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Foreword from the Associate Editor

In this issue, we host a paper by Pavel Nikitin on Leon Theremin (1896-1993), a Russian inventor who was in the US for quite a long time (from 1927 to 1938). Theremin discovered that the effects of moving objects on the capacitance of nearby circuits could be used to tune a resonant circuit to different frequencies. He then discovered that the movement of a vibrating membrane could be used to change – through capacitive coupling – the input impedance of a monopole antenna the backscattering from which, if illuminated via a continuous wave, would in turn be modulated.

This was exploited by Theremin to build the first known passive bug (1945). However, it also can be viewed as the first passive RFID system, where a remote station interrogates a tag on its state, in this case, varying with sound pressure in the environment. This was well in advance with respect to the simple one-bit tags that were developed in the 1960s as anti-theft devices. It also was well in advance of the first true RFID tag with writable memory, patented on January 23, 1973 (M. Roberti, “The History of RFID Technology,” *RFID Journal*, online at <http://www.rfidjournal.com/article/view/1338>).

Besides our Corner’s article, I would also like to remember (as I did in last issue) that we are approaching the 150th anniversary of Maxwell’s original lecture on “A Dynamical Theory of the Electromagnetic Field.” This was later published in 1865 in the *Philosophical Transactions of the Royal Society of London*.

The IEEE honored Glenlair (Figure 1) at Castle Douglas, Kirkcudbrightshire, UK (J. C. Maxwell’s home, where he conceived his equations) with an IEEE Milestone on August 13, 2009. You can read about this on the IEEE Global History Network Web site (http://www.ieeeahn.org/wiki/index.php/Milestones:Maxwell%27s_Equations,_1860-1871).

It is interesting to read the motivation of the Milestone at the aforementioned Web page, since it condenses in one page the development of Maxwell’s equations from their first form, to the final version by Oliver Heaviside (1850-1925) (see also



Figure 1a. Maxwell’s House at Glenlair, Castle Douglas, Kirkcudbrightshire, UK.

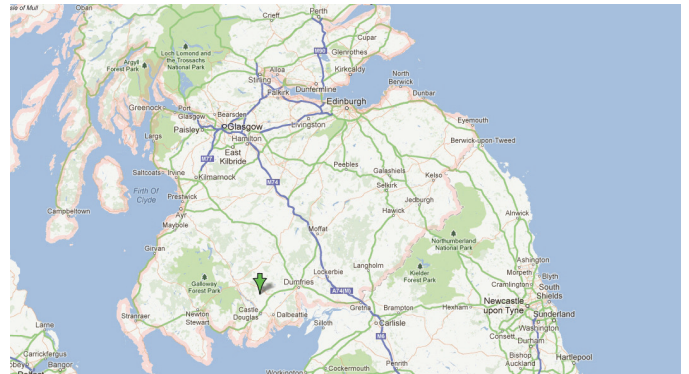


Figure 1b. The location of Maxwell’s House in southern Scotland (from Google Maps, <https://maps.google.com>).

my foreword in this Corner of the last issue of the *Magazine*). On the other hand, such a page does not remember Josiah Willard Gibbs (1839-1903). Even if it is commonly agreed that Heaviside developed his vector calculus independently from Gibbs, Heaviside himself admitted to have read Gibbs’ privately printed book of 1881 in 1888 (M. J. Crowe, *A History of Vector Analysis: The Evolution of the Idea of a Vectorial System*, Notre Dame, Indiana, University of Notre Dame Press, 1967). Gibbs should thus stand close to Heaviside (Figure 2) among the preminent contributors to the classical form of Maxwell’s equations.

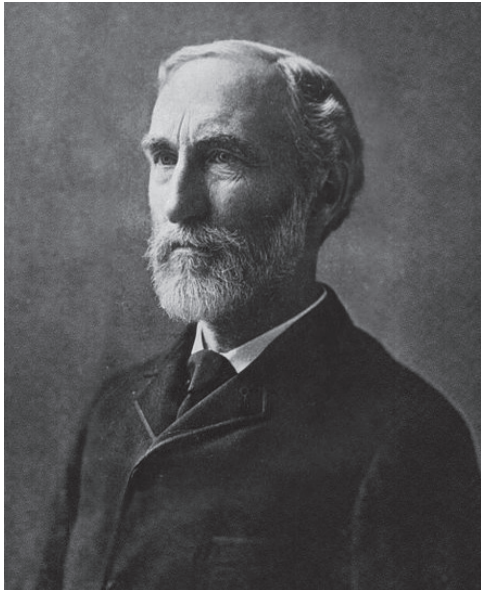


Figure 2a. Josiah Willard Gibbs (1839-1903) (from Wikipedia, <http://www.wikipedia.org>).

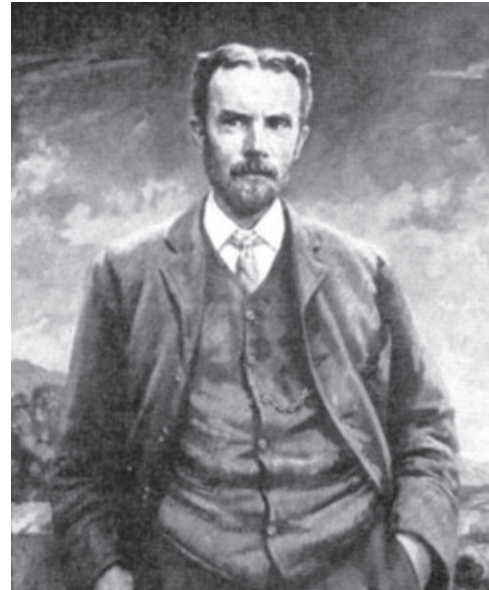


Figure 2b. Oliver Heaviside (1850-1925) (from Wikipedia, <http://www.wikipedia.org>).

Leon Theremin (Lev Termen)

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1. Introduction

This paper is dedicated to Leon Theremin [1], a Russian engineer who stood at the roots of electronic musical instruments, as well as modulated-backscatter technology. Among other things, he was the inventor of the contact-less musical instrument, thereminvox, named after him [2]; the capacitance-based alarm system; and the first passive eavesdropping device (the Great Seal bug [3]). The reader is invited to take a brief look at his extraordinary life and to follow the cited references, such as [4-6], for more details.

2. The Life

On April 25, 1930, Carnegie Hall was very busy. Everyone wanted to see the concert performed by ten musicians,

each simultaneously playing a thereminvox, a new electronic musical instrument invented by a Russian who organized the concert and was playing in it himself [7]. Thirty years later, on May 26, 1960, US ambassador Henry Cabot Lodge, Jr., was showing at the United Nations meeting a passive eavesdropping device that was discovered in the US embassy in Moscow, Russia. What links those two events? The creator of both the thereminvox and the Great Seal bug was the same person: a prominent inventor and musician, Leon Theremin.

Lev Sergeevich Termen (he became known as Leon Theremin after he came to America in 1927) was born August 15, 1896, in St. Petersburg, Russia. He started learning music and physics at an early age, and then went to study physics and astronomy at the University of St. Petersburg. He also studied cello at the St. Petersburg Music Conservatory. During World War I, he was drafted, graduated from the Officers' Electro-Technical School, and served as an officer. After

the Russian Revolution of 1917, he worked on equipment for the first radio stations of Soviet Russia. His life, like the lives of many others, was affected by the revolution: he spent time in prison in 1919-1920, after being accused of counter-revolutionary activity.

In 1920, he joined Ioffe Physical Technical Institute, where he became the head of the new experimental laboratory, and started working on high-frequency measurement methods. He found that the movement of one's hands affected the capacitance of electronic circuits, and thus could be used to control oscillator pitch and volume. Using this effect, Leon Theremin created the first contact-less musical instrument. This was originally called the aetherphone, and later, the thereminvox, or simply the theremin. The player played music by moving hands in the direct vicinity of volume- and pitch-controlling antennas (the physics of this instrument was analyzed in detail in [8]). Leon Theremin also invented an alarm system based on the same capacitance-sensing effect. He worked on a cathode-ray-based mirror-drum mechanical television, and demonstrated early prototypes that received good reviews from Boris Rosing, one of the television pioneers [9]. In 1922, Theremin showed his inventions, including the thereminvox, to Vladimir Lenin, who liked them very much. In this period of time, Leon Theremin traveled a lot across the country to demonstrate his inventions, and was often referred to as the "Soviet Edison."

To promote his inventions, Leon Theremin went on an international tour, visiting Germany, England, France, and arriving in the United States in 1927. The thereminvox created a sensation there [10]. Leon Theremin established a laboratory in New York City, where he worked on the thereminvox and other electronic musical instruments (the terpistone, rhythmicon, keyboard theremin, theremin cello, etc.). In 1928, he received a US patent for the thereminvox [11]. RCA acquired the patent, and began producing his instrument [12]. The instruments were expensive: in 1930, the cost of a simple radio set was \$30, while the complete thereminvox system with speakers cost \$230 (approximately \$3,000 in today's dollars). Only about 500 instruments were produced and sold. In 1930, Leon Theremin demonstrated ten thereminvoxes on the concert stage at Carnegie Hall [7]. In 1932, he conducted the first electronic orchestra performance there [13]. In that time period, Theremin closely interacted with many famous scientists and musicians, including Albert Einstein and composer Joseph Schillinger. Leon's close friend, thereminvox virtuoso Clara Rockmore, often accompanied him and helped him to promote his instrument.

In 1931, Theremin became a Vice President of TeleTouch Corporation, which sold his patented "radio watchman" [14], a capacitance-based alarm system, and other devices, such as metal detectors. Several of its customers were correctional facilities, such as Alcatraz and Sing Sing. In 1936, he received his third US patent, for an electrical clock run by dc current [15]. In 1938, Leon Theremin married African American ballet dancer Lavinia Williams, who bore him twin daughters (he had divorced his first wife, Katia Konstantinova, soon after he arrived in the US).



Figure 1. Leon Theremin playing the thereminvox (1924) (courtesy Wikimedia Foundation).

In September 1938, Theremin abruptly returned to the Soviet Union. Whether he returned voluntarily or was forced to is a subject of debate. In March 1939, he was arrested and sentenced to eight years in prison. He was sent to the camp in Magadan, Kolyma, one of many in Stalin's Gulag prison and labor-camp system [16, 17]. Leon Theremin would have probably died, as the survival rate there was very low. Fortunately, in 1940, he was transferred to the Moscow secret research and development laboratory, an elite part of the prison system, where he remained until 1947 working on various military projects. He worked with Sergei Korolev, who later became a key figure in the Soviet space program. Korolev went on to develop the rocket for the Sputnik launch, and started the Soviet lunar program [18].

One of the projects that Leon Theremin worked on in prison became known as the Great Seal bug [3]. In 1945, Soviet Young Pioneers (analogous to Boy Scouts and Girl Scouts) presented to the US ambassador in Moscow a carved wooden replica of the Great Seal of the United States. This gift contained a passive listening device, which was finally discovered by accident only seven years later, in 1952. The device consisted of a monopole antenna connected to a resonant cavity with a flexible sound-sensitive conductive membrane. The deformations of the membrane changed the resonant

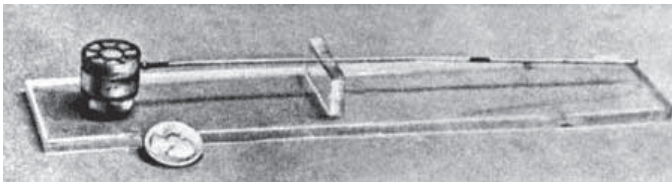


Figure 2a. The Great Seal bug: the antenna with the resonator (courtesy Wikimedia Foundation).

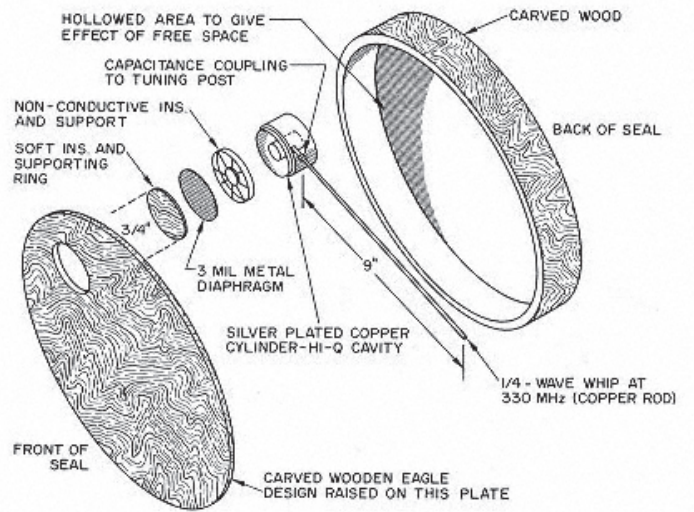


Figure 2c. The Great Seal bug: an exploded view of the device (courtesy Wikimedia Foundation).

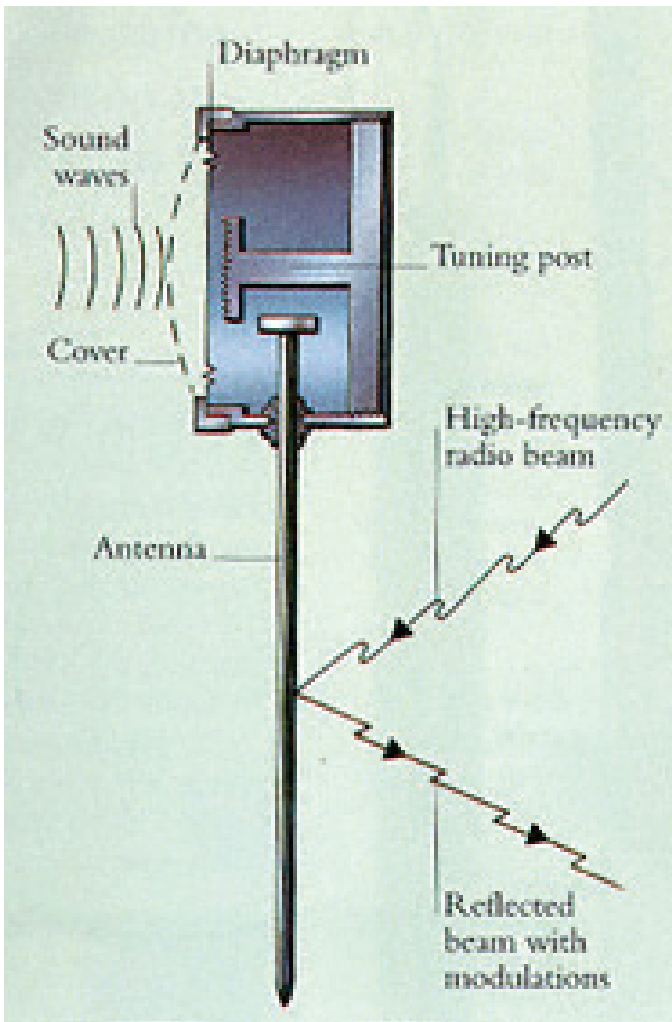


Figure 2b. The Great Seal bug: the principle of operation (courtesy Wikimedia Foundation).



Figure 2d. The Great Seal bug: the US Great Seal with the embedded device (courtesy Wikimedia Foundation).

frequency of the cavity and the antenna's load. As a result, the device backscattered an incident carrier-wave radio-frequency signal (originating from a transceiver in a van parked near the embassy), modulated with the voices of those present in the room.

This device was essentially the first long-range passive RFID tag. Modern tags use similar modulated-backscatter operating principles. The Great Seal bug was demonstrated by Americans during the 1960 UN General Assembly session as an example of Soviet espionage. A replica of the Great Seal bug is currently on display at the NSA National Cryptologic Museum in Annapolis Junction, Maryland [19].

In 1947, Leon Theremin was freed, and awarded the Stalin Prize for his work on eavesdropping devices. Beside the Great Seal bug, his other invention was Buran, an eavesdropping system that used a microwave beam to detect glass vibrations caused by sounds inside a room (the physics of this sensing technique was well described in [20]). After his release, Leon Theremin continued to work on various special projects for the KGB (Committee for State Security). He married for the third time, and had twin daughters. After retiring, he joined Moscow Conservatory, where he continued to work on various electronic musical instruments. In 1967, an American journalist found him in Russia, interviewed him, and published an article about him in the *New York Times* [21]. It was the Cold War era. Soon after the article came into print, Leon Theremin was fired, his laboratory was closed, and most of his instruments were destroyed. For a long time, he could not find any job. Finally, with the help of his friends, he started working as a technician and lab assistant at the Physics Department of Moscow State University, where he remained for the rest of his life. All those years he continued to work on the thereminvox and other electronic instruments.

In 1991, Steven M. Martin filmed a documentary about Leon Theremin [6], and brought him to the US to give lectures and thereminvox demonstrations. There, Leon again met Clara Rockmore. Lavinia Williams, his wife whom he never saw after 1938, died in 1989, just two years before his visit. In 1991, Stanford University awarded Leon Theremin a Centennial Medal for contributions to electronic music. Leon Theremin died in Moscow on November 3, 1993, at the age of 97.

3. Theremin's Inventions Today

The thereminvox still holds an important place in electronic musical instruments. It was used in musical albums (such as the Beach Boys' "Good Vibrations," Led Zeppelin's "Whole Lotta Love," and others) and in the soundtracks of Hollywood movies (such as *The Day the Earth Stood Still* and *It Came from Outer Space*). The thereminvox also inspired other electronic-music pioneers, such as Robert Moog [22]. Amateur Theremin societies are abundant today [23-25], and thereminvoxes continue to be built and sold [26, 27]. Patents stemming from the original Theremin idea continue to be filed and issued [28], a

variety of thereminvox-based instruments are being developed [29-31], and even Thereminist robots are being designed [32].

Modulated-backscatter systems, the early example of which was the Great Seal bug [3], are now widely used, not only for electronic surveillance [33], but also for measurements [34]. Such systems are also the foundation of commercial wireless technology (RFID), which has its own history [35], dating back to the 1940s [36].

Electrostatic capacitive sensing, used in Leon Theremin's instruments and alarm system, also has numerous applications today. These range from personal [37] and automobile safety [38], to medical sensing [39], graphical interfaces [40], and touch-screen technology in modern smart phones [41].

Leon Theremin once said in an interview about the thereminvox [42]:

I conceived of an instrument that would create sound without using any mechanical energy, like the conductor of an orchestra. The orchestra plays mechanically, using mechanical energy; the conductor just moves his hands, and his movements have an effect on the music artistry.

Current technology presents several ways to realize Leon Theremin's vision of creating a remotely played contact-less musical instrument. This includes motion-sensing technology such as Kinect [43], active wireless controllers such as the Nintendo Wii [44], and even passive tags [45], the signals of which can control the characteristics of electronic sound.

4. Conclusion

While Leon Theremin is mostly known to a wide audience for the thereminvox, his other pioneering work is not less important and should not be forgotten. As it is clear from his biography, he spent a significant period of his life working for state security, and much of that work will probably never be made available to the public. However, even what is known is enough to make one admire his talent, creativity, and determination, all of which he carried throughout his long, difficult, and extraordinary life. Quoting Nick Holonyak, the inventor of the light-emitting diode (LED): "Theremin (Lev Termen) should be known for more than just a musical instrument" [44].

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Correction

In the first paragraph of the Foreword to the June Historical Corner (*IEEE Antennas and Propagation Magazine*, **54**, 3, June 2012, p. 248), there was a typographical error in the date of Maxwell's speech to the Royal Society. The correct date was December 8, 1864. 