Radio-Frequency Metrology from NBS to NIST: The Legacy

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***Abstract* — We review a century of radio metrology research and development in the U.S. that paralleled the birth and evolution of radio/wireless and other electromagnetic technologies. The interplay between the scientific and technological advances and the research, measurement and standards development programs at the National Institute of Standards and Technology (formerly the National Bureau of Standards (NBS)) was a factor that facilitated both commercialization of products and implementation of systems for the public benefit.**

I. CONGRESS CREATES NBS

The year 2001 is the centennial anniversary of the National Institute of Standards and Technology (NIST), formerly the National Bureau of Standards (NBS). The organic act that created NBS was enacted on March 3, 1901, and the first transatlantic radio transmissions followed shortly on December 12, 1901. The Bureau's creation coincided with the emergence of radio technology and resulted in the first new and original technical programs at NBS. Radio technology, then called wireless, has played a critical role in the first hundred years of NIST’s activities [1-5].

The radio technology of the day consisted of spark-gap transmitters, inherently broadband devices. As the number of transmitters increased, interference became a serious limiting factor, particularly for maritime applications. NBS explorations in radio technology began in 1905, under Navy funding and with civilian Navy technical staff assigned to the Bureau. The first formal radio project, in 1911, involved the design and construction of a standard wavemeter. An unexpected byproduct of this effort was a totally new instrument, known as the Kolster Decremeter, which measured both the nominal wavelength and the time-decay, or decrement, of the spark-gap impulse. An international agreement was reached in London in 1912 to limit the logarithmic decrement of spark-gap transmissions to no more than 0.2, and to allocate a band exclusively for maritime use. The Kolster Decremeter is an example of how new NBS measurement technology allowed for the enforcement of new regulations. This technology facilitated the first steps toward achieving order in the use of the radio spectrum and reliability in radio communications.

In 1915, Congress allocated $10,000 as the first appropriation for radio research, and in 1916 they allocated $50,000. While this seems a paltry sum by today’s standards, it allowed for the construction of a complete radio laboratory on the NBS campus in Washington, D.C. Just prior to and after the U.S. entered World War I, in 1917, NBS began a program focused on aircraft radio. The shortage of trained men caused by the war in Europe, led to the employment of the first woman in a technical capacity. Although a college physics professor, she was retained only as a temporary Guest Researcher. In 1918, the Armistice was signed, and the new Radio Building was occupied. Although this building no longer exists, its legacy is preserved in the name of the main building on the NIST Boulder site.

II. THE PEACE BETWEEN THE WARS

Toward the end of World War I, NBS also initiated research on radio antennas and radio propagation. These programs required both spatial separation for experiments and a less cluttered electromagnetic environment than downtown Washington, D.C. The first NBS field site was created in 1919 at Kensington, MD. It was to be the first of many.

Spark-gap technology became obsolete as vacuum-tube technology emerged, and NBS played a

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key part in the development and acceptance of this (then) new technology. The NBS role as an expert and impartial laboratory that developed standard measurement-based methods for characterizing the new devices greatly facilitated the adoption of vacuum-tube technology. NBS also played a key role in the development of methods for circuit design using vacuum tubes. Technical reports, called Circulars, were sold to the public and aided the transition to vacuum-tube technology for both the hobbyist and the new radio manufacturing industry. Many years elapsed before the first textbook on vacuum tube circuit design appeared. In addition, NBS developed the first receiver designs that could be powered from 60 Hz power lines, eliminating the dependence on batteries.

NBS also helped pioneer commercial broadcast radio. In May 1920, NBS began weekly broadcasts from its new Washington, D.C. station, WWV. Initial programming consisted, not of time and frequency broadcasts, nor weather reports, nor anything technical. It was pure entertainment, and consisted of a few hours of recorded music broadcast every Friday night to the fortunate few in the Washington area who owned radio receivers.

The scarcity of receivers nationwide was to change rapidly. In 1920 very few American households possessed radio receivers, but by 1928, almost every household had one. The commercial development of radio and the salaries that the private sector was able to offer made it very difficult for NBS to recruit and maintain technical staff. Furthermore, in the years between World War I and World War II, NBS suffered reductions in funding and workforce size.

However, with the persistence of a few dedicated, quality people, research continued on radio propagation and radio technology. The main programs were: propagation research in specific bands; continued work on vacuum tube characterization and design; antenna theory and design; aircraft radio technology; radio navigation, for both ships and aircraft; research on the causes and prevention of radio interference; the accurate measurement of EM field intensity; the development of radiosondes for meteorological studies; the study of insulating materials for RF applications; and early research on cathode ray oscilloscopes. In addition to carrying out this research, NBS developed and provided measurement services to the nation for a wide range of electrical and radio-related physical quantities, and published a wide range of technical reports that advanced the state of knowledge in radio science and technology.

III. World War II

World War II generated new funding, staff and programs that enabled the Bureau to support military and strategic needs. Work continued on more advanced radiosondes to improve meteorological predictions, and included not only balloon-based devices, but also the first remotely operated ground-based devices parachuted behind enemy lines. Propagation programs were extended to include ionospheric measurements and research to facilitate more reliable communications.

The Ordnance Development Division was formed during World War II to develop reliable radio proximity fuses for weapons applications. A branch of this Division later focused on guided missile applications. Earlier research on radio direction finders was extended to higher frequencies in pursuit of greater accuracy. Programs were initiated to develop critical new strategic materials needed for radio technology, such as mica for capacitors, Bakelite for structural insulators, and quartz crystals for oscillators.

During this period, the collection of different programs in radio propagation research grew to significant proportions and impacted the entire military as well as civilian communications. This led to the formation, in 1942, of the Interservice Radio Propagation Laboratory at NBS. The purpose was to centralize all of the radio propagation activities as well as future research, and to provide a single body of expertise to support all government needs in radio propagation.

As a key new wartime technology, the primary responsibility for radar development was assigned to the Radiation Laboratory under the administration of MIT. However, NBS also played a key role in radar development. One program, an extension of earlier radio-based remote weather measurements, was to develop a method of using the Mark 4 radar on-board Navy ships to measure wind velocity. Another program was directed at passive radar reflectors, the objective of which was to develop practical balloon-borne targets with maximized radar cross section. There was also an extensive radar countermeasures program at NBS that led to the development of systems for both deception and jamming.

Another event that was to have a significant impact on the future of microwave technology was a classified letter from the chairman of the Joint Chiefs of Staff and the Secretary of Commerce that arrived at NBS in April 1944. In addition to declaring all standards and information about frequencies above 2.4 GHz to be classified, the letter directed the Bureau to develop, "as promptly as possible," measurement standards for frequencies between 1.55 and 11 GHz. Furthermore, the document set in place sufficient funding to carry out this mandate, and the Radiation Laboratory and others were directed to provide support to NBS in this effort. The most critical need was for frequency standards and before the end of hostilities, NBS was able to provide frequency calibrations up to 30 GHz to the US military and its allies. These were based on a family of quartz oscillators that comprised the national frequency standard.

IV. The Move West

It is no surprise that the post-war period resulted in downsizing and regrouping of the technical agencies. However, international conflict simply changed in form with a rapid transition into the (sometimes hot) Cold War. Consequently the emphasis on scientific and technological development never waned, and the programs that exploited the radio-frequency spectrum continued to advance within a changing federal structure. During this period of time, various NBS wartime programs evolved into separate agencies or laboratories. One of the first was the NBS Central Radio Propagation Laboratory (CRPL), established in 1946, in which all of the radio-related work at NBS was concentrated.

In 1951, the NBS programs related to radio missile guidance were moved to Corona, CA. In 1953, this operation was transferred to the Navy and the ordnance-related radio proximity fusing programs at NBS were transferred to the Army, and became known as the Harry Diamond Laboratory.

Field sites were critical to the radio research at NBS and were becoming difficult to find. Recall that in 1919 the first "unofficial" field site was established at Kensington, MD, where antennas and portable hardware could be tested. In 1921, a new field site with some essential facilities was established at Chevy Chase, MD, but it had to be abandoned, due to development, in 1926. The Kensington site was then upgraded, and it became the formal NBS field site until 1933. At that time, it was replaced by two larger and more remote field sites: one in Beltsville, MD and the other in Meadows, MD. Although the Beltsville site was used for NBS time transmissions until 1966, the Meadows site was closed in 1943 to create Andrews Air Force Base. A new and more remote site was established in Sterling, VA, in 1943. In less than a decade it became apparent that an even more remote site for radio research was necessary because the NBS Sterling site was needed for the planned Dulles International Airport. After a long and thorough search for a new site, Boulder, CO was chosen and, in 1954, the Sterling field station was closed and the Boulder laboratories were dedicated and occupied.

The entire NBS CRPL staff and all of the laboratory equipment were transferred to Boulder between 1951 and 1954 and operated in temporary quarters until completion of construction. While there was always a metrology and measurement service component in the electrical and radio programs at NBS, the radio work was dominated by fundamental research and technology development from its inception until just after World War II. The return to fundamental metrology programs for RF and microwave technology was finally realized in the

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Boulder labs. In 1956, the CRPL Radio Standards Laboratory was created. As requested and funded in a 1944 Department of Defense (DOD)-Department of Commerce (DOC) agreement, basic metrology and measurement services began to flourish and to become the dominant theme in NBS radio-frequency programs.

In 1965, all CRPL programs in radio propagation, upper and lower atmospheric studies, solar physics, and space environmental forecasts were transferred to a new agency called the Environmental Science Services Administration (ESSA). The Radio Standards Laboratory remained in NBS and the Bureau's radio work was finally concentrated on its primary mission, basic radio metrology and national measurement traceability. In 1970, ESSA was split into the Institute for Telecommunications Sciences (and placed under the National Telecommunication and Information Administration) and the National Oceanographic and Atmospheric Administration (NOAA), both of which are still located in Boulder. Also in 1965, the NBS Boulder Labs became part of the DOC and the Electromagnetics Division was formed in 1970.

Early Boulder programs included attenuation, impedance, power, RF voltage and current, noise, EM field strength, antennas, pulsed fields, material characterization, coaxial connector evaluations, and automated measurements. New technologies over the intervening years had a significant impact on the Electromagnetics Division. There are currently four Divisions in Boulder, focused on cryoelectronic technology (the Electromagnetic Technology Division), optoelectronics (the Optoelectronics Division), magnetic information storage (the Magnetic Technology Division), and both guided-wave and free-field EM metrology (the Radio-Frequency Technology Division). The original radio programs are most closely linked to this fourth Division. Present program areas include: Fundamental Microwave Quantities, High-Speed Microelectronics including microwave digital technology, Wireless Systems including the characterization of nonlinearities, Electromagnetic Properties of Materials, Antenna and Antenna Systems, and Electromagnetic Compatibility.

V. A New Focus

The work on fundamental RF metrology that served both industry and all aspects of government (civilian as well as military) was funded almost entirely by the DOD in 1944. This process was to continue for another 45 years until the end of the Cold War. In the past decade, a shift in microwave metrology funding from the DOD to NIST has taken place, along with a significant reduction in staff. The Technology Competitiveness Act of 1988 changed the name of NBS to NIST and broadened the mission to include support for technology development. New technology development mandates are carried out in separate non-laboratory functions.

However, the core NBS metrology mission has not changed, and remains a critical part of the NIST mission. The RF Technology Division's programs are strong and focused on the most critical current needs of the wireless, the microwave, and the electronics industries. Many of our accomplishments are documented in IEEE, MTT, EMC, and APS archival and conference publications.

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