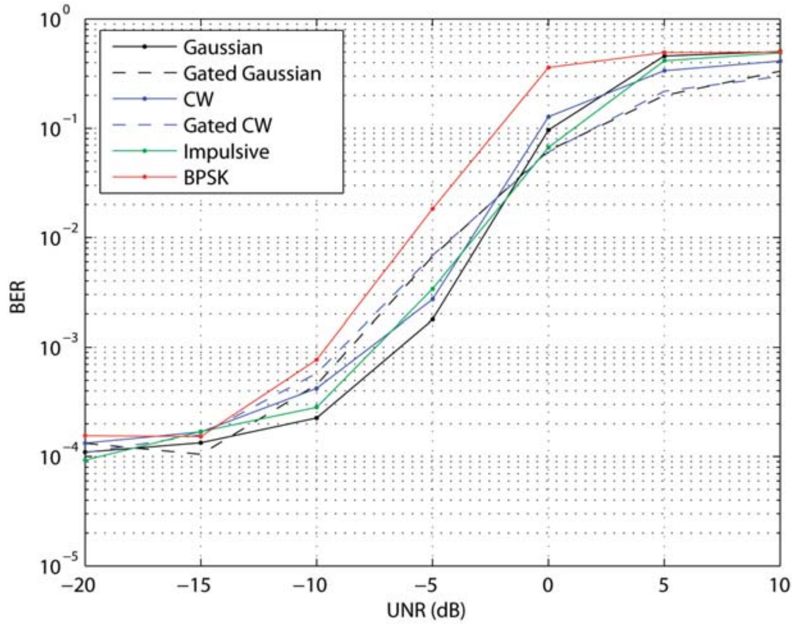

Figure 2. Bit error rate (BER) versus undesired to noise ratio (UNR) for Viterbi configuation and various undesired signals. UNR at 10^{-3} is our performance metric.

Initially the model used the simplest of signal processing algorithms — a threshold detector. In FY 2008, three new configurations were developed based on Viterbi detection, equalization, and correlation signal processing algorithms. Simulations using the three new configurations were run with continuous wave, impulsive, binary phase-shift keying, gated Gaussian, and gated continuous wave signals. Results for the Viterbi configuration, shown in Figure 2, indicate that the performance degraded to 10^{-3} with less power than Gaussian noise for all the undesired signals. In other words, the Viterbi detector was less effective in rejecting interference due to the undesired signals as compared to Gaussian noise. In fact, we found that of 15 combinations of signal processing algorithms and undesired signals, a total of 12 were less effective.

In addition, bit errors at 10^{-3} were found to be independent for the equalization and correlation configurations but not for Viterbi. Therefore rejection by subsequent block forward error correction can be determined with efficient analytic expressions for the equalizer and correlation configurations but not for the Viterbi.

Purely analytic work advanced in FY 2008 with the technical review of “Statistical considerations for noise and interference measurements” by R.A. Dalke. Methodologies in this report (published in FY 2009) show how uncertainties of statistics (mean power, APD percentiles, and power spectral density) commonly computed from noise and interference measurements can be evaluated. This work lays a firm scientific foundation to our efforts. Work has also begun on deriving an analytic expression for the bit error rate of a Viterbi detector in the presence of a gated Gaussian noise signal. This effort is critical for verifying simulation of legacy radio systems operating in the presence of ultrawideband radio signals which resemble gated Gaussian noise.

Recent Publication

M. Cotton, “A methodology for approximating BPSK demodulator performance in the presence of various undesired signals,” in “Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008,” P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP-08-452, Jun. 2008, pp. 36-42.

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Interference Effect Measurements in an Allocated Radar Band

Outputs

- Predictions of the effects of interference from non-radar systems with air surveillance radars.
- Development of plans to measure these effects and verify the predictions of theoretical models against actual effects.
- Measurements at field sites during interference events, and injection of simulated interference signals at those sites to further verify theoretical predictions.
- Analysis of measurement data to formulate methods for coping with interference, if possible.

Contrary to popular impressions and portrayals, radar receivers are not robust against the effects of radio interference from non-radar systems. But the actual effects of interference, and the thresholds at which various types of interference cause degradation of radar system performance, have not been well understood on a technical, quantifiable basis. For the past decade, NTIA has conducted an aggressive effort to thoroughly understand these effects. The purposes of this program are four-fold: to predict the effects of new, non-radar systems that might try to share systems with radars; to provide technical advice to other agencies and the President regarding the threats that new interference sources might pose to defense and safety-of-life radars; to determine the extent to which new technologies might be able to make spectrum sharing between radars and non-radar systems more technically feasible; and to devise new technical methods that might possibly mitigate the effects of existing interference.

Past work in this area by NTIA has been broadly directed toward the characteristics and performance of the following types of radars in the presence of interference: air traffic control; airport surface search and control; air defense; ground-based and aeronautical meteorological; and maritime navigation and surface search.[1] In the past year, special attention has been focused on the effects of interference to air search radars in particular. NTIA engineers from the Institute, working closely with their colleagues at the Office of Spectrum Management (OSM) and other Federal agencies, have undertaken predictions and analyses of interference effects from non-radar systems on these radars. This effort has required careful advance work to analyze and predict the effects of the interference, followed by actual measurements of interference at operational facilities.

In FY 2008, specific radars were identified for injection of signals that have caused interference in operational systems. Both the actual interference signals and hardware replications of these signals, made with vector signal generators, or VSGs, were used during highly detailed tests and measurements at operational radar sites. The FY 2008 results have reinforced the conclusions of existing, published results from NTIA, that radars do not perform well in the presence of even low-level signals that are as much as 6-10 dB below the noise floors of radar receivers. The Institute and OSM plan to continue these analyses and measurements in FY 2009, and are incorporating the results into analyses of the overall spectrum efficiency of radars.

1 F.H. Sanders, R.L. Sole, B.L. Bedford, D. Franc, and T. Pawlowitz, "Effects of RF interference on radar receivers," NTIA Technical Report TR-06-444, Sep. 2006.

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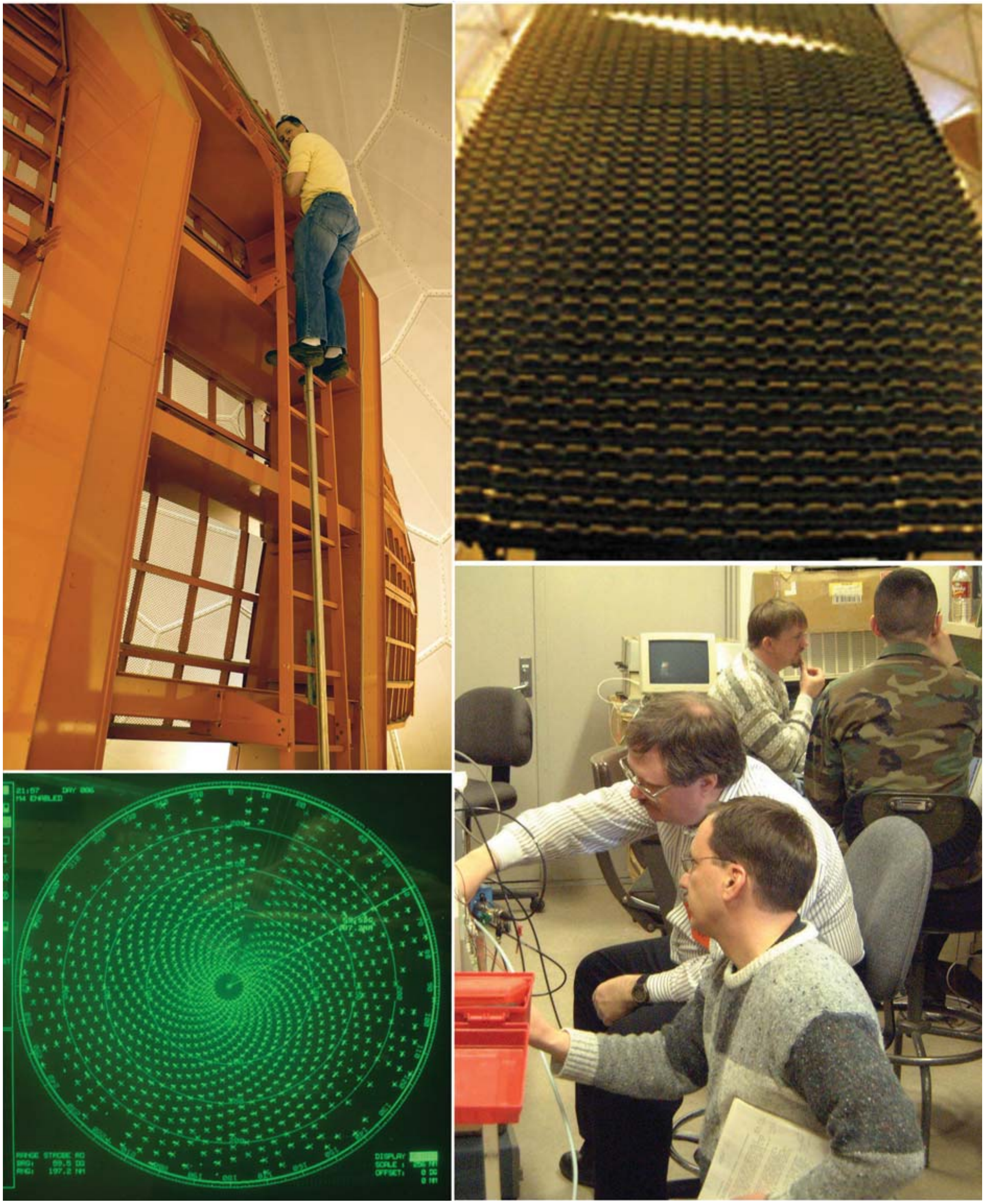

Clockwise from the upper left: An NTIA engineer climbing a radar antenna; a phased-array air surveillance radar antenna; a team of ITS engineers and engineers from other agencies during interference tests and measurements; a radar data display.

Video Quality Research

Outputs

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

Objective metrics for quantifying the performance of digital video systems (e.g., direct broadcast satellite, digital television, high definition television, video teleconferencing, telemedicine, internet, and cell phone video) are required by end-users and service providers for specification of system performance, comparison of competing service offerings, network maintenance, and use optimization of limited network resources. The goal of the ITS Video Quality Research project is to develop the required technology for assessing the performance of these new digital video systems and to actively transfer this technology to other Government agencies, end-users, standards bodies, and the telecommunications industry, thereby producing increases in quality of service that benefit all end-users and service providers.

To be accurate, digital video quality measurements must be based on perceived "picture quality" and must be made in service. This is because the performance of digital video systems is variable and depends upon the dynamic characteristics of both the input video and the digital transmission system. To solve this problem, ITS has continued to develop new measurement paradigms based upon extraction and comparison of low bandwidth perception based features that can be easily communicated across the telecommunications network. These new measurement paradigms (now commonly known throughout the world as RR or "Reduced Reference" measurements) have received four U.S. patents, been adopted as the North American Standard for measuring digital video quality (ANSI T1.801.03-2003), been included in three International Recommendations (ITU-T Recommendation J.144, J.244, and ITU-R Recommendation BT.1683), and are currently being used by hundreds of individuals and organizations worldwide.

To facilitate the transfer of ITS-developed video quality metrics (VQMs) into the private sector, ITS has developed and maintains three software tools that run under the Windows and Linux operating systems. Using these software tools, users and service providers can quantify the digital video quality of their networks using methods standardized by ANSI and the ITU. The first tool, called Command-Line VQM (CVQM), provides a simple command

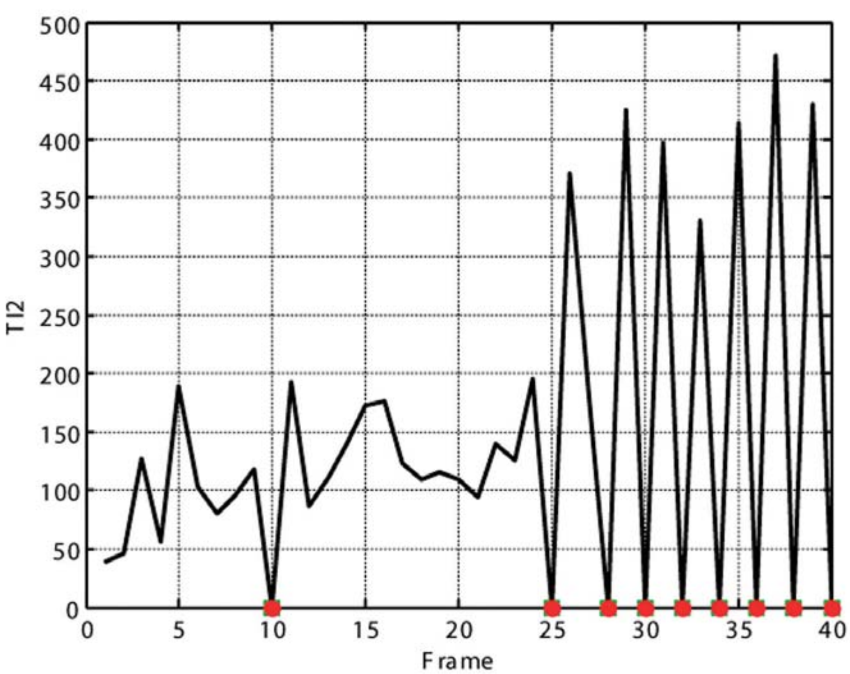

Figure 1. NR metric detecting dropped video frames.

line interface for processing (i.e., calibration and video quality measurements) a pair of video files that have been captured from the source and destination ends of a video transmission system. The second tool, called Batch VQM (BVQM), allows the user to perform Graphical User Interface (GUI) based batch mode processing of many captured video streams, or files. The third tool, called In-Service VQM (IVQM), requires two PCs, one located at the source end and the other located at the destination end of a video transmission system. The two PCs communicate their reduced reference features via the Internet, producing in-service end-to-end video quality monitoring results. Source code and executable binaries of these tools are available royalty free to all interested parties.

In FY 2008, a No Reference (NR) video quality metric was developed that detects dropped or repeated video frames, which visually appear as pauses in the flow of motion. NR metrics do not require any reference information from the source video stream and are thus easy to implement for in-service quality monitoring. There are two primary reasons why digital video systems drop frames: (1) the video encoder may decide to reduce the video frame transmission rate in order to save bits, and (2) the video decoder may decide to freeze the last good video frame when transmission errors are detected. Figure 1 shows a plot of the scene motion energy (i.e., the square of the Temporal Information, denoted as TI2) and the detected frame drops (shown in red) where the video coder performs dynamic frame dropping that depends upon the amount of motion in the video scene. Low motion portions of the scene are transmitted at full or near full frame rates (from frames 1 to 24) while high motion portions are transmitted at reduced frame rates by dropping selected video frames (from frames 25 to 40).

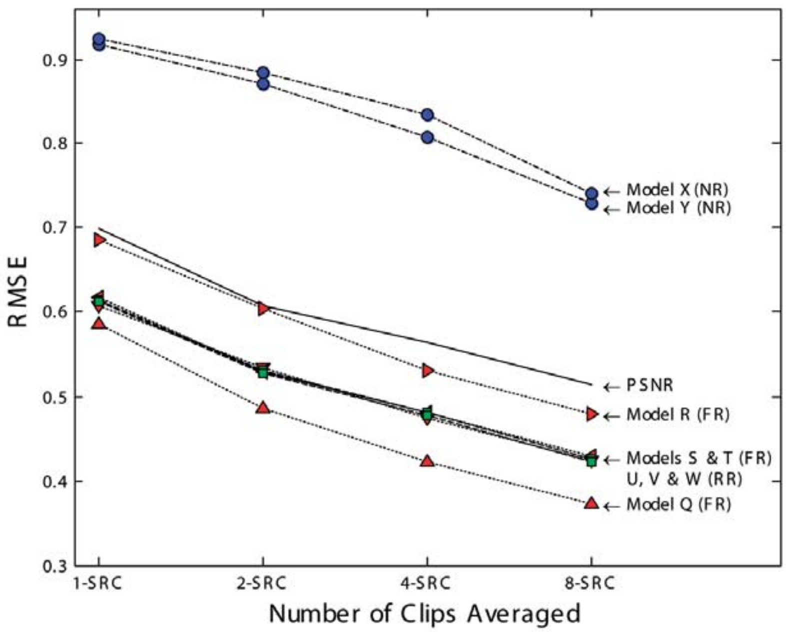

Figure 2. Video quality model RMSE vs. number of clips averaged.

ITS worked as an independent laboratory within the Video Quality Experts Group (VQEG) to validate objective video quality models for mobile/PDA, and internet communication services. One of ITS' investigations examined how the models' accuracy changes when several scenes are passed through a single system, and the scores for those scenes are averaged to produce an average quality score for the system. Figure 2 depicts the accuracy of ten models as an increasing number of scenes are averaged. The root mean squared error (RMSE) accuracy improved steadily for all models as the number of scenes averaged increased from 1 to 2 to 4 to 8.

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

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Technology Transfer to Industry and Academia

Outputs

- Cooperative research and development agreements with private companies and universities to perform telecommunications research and/or to use the Table Mountain field site for telecommunications-related research.
- Patented Video Quality Metric (VQM) software moved into the public domain and made available without license (on the ITS website) to all interested parties.

Technology transfer is the process by which existing knowledge, facilities, or capabilities developed under Federal research and development (R&D) funding are utilized to fulfill public and private needs. This definition was developed by the Federal Laboratory Consortium for Technology Transfer (FLC), a network of over 700 Federal laboratories including ITS, and the only government-wide forum for technology transfer. Organized in 1974, the FLC promotes and facilitates technical cooperation among Federal laboratories, industry, academia, and State and local governments.

ITS participates in technology transfer and commercialization efforts in a number of ways: through fostering cooperative telecommunications research with industry where benefits can directly facilitate U.S. competitiveness and market opportunities, through making the Table Mountain field site available for research by industry and academia, and also through distribution of our patented software.

The Federal Technology Transfer Act of 1986 (FTTA), as amended, allows Federal laboratories to enter into cooperative research agreements with private industry, universities, and other interested parties. Under this Act, an agency can implement a cooperative research and development agreement (CRADA) that protects proprietary information, grants patent rights, and provides for user licenses to corporations, while allowing Government expertise and facilities to be applied to interests in the private sector.

ITS has participated for a number of years in CRADAs with non-Federal organizations to design, develop, test, and evaluate advanced telecommunication concepts. Research has been conducted under agreements with the following organizations:

- American Automobile Manufacturers Association
- Arete Associates
- ARINC
- AudioLogic, Inc.
- Bell Atlantic Mobile Systems
- Bell South Enterprises
- Lockheed Martin/ Coherent Technologies
- East Carolina University's Brody School of Medicine
- Eton Corporation
- FirstRF Corporation
- General Electric Company
- GTE Laboratories Inc.
- Hewlett-Packard Company (HP)
- Integrator Corporation
- Intel Corporation
- Johnson's Jobs
- Lehman Chambers
- Lucent Digital Radio
- Lucent Technologies
- Motorola/Freescale Inc.
- Netrix Corporation
- RF Metrics Corporation
- Savi Technologies
- Sensis Corporation
- Spectrum Mapping LLC
- State of Wyoming
- Telesis Technology Laboratories
- University of Colorado
- University of Pennsylvania
- US WEST Advanced Technologies
- US WEST New Vector Group

Not only does the private sector partner benefit, but the Institute is able to undertake research in commercially important areas that it would not otherwise be able to do.

While ITS often participates in CRADAs that involve performing measurements for an organization (thus transferring the Institute's knowledge and expertise), another common form of technology transfer utilized by ITS is to make the Table Mountain field site available for telecommunications research. Federal facilities such as Table Mountain often contain resources (or, as in this case, *are* resources) otherwise unavailable to the general public. Active Table Mountain CRADAs in FY 2008 and publications resulting from them are described on pp. 10-11.

Laser research at Table Mountain (photograph courtesy Lockheed Martin/Coherent Technologies).

Another major technology transfer mechanism is the use of intellectual property resulting from R&D activities at Federal laboratories. In the past, ITS made its patented Video Quality Metric (VQM) software available to the public through royalty-based licenses. However, this was problematic because the VQM software is incorporated into a number of ITU-T and ITU-R standards, which are supposed to be made available to all interested parties. While in some cases, restricting the availability of patented material through licensing increases the likelihood of commercialization, in the case of VQM, licensing stymied its adoption. Because VQM is an international standard there was worldwide interest in the technology. As such, companies wanted easy access to the software and assurances that the standard was being widely adopted. In an effort to make the VQM software more widely available, ITS began distributing it royalty-free in FY 2007. Finally, in FY 2008, the VQM software was moved into the public domain and made available without license to all interested parties, through simplified web-based distribution. This move has achieved its goal of wider distribution of this very popular software. Further information about VQM can be found on pp. 58-59.

Cooperative research with private industry has helped ITS accomplish its mission to support industry's productivity and competitiveness by providing insight into industry needs. This has led to adjustments in the focus and direction of other Institute programs to improve their effectiveness and value.

ITS is interested in assisting private industry in all areas of telecommunications. The pages of this technical progress report reveal many technological capabilities that may be of value to private sector organizations. Such organizations are encouraged to contact ITS if they believe that ITS may have technology useful to them. Because of the great commercial importance of many new and emerging telecommunication technologies, ITS will continue to pursue technology transfer to the private sector through CRADAs and thereby contribute to the rapid commercialization of these new technologies.

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Support to Private Sector Telecommunications Activities:

ITU-R Standards Activities

Outputs

- Ongoing technical support to the U.S. Administration in ITU-R Working Party 5B, the Radar Correspondence Group, and the Radar Unwanted Emissions Group, on international radar-related spectrum use and spectrum sharing issues, and on propagation studies in ITU-R Study Group 3.
- Hosted the 2008 Block Meetings of ITU-R Working Parties 3J, 3K, 3L, and 3M (see pp. 44-45 for more information).
- Measurements of the effects of interference from signals of radionavigation satellite systems (RNSS) on long-range air surveillance radars.
- Presentation on the radio spectrum occupancy measurements for the International Symposium on Advanced Radio Technologies (ISART) in Boulder, CO.

Success in worldwide telecommunication markets, as well as effective and compatible use of telecommunications technologies both domestically and abroad, is critical to the long-term health of the United States, both economically and otherwise. To achieve these goals, the U.S. Administration actively participates in the single most important worldwide telecommunications standards and regulatory body, the International Telecommunication Union — Radiocommunication Sector (ITU-R), to further its objectives with regard to all forms of wireless communication on a worldwide basis. ITS in turn provides important, ongoing technical support to the U.S. Administration in ITU-R Study Groups 3 and 5; Working Parties 5B and 5D; the Radar Correspondence Group (RCG); and the Radar Unwanted Emissions Group. Current areas of interest include (but are not limited to): potential reallocation of radar spectrum; effects on radars of interference from communication systems; dynamic frequency selection technology proposed for 5-GHz spectrum sharing between communication systems and radars; development of radar emission spectrum measurement techniques; and development of more efficient radar spectrum emission criteria.

Proposals have been made by non-U.S. Administrations in ITU-R to introduce communication systems into bands that have heretofore been allocated for radars on a primary basis. Currently, a debate surrounds the introduction of WiMAX systems into radar bands on a worldwide basis. Another area of interest and debate is the impact of radionavigation satellite system (RNSS) signals on the performance of long-range air surveillance radars that use the same band.

Since the U.S. Administration has made an enormous investment in the development and deployment of both military and civilian radars, it is essential that new systems proposed for spectrum sharing with radars be examined for electromagnetic compatibility with existing and future radars. To this end, ITS engineers in FY 2008 were leaders in an extensive, multi-agency effort to further measure the effects of RNSS signals on long-range air surveillance radars. Interference signals were injected into the radar receiver while targets were observed. At a variety of interference levels, the effects on target detection were observed. The results of that work have been prepared for submission to ITU-R Working Party 5B. More generally, interference test results have been used for U.S. Contributions in WP 5B, the International Symposium on Advanced Radio Technologies (ISART), and NTIA Reports and Technical Memoranda.

To support the U.S. Administration's spectrum efficiency goals in FY 2008, ITS and OSM engineers analyzed emission spectra from FM-pulse (chirped) radars and compared the analysis results to measurement results. Additional work in the ITU-R has been devoted to chairmanship of the Radar Correspondence Group by an ITS engineer, as well as ongoing support for the U.S. Administration in the Radar Unwanted Emissions Group on the topic of future development of radar spectrum emission criteria.

An air surveillance radar station. A major focus of ITS support for the U.S. Administration in the ITU-R is the protection of these and other radars with major defense and safety-of-life radar missions from interference from non-radar systems.

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ITU-T & Related U.S. Standards Development

Outputs

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

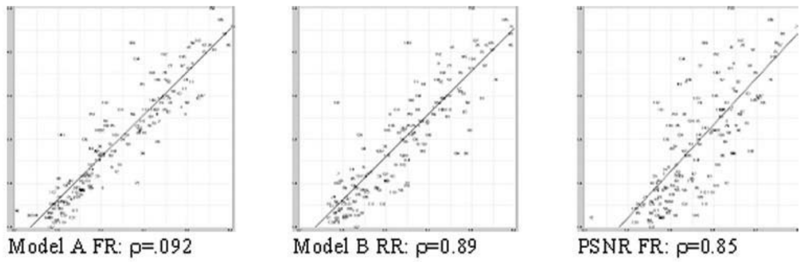
The Institute has a long history of leadership, technical contributions, and advocacy of U.S. Government and industry proposals in the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T) and related U.S. standards organizations. ITU-T is a specialized agency of the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

The Institute's long-term goal in ITU-T (and related national standards work) is to motivate the standardization of user-oriented, technology-independent measures of telecommunication service quality, and to relate those measures with 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 interworking among independently-operated networks and dissimilar technologies, and helps users define their telecommunication needs and select products and services that best meet them.

In FY 2008, the Institute provided leadership in two key ITU-T groups: Study Group (SG) 13 and SG 9's Working Group on Quality Assessment. Institute staff also provided leadership in the Alliance for Telecommunications Industry Solutions (ATIS) Network Performance, Reliability, and Quality of Service Committee (PRQC). SG 13 is developing international standards for Internet Protocol (IP) based Next Generation Networks (NGNs) that will offer integrated voice, video, data, and multimedia services — and innovative new services like IP television (IPTV) — with assured quality levels. An ITS staff member served as Vice Chair of ITU-T SG 13 and chaired SG 13's Working Party (WP) 4, which was responsible for 24 NGN Quality of Service (QoS) and Operation, Administration and Management (OAM) standards development projects. An ITS staff member chairs SG 9's Working Group on Quality Assessment, which defines quality objectives for integrated broadband cable networks and television and sound transmission. In that group, ITS chairs Question 14/9 (Objective and Subjective Methods for Evaluating Audiovisual Quality in Multimedia Services). ITS also leads and contributes to the ITU-affiliated Video Quality Experts Group (VQEG), which works with SG 9, SG 12 (Performance and QoS), and ITU-R WP 6C (Broadcasting Services — Programme Production and Quality Assessment) to develop objective, computer implementable, perception-based video and multimedia quality metrics that emulate the human visual system. In related work, ITS leads the Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA), a cross-cutting ITU-T standards body that unites the video quality expertise of SG 9 with the audio 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. ATIS PRQC develops national standards and contributes to ITU-T standardization in all of these technology areas. During FY 2008, Institute staff members led PRQC's QoS and Security Task Forces.

In FY 2008, Institute leaders contributed strongly to management of the Next Generation Network Global Standards Initiative (NGN-GSI), a SG 13-based standards development program that coordinates and accelerates NGN standardization across many ITU-T Study Groups. During FY 2008 SG 13's NGN-GSI handled over 1000 input documents and produced over 130 output documents, including 38 new ITU-T Recommendations and other specifications.

The Institute's PRQC leaders organized and managed seven PRQC meetings during FY 2008. Among other outputs, the group produced a new American National Standard (ANS) that defines an equipment-oriented availability metric for IP-based networks and services; a new ANS that defines Emergency Telecommunication Service (ETS) connection admission and service restoral priority levels for NGNs; and a new ANS that specifies an algorithm (developed at ITS) for calibrating transmitted and received video streams. ITS staff members spearheaded PRQC contributions enabling ITU-T SG 12 to complete two new ITU-T Recommendations on IP QoS interworking.



Example correlations from VQEG's Multimedia Phase I test using ITU-T Recommendations J.247, J.246, and PSNR.

An ITS staff member founded the Video Quality Experts Group and has co-chaired it since 1997. VQEG enables video experts from many countries to collaborate in developing and evaluating video quality metrics (VQMs), and its results strongly impact the standardization of VQMs in both ITU-T and ITU-R. The group works primarily via an e-mail reflector, publicly accessible at http://www.VQEG.org. During FY 2008 the number of participants subscribed to this reflector grew to 650. ITS chaired two physical VQEG meetings in FY 2008. ITS also contributed to VQEG's Reduced Reference-No Reference (RRNR) TV, HDTV, and Multimedia video test plans and provided key video source material to VQEG during FY 2008. ITS is spearheading new ITU-T work on multimedia quality assessment through its leadership in VQEG and the JRG-MMQA.

FY 2008 saw the completion of VQEG's multi-year Multimedia Phase I Project. The results of this validation test were reported to the ITU, and ITU-T Study Group 9 approved two new Recommendations based upon VQEG's test results:

- J.247, "Objective perceptual multimedia video quality measurement in the presence of a full reference"
- J.246, "Perceptual visual quality measurement techniques for multimedia services over digital cable television networks in the presence of a reduced bandwidth reference."

The figure above gives three plots showing results from one of the 41 subjective experiments in VQEG's Multimedia Phase I test. The left plot shows the correlation (ρ) for a full reference (FR) model from ITU-T Recommendation J.247; the middle plot shows the correlation for a reduced reference (RR) model from J.246; and the right plot shows the correlation for Peak Signal to Noise Ratio (PSNR), which is the traditional method used to measure signal quality. The new standardized methods show considerable improvement over PSNR.

Other Recommendations approved under ITS leadership in ITU-T Study Group 9 in FY 2008:

- J.244, "Calibration methods for constant misalignment of spatial and temporal domains with constant gain and offset." This Recommendation contains methods for calibrating transmitted video against source video in preparation for objective quality assessment.
- P.910 Revised, "Subjective video quality assessment methods for multimedia application." The major change in this Recommendation was the addition of the Absolute Category Rating – Hidden Reference (ACR-HR) method for subjectively assessing multimedia video.
- P.912, "Subjective video quality assessment methods for recognition tasks." This new Recommendation provides video quality assessment methods for applications that require a measurement of the ability to perform tasks using video.

Follow-on VQEG/SG 9 work will include Reduced Reference/No Reference, High Definition Television, and Hybid Perceptual/Bit Stream VQM validation tests.

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The Short Range Mobile-to-Mobile Project for NTIA/OSM used the ITS mobile radio propagation measurement facilities to conduct field measurements for a variety of environments, e.g., rural, suburban, urban. The photographs above show the equipment setup in an urban environment (photographs by C. Behm).

ITS Tools and Facilities

Audio-Visual Laboratories

The ITS Audio-Visual Laboratories offer a wide range of audio and video recording, storage, processing, reproduction, objective quality assessment, and subjective testing capabilities. These capabilities in turn support the development and verification of new quality estimation techniques for compressed digital audio and video, the development of novel subjective testing techniques for audio and video signals, and the development of efficient and robust coding algorithms.

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

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

Three separate rooms with controlled visual and/or acoustic environments are available for the subjective testing of audio and video signals. The controlled environments are specified in ITU-T Recommendation P.800 and ITU-R Recommendation BT.500, respectively. These specifications address background noise levels, wall colors, light levels, room dimensions, and other properties.

Finally, the labs feature an array of audio and video signal generators and analyzers to support laboratory measurement and calibration activities. Computers play a key role in laboratory operations. Four systems offer the ability to record and play back uncompressed digital audio bit-streams together with synchronized uncompressed SD and HD video bit-streams that conform to ITU-R and SMPTE Recommendations (e.g., SMPTE 259M/272M, 292M). Much audio and video processing is performed on high-performance workstations, supported by high capacity RAID arrays for storage of the uncompressed audio and video streams.

Lab activities include objective estimation of audio and video quality, and subjective testing of audio and video quality. Random access digital audio-video playback systems coupled with discrete-time and continuous-time wired and wireless electronic data entry systems greatly facilitate many of the subjective testing activities. Because multiple subjective testing rooms are available, the laboratory can support conversation, teleconferencing, and video teleconferencing tests as well as viewing and listening tests. Objective video quality estimation software, written in C++ and MATLAB, processes video signals in accordance with ANSI T1.801.03-2003, ITU-T Recommendation J.144, and ITU-R Recommendation BT.1683, resulting in estimates of video quality that show good correlation with subjective test results. Several different objective speech and audio quality estimation algorithms are available, including those defined in ANSI T1.518, ITU-T Recommendation P.862, and ITU-R Recommendation BS.1387. The labs support both batch-mode and real-time objective quality estimation.

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Digital Sampling Channel Probe

The digital sampling channel probe (DSCP), designed and patented at ITS, is used to characterize the wideband propagation characteristics of the radio channel. Consisting of a transmitter, receiver, and data acquisition system, the DSCP is used to make complex impulse-response measurements. The DSCP can transmit variable rate psudo noise codes at the same RF frequency for multiple-input multiple-output (MIMO) studies or multiple RF frequencies as desired. The DSCP receiver down-converts and digitizes the pseudo-noise signal at an intermediate frequency (IF), and then post-processes the data to calculate the channel impulse response. The system can collect data on multiple channels every 600-800 μs, allowing characterization of the Doppler spectrum and time variability of the mobile channel for HF systems (up to 5.8 GHz). Historically, the DSCP was employed extensively for channel characterization of cellular and personal communications services. ITS expanded the probe to eight channels capable of mobile phased array or MIMO measurements. Also available is a wide-bandwidth, high-frquency probe, particularly suited for high-resolution requirements such as wireless local area network (LAN) applications up to 30 GHz. Most recently, the probe's measurement range has been expanded down to the UHF TV bands, and has been used for short-range mobile-to-mobile propagation channel characterization. In this mode of operation, a variable bit rate code generator is used to allow simultaneous recordings at different bandwidths and frequencies.

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Green Mountain Mesa Field Site

The main Department of Commerce Boulder Laboratories campus contains a field site used for outdoor wireless network research. The site is connected to the ITS laboratories via both fiber optic and 802.11 links. The fiber optic link provides access to the ITS local area network (LAN) while the 802.11 link connects this field site to ITS' Wireless Networks Research Center (see p. 73). 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 for capability to operate remote data collection equipment. The outdoor router, located on an 80-foot tower, provides long range 802.11 links to other sites. These links provide 802.11b services and are also used for network performance testing. The site's unique location, several hundred feet above the main Department of Commerce campus, allows for the provisioning of wireless test links over a large portion of eastern Boulder county. The site is operated year round.

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ITS home page: http://www.its.bldrdoc.gov

ITS Internet Services

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

- Information about ITS programs and projects. Available at http://www.its.bldrdoc.gov/programs/.
- An ITS organization chart and listing of ITS staff with contact information. Available at http://www.its.bldrdoc.gov/organization.php.
- Recent ITS publications including NTIA Reports, special publications, and journal articles. Available at http://www.its.bldrdoc.gov/pub/pubs.php.
- Radio propagation data. Available at http://www.its.bldrdoc.gov/data/radio_propagation_data/.

- Radio propagation software. Available at http://www.its.bldrdoc.gov/software/.
- Information about the Table Mountain Field Site. Available at http://www.its.bldrdoc.gov/table_mountain/.
- Telecommunications Analysis Services. Available at http://tas.its.bldrdoc.gov/.
- Video Quality Metric software. Available at http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm.
- Information about ITS-sponsored events such as ISART. Available at http://www.its.bldrdoc.gov/meetings/.
- The ITS brochure. Available at http://www.its.bldrdoc.gov/ITS_brochure/ITS_brochure.pdf.

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ITS Local Area Network

ITS maintains a highly flexible local area network to support local networking services and laboratory interconnections. A structured cabling system interconnects all offices and laboratories with optical fiber, category 5, and category 6 twisted-pair cabling to support high-bandwidth communications on demand. Over 200 devices are supported on 10Base-T, 100Base-T, and gigabit segments. This provides ITS with great flexibility and rapid reconfiguration capability for new programmatic needs. A firewall-based VPN capability securely extends the network to authorized personnel anywhere in the world.

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Mobile Radio Propagation Measurement Facilities

ITS maintains and continually develops a pair of measurement vehicles comprising a transmitter-receiver system that characterizes the properties of radio channels over a wide frequency range, from VHF to 30 GHz. The transmitter vehicle has an on-board generator, a pair of telescoping masts, and a set of radio modulators and transmitters. The receiver van is equipped with on-board power, a telescoping mast, azimuth and elevation controllers, and global positioning system (GPS) devices with a dead-reckoning backup. A suite of measurement equipment, much of it designed and hand-built by ITS engineers, is used in the vehicle. These include wideband systems for measuring radio channel impulse responses; impulse response measurement capability at 30 GHz with 2-ns resolution is enhanced with a digital wideband recording system. To support mobile-to-mobile short-range propagation model development, an 8-channel receiver and an 8-channel, 14-bit data acquisition system have been developed. Multi-channel synchronous acquisition can be used for antenna array measurements and multi-frequency broadband measurements. Mobile measurement capability allows space division multiple access (SDMA) algorithms to be implemented using data collected in a wide variety of environments (e.g., urban, rural, and suburban). This data can in turn be used to model and simulate the performance of radio systems in such environments. A suite of analysis software is continuously developed and maintained for calculating mobile propagation metrics from impulse response data. Typical metrics are power delay profiles, delay spread, received power versus bandwidth, Doppler spectrum, and coherence bandwidth.

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Public Safety Audio & Video Laboratories

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

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

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

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

The primary role of the PSVL is to support the PSVQ project (see pp. 38-39). In accomplishing this mission, scenes that contain selected vital elements of public safety responder uses are created and filmed on high-definition cameras. These scenes include simulations of surveillance cameras (indoor and outdoor), in-car police cameras, and search and rescue robot cameras, among others. The video is then captured and edited on the PSVL workstations. Selected scenes are processed through controlled versions of the communication systems that might be typical of what a jurisdiction may consider purchasing. The communication systems processing includes compression schemes and simulated wired and wireless networks.

To determine if a system is adequate for use in specified applications, first responders view the video and attempt to perform certain tasks such as identifying an object or reading a license plate. The results of these tests provide data for developing recommendations.

Together, the PSAL and PSVL provide valuable insight into the requirements for public safety audio and video communications.

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Public Safety RF Laboratory

ITS’ management of the Public Safety RF Laboratory (PSRF Lab) supports sponsor efforts to test Land Mobile Radio (LMR) systems and components according to Telecommunications Industry Association (TIA) Project 25 (P25) testing standards for LMR (the TIA-102 suite of standards). ITS’ PSRF Lab staff contributes to the development and maturation of all three facets of the P25 testing standards: performance, conformance, and interoperability. The PSRF Lab implements these test standards in the lab in support of internal research, outside agency (OA) interagency agreements (IAAs), and cooperative research and development agreements (CRADAs) with other non-Federal government entities.

In 2007, the PSRF Lab completed installation of an RF screen room and developed automated test software to assess the RF performance characteristics of P25 equipment. In 2008, PSRF Lab staff installed a functional working two-site, three-channel VHF trunking system and a single-site, four-channel UHF trunking system, using commercial P25 equipment. These trunking systems are facilitating the PSRF Lab mission to contribute to the development of the Inter-RF Subsystem Interface (ISSI) as defined by TIA.

An ongoing external program of great interest to the PSRF Lab is the Department of Homeland Security (DHS) P25 Compliance Assessment

Program (P25 CAP), a voluntary program that allows P25 equipment suppliers to formally demonstrate their products' compliance with a select group of requirements within the TIA-102 suite of P25 standards. The purpose of the program is to provide emergency response agencies with evidence that the communications equipment they are purchasing meets P25 standards for performance, conformance, and interoperability, and to ensure that testing entities are implementing P25 test procedures correctly. The PSRF Lab is now undertaking the task of implementing the practices developed by the DHS P25CAP Governing Board, in order to allow the PSRF Lab to be as capable of performing the performance, conformance, and interoperability tests that P25CAP-recognized laboratories perform.

While the primary use for ITS' PSRF Lab test and measurement capability is the testing of P25 LMR systems and components, the underlying infrastructure and analysis facilities of ITS' PSRF lab can support a much broader range of tests and radio equipment. This capability is available on a first-come, first-served basis to both NTIA and other agencies.

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Pulsed Radar Target Generator

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

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Radio Spectrum Measurement Science (RSMS) System Tools

The Radio Spectrum Measurement Science (RSMS) system is a state-of-the-art measurement system designed for gathering information on spectrum occupancy, equipment compliance, electromagnetic compatibility, and interference resolution. Its purpose is to provide NTIA's Office of Spectrum Management (OSM) with critical measurement support from ITS for determining policies regarding government radio systems and spectrum utilization. The RSMS system is a dynamic and flexible system that incorporates automated, semi-automated, and manual techniques for the measurement and analysis of radio emissions. While not defined by any single hardware configuration, the system includes such devices as the latest in spectrum analyzers, digital oscilloscopes, vector signal analyzers, and signal intercept and collection systems. Measurements can take place in a laboratory or in the field, and they can be mobile or stationary; therefore the system has been made flexible enough to accommodate each of these situations.

An integral part of the system is the measurement vehicle, which is now in its 4th generation. The vehicle has a highly shielded enclosure (60 dB) with three equipment racks, three 10-meter masts, and a 20-kW diesel generator, as well as internet connections, fiberoptic control lines, multiple power outlets, and overhead cable racks.

The control and acquisition software is fully developed by ITS so that new and innovative measurement techniques can be easily altered to meet immediate needs. A major objective in the development of the 4th generation software has been to provide a tool that can easily accommodate new equipment and different hardware configurations, and to expand on existing measurement capabilities.

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SIPRNET Capability

ITS maintains a connection to the Secret Internet Protocol Routable Network (SIPRNET). This connection allows ITS sponsors and Department of Defense users direct access to ITS tools and facilities in a secure environment, improving the quality of support that the Institute can give organizations with classified needs. Since many of the planning and associated support activities of the military require a classified channel for discussions and data transfer, the need exists for a secure environment within which project planning and support can be carried on without interruption. ITS maintains several computer systems with a variety of software capabilities to support propagation planning and modeling, as well as emerging technologies research. The secure facilities allow users to import data from many military facilities and support organizations into propagation models and other management software. A complete end-to-end propagation planning capability in a secure environment is available for classified needs. Various research studies that ITS conducts (that are determined as classified information) can also reside on the SIPRNET, allowing access by agencies on a need to know basis.

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Spectrum Compatibility Test and Measurement Sets

The introduction of new radio technologies in close physical and frequency proximity to older 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 actual or proposed operating environment to determine its impact on other users of the radio spectrum. 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 communication systems. In these sorts of situations a system is needed that simulates the spectral emissions of other devices with a wide range of latitude and 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 a variety of 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 two different approaches to generating interference signals. One approach is to build custom hardware and software combinations of discrete-component equipment, including programmable arbitrary waveform generators, mixers, RF signal generators, and amplifiers. ITS has used a number of these configurations to simulate the spectral output of a wide variety of communication systems. These signals can be coupled directly into a system under test or they can be transmitted through space into a target system's receiver to more accurately gauge its response to a real interference situation.

The second approach that ITS uses for generating interference is to utilize high-speed digitizers, called vector signal analyzers (VSAs), to record interference waveforms in bandwidths up to 36 MHz, and to then either radiate or hardline-couple those waveforms into victim receivers using vector signal generators (VSGs) that operate somewhat as inverses to VSAs. Alternatively, VSGs may be preprogrammed with the requisite mathematical information to create particular waveform modulations, such as quadrature phase shift keyed (QPSK) signals.

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

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Sign at the west entrance to the Table Mountain field site (photograph by J.D. Ewan).

Table Mountain Field Site and Radio Quiet Zone

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

- **Spectrum Research Laboratory** — A state-of-the-art facility for research into radio spectrum usage and occupancy. Radio Quiet restrictions ensure that no signal incident on the mesa overpowers any other.
- **Open Field Radio Test Site** — 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 mesa, ranging from 4-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 as well as the control equipment and motors to rotate the turntable. This facility can be operated remotely by computer.
- **18.3 Meter (60 Foot) Parabolic Dish Antennas** — These two antennas are steerable in both azimuth and elevation and have been used at frequencies from 400 MHz to 6 GHz.
- **Radar Test Range** — A large space just south of the Spectrum Research Laboratory is available for testing radar systems.

The Table Mountain Research program supports a number of research activities, e.g., studying the effects of radio propagation on digital signal transmission, environmental and man-made noise, verification of antenna propagation models, and the development of measurement methods needed to assess efficient spectrum occupancy and usage (see pp. 10-11). Partnerships and cooperative research activities are encouraged at the site. Other agencies currently using the facilities include the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS).

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Telecommunications Analysis Services

The Telecommunications Analysis (TA) Services program provides the latest ITS-developed engineering models and research data to industry and other Government Agencies via a web-based interface (http://tas.its.bldrdoc.gov/). User-friendly and efficient, it offers a broad range of programs that allow the user to design or analyze the performance of telecommunications systems. Currently available are: on-line terrain data with 1-arc-second (30 m) resolution for CONUS and 3-arc-second (90 m) resolution for much of the world, and GLOBE (Global Land One-km Base Elevation) data for the entire world; the U.S. Census data for 2000, 1997 update, and 1990; FCC databases; and GIS databases (ArcInfo). TA Services has developed models that predict communication system coverage and interference for many broadcast applications. New models in the GIS environment have been developed (see pp. 40-41). The following is a brief description of programs available through TA Services.

HAAT – Calculates Height Above Average Terrain for an antenna at a specified location.
PCS/LMDS – Allows the user to create or import surfaces which may include terrain, buildings, vegetation, and other obstructions in order to perform line of sight (LOS) and diffraction studies.
FCCFIND, FMFIND, TVFIND, AMFIND, and TOWERFIND – Allows the user to search the FCC database for particular stations or by search radius around a point of interest.
PROFILE – Extracts path profiles according to user-specified input parameters. After the data is extracted, either the individual elevations or an average elevation along the profile can be obtained. A user can also receive plots of the profiles adjusted for various K factors. For microwave links, Fresnel zone clearance can be determined so that poor paths can be eliminated from a planned circuit or network.
SHADOW – Plots the radio LOS regions around a specified location in the United States using digitized topographic data. The program shows areas that are LOS to the base of the antenna, areas that are LOS to the top of the antenna, and areas that are beyond LOS to the antenna.
TERRAIN – Plots terrain elevation contours from any of the terrain databases available (1-arc-second SDTS for CONUS, 3-arc-second USGS, and GLOBE for the whole world).
COVERAGE – Calculates the received signal levels along radials that are spaced at user-defined intervals of bearing around the transmitter. The program lists the contours of signal coverage of the transmitter along each radial and lists distances to user-specified contours for each radial. Either the FCC broadcast rules or the ITS Irregular Terrain Model (ITM) can be chosen for calculations.
CSPM – Determines the system performance of mobile and broadcast systems in detailed output plots of signal intensity. Plotted outputs can be faxed to the user, plotted on clear plastic for overlaying on geopolitical maps, or downloaded to the user site (in HPGL, GIF, or TARGA format). This program uses the ITS ITM in a point-to-point mode, or other user-chosen algorithms for path loss calculation.
HDTV – Allows the user to analyze interference scenarios for proposed digital television (DTV) stations. The model contains current FCC and MSTV allotment tables and maintains the catalogs created by all program users. The user can create new stations by hand, or by importing station information directly from the FCC database. Analyses may be performed using existing FCC database and allotment assignments, or the user can replace a station with one created and maintained in his/her catalog.
NWS – A specialized application to assist the National Weather Service in maintaining its catalog of weather radio stations (currently about 920).
PBS – An analysis model similar to the HDTV model, but specialized for Public Broadcasting Stations (PBS). Typical outputs may consist of composite plots showing Grade A and B coverage of several stations or "overlap" plots which show areas covered by more than one station.
ICEPAC/VOACAP/REC533 – High Frequency prediction models which can be downloaded (free) and executed on Windows based platforms.
ITM – Source code available for the ITS Irregular Terrain Model (Longley/Rice).
IF-77 – Source code available for the IF-77 Air/Ground, Air/Air, Ground/Satellite prediction software (.1 to 20 GHz).

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Wireless Networks Research Center (WNRC)

The Wireless Networks Research Center (WNRC) provides a common laboratory area for research in wireless networks and wireless network access technologies. The WNRC allows the Institute 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, non-cooperative 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 device has the ability to perform provider-independent PN offset scans and cdma2000 level 3 message logging.

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

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American Kestrels at the Table Mountain Field Site (photograph by J.W. Allen).

An ITS engineer running propagation modeling software. The Institute has developed and maintains some of the world's most recognized propagation models (photograph by F.H. Sanders).

A P25 radio base station at the ITS laboratory (photograph by F.H. Sanders).

ITS Projects in FY 2008

NTIA S&E 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
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Broadband Wireless Research
Deploy state-of-the-art measurement systems for collecting broadband radio-wave propagation data, to promote spectrum extension, aid in the development of 3G and 4G cellular systems, and evaluate proposed short range unlicensed device interference.
Project Leader: Robert T. Johnk (303) 497-3737
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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
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Network Interoperability
Conduct research in multimedia quality, enterprise architecture planning, and various methodologies in developing and documenting interoperable architectures. Participate in P25/TIA TR-8 and other standards organizations (e.g., VQEG, ATIS, IETF). Investigate multimedia applications and establish baseline interoperability for multimedia applications.
Project Leader: Arthur A. Webster (303) 497-3567
awebster@its.bldrdoc.gov

Network Performance
Provide objective, expert leadership and key technical contributions in ITU-T and related U.S. industry committees responsible for developing broadband network performance, Quality of Service (QoS), and resource management standards.
Project Leader: Neal B. Seitz (303) 497-3106
nseitz@its.bldrdoc.gov

Networking Technology
Research, develop, and demonstrate state-of-the-art methods and tools related to the measurement of wireless data networks, such as wireless local area networks (WLANs). Develop network-based measurement methods for Voice over IP (VoIP) quality.
Project Leader: Robert B. Stafford (303) 497-7835
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Noise and Spectrum Occupancy Measurement Research
Characterize and track over time the levels of radio channel noise in various frequency bands and environments. Identify areas of greatest need, design and implement systems to perform measurements in those areas, and report on the results. Conduct spectrum usage surveys.
Project Leader: Jeffery A. Wepman (303) 497-3165
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RSMS Enhancements
Support RSMS operations through the development and maintenance of software, hardware, systems, and equipment for FY 2008 operations tasks.
Project Leader: John E. Carroll (303) 497-3367
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RSMS 4th Generation Development
Provide new and innovative measurement hardware and software tools for current and future RSMS capabilities. Project future needs and develop long-term strategies for building the necessary tools.
Project Leader: J. Randy Hoffman (303) 497-3582
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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
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Table Mountain Modernization
Maintain and upgrade the Table Mountain Field Site infrastructure, ensure a safe working environment there, and provide logistical support for research activities at the field site.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

Table Mountain Research
Utilize the Table Mountain Field Site and Radio Quiet Zone to support fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services in order to expand ITS' knowledge base, identify emerging technologies, and develop new measurement methods.
Project Leader: J. Wayde Allen (303) 497-5871
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Third Generation Wireless Interference Modeling and Characterization
Present technical contributions on PCS interference effects to ATIS Technical Subcommittee WTSC-RAN. Contribute to related fora (e.g., ITU-R WP 5D, SG 3K and 3M) as appropriate. Develop a technology-independent, multi-channel PCS interference model for use in the evaluation of CMRS and other potentially affected (e.g., public safety) systems.
Project Leader: Timothy J. Riley (303) 497-5735
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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 RR measurement technology for both Standard Definition (SD) and HD TV systems.
Project Leader: Stephen Wolf (303) 497-3771
swolf@its.bldrdoc.gov

NTIA/OSM Projects

Antenna Polarization Mismatch
Perform measurements of antenna polarization mismatch loss that can be used in analyses to determine EMC between antennas using the same radiocommunication service or operating in different services. Perform measurements to determine the variation of antenna gain over frequency.
Project Leader: Brent L. Bedford (303) 497-5288
bbedford@its.bldrdoc.gov

Characterization of Low Noise Amplifiers
Characterize the response of low noise amplifiers (LNA) from several manufacturers to single and multiple interfering signals. Attempt to gain insight into the effects of manufacturer design choices on the performance of LNAs.
Project Leader: Yeh Lo (303) 497-3393
ylo@its.bldrdoc.gov

Development of Methodology for Statistical Combinations of Noise and Interference
Develop guidance/guidelines as to when an interfering signal that is combined with a noise signal can be considered "noise-like." Document the guidance and guidelines in a technical memorandum that will be incorporated into the Best Practices Handbook.
Project Leader: Michael Cotton (303) 497-7346
mcotton@its.bldrdoc.gov

Effects of Receiver Signal Processing on Interference Rejection
Determine the feasibility of using a commercially available computer capability to simulate the signal processing for a range of different error correction schemes. Implement this capability to evaluate the performance of a radio system subjected to signals from other radio links.
Project Leader: Robert J. Achatz (303) 497-3498
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Minimum Detectable Signal in GPS Bands
Perform technical measurements and analyses to investigate the problem of determining minimum detectable signal levels in GPS bands, at and near 1575 MHz. Report results to OSM.
Project Leader: Yeh Lo (303) 497-3393
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Initial Spectrum Testbed and Antenna Harmonic Characterization
Perform technical planning related to the spectrum testbed effort, and provide outputs to Working Level Group E (WLG-E). Perform measurements of electrical characteristics and beam-forming properties of various antennas at their harmonic frequencies.
Project Leader: Frank H. Sanders (303) 497-7600
fsanders@its.bldrdoc.gov

International Symposium on Advanced Radio Technologies (ISART)
Develop and conduct ISART 2008. The focus will be on noise and interference and propagation prediction modeling for more efficent spectrum management. Gather information on these technologies and applications relevant and useful to NTIA/OSM's mission.
Project Leader: Patricia J. Raush (303) 497-3568
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Radar Support Tasking
Support USWP8B, USJRG, and the U.S. Administration's positions in ITU-R WP8B and JRG 1A-1C-8B by providing position papers, technical reports, and attendance in these forums. Also support the Radar Correspondence Group (RCG) and the JRG 1A-1C-8B and RCG websites.
Project Leader: Frank H. Sanders (303) 497-7600
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Short-Range Mobile-to-Mobile Propagation Prediction Model
As part of a multi-year effort to address the need for an under-1 km propagation prediction model, continue looking at this specific scenario and its unique environmental influences. Continue model development and a field measurement campaign to verify and validate those models. Bring the results of the project to the ITU-R and IEEE, as appropriate.
Project Leader: Paul M. McKenna (303) 497-3474
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Spectrum Efficiency of the Radiodetermination Service
With OSM, develop a report on the basic parameters and trade-offs to consider in an analysis of spectrum efficiency of the radiodetermination service, and provide example calculations of spectrum efficiency for some simple radars. Develop an analytical approach to radar spectrum efficiency in general.
Project Leader: Frank H. Sanders (303) 497-7600
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Other Agency Projects

Department of Commerce / National Institute of Standards and Technology EEEL / Office of Law Enforcement Standards

Public Safety Telecommunications Interoperability
Provide engineering support, scientific analysis, technical liaison, and test design and implementation to allow the identification/development and validation of interoperability standards for the justice/public safety/homeland security community. Provide technical assessments and evaluations of commercial products and services that may provide interim solutions for various interoperability scenarios.
Project Leader: Jeffrey R. Bratcher (303) 497-4610
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Analysis, Demonstration, T&E
Project Leader: DJ Atkinson (303) 497-5281
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Assessment of Integration Strategies
Project Leader: Kameron A. Behnam (303) 497-3830
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Development of Requirements, AF Interoperability Standards
Project Leader: Andrew P. Thiessen (303) 497-4427
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Public Safety Architecture Framework (PSAF)
Develop a User's Manual for the Public Safety Architecture Framework (PSAF).
Project Leader: Christopher Redding (303) 497-3104
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Public Safety Video Quality Testing
Develop and conduct video quality tests to assist public safety agencies with telecommunications systems and equipment selections. Analyze data and write a report on the results.
Project Leader: Dr. Carolyn Ford (303) 497-3728
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Speaker ID in Public Safety Communications
Produce a qualitative assessment of how speaker identification (SID) is degraded by several example Public Safety Communications systems.
Project Leader: Stephen Voran (303) 497-3839
svoran@its.bldrdoc.gov

Department of Commerce / National Oceanic and Atmospheric Administration / NOAA Weather Radio Program Office

NOAA Weather Radio Receiver Tests
Compile the characteristics and responses of NWR receivers to various simulated NWR transmissions.
Project Leader: Raian F. Kaiser (303) 497-5491
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Department of Defense

Enhancements to Communication System Planning Tool (CSPT) for DOD
Enhance the ITS CSPT model through improvements in the incorporated models and addition of models, as well as user support.
Project Leader: Robert O. DeBolt (303) 497-5324
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Department of Defense / U.S. Air Force

Development of RNSS Sampled Waveforms
Measure the emission spectra and capture I/Q waveforms for four RNSS SV transmission modulations in the 1215-1400 MHz frequency band.
Project Leader: Brent L. Bedford (303) 497-5288
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Department of Homeland Security / Federal Partnership for Interoperable Communications

DHS/FPIC Technical Engineering Support
Provide engineering support to FPIC for public safety radio standards development and testing in the ITS test facility. Assist in the development of P25 standards in accordance with the APCO P25 Interface Committee (APIC) and TIA procedures. Identify conditions advanced by P25 vendors or interested parties that require further engineering analysis by an independent entity.
Project Leader: DJ Atkinson (303) 497-5281
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Department of Homeland Security / National Communications System

ETS Standards Development
Facilitate the standardization of NS/EP specifications, protocols, and mechanisms. Develop and/or verify emergency telecommunications service (ETS) mechanisms. Assist NCS in support of PDD-63 and associated CIP initiatives.
Project Leader: Arthur A. Webster (303) 497-3567
awebster@its.bldrdoc.gov

Department of Homeland Security / Office of the CIO

Standardization of Measurement Methods for Investigative Devices
Provide engineering and technical support to the OCIO Wireless Management Office for development of standardized measurement methods of investigative devices. Conduct measurements on new and/or proposed investigative devices defined by DHS.
Project Leader: DJ Atkinson (303) 497-5281
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Department of Transportation / Federal Aviation Administration

Wind Turbine Radar Interference Assessment
Provide an independent and objective assessment of the effects that wind turbines may have on air traffic control radar operations and suggest methods for mitigating such effects if found to be harmful.
Project Leader: Frank H. Sanders (303) 497-7600
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Department of Transportation / Federal Railroad Administration

Railroad Telecommunications Study
Continue technical support to the Federal Railroad Administration as it pertains to railroad telecommunications and the activities of the Association of American Railroads' (AAR) Wireless Communications Committee (WCC).
Project Leader: John M. Vanderau (303) 497-3506
jvanderau@its.bldrdoc.gov

National Archives and Records Administration

NARA E-Government Study
Demonstrate and evaluate the "Information Portal" concept to allow NARA to offer a system that will improve knowledge sharing across the organization and complement their physical records storage practice with an electronic version of the same.
Project Leader: Alan W. Vincent (303) 497-3500
avincent@its.bldrdoc.gov

Various Federal & Non Federal Agencies

Telecommunications Analysis Services
Develop and maintain TA Services analysis tools (propagation models) and their corresponding interfaces to users and databases, including maintenance and development of GUIs and various databases.
Project Leader: Robert O. DeBolt (303) 497-5324
rdebolt@its.bldrdoc.gov

Cooperative Research and Development Agreements (CRADAs)

Areté Associates

Coded Aperture Ladar for Long Range Applications
Support Areté Associates in testing and demonstrating laser radar technologies at the Table Mountain Field Site.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

First RF Corporation

Installed Performance of Antennas
Support First RF in testing antenna system performance on a number of vehicles including UAVs, using the turntable facility at the Table Mountain Field Site.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

Lockheed Martin Coherent Technologies

Laser Testing at Table Mountain
Support LMCT's field-testing and characterization of components, subsystems, and systems for eyesafe coherent laser radar at Table Mountain Field Site.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

RF Metrics

A Study of the Use of a Novel Antenna Pattern Collection Technique for Radar Emissions
Support RF Metrics' attempts to measure a radar system using the test procedures outlined in the ITU-R M-1177 standard and measure the antenna pattern using the technique described in NTIA Report TR-06-436.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

Sensis Corporation

X-Band Radar Emission Measurements
Assess the compliance of a new X-band radar's RF emissions with the radar spectrum engineering criteria (RSEC).
Project Leader: John E. Carroll (303) 497-3367
jcarroll@its.bldrdoc.gov

Spirent Communications

IP-Based Video Quality Measurements
ITS and Spirent will work cooperatively to develop new video quality measurement technology for IP-based TV and video telephony services being deployed by service providers.
Project Leader: Stephen Wolf (303) 497-3771
swolf@its.bldrdoc.gov

State of Wyoming

Public Safety Radio Testing Program
Test and evaluate P25 subscriber units from a variety of different vendors, in order to provide the State of Wyoming with technical results to aid in determining the viability of using multi-vendor P25 subscriber units in the WyoLink Statewide system.
Project Leader: John M. Vanderau (303) 497-3506
jvanderau@its.bldrdoc.gov

University of Colorado

Ad hoc UAV Ground Network Test Bed (AUGNet)
Support CU's experiments with communication networks between low-cost small unmanned aerial vehicles similar to model radio-controlled (RC) airplanes, and ground-based radios.
Project Leader: J. Wayde Allen (303) 497-5871
wallen@its.bldrdoc.gov

ITS Publications and Presentations in FY 2008

NTIA Publications

D.J. Atkinson and A.A. Catellier, "Intelligibility of selected radio systems in the presence of fireground noise: Test plan and results," NTIA Technical Report TR-08-453, Jun. 2008.

> This report describes an experiment conducted to measure the intelligibility of selected radio communication systems when those systems are employed in high-background-noise environments experienced by firefighters. The test plan for a Modified Rhyme Test (MRT) is detailed, including requirements for source material preparation and listening test conduct. Finally, the results of the test are presented, along with the data analysis. The results indicate that in some environments analog radios performed better than digital radios, and in some environments no radios performed well. This information should be considered whenever an agency is preparing to purchase and deploy a new communications system.

J.E. Carroll, J.R. Hoffman, and R.J. Matheson, "Measurements to characterize land mobile channel occupancy for Federal bands 162–174 MHz and 406–420 MHz in the Denver, CO area," NTIA Technical Report TR-08-455, Sep. 2008.

> This report describes field measurements to characterize Land Mobile Radio (LMR) channel occupancy of Federal bands 162–174 megahertz (MHz) and 406–420 MHz at a single location overlooking the Denver, Colorado metropolitan area. This is part of the National Telecommunications and Information Administration effort to improve the spectrum efficiency of Federal radio usage. Measurements of the received radio traffic levels in these LMR frequency bands were performed over an 8-day period for the purpose of determining radio channel usage within the receiver spatial coverage of approximately 100-kilometer (km) radius for base stations, 50-km radius for mobile units, and 25-km radius for handheld units. The measurements were made using newly developed techniques that digitize as much as a 5-MHz segment of spectrum and process it to obtain simultaneous signal levels of up to 400 individual LMR channels. These techniques provided faster measurements, but also allowed enhanced post-processing of the data to remove effects of impulsive noise-like sources.

J.J. Lemmon, J.E. Carroll, F.H. Sanders, and D. Turner, "Assessment of the effects of wind turbines on air traffic control radars," NTIA Technical Report TR-08-454, Jul. 2008.

> This technical report describes the results of a study exploring the effects of power-producing wind turbines on Federal Aviation Administration (FAA) air traffic control (ATC) radars. The study was performed to identify the extent to which these effects exist, and to identify mitigation techniques and parameters for such effects. The topics addressed in this report are: review of the current state of the literature on wind turbine effects on ATC radar performance; determination of criteria for recommended no-interference radii between ATC radars and wind turbines; determination of methodology for assessing effects of wind turbines on radars that are within no-interference radii; analysis of the potential for desired targets to be lost in azimuths other than those of wind turbine farms; and consideration of the effects of wind turbines on secondary radar (i.e., ATC beacon interrogator, or ATCBI) performance. The study results indicate that documented cases of deleterious effects from wind turbines do exist and are numerous. Due to the large number of parameters that enter the analysis, a simple, universally applicable set of guidelines for siting of wind turbines near radars is not feasible. However, this study shows that, by making nominal assumptions about turbine characteristics and siting parameters such as local topography, it is possible to develop a universally applicable methodology for assessing potential interference between wind farms and ATC radars.

P.J. Raush and K.E. Davis (Eds.), "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008, June 2-4, 2008," NTIA Special Publication SP 08 452, Jun. 2008.

No abstract available.

Outside Publications

Articles in Conference Proceedings

K. Brunnström, D. Hands, F. Speranza, and A. Webster, "Evaluation of video quality models for multimedia," in *Proc. Electronic Imaging 2008*, San Jose, California, Jan. 27-31, 2008.

The Video Quality Experts Group (VQEG) is a group of experts from industry, academia, government and standards organizations working in the field of video quality assessment. Over the last 10 years, VQEG has focused its efforts on the evaluation of objective video quality metrics for digital video. Objective video metrics are mathematical models that predict the picture quality as perceived by an average observer. VQEG has completed validation tests for full reference objective metrics for the Standard Definition Television (SDTV) format. From this testing, two ITU Recommendations were produced. This standardization effort is of great relevance to the video industries because objective metrics can be used for quality control of the video at various stages of the delivery chain.

Currently, VQEG is undertaking several projects in parallel. The most mature project is concerned with objective measurement of multimedia content. This project is probably the largest coordinated set of video quality testing ever embarked upon. The project will involve the collection of a very large database of subjective quality data. About 40 subjective assessment experiments and more than 160,000 opinion scores will be collected. These will be used to validate the proposed objective metrics. This paper describes the test plan for the project, its current status, and one of the multimedia subjective tests.

A. Catellier and S. Voran, "Speaker identification in low-rate coded speech," in *Proc. 7th International Conference on Measurement of Audio and Video Quality in Networks (MESAQIN)*, Prague, Czech Republic, May 2008.

While useful speech communication systems must be intelligible, most systems aim to transmit secondary information, such as attributes of a speaker's voice, as well. This secondary information can allow a listener to identify the speaker and his emotional state. Testing speech communications systems for the delivery of intelligible speech is common, but testing for human perception of the delivery of this secondary information is less common, though some prior work has been done. Building on this prior work, we describe the design, implementation, analysis and results of a new listening experiment that characterizes the listener identification of six different speakers using six different low-rate digital speech communication systems.

We display these experimental results along with results from our prior work to quantify listener detection of dramatized speaker urgency and word intelligibility in sentence context for the same six speech communication systems. We conclude that the speaker identification task used in this experiment is about three times more robust to communication system degradations than word intelligibility in sentence context.

M. Cotton, "A methodology for approximating BPSK demodulator performance in the presence of various undesired signals," in "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008," P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP 08 452, Jun. 2008, pp. 36-42.

This paper describes a methodology for analyzing binary phase-shift keyed demodulator performance in the presence of various types of undesired signals. It utilizes models of the underlying random processes to determine the probability of a bit error. The basic calculation involves integrating the probability distribution function of the internal receiver noise (assumed to be Gaussian) plus the undesired signal. When this integral cannot be solved analytically, a sample-function analysis is utilized. Results are given that compare the effects of various undesired signals (i.e., continuous-wave, MPSK, impulsive noise, and gated noise) to those of Gaussian noise.

N. DeMinco and P. McKenna, "A comparative analysis of multiple knife-edge diffraction methods," in "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008," P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP 08 452, Jun. 2008, pp. 65-69.

This report describes the comparative analysis of four alternative methods to a rigorous method for computing multiple knife-edge diffractions in non-line-of-sight scenarios. These alternative methods are candidates for use with the short-range mobile-to-mobile radio-wave propagation model under development at the Institute for Telecommunication Sciences. The results of this analysis show where alternative methods that reduce computation time can be used for analyzing knife-edge diffractions while maintaining suitable accuracy.

R.T. Johnk, "High-resolution propagation measurements using conventional EMC test antennas—A numerical study," in "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008," P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP 08 452, Jun. 2008, pp. 133-138.

This paper explores the possibility of using common types of electromagnetic compatibility (EMC) test antennas to perform high-resolution time-domain propagation measurements. The objective of this research is to provide wireless engineers with a tool to perform propagation measurements using a combination of commercial-off-the-shelf EMC test antennas and a stepped-frequency measurement system such as a vector network analyzer. Numerical simulations are used to model propagation path transmission with biconical antennas, log-periodic dipole arrays, and dipoles. A two-step measurement procedure and an efficient data processing sequence are used to generate high-resolution time-domain waveforms. The results are promising, and demonstrate that high-resolution waveforms can be obtained using models of conventional, low-frequency EMC antenna types.

R.T. Johnk, "High-resolution time-domain site attenuation measurements using conventional EMC test antennas—A numerical study," in *Proc. 2008 IEEE EMC Symposium*, Detroit, Michigan, Aug. 18-22, 2008.

This paper explores the possibility of using common types of electromagnetic compatibility (EMC) test antennas to perform high-resolution time-domain site attenuation measurements. The objective of this research is to provide EMC engineers with a tool to perform evaluations of radiated emissions test sites. Numerical simulations are used to site attenuation behavior using biconical antennas, log-periodic dipole arrays, and dipoles. A two-step measurement procedure and data processing sequence are used to generate high-resolution time-domain waveforms. The results are promising, and demonstrate that high-resolution waveforms can be obtained using models of conventional EMC antenna types.

R.T. Johnk, P. McKenna, P. Papazian, N. DeMinco, G. Sanders, H. Ottke, B. Arment, J. Shankel, and D. Strouse, "A mobile-to-mobile propagation measurement system," in "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008," P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP 08 452, Jun. 2008, pp. 28-35.

This paper describes a mobile-to-mobile propagation measurement system that is currently being developed at the Institute for Telecommunication Sciences under the sponsorship of the Office of Spectrum Management. This system uses a fixed transmitter truck and a moving receiver van to characterize radio-frequency channels of selected urban and rural environments. The transmitter and receiver architectures are described, and selected time- and frequency-domain measurement results are presented. The results obtained so far are very promising and demonstrate the versatility and effectiveness of this measurement system.

K.A. Remley, G. Koepke, C.L. Holloway, C. Grosvenor, D.G. Camell, and R.T. Johnk, "Radio communications for emergency responders in high-multipath outdoor environments," in "Proceedings of the International Symposium on Advanced Radio Technologies/ClimDiff 2008," P.J. Raush and K.E. Davis, Eds., NTIA Special Publication SP 08 452, Jun. 2008, pp. 106-111.

We present measurement data to support development of technology and standards for broadband, digitally modulated radio communications used by emergency responders. Measurements were conducted at an oil refinery having extensive outdoor piping and other metal components. This structure represents a class of high-multipath, outdoor propagation environments that includes electrical generation facilities, chemical plants, and other outdoor, heavy industrial environments where reliable emergency responder communications is critical. The measurement results presented here quantify the extent of the multipath, loss, and other propagation effects in such high-multipath outdoor environments.

S. Voran, "Lossless audio coding with bandwidth extension layers," in *Proc. 2007 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics*, New Paltz, New York, Oct. 2007.

Layered audio coding typically offers reduced distortion as bit rate is increased, but that distortion is spread across the entire band until the lossless coding bit rate is reached and distortion is eliminated. We propose a layered audio coding paradigm of bandwidth extension, rather than distortion reduction. For example, a core layer can provide lossless coding of a 24 kHz bandwidth signal (f_s=48 kHz), then first and second bandwidth extension lossless layers can extend that signal to losslessly coded 48 and then 96 kHz bandwidths (f_s=96 and 192 kHz).

S. Voran, "Listener detection of talker stress in low-rate coded speech," in *Proc. 2008 International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, Las Vegas, Nevada, Mar.-Apr. 2008.

We describe an experiment where listeners were asked to detect two specific forms of stress in talkers' recorded voices heard via six different simulated communication systems. Both task-induced stress and dramatized urgency were used. Communication systems included low-rate digital speech coding combined with bit errors, packet loss, and packet loss concealment. Twenty-four listeners participated in a total of 11,520 detection trials. A parallel investigation of word intelligibility in sentence context used 576 trials. Intelligibility results showed wide variance due to communication system and stress detection results showed less variance. More specifically, we found that listener detection of dramatized talker urgency was 4.7 times more robust to communication system degradations than word intelligibility in sentence context.

Journal Articles

A. Thiessen, "Rethinking 4.9 GHz broadband," *MissionCritical Communications*, vol. 23, no. 2, pp. 14-16, Feb. 2008.

With the advent of 700 MHz broadband on the horizon, the public safety community is in a position to take stock and rethink its use of the 50 MHz of spectrum at 4.9 GHz granted by the FCC in 2002. For the last three and a half years, public safety has been defining its requirements for 4.9 GHz broadband and dovetailing with the APCO Project 25 Interface Committee's Broadband Task Group. This public safety/industry effort takes public safety's requirements and compares these with the two technologies being proposed for the band: IEEE 802.11-2007 and 802.16e-2005.

J.B. Allen, G. Chan, and S.D. Voran, "Perceptual models for speech, audio, and music processing," *EURASIP Journal on Audio Speech, and Music Processing*, Vol. 2007, 2007.

No abstract available.

Book Chapters

S. Voran, "Estimation of speech intelligibility and quality," Ch. 28 of *Handbook of Signal Processing in Acoustics*, D. Havelock, S. Kuwano, and M. Vorländer, Eds., Vol. I, Part V (Speech, D.D. O'Shaughnessy), Springer Science+Business Media, LLC, 2008, pp. 483-520.

No abstract available.

Unpublished Presentations

N. DeMinco, “Propagation model development considerations for close-in distances and low-antenna height applications,” presented at the USNC-URSI National Radio Science Meeting, Boulder, Colorado, Jan. 5, 2008.

M. Ossmann, “Software radio and the future of wireless security,” presented at Black Hat Briefings, Las Vegas, Nevada, Aug. 6, 2008.

F.H. Sanders, “Broadband spectrum surveys: Approaches and results,” presented at International Symposium on Advanced Radio Technologies (ISART), Boulder, Colorado, Jun. 2008.

A. Webster, “Progress and future plans for VQEG,” Keynote presentation at ETSI STQ Workshop on Multimedia Quality of Service, Prague, Czech Republic, Jun. 2008.

Conferences Sponsored by ITS

International Symposium on Advanced Radio Technologies (ISART 2008)

The International Symposium on Advanced Radio Technologies (ISART 2008) was held June 2-4, 2008, in Boulder. This symposium explores the current state of the radio art with an eye towards forecasting the use of wireless technology in the future. The keynote was given by Karl Nebbia, Director of NTIA’s Office of Spectrum Management. The proceedings were produced in an electronic DVD format as NTIA Special Publication SP-08-452.

ISART 2008 was held in conjunction with ClimDiff 2008, which covers topics in radio-climatological and diffraction effects on radio propagation.

ISART brings together people from academia, business, and government agencies to discuss the interplay between technological “how-to,” the possibilities and restrictions created by regulation and policy, and the economic motivation of the business world.

The ITS Radio Spectrum Measurement Science (RSMS) vehicle set up to perform measurements at the Table Mountain Field Site (photograph by J.W. Allen).

ITS Standards Work in FY 2008

Standards Leadership Roles and Membership in Standards Development Organizations

David J. Atkinson, Vice-Chair of the APIC Vocoder Task Group and Vice-Chair of the APIC Audio Performance Working Group, both affiliated with TIA TR-8.

Christopher J. Behm, Member of Working Party 3L and 3K, ITU-R Study Group 3.

Randall S. Bloomfield, Vice-Chair of the ISSI Task Group (ISSI TG) and Vice-Chair of the P25 Systems Architecture Working Group (PSAWG) (both within the APCO Project 25 Interface Committee); Facilitator of the P25 User Needs Subcommittee (P25 UNS) and Editor of the Project 25 Statement of Requirements (P25 SoR).

Carolyn Ford, Member of Video Quality Experts Group (VQEG), U.S. Delegate of ITU-T Study Group 9.

Paul M. McKenna, U.S. Chair of ITU-R Study Group 3 (Radiowave Propagation); Working Party 3J, 3K, 3L, and 3M; International Chair of Subgroup 3K.2.

Margaret Pinson, Independent Lab Group member for Multimedia test and Co-chair of HDTV effort, Video Quality Experts Group (VQEG).

Patricia J. Raush, Member of Working Party 3J and 3K, ITU-R Study Group 3.

Timothy J. Riley, Member of Alliance for Telecommunications Industry Solutions (ATIS) committee WTSC-RAN (Wireless Technologies and Systems Committee — Radio Access Networks) and issue champion and editor for development of a document addressing interference issues affecting wireless communication systems. Member of the US delegation to Working Party 5D (IMT Systems), ITU-R Study Group 5 (Terrestrial Services) (formerly Working Party 8F (IMT-2000 and systems beyond IMT-2000), ITU-R Study Group 8 (Mobile, radiodetermination, amateur and related satellite services)).

Teresa Rusyn, Member of Working Party 3K and 3M, ITU-R Study Group 3.

Frank Sanders, Chair of ITU-R Radar Correspondence Group (radar technical spectrum issues); Delegate to ITU-R Working Party 8B (radar spectrum allocation and sharing) and Joint Rapporteur Group 1A-1C-8B (radar spectrum efficiency issues).

Neal B. Seitz, Vice Chair of ITU-T Study Group 13 (Next Generation Networks); Chair of ITU-T Study Group 13 Working Party 4 (OAM and QoS); Vice Chair of ATIS Network Performance, Reliability, and Quality of Service Committee (PRQC); Chair of PRQC's Quality of Service Task Force (PRQC-QoS).

Bruce R. Ward, Co-Editor (TIA TR8.19), TIA.102-CACA, "ISSI Measurement Methods for Voice Services," and TIA.102-CACB, "ISSI Performance Recommendations for Voice Services."

Arthur Webster, Co-chair of Video Quality Experts Group (VQEG); Rapporteur for Question 14/9 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia services within the terms of Study Group 9) in ITU-T Study Group 9 (Integrated broadband cable networks and television and sound transmission); Chair of Joint Rapporteur Group on Multimedia Quality Assessment (JRG-MMQA); Vice-chair of ATIS PRQC's Security Task Force. Study Group 9's Liaison Officer for the ITU's Telecommunications for Disaster Relief and Mitigation - Partnership Co-ordination Panel (PCP-TDR); Co-Chair of ITU-T Study Group 9's Working Group 5 "Quality Assessment"; Head of U.S. Delegation to ITU-T Study Group 9.

Representative Technical Contributions

Contributions listed below are a sample of the extensive standards work that ITS does each year. More details of this work can be found in the individual write-ups throughout this report.

Emergency Telecommunications Service (ETS) Standardization

- "Revisions to Draft New Recommendation J.preffr 'Roadmap for implementing preferential telecommunications in IPCablecom networks,'" ITU-T Study Group 9 Contribution 115 (USA), May 2008, (A. Webster, G. Bain (NCS/DHS)).
- IETF Internet Drafts relevant to Security and QoS Performance, ATIS PRQC-2007-151, Oct. 2007 (A. Webster, A. Nguyen (NCS/DHS)).
- Security Architecture and Requirements for Legacy and NGN Infrastructures, ATIS PRQC-2008-030, Feb. 2008 (A. Webster, S. Jacobs (YCS Consulting)).
- Media Plane Performance Security Impairments Standard for Evolving VoIP/Multimedia Networks, ATIS PRQC-2008-091, Aug. 2008 (A. Webster, S. Jacobs (YCS Consulting)).
- Draft New Recommendation J.prefp2 – "Specifications for priority in preferential telecommunications over IPCablecom2 networks," ITU-T Study Group 9 TD 942, Sep. 2008 (A. Webster, G. Bain (NCS/DHS)).
- Draft New Recommendation J.prefa2 – "Specifications for authentication in preferential telecommunications over IPCablecom2 networks," ITU-T Study Group 9 TD 941, Sep. 2008 (A. Webster, G. Bain (NCS/DHS)).

APCO Project 25

- Comments on APCO Project 25, Half-Rate Vocoder Annex, Version 1.0.0, Oct. 2007 (D. Atkinson).
- TIA TR8.4-07-09-001R2, TSB-102.BABF, TIA Telecommunications System Bulletin, "Experiment 3 MOS Test Plan for Vocoder Technology for Project 25 Phase 2," Mar. 2008 (D. Atkinson).
- ITS White Paper: Project 25 Interoperability Testing for Voice Operation in Trunked Systems Involving the ISSI, ISSI TG, Apr. 2008 (B. Ward, N. Walowitz (Protiro for ITS) and A. Sharon (Protiro for ITS)).
- ITS and NIST/ANTD Comments on ISSI Conformance Test Document (07-019-R3), ISSI TG, Oct. 2007 (B. Ward, M. Ranganathan (NIST/ANTD), N. Walowitz (Protiro for ITS)).
- ITS Technical Comments on 08-043 P25 Interoperability Testing for Wide Area ISSI - Level 3 - RevB, ISSI TG, Aug. 2008 (B. Ward, N. Walowitz (Protiro for ITS) and A. Sharon (Protiro for ITS)).
- ITS Comments on Two-Slot TDMA Overview v.37 (07-088-R6), TDMA TG, Mar. 2008 (C. Redding, I. Stange).
- ITS Comments as of January 3, 2008 on 07-022 ISSI Measurement Methods - Addendum 1", TR8.19, Jan. 2008 (B. Ward, N. Walowitz (Protiro for ITS)).
- ITS Comments as of January 3, 2008 on 07-023 ISSI Performance Recommendations - Addendum 1, TR8.19, Jan. 2008 (B. Ward, N. Walowitz (Protiro for ITS)).

- Considerations in Developing a Level 3 ISSI Interoperability Test Procedures Standard, ISSI TG, May 2008 (B. Ward, N. Walowitz (Protiro for ITS), A. Sharon (Protiro for ITS)).

- NIST/OLES Letter Ballot Comments on Draft TIA-102.CACA Addendum 1 (CSSI Measurement Methods for Voice Services), TR8.19, May 2008 (R. Bloomfield, B. Ward, N. Walowitz (Protiro for ITS)).

- NIST/OLES Letter Ballot Comments on Draft TIA-102.CACB Addendum 1 (CSSI Performance Recommendations for Voice Services), TR8.19, May 2008 (R. Bloomfield, B. Ward, N. Walowitz (Protiro for ITS)).

- ITS Comments as of September 8, 2008 on ISSI Availability Monitoring Proposal, TR8.19, Sep. 2008 (R. Bloomfield).

- NIST/OLES Comments on Two-Slot TDMA Overview v0.39 (08-07-001), TR8.12, Jul. 2008 (R. Bloomfield).

- TIA 102.CABA-A Project 25 Interoperability Testing for Voice Operation in Conventional Systems - Draft Revision 3, CAPP TG, Jul. 2008 (N. Walowitz (Protiro for ITS), R. Crosthwaite (Mindbank Technical Solutions for DOI)).

- ITS Comments as of June 20, 2008 on ISSI Conformance Test Update (08-041), TR8.19, Jun. 2008, (B.Ward, K. Behnam).

- Working Document – Issue H, Identification of P25 SoR Requirements for Updating of Current (August 4, 2007) P25 SoR, P25 UNS, Sep., 2008 (R. Bloomfield).

Video and Multimedia Quality

- ITU-T Recommendation J.244 “Calibration methods for constant misalignment of spatial and temporal domains with constant gain and offset,” approved May 2008 (A. Webster (editor), S. Wolf, M. Pinson, C. Lee (Yonsei Univ.)).

- ITU-T Recommendation J.246 “Perceptual audiovisual quality measurement techniques for multimedia services over digital cable television networks in the presence of a reduced bandwidth reference,” approved Aug. 2008 (A. Webster, editor, C. Lee (Yonsei Univ.)).

- ITU-T Recommendation J.247 “Objective perceptual multimedia video quality measurement in the presence of a full reference,” approved Aug. 2008 (A. Webster (editor), C. Lee (Yonsei Univ.), A. Takahashi, J. Okamoto (NTT), Q. Huynh-Thu (Psytechnics), C. Schmidmer (Opticom), J. Beerends (TNO)).

- ITU-T Recommendation P.910 Revised “Subjective video quality assessment methods for multimedia applications,” approved May 2008 (A. Webster, M. Pinson).

- ITU-T Recommendation P.912 “Subjective video quality assessment methods for recognition tasks,” approved Aug. 2008 (C. Ford, M. McFarland).

ITS Awards in FY 2008

Department of Commerce Silver Medal Award

In November 2007, Jeffery Wepman of the Spectrum and Propagation Measurements Division was part of an NTIA team awarded the Department of Commerce Silver Medal, the second highest honor given by the Department, for personal and professional excellence (see photo below).

The NTIA team was awarded the Silver Medal for their outstanding work in designing the rules for the Digital Television Coupon Program. This effort laid the foundation for the ongoing efforts and responsibilities that NTIA was given in the transition of analog to digital television which will take place on February 17, 2009.

In addition to Mr. Wepman, the Silver Medal team included Wayne Ritchie, Tony Wilhelm, Anita Wallgren, Chuck Mellone, and Bill Cooperman of NTIA's Office of Telecommunications and Information Applications, and Milton Brown of NTIA's Office of Chief Counsel.

Recipients of the Department of Commerce Silver Medal Award share the stage with Department of Commerce leaders. Left to right: Secretary of Commerce Carlos Gutierrez, Jeffery Wepman, Wayne Ritchie, Tony Wilhelm, Anita Wallgren, Chuck Mellone, Bill Cooperman, Milton Brown, and former Assistant Secretary of Commerce for Communications and Information John Kneuer.

Abbreviations/Acronyms

2D	two-dimensional
3D	three-dimensional
3G	third generation
4G	fourth generation

A

AAR	Association of American Railroads
AC	alternating current
ACR-HR	Absolute Category Rating - Hidden Reference
AM	amplitude modulation
ANS	American National Standard
ANSI	American National Standards Institute
APCO	Association of Public-Safety Communications Officials
APD	amplitude probability distribution
APIC	APCO Project 25 Interface Committee
ATC	air traffic control
ATCBI	air traffic control beacon interrogator
ATIS	Alliance for Telecommunications Industry Solutions
AUGNet	Ad hoc UAV Ground Network
AUT	antenna under test

B

BER	bit error rate
BPSK	binary phase shift keying
BVQM	Batch VQM

C

CAI	Common Air Interface
CAP	Compliance Assessment Program
CAPPTG	Compliance Assessment Process and Procedures Task Group (a subcommittee under APIC)
CCV	Coordination Committee for Vocabulary
CD	compact disk
CDA	Code Domain Analyzer
CDMA	Code Division Multiple Access
CEA	Consumer Electronics Association
CG	correspondence group
CIF	common intermediate format
CIP	Critical Infrastructure Protection
CMRS	Commercial Mobile Radio Services
CONUS	Continental U.S.
COTS	commercial off-the-shelf
CRADA	Cooperative Research and Development Agreement
CRPL	Central Radio Propagation Laboratory
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSPM	Communication System Performance Model
CSPT	Communication System Planning Tool
CSSI	Console Subsystem Interface
CU	University of Colorado
CVQM	Command Line VQM

D

DAT	digital audio tape
dB	decibel
DFS	Dynamic Frequency Selection
DGPS	differential GPS
DHS	Department of Homeland Security
DNR	Draft New Recommendation
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of Interior
DRM	Digital Radio Mondiale
DSCP	Digital Sampling Channel Probe
DSES	Deep Space Exploration Society
DSR	Documentation Suite Reference
DTV	digital television

E

EFI	error free interval
EIA	Electronic Industries Alliance
EMC	electromagnetic compatibility
EMI	electromagnetic interference
ESSA	Environmental Science Services Administration
ETS	Emergency Telecommunications Service

F

FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEC	forward error correction
FLC	Federal Laboratory Consortium for Technology Transfer
FM	frequency modulation
foF2	F2-peak plasma frequency
FPGA	Field Programmable Gate Array

FPIC	Federal Partnership for Interoperability Communications
FR	full reference
FRA	Federal Railroad Administration
FSI	Fixed Station Interface
FTP	File Transfer Protocol
FTTA	Federal Technology Transfer Act 1986
FY	Fiscal Year

G

GETS	Government Emergency Telecommunications Service
GHz	gigahertz
GIF	Graphics Interchange Format
GIS	Geographic Information System
GLOBE	Global Land One-km Base Elevation
GPS	Global Positioning System
GSM	Global System for Mobile
GUI	Graphical User Interface

H

HATS	head and torso simulator
HD	high definition
HDTV	High Definition Television
HF	high frequency
HP	Hewlett-Packard Company

I

I/Q	in-phase/quadrature
IAA	interagency agreement
IAFC	International Association of Fire Chiefs
IBOC	in-band on-channel
ICEPAC	Ionospheric Communications Enhanced Profile Analysis and Circuit Prediction Program
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IF	intermediate frequency
ILG	Independent Lab Group
IM	intermodulation
IMT	International Mobile Communications
IP	Internet Protocol
IPTV	Internet Protocol Television
ISART	International Symposium on Advanced Radio Technologies
ISSI	Inter-RF Subsystem Interface
IT	information technology
ITM	Irregular Terrain Model
ITS	Institute for Telecommunication Sciences
ITSA	Institute for Telecommunication Sciences and Aeronomy
ITT	ISSI Test Tool
ITU	International Telecommunication Union
ITU-R	ITU — Radiocommunication Sector
ITU-T	ITU — Telecommunication Standardization Sector
IVQM	In-Service VQM

J

JRG	Joint Rapporteur(s) Group
JRG-MMQA	Joint Rapporteur Group on Multimedia Quality Assessment

K

kHz	kilohertz
km	kilometer
kbps	kilobytes per second
kW	kilowatt

L

LAN	Local Area Network
L-Band	1215-1400 MHz band
LF	low frequency
LFMF	low frequency/medium frequency
LMCT	Lockheed Martin/Coherent Technologies
LMDS	Local Multipoint Distribution Service
LMR	Land Mobile Radio
LNA	low noise amplifier
LO	local oscillator
LOS	line of sight
LTE	long term evolution

M

m	meter
Mbps	megabits per second
MD	multimedia definition
MF	medium frequency
MHz	megahertz
MIMO	Multiple Input Multiple Output
MRT	Modified Rhyme Test
MPSK	multiple phase-shift keying
ms	millisecond
MSC	message sequence chart
MSTV	Association for Maximum Service Television
MTOM	mobile-to-mobile

N

NARA	National Archives and Records Administration
NB	narrowband
NCS	National Communications System
NDGPS	Nationwide Differential Global Positioning System
NGN	Next Generation Network
NGN-GSI	Next Generation Network Global Standards Initiative
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NR	no reference
NS/EP	National Security and Emergency Preparedness
NTIA	National Telecommunications and Information Administration
NWR	National Weather Radio

O

OA	outside/other agency
OAM	Operation, Administration and Maintenance
OCIO	Office of the Chief Information Officer
OIC	Office of Interoperability and Compatibility (of DHS)
OLES	Office of Law Enforcement Standards
OMB	Office of Management and Budget
OQPSK	Offset Quadrature Phase-Shift Keying
OSM	Office of Spectrum Management
OT	Office of Telecommunications
OTP	Office of Telecommunications Policy

P

P25	Project 25
PASS	personal alert safety system
PBS	Public Broadcasting System
PC	personal computer
PCAP	packet capture
PCP-TDR	Telecommunications for Disaster Relief and Mitigation — Partnership Co-ordination Panel
PCS	Personal Communications Services
PDA	personal digital assistant
PDD-63	Presidential Decision Directive No. 63 (on critical infrastructure protection)
PDNR	Preliminary Draft New Recommendation
PESQ	Perceptual Evaluation of Speech Quality
PIN	personal identification number
PLMR	private land mobile radio
PMW	Propagation Modeling Website
PRQC	Network Performance, Reliability and Quality of Service Committee
PS	public safety
PSAF	Public Safety Architecture Framework
PSAL	Public Safety Audio Laboratory
PSAWG	P25 Systems Architecture Working Group
PSNR	peak signal to noise ratio
PSRF lab	Public Safety RF laboratory
PS-SoR	Public Safety Statement of Requirements
PSTN	Public Switched Telephone Network
PSVL	Public Safety Video Laboratory
PSVQ	Public Safety Video Quality
PTT	Push-to-Talk

Q

QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying

R

R&D	research and development
RAID	redundant array of independent disks
RC	radio-controlled
RCG	Radar Correspondence Group
RF	radio frequency
RFSS	Radio Frequency Subsystem
RLC	radio link core
RMSE	root mean squared error
RNSS	Radionavigation Satellite Service
RR	reduced reference
RR-NR	Reduced Reference – No Reference
RSEC	Radar Spectrum Engineering Criteria
RSMS	Radio Spectrum Measurement Science
RSMS-4G	4th Generation RSMS
RTP	Real-time Transport Protocol

S

S&E	salaries and expenses
SCBA	self-contained breathing apparatus
SCTE	Society of Cable Telecommunications Engineers
SD	Standard Definition
SDMA	Space Division Multiple Access
SDO	Standards Development Organization
SDR	software defined radio
SDTS	Spatial Data Transfer Standard
SG	Study Group
SID	speaker identification

SIP	Session Initiation Protocol
SIPRNET	Secret Internet Protocol Routable Network
SoR	Statement of Requirements
SV	Systems View

T

TA Services	Telecommunications Analysis Services
TDMA	time division multiple access
TG	Task Group
TIA	Telecommunications Industry Association
TIREM	Terrain Integrated Rough Earth Model
TM	Technical Memorandum
TMFCW	Table Mountain Frequency Coordination Website
TR	Technical Report
TR-8	Personal and Private Land Mobile Radio (a TIA standards development committee)
TSB	Telecommunications Systems Bulletin Technical Service Bulletin
TV	television

U

UAV	unmanned aerial vehicle
UHF	ultra high frequency
UK	United Kingdom
U-NII	Unlicensed National Information Infrastructure
UNR	undesired signal to noise ratio
UNS	User Needs Subcommittee
U.S.	United States
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

V

VHF	very high frequency
VNB	very narrowband
VoIP	Voice over Internet Protocol
VPN	Virtual Private Network
VQEG	Video Quality Experts Group
VQM	Video Quality Metric
VSA	vector signal analyzer
VSG	vector signal generator
VQiPS	Video Quality in Public Safety (conference)

W

WB	wideband
WCC	Wireless Communications Committee
W-CDMA	Wideband CDMA
Wi-Fi	Wireless Fidelity
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WLG-E	Working Level Group E
WNRC	Wireless Networks Research Center
WP	Working Party
WTSC-RAN	Wireless Technologies and Systems Committee - Radio Access Networks

Y

YIG	yttrium-iron-garnet