Testimony of

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Avoiding the Spectrum Crunch: Growing the Wireless Economy through Innovation

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Chairman Quayle, Ranking Member Edwards, members of the Subcommittee, my name is Dr. James Olthoff. I am the Deputy Director of the Physical Measurement Laboratory (PML) at the National Institute of Standards and Technology (NIST) of the United States Department of Commerce. Thank you for the invitation to testify before you today on the so-called "spectrum crunch," and what NIST is doing to advance innovation in wireless communications. The Federal Communications Commission (FCC) website defines "spectrum crunch" in the context of mobile broadband as follows: "demand for mobile broadband service is likely to outstrip spectrum capacity in the near-term."[1] NIST's efforts, in collaboration with other Federal partners such as the National Telecommunications and Information Administration (NTIA) of the Department of Commerce, are helping to drive innovation here at home, thereby helping U.S. manufacturers and industries succeed on the global playing field.

The President and Secretary of Commerce John Bryson are committed to pursuing policies that promote innovation in the use of spectrum through research and development. The President has stated, "This new era in global technology leadership will only happen if there is adequate spectrum available to support the forthcoming myriad of wireless devices, networks, and applications that can drive the new economy."[2] The projects and activities about which I will testify today share a common theme of accelerating innovation for the benefit of U.S. manufacturers and consumers in the wireless telecommunications sector.

NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.

I am pleased to discuss today NIST's efforts to address the "spectrum crunch," as well as related activities impacting the wireless space.

Overview

In a February 2012 Report, *The Economic Benefits of New Spectrum For Wireless Broadband*, the President's Council of Economic Advisors states, "the only feasible way to realize the full potential of wireless broadband is to make new spectrum available for wireless services."[3] The Chairman of the Federal Communication Commission (FCC)echoes this concern, stating, "The biggest threat to the future of mobile in America is the looming spectrum crisis."[4]

The United States is at a technological crossroads that is unique in our lifetimes: The FCC has recently allocated spectrum at frequencies in the 70, 80 and 90 GigaHertz (GHz) range that is thirty times the total cellular bandwidth available today. Concurrently, semiconductor processing advancements have, for the first time, enabled inexpensive silicon radio chips that operate above 50 GHz.

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[1] http://www.fcc.gov/encyclopedia/spectrum-crunch

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

[3] http://www.whitehouse.gov/sites/default/files/cea_spectrum report_2-21-2012.pdf at 2.

[4] Cellular Telecommunications Industry Association Keynote, October 2009

President Obama understands the critical need to ensure sufficient spectrum is available for wireless services – to drive economic growth, create jobs, promote innovation, support federal agencies' missions, and improve public safety. In 2010, the President directed the Department of Commerce, through NTIA and working with the FCC and affected Federal agencies, to make available for commercial wireless use an additional 500 MHz of federal and non-federal spectrum. Additionally, the President's National Wireless Initiative – much of it enacted as part of the Middle Class Tax Relief and Job Creation Act – invests in NIST's cutting-edge wireless innovation R&D, establishes at long last a modern, nationwide interoperable public safety wireless broadband network, and puts in place multiple incentives and other reforms to drive more efficient use of spectrum by both private entities and federal agencies.

NIST is proud to be a full partner in these efforts. The following research activities underway at NIST are attacking the spectrum crunch and related issues:

Millimeter-Wave Research

NIST is working to provide industry with the new, sufficiently precise measurement methods it needs to lead internationally in the development of innovative millimeter-wave wireless technologies and associated standards. NIST's work will impact both the state of the art in telecommunications and the national economy as a whole.

New more precise test methods are needed to help industry utilize these new frequency ranges. The current 1 GHz methods used by the telecommunications industry must become nearly 70 times more precise to maintain equivalent accuracy, because measurement errors on the order of a few degrees can translate into erroneously demodulated information bits.

NIST innovation and expertise applied to the challenges of higher-speed wireless will offer new metrology so that US industry can realize significant increases in efficiency – not only in standardization, but in system modeling design, test and spectrum utilization – over the entire millimeter-wave region.

NIST is familiar with the needs of current U.S. telecommunications industry through its interactions with the Cellular Telecommunications Industry Association certification programs. NIST is leveraging recent funding from DARPA, with whom we are (1) developing oscilloscope-based techniques to provide a calibrated broadband modulated signal source for use in characterizing millimeter-wave receivers and (2) investigating the use of reverberation chambers for free-field testing of radiated power. Our interactions with the Institute of Electrical and Electronics Engineers (IEEE) on standards for 60 GHz systems are well under way (IEEE 802.15.3c) and, even though new transmission protocols will need to be developed, our experience on these committees will be leveraged.

As stated above, this work will accelerate the modeling design, verification, standardization, and interoperability of the Gbps (Giga Bits per second) millimeter-wave wireless systems of the future, positioning the US at the forefront of the competitive telecommunications industry. The ability to measure – not just model – components, circuits and entire systems at higher frequencies and bandwidths will provide tools for more economical wireless system development that can take advantage of this new spectrum.

The potential economic impact of this challenging work is great. This new bandwidth is large enough to provide inexpensive, ubiquitous multi-Gbps mobile and fixed wireless access throughout the US, encouraging business growth through improved connectivity, and energy savings through mobile telecommunications. New mobile applications are envisaged, such as virtual meetings and telemedicine, and a cost-effective solution to fiber's "last mile." The economic impacts that may be realized if the U.S. telecommunications industry can become the ground-breaking international leader in this technology far exceed the current multi-hundred-billion-dollar industry.

Electromagnetic Compatibility and Radio frequency

In addition to more precise frequency measurements NIST is also looking at challenges related to radio frequency in spectrum, particularly electromagnetic compatibility and interference issues.

Work at NIST develops and promotes electromagnetic measurements, standards, and technology to support a broad range of technical needs. NIST's programs focus on accurate and reliable measurements throughout the radio spectrum, in particular at radio and microwave frequencies. Key program directions include: (1) the development of advanced measurement technologies required by both research-and-development and manufacturing communities; (2) the development and characterization of standard reference artifacts, measurement methods, and services that provide the basis for international recognition of measurements; and (3) the provision of expert technical support for national and international standards activities.

NIST carries out our programs in close coordination with our colleagues in industry, academia, and other government agencies, such as NTIA, the Departments of Defense, Energy, and Homeland Security to ensure that we are responsive to their most pressing measurement needs. Examples that reflect the breadth of areas influenced by our programs include high-speed microelectronics for computation and telecommunications, advanced antenna systems for applications in military radars and deep space communications, remote observation of the Earth's biosphere, acquisition and quantitative characterization of high-speed waveforms, medical diagnostic imaging, and reliable communications for our Nation's emergency first responders.

NIST provides a broad range of state-of-the-art calibration services for fundamental radio-frequency and microwave quantities, which ensures that the U.S. scientific and industrial base has access to a measurement system that is reliable, accurate, and internationally accepted. Furthermore, NIST extends new measurement tools and theories to higher operating frequencies, wider signal bandwidth, and smaller length scales. These are required for next-generation applications in microelectronics, high-speed communications, computing, and data storage. In addition, NIST also develops new methods to measure the electromagnetic properties of materials and understand the interactions of electromagnetic waves with advanced materials.

The Radio-Frequency Fields Group develops theory and measurement techniques for the characterization of fundamental properties of advanced antenna systems and for the accurate measurement of electromagnetic fields. These capabilities are applied to the measurement of emissions and susceptibilities of electronic systems and devices. Of growing interest is the development of advanced measurement methods to characterize complex modulated telecommunication signals and the study of challenges faced by advanced communications when operated in complex real-world environments.

Within the Radio-Frequency Fields Group are two areas of research related to radio-frequency and spectrum: the Wireless Systems Metrology Program, and the Field Parameter Metrology Program.

Wireless Systems Metrology Program

The Wireless Systems Metrology Program supports the growing wireless industry by developing methods to test the operation and functionality of wireless devices in the presence of various types of distortion.

The Wireless Systems Metrology Program is also concerned with the impact of nonlinear distortion on the transmission of wireless signals, which can be especially severe for new wideband modulated signal transmissions. Accurately measuring distortion behavior of nonlinear radio-frequency devices is a key element in understanding how such devices will perform once incorporated into a system. Even under weakly nonlinear conditions, low-noise devices such as those used in receiver front ends will exhibit nonlinear behavior that includes harmonic generation and intermodulation distortion. The program has studied problems that commonly arise in performing and interpreting nonlinear measurements, such as power- and wave-based representations and the effects of terminating impedance on intermodulation distortion.

Researchers are also working to develop traceability to fundamental parameters such as power and electric field.

The program has had a number of accomplishments:

- Demonstrated that a reverberation chamber can be used to generate a variable multipath environment, which allows wireless devices to be tested in the laboratory rather than in field tests. This is an accurate and repeatable approach that improves on “Can you hear me now?”
- Developed standards to ensure reliable wireless communications for emergency responders in difficult radio environments.
- Assisted the National Institute of Environmental Health Sciences, which is conducting a long-term animal study to evaluate health risks associated with cellular telephone fields, by testing the performance of 21 reverberation chambers that will be utilized in the study.

Field Parameter Metrology Program

Consider the consequences if nearby electronics could interfere with a jet's instruments or cause an automobile to stall. The Field Parameter Metrology Program develops ways of measuring electromagnetic (EM) emissions and susceptibilities to electronic interference of electronic devices and systems. The program maintains the capability to provide EM field strength measurements.

Applications include the communications needs of first-responders to emergencies, measurements of the shielding effectiveness of advanced materials, effects from and on other electronic components, the statistics of electromagnetic fields in rooms and buildings, and the effects on biological subjects.

This program generates reference EM fields and calibrates EM probes required for their accurate measurement. Accurate EM field measurements are needed to characterize our wireless world and ensure that the valuable electromagnetic spectrum is optimally used, that electronic systems are compatible and neither sources nor victims of EM interference, and that people are not exposed to hazardous fields. As instrumentation and electronics achieve higher clock rates, EM field parameter metrology is needed at ever higher frequencies. The program is working to extend current methods and facilities to higher frequencies, and develop new test methods to increase accuracy and reduce measurement costs.

Research has begun on a quantum based electric field strength measurement probe that will potentially improve both the accuracy and sensitivity of field strength calibrations by more than an order of magnitude, as well as directly linking the measurements to SI units. The probe can be housed in the tip of an optical fiber, making it both extremely small and non-metallic thus presenting a minimal perturbation to the field being measured. In addition to calibrations, such a probe could find application to spectrum surveys and to the currently unaddressed problem of deterring interfering and emitted fields in-situ, that is, inside complex electronics to better solve electromagnetic compatibility and interoperability problems.

The program provides information to standards organizations to help correlate measurements between various electromagnetic compatibility (EMC) test facilities. The program also cooperates with the national test laboratories of our international partners to perform round-robin testing and comparison of standard antennas and probes. This assures international agreement in their performance and reduces the uncertainties in the areas of metrology that affect international trade. Our goal is to develop and evaluate reliable and cost-effective standards, test methods, and measurement services related to complex EM fields for EMC of electronic devices and other applications in health, defense, and homeland security.

The program has had a number of accomplishments:

- In collaboration with DHS, developed standards for testing communication links used by urban search and rescue robots.
- Helps develop standards for using TEM cells (IEC-61000-4-20) and reverberations chambers (IEC-61000-4-21) for EMC testing.
- Completed and documented high intensity radiated field (HIRF) shielding effectiveness tests on representative commercial aircraft (Boeing 737-200, Boeing 767-400ER, Bombardier Global 5000, Beechcraft Premier 1A Composite Business Jet); the results were delivered to the Federal Aviation Administration (FAA).

Mr. Chairman, we need to do more. The President recognized the need for further investments in this area. In the FY 2013 budget request for NIST, the President proposed the Advanced Telecommunications Initiative.

Advanced Telecommunications Initiative[5]

NIST's FY2013 budget also includes a $10 million initiative to accelerate innovation in advanced telecommunications. Broadband communications networks have become as essential to today's economy as the electrical power grid was to the Industrial Revolution. To compete effectively in this global business environment, communities and companies will need reliable, secure access to huge amounts of data, available anytime, anywhere. However, the U.S. currently lacks the technology to ensure adequate capacity to achieve a large-scale network capable of this vision.

This network will need to seamlessly integrate wireless and land-based communication technology, and it will rely on revolutionary advances in network architecture. Current networks are already showing signs of strain. There has been a 5,000 percent growth in demand for wireless Internet data in the last three years alone. Currently, three percent of wireless smart-phone customers use up to 40 percent of the total available cell-phone bandwidth[6] causing large bottlenecks in mobile broadband access.

Services are striving to address the rapid increase in demand, but new technologies and approaches are needed. Add to this the many new fields where reliable, efficient, secure, and low-cost networks are critical, such as medicine (e.g., Health IT, telemedicine), sensor and control networks (e.g., Smart Grid, environmental monitoring), and information systems (e.g., cloud computing), and it is clear that incremental advances in broadband technology or network capacity will not be sufficient to meet the future needs of a hyper-connected world.

The request would provide funds for NIST modeling and measurement science that would address three key areas to enable significant innovation in communications in both the commercial and public safety sectors:

- ***Robust Next-Generation Network Technologies***
  A vast chasm exists between academic designs and commercially viable Internet-scale technologies. NIST would help bridge this gap by developing and employing advanced test and measurement techniques to characterize critical design requirements for next-generation Internet architectures. NIST also would work with industry to evaluate and improve emerging designs.
- ***Signal Metrology for 21st-Century Communications***
  The latest wireless networks are capable of carrying gigabits of data per second. However, an essential technology—the ability to measure complicated signals at new bandwidths—is not available. NIST's ultrafast electro-optic measurement technology, an approach not currently in place for the wireless industry, can be used as a precision source of quality control for wireless communications, enabling Internet access at these potential high data rates. Working closely with industry, NIST would also use the

[5] http://www.nist.gov/public_affairs/factsheet/adv_comm2013.cfm
[6] http://www.pcworld.com/article/173320/atandt_wireless_ceo_hints_at_managing_iphone_data_usage.html

requested funding for research to improve the capacity of fiber optic communications links.

- ***700 MHz Public Safety Broadband Demonstration Network***
  There is clear need for a unified, interoperable public safety communications system to help the Nation's first responders and other personnel respond most effectively to local, regional, and national emergencies. The Department of Commerce's Public Safety Communications Research program (conducted by NIST with the National Telecommunications and Information Administration) has created a 700 MHz Public Safety Broadband Demonstration Network to provide manufacturers a site for early deployment of their systems, to evaluate systems in a multi-vendor environment, and to stimulate integration opportunities for commercial service providers. The requested funding would support the continued operation of this facility.

Benefits expected from funding of this initiative include:

- a U.S. broadband network with potentially 10 or more times current capacity, but that requires only a marginal increase in capital and operating expenditures;
- progress in developing "frequency-agile" wireless systems based on intelligent hardware faster microchips and other new technologies that take advantage of temporarily available spectrum; and
- continuation of a test-bed and collaboration with the telecommunications industry to help in laying the groundwork for an interoperable public safety communications network that seamlessly delivers voice, data, and video to first responders and other emergency personnel through whatever communication avenues are available.

<u>Advanced Public Safety Communications Research and Development</u>

Finally, the recently-enacted Middle Class Tax Relief and Job Creation Act of 2012 (P.L. 112-96) contains a provision very similar to that envisioned by the President's National Wireless Initiative, that would provide NIST with up to $300 million to help develop cutting-edge technologies for public safety users. Funding for the program would come from auctions of reallocated spectrum licenses.

The overriding objective is to build a broadband system to allow first responders and other public safety personnel anywhere in the Nation to send and receive data, voice, and other communications to save lives, prevent casualties, and avert acts of terror. Such improvements depend upon advances in measurement science as it pertains to radio-frequency and optimization of available spectrum.

The technological challenges that stand in the way are significant. Current market forces are insufficient to drive the research and development efforts needed to accomplish the transformation in public safety communication technologies and capabilities, as first responders as a group are relatively small compared to the larger market. Also, public safety users often demand specifications, such as mission-critical voice services, enhanced security requirements, unique applications, and specialized testing needs that have not been fully developed or tested in a broadband context. NIST's R&D work can contribute to developing and testing these requirements to enhance first responder's capabilities, while leveraging commercial infrastructure, where feasible. Achieving these requirements in the most efficient manner possible will be critical to the success of a broadband system for first responders..

In conclusion, NIST's expertise in measurement science and standards is being leveraged in a number of areas to directly help address the numerous technical challenges involved in solving the spectrum crunch issue. NIST will continue to work with partners across the Federal government, academia, and industry, to drive technological innovations that will enable U.S. manufacturers to maintain their leadership in wireless telecommunications.

I would be happy to answer any questions you may have.

James Olthoff

Dr. Olthoff is the Deputy Director of the Physical Measurement Laboratory of the National Institute of Standards and Technology (NIST). As Deputy Director of PML, Dr. Olthoff is responsible for the realization of the fundamental units at NIST and for all related calibration services. Dr. Olthoff has worked at NIST since 1987 where he performed research related to electrical breakdown in gases of interest to the electric power and semiconductor industries, and performed calibrations of high voltage transformers and capacitors. In 2001 he became the Chief of the Quantum Electrical Metrology Division, which was the organization that maintains the fundamental electrical standards for the United States, until he was appointed Deputy Director of the Electronics and Electrical Engineering Laboratory in 2007.

Dr. Olthoff received his Ph.D. in physics from the University of Maryland in 1985 in the area of atomic and molecular physics. He then held a two-year appointment at The Johns Hopkins School of Medicine before being hired by NIST. He has published over 120 publications and has co-authored/edited four books. His international metrology responsibilities include serving as the Chair of the Sistema Interamericano de Metrologia (SIM) Quality System Task Force (QSTF), participation on Joint Committee of the Regional Metrology Organizations (JCRB), serving as the Chair of the Conference on Precision Electromagnetic Measurements, and representing NIST on the Consultative Committee on Electricity and Magnetism. Jim also serves as the NIST representative to the Boards of the NCSL International and iNEMI.