Spectrum and Propagation Measurements

The radio spectrum is an enigmatic natural resource that offers immense benefit to industry, government, and private citizens by supporting radio/wireless communications and a wide variety of other systems such as radar and remote sensing. It is non-depleting and exists everywhere, but it is finite and can be rendered less useful by noise and interference.

Until recently, traditional methods of allocating spectrum and assigning channels have ensured effective and efficient use of the spectrum. Today, the rapidly expanding competition for spectrum use and the plethora of new signal types and applications have created an apparent shortage of radio spectrum. While new spectrum management methods can alleviate this problem, they cannot do so without increasingly more in-depth knowledge of the existing signals and noise environment and better understanding of how systems that share spectrum affect each other.

The Spectrum and Propagation Measurements Division provides the technical information needed to enable more effective and efficient use of the spectrum, thus enabling spectrum allocation and sharing regulations and policies that are effective, reliable, and enduring. To do so, the Division performs measurements to characterize the existing radio environment, studies the effects of existing radio signals on electronic systems, and analyzes the potential effect and impact of new radio signals.

Measurements and assessments of spectrum occupancy can be accomplished at any location using the mobile Radio Spectrum Measurement Science system. New measurement methods are developed and complex testing is accomplished in the well-equipped ITS laboratories and at the Table Mountain Field Site.

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) Operations
The RSMS system is a complex toolbox of laboratory equipment, analysis tools, and mobile facilities. This capability is used to assess spectrum occupancy and usage, electromagnetic compatibility, and to resolve interference problems. This project is funded by NTIA.

RSMS 4th Generation System Development
The Institute continually refines and develops measurement methods, both established and new, supported by hardware and software. The RSMS fourth generation system software is capable of fully autonomous operation and remote monitoring, uniform data recording and storage, and powerful analysis and display routines. This project is funded by NTIA.

Table Mountain Research Program
The Table Mountain Field Site is designated as an area where the magnitude of strong, external signals is restricted (by State Law and Federal Regulation). It is the principal experimental field site for the U.S. Department of Commerce Boulder Laboratories, and is used for experiments requiring protection from vibration and strong, external radio signals. Research at this site includes development and evaluation of: new spectrum occupancy measurement methods, radio noise measurements, new antennas, and complex radar testing. These projects are 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 to verify usage of fixed-service assignments located in the 7125-8500 MHz band.
- Measurements to determine the emissions of various radars with different output devices, including solid state and tube devices employing various modulation schemes.

The Radio Spectrum Measurement Science (RSMS) group is given 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 at ITS in Boulder, Colorado, and is tasked to perform measurements in support of OSM as required to fulfill their 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 1) spectrum surveys and channel usage, 2) equipment characteristics and compliance, 3) interference resolution and compatibility, and 4) signal coverage and quality. In FY 2007, several different measurements were performed in support of the basic mission.

In the summer of 2007, 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 where Unlicensed National Information Infrastructure (U-NII) devices, which use the 5-GHz band for unlicensed operations, will detect the operations of a radar and promptly vacate the channel if a radar is present. In FY 2006, OSM and ITS personnel bench- and field-tested devices from three U-NII vendors. The FCC adopted compliance rules and procedures for U-NII devices in FY 2006 and they will be sold to the public. In order to monitor the performance of the devices on the market, NTIA purchased two 5-GHz U-NII devices "off the shelf" and tested them to the published compliance standards. More of this type of testing is expected to occur in FY 2008.

Fixed-services measurements to verify assigned usage were conducted in the winter of FY 2007 (see photo). As part of the Presidential Initiative, this project provided technical direction and support in the study of ways to improve spectrum efficiency and effectiveness. In spring 2006 some cursory measurements of the fixed services in the 7125-8500 MHz band were conducted in the Washington, D.C., area. The measurements of the fixed services did not align with predicted results for signal presence, power levels, directions, and assignment activity. For those measurements, OSM prepared a report that predicted that information based on measurement location. To verify that the initial analyses and measurement procedures were correct and that the data for the fixed assignments in the GMF may be flawed, OSM prepared a similar report that ITS used in a measurement of fixed-service activity in the Denver area. Two methods were explored: one using an azimuthal scan in a fixed location and the other using a drive-up method where measurements are conducted in close proximity to several microwave towers. A summary of these methods will be published in an NTIA Technical Memorandum. Also in support of the Presidental Initiative, previously ITS surveyed the activity in Federal land mobile radio (LMR) services in the Washington, D.C., area. A report on the results was published in FY 2007.

In January of 2007, measurements were conducted to determine the emission characteristics of an HF FMCW radar located in New Jersey. In addition, spectrum measurements were conducted on various emulated pulsed waveforms to verify theoretical models. Both of these measurements are part of an ongoing effort to determine the emissions of various radars with different output devices, including solid state and tube devices employing various modulation schemes. These measurements will assist NTIA in revising the Radar Spectrum Engineering Criteria's

ITS engineers preparing for fixed-services measurements in Denver, Colorado (photograph by J.R. Hoffman).

(RSEC) 40-dB bandwidth equations and emission limits. They will also help NTIA develop implementation factors and guide similar efforts at the ITU-R, as Recommendation SM.1541 is revised. The United States has been actively involved in modifying ITU-R SM.1541 for out-of-band and spurious emissions.

Over the course of the year, measurements were conducted to characterize various off-the-shelf low noise amplifiers (LNAs). One of the primary components of an electromagnetic compatibility analysis is determining the interference effects on a receiver. The potential impact to the front-end of a receiver can be determined by characterizing the response of an LNA to single and multiple interfering signals. Compatibility problems can arise when front-end overload occurs, saturating the receiver front-end (e.g., the LNA). The objective of this task is to examine the response of LNAs to a variety of single-signal and multi-signal stimuli.

During FY 2007 ITS provided support for two separate measurements to determine interference potential to L-Band radars from new Radionavigation Satellite Services (RNSS) operating in the same frequency band. The Department of Defense, the Federal Aviation Administration, NTIA, and other Federal agencies have concerns about the operations of these RNSS devices in the 1215-1400 MHz band (L Band). Specifically, measurements and analyses show that RNSS signals coupling into radars operating in the L Band can cause interference which can lead to loss of targets and/or reduced detection range. Within the ITU-R, work has already begun on a study of the issues. The L-Band group in the United States was 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.R. Hoffman, R.J. Matheson, and R.A. Dalke, "Measurements to characterize land mobile channel occupancy for federal bands 162-174 MHz and 406-420 MHz in the Washington, D.C., area," NTIA Report TR-07-448, Jul. 2007.

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RSMS 4th Generation System Development

Outputs

- Development of low-frequency preselectors and duplication of high-frequency preselectors.
- Real-time fully automated direction-finding system that can be used with pulsed signals such as radar.
- Several new ITS custom-designed software modules for instrument control and measurement.

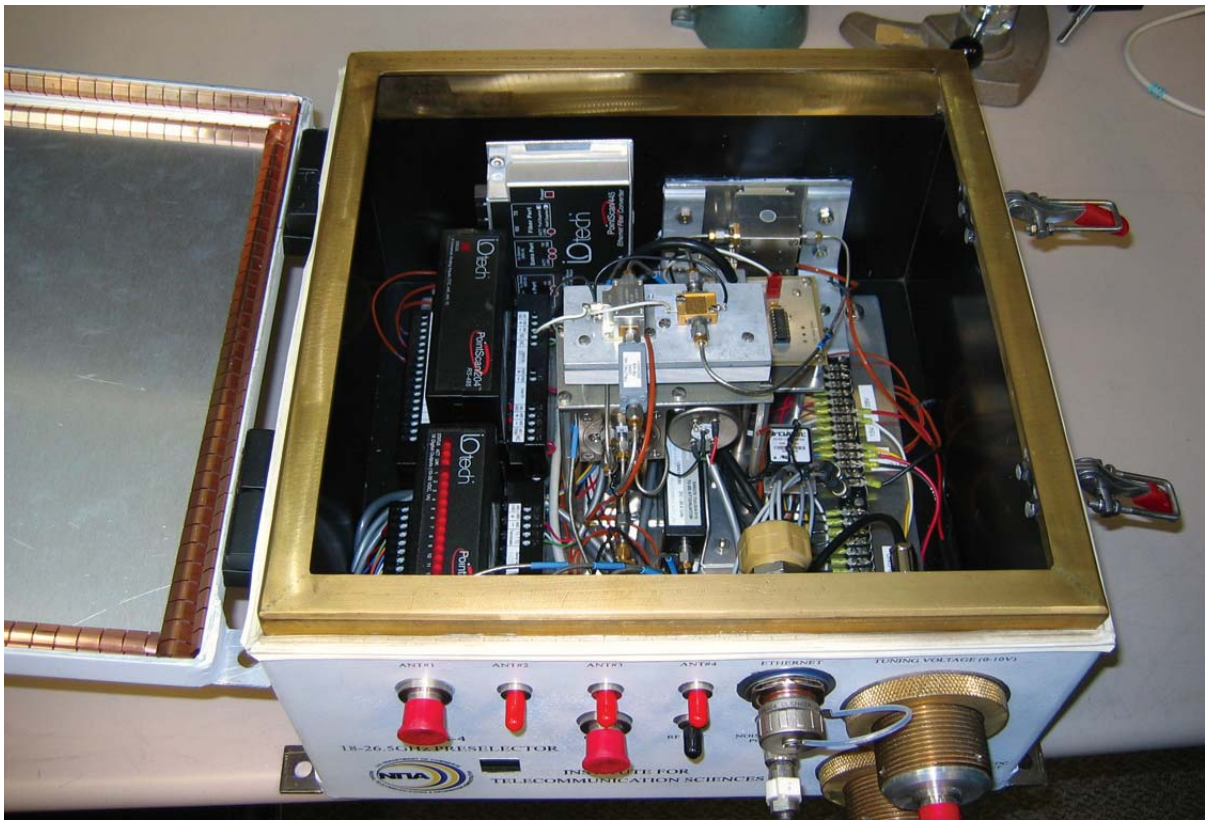
The 4th generation system for Radio Spectrum Measurement Science (RSMS) consists of state-of-the-art tools (vehicle, software, and hardware) necessary for making measurements to characterize spectrum occupancy, ensure equipment compliance, determine electromagnetic compatibility, and analyze interference problems. The development of the 4th generation system originated out of the recognized need to upgrade to the latest technology for 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 2007.

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 (see figure). To provide redundancy in case of failure or dual system requirements, a second copy of each preselector is currently under construction. Both preselectors are protected against strong signals by highly shielded enclosures and are controlled via fiberoptic connections to prevent signals coupling into control lines. In addition to these higher frequency preselectors, a 4th generation low-frequency preselector (1.5–1000 MHz) was designed and parts were purchased in FY 2007; final construction will occur in the next fiscal year. In 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 preselector units for different applications of the same measurement capabilities.

During FY 2007, several improvements were made to existing tunable YIG filter systems frequently used for radar measurement. A YIG tracking system is currently under development for the purpose of tracking frequency sweeps of spectrum analyzers, and a YIG calibration software routine was developed that allows periodic characterization of the filter for offset control.

In preparation for fixed services measurements that occurred in the winter of 2007, a specialized azimuthal and spectrum scan measurement was developed. This measurement controls an antenna rotator so that a high-gain dish antenna is pointed in 1° increments through a full 360° azimuthal sweep. A spectrum trace is acquired and stored in association with each degree increment. The data is then plotted three-dimensionally in a contour plot: frequency, angle, and power in the x, y, and z planes respectively. This provides a visual display of the different signals and their angle of arrival, both of which can then be correlated with a transmitter database to verify spectrum usage.

Currently in progress is the development of real-time “signal direction-finding” capabilities. ITS engineering staff have been working together to develop these capabilities through implementation of digital control and processing using Field Programmable Gate Array (FPGA) technology. The system switches through the different antennas of a six-sided array to determine the angle of signal arrival. Using rapid digital processing and a switch controlled by the FPGA, information is relayed via the Internet to a computer, which can then be used for real-time high-gain antenna positioning toward stationary or moving targets. One of the advantages of this system over most off-the-shelf systems is that it can be used with intermittently pulsed signals such as radar. Because it is implemented in software as an instrument module, this system is easily integrated into the larger RSMS software package for use with



18.0–26.5 GHz 4th generation preselector (photograph by J.R. Hoffman).

a variety of measurement capabilities. Development of this system using FPGA technology will not only provide signal direction-finding capabilities but will also open up a whole new way of acquiring and processing data, using what is essentially a hardware re-programmable instrument that can be used for many different applications.

Several new additions and improvements have also been made to software measurement routines. These include an automated "noise-diode to noise-diode calibration" procedure, the "stepped" measurement, the "manual spectrum analyzer data dump" measurement, the "swept" and "swept calibration" measurements and new instrument control modules for the HP8566 and HP8563 spectrum analyzers. The "noise-diode to noise-diode calibration" procedure is an automated routine used to calibrate measurement noise diodes against a "gold standard" noise diode that is kept in pristine condition, with a calibration that is traceable to NIST. Noise diodes are used in laboratory and field measurements to calibrate measurement systems for gain and noise figure. The "stepped" measurement is an automated routine that is used frequently to characterize the emission characteristics of radars; improvements to this routine include a fully automated attenuation routine and re-measurement capabilities, as well as a "data viewer" used to examine data and output the data into various other file formats. "Data viewers" were also added to the "manual spectrum analyzer data dump" measurement, and the "swept" and "swept calibration" measurements. The instrument control modules for the HP8566 and HP8563 spectrum analyzers are still in progress but near completion.

Further developments expected in FY 2008 include enhanced data file management, a scheduler for automated control of multiple measurements, an RF noise measurement routine, further work on the FPGA re-programmable instrument module, the completion of the YIG tracking system, and the completion of the RSMS4G low-frequency preselector.

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Table Mountain Research Program

Outputs

- NOAA Weather Radio receiver performance testing.
- Antenna performance evaluation and testing.
- Geographic Information System (GIS) database to support radio propagation studies.

The Table Mountain Field Site and Radio Quiet Zone supports fundamental research into the nature, interaction, and evaluation of telecommunication devices, systems, and services. To achieve this goal, the Table Mountain Research Program actively solicits research proposals both from inside the Institute and from external agencies.

The results of this work are disseminated to the public via reports, technical papers, journal articles, conference papers, web documents, and computer programs. Activities this year have included:

NOAA Weather Radio Testing:
To help ensure that radios displaying the National Oceanic and Atmospheric Administration (NOAA) Weather Radio (NWR) emblem meet the NOAA performance criteria, 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.

Antenna Performance and Evaluation Testing:
Knowledge of the performance characteristics of antennas (radiation pattern, gain, polarization, etc.) is necessary to ensure the correct operation of a radio system as well as to assess the compatibility of a system with other electronic devices and services. The controlled radio environment at the Table Mountain field site, and the 10.4 meter (34 foot) diameter turntable facility, make this an ideal place to gather these data.

Projects undertaken by the Table Mountain Research Program have included: measurement of open air antenna patterns, testing the effects of support vehicles on mobile antenna systems, evaluating the performance of new antenna designs, and studying the effect of antenna characteristics on radio system performance.

DSES group replacing the jack screw boots on the main dish drive mechanism of one of the 18.3-meter parabolic dish antennas at the Table Mountain field site (photograph by J.W. Allen).

FY 2007 Cooperative Research and Development Agreement (CRADA) Partners

- Lockheed Martin/Coherent Technologies
- First RF Corporation
- RF Metrics Corporation
- University of Colorado, AUGNet
- Deep Space Exploration Society (DSES)

Interior of one of the ITS buildings at the Table Mountain field site, set up for radar measurements (photograph by J.R. Hoffman).

Recent Publications

A. Jenkins, D. Henkel, and T. X Brown, "Sensor data collection through unmanned aircraft gateways," in *Proc. AIAA Infotech Aerospace Conference*, May 7–10, 2007.

E.W. Frew, C. Dixon, J. Elston, B. Argrow, and T. X Brown. "Networked communication, command, and control of an unmanned aircraft system." Submitted to *AIAA Journal of Aerospace Computing, Information, and Communication*, under review (revision submitted May 2007).

A. Jenkins, D. Henkel, and T. X Brown, "Sensor data collection through gateways in a highly mobile mesh network," in *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, Hong Kong, Mar. 2007.

J. Diverdi, "Simple mapping project (SMP) Interim Report," Deep Space Exploration Society, Jun. 2006.

F. Sanders, J. Wepman, and S. Engelking, "Development of performance testing methods for dynamic frequency selection (DFS) 5-GHz wireless access systems (WAS)," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 7-9, 2006," P. Raush and K. Novik, Eds., NTIA Special Publication SP-06-438, Mar. 2006, pp. 39-48.

D. Henkel and T. X Brown, "On controlled node mobility in delay-tolerant networks of unmanned aerial vehicles," in "Proceedings of the International Symposium on Advanced Radio Technologies: March 7-9, 2006," P. Raush and K. Novik, Eds., NTIA Special Publication SP-06-438, Mar. 2006, pp. 29-38.

R. Howe, "Detection of gamma ray bursts and X-ray transient SGR 1806-20 with VLF radio telescopes," *Open European Journal on Variable Stars*, ISSN: 1801-5964, OEJV# 0022, Feb. 2006.

F. Sanders and B. Ramsey, "Comparison of radar spectra on varying azimuths relative to the base of the antenna rotary joint," NTIA Technical Memorandum TM-05-430, Aug. 2005.

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