RFID-Vox: WISP Accelerometers as Musical Input Devices

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Abstract This chapter is dedicated to Leon Theremin, the inventor of the first passive RFID tag-like device, who is more widely known as an inventor of contactless musical instrument thereminvox. A biographical overview of Leon Theremin and his works is presented together with a concept of a wireless musical instrument named RFID-vox, which combines basic principles of thereminvox with current passive UHF RFID technology.

1 Introduction

RADIO frequency identification is an automatic wireless data collection technology with a long history [1] which is usually traced back to World War II British aircraft identification transponders [2] and seminal paper by Harry Stockman on principles of modulated backscattered communication [3]. A person who deserves special mentioning in RFID history is Leon Theremin [4], the inventor of the first passive RFID tag-like device known as the Great Seal Bug, more widely known as an inventor of the thereminvox, a contactless musical instrument (also known as simply theremin). Interestingly enough, combining basic principles of thereminvox with current passive UHF RFID technology allows one to create a long range contactless musical instrument ("RFID-vox") which can be played by moving passive tags in the far field of the instrument antennas.

Section II presents a biographical overview of Leon Theremin and his works. Section III describes RFID-vox concept. Conclusions are drawn in Section IV.

2 Leon Theremin

On April 25, 1930, Carnegie Hall was very busy. Everyone wanted to see the concert performed by 10 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 [5]. Thirty years later, in 1960, a US ambassador Henry Cabot Lodge, Jr. was showing at the United Nations meeting a passive eavesdropping device that was discovered in US embassy in Moscow.

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What links those two events? The creator of both thereminvox and the Great Seal bug was the same person – a prominent inventor and a musician Leon Theremin. We invite a reader to take a brief look at his life. For more detailed information, we refer a reader to the article [6], the book [7], and the excellent documentary movie [8] about the life of this extraordinary person.

Lev Sergeevich Termen (he became known as Leon Theremin after he came to America in 1927) was born on August 15, 1896 in St. Petersburg, Russia. He started learning music and physics at the early age, and then went to study physics and astronomy at the University of St Petersburg. He also studied cello at the St. Petersburg conservatory of music. During World War I, he graduated from the Higher Officers Training School of Electrical Engineering and served as an officer. After the Russian Revolution of 1917, he worked on equipment for first radio stations of the Soviet Russia.

In 1920, he joined Petrograd's Ioffe Physical technical Institute and became the head of experimental electronic oscillation laboratory there. There he discovered that the movement of one's hands could affect the capacitance of electronic circuits and thus be used to control oscillator volume and frequency. Based on that, he made the first contactless musical instrument, originally called aetherphone. Based on the same effect, he invented an alarm system. In May 1922 he showed both inventions to Vladimir Lenin who liked them very much. Leon Theremin also worked on mechanical television and successfully demonstrated first prototypes in 1925. He was often referred to as "Soviet Edison".

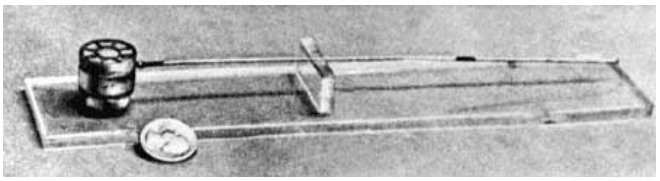
To promote his inventions, Leon Theremin went to Germany in 1925 and then to United States in 1927. The thereminvox created a sensation there [9]. Leon Theremin established a laboratory in Manhattan where he worked on the thereminvox and other electronic musical instruments (electronic cello, terpsitone, etc.). In 1928, he received a US patent for thereminvox [10]. In 1929, RCA licensed it and began producing his instrument. In 1930 he demonstrated ten thereminvoxes on the concert stage at Carnegie Hall [5], and in 1932 he conducted the first electronic orchestra performance there [11]. In that time period, Theremin closely interacted with many famous scientists and musicians, including Albert Einstein (who played violin), composer Joseph Schillinger, and thereminvox virtuoso Clara Rockmore, who helped him to promote his instrument.

Figure 1: Leon Theremin plays theremin (1924). Courtesy Wikimedia Foundation.

In 1931 he became a Vice-President of TeleTouch corporation which sold his patented “radio watchman” [12], a capacitance-based alarm system (one of its customers was Alcatraz prison). In 1936, he received his third US patent, for the electrical clock run by DC current [13]. In 1938 Leon Theremin married African American ballet dancer Lavinia Williams who born him twin daughters (he divorced his first wife, Katia Konstantinova soon after he arrived to the US).

In September 1938, he abruptly returned to the Soviet Union (there are many theories whether he did that voluntarily or was forced to). In March 1939 he was arrested, falsely accused of assisting in assassination of Sergei Kirov, a prominent Bolshevik leader, sentenced to 8 years in prison and sent to the camp in Magadan, Kolyma, one of many in GULAG prison and labor camp system [14, 15]. Leon Theremin would have probably died there (the survival rate in Stalin camps was very low), but fortunately, in 1940, he was transferred to Moscow secret research and development laboratory (elite part of the prison system) where he remained until 1947, working on various military projects. His assistant at that time was Sergei Korolev, who later became a key figure in Soviet space program.

One of the projects which Leon Theremin worked on at prison became known as the Great Seal Bug [16]. In 1945, Soviet children presented to US ambassador in Moscow a panno replica of the US Great Seal made of expensive wood. This gift contained a passive listening device which was accidentally discovered by Americans only in 1952. The device was the UHF antenna connected to a resonator with a flexible sound-sensitive membrane. When illuminated with the strong RF CW (carrier wave) signal, the device backscattered the RF signal, modulated with the voice of those present in the room where the Great Seal hung on the wall. This device was essentially the first long range passive UHF RFID tag. Modern tags use basically the same operating principles of modulated backscatter. US ambassador Henry Cabot Lodge, Jr. demonstrated the Great Seal bug during 1960 UN meeting as an example of Soviet espionage. A replica of the Great Seal Bug is currently on display at NSA National Cryptologic Museum in Washington, DC [17].



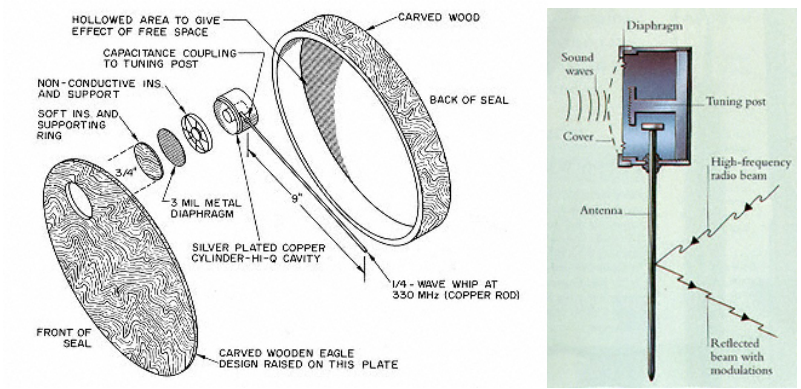


Figure 2: The Great Seal bug: the antenna with the resonator (top), principle of operation (middle), the US Great Seal with the embedded device (bottom). Courtesy Wikimedia Foundation.

In 1947 Leon Theremin was freed and awarded Stalin medal of 1st degree for his work on eavesdropping devices. After that, Leon Theremin continued to work on different military projects. He married for the third time and had twin daughters. In 1964 he joined Moscow Conservatory as professor of acoustics and started a laboratory of electronic musical instruments. In 1967, an American journalist found him in Russia, interviewed, and published an article about him in New York Times [18]. It was a Cold War era. After the article came into print, because Leon Theremin was immediately fired, his laboratory was closed, and all his instruments and prototypes were destroyed. He couldn't find any job after that. Famous Russian physicist Rem Khokhlov, head of Moscow State University (MSU), helped him to get a technician position at MSU Physics Department where Leon Theremin worked for the rest of his life.

In 1991, Steve Martin filmed a famous documentary about Leon Theremin [8] and brought him to the US where Leon met again Clara Rockmore, after more than 50 years. Lavinia Williams, his wife whom he never saw since 1938, died in 1989, just two years before his return to the US. In 1991, Stanford Universty 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 RFID-vox

Thereminvox still holds an important place in electronic musical instruments. It was used for composing music by Beach Boys (*Good Vibrations*, 1966), in Hollywood movies (*The Day the Earth Stood Still*, 1951; *It Came from Outer Space*, 1953), etc. Theremin amateur societies are abundant today [19-21], thereminvoxes continue to be built [22, 23], and patents based on original Theremin idea continue to be filed and issued [24]. There, of course, exists a variety of other electronic musical instruments, both thereminvox-based [25, 26] and using other principles [27-29].

Leon Theremin once said in an interview about thereminvox [30]: "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" [30]. The near field nature of original thereminvox construction required a player to be in the direct vicinity of volume- and pitch-controlling antennas (essentially, it is electric field sensing [31]). Interestingly enough, the current UHF RFID technology allows one to realize the original vision of Leon Theremin and to create a contactless musical instrument which can be played remotely, like conductor manipulating an orchestra.

The main concept of such instrument (we call it "RFID-vox") is illustrated in Fig. 3. A person plays it by moving one or more tags (passive or semi-passive) in

the far field of the reader antenna system. Tag signals from the RFID reader control the electronic sound characteristics, such as volume and pitch, like in classical thereminvox. The reader can provide to the musical controller either analog, or digital signals, or both. Examples of analog tag signals can be the received signal strength (RSSI) and phase of the backscattered tag signal, which are already available in commercial Gen2 (ISO-18000 6C [32]) UHF RFID readers [33]. Examples of digital tag signals can be tag ID or data from sensors integrated into the tags. The Gen2 protocol allows for the tag to be read more than one thousands times per second. Mapping and linking the received input from each tag to the sounds produced by the instrument is by itself a rich area of computer music research [34, 35]. Multiple tags could be used control many musical parameters or play an orchestra of such instruments. Using the latest passive Gen2 ICs with a sensitivity on the order of -18 dBm [36, 37], such an instrument can be played at a distance of 50 ft or more. If semi-passive (battery-assisted) chips are used that have sensitivities on the order of -30 dBm [38], the operating range can be extended even further.

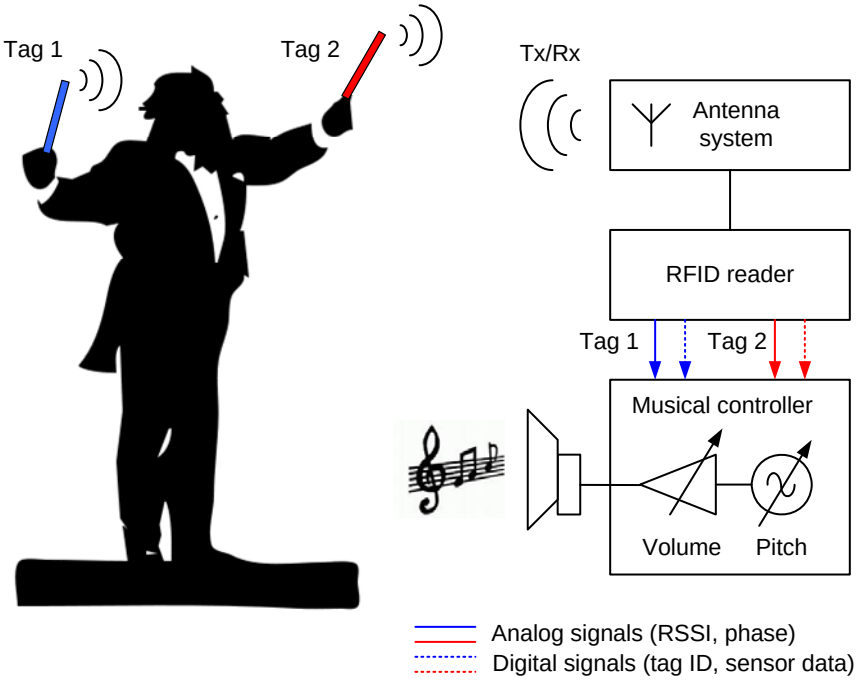


Figure 3. RFID-vox concept: analog and digital. Courtesy Wikimedia Foundation for person silhouette.

A simple analog version of RFID-vox can easily be realized using a Gen2 reader (which provides tag RSSI and phase readings) and a computer with a sound card. RFID-vox can be played, for example, using two sticks, similar to conductor batons, with embedded dipole-like RFID tags as shown. The tag in each baton will have its own ID, which allows one to associate the received RSSI and phase with

the particular tag. The received RSSI and phase of the tag signals change with the tag position (in free space, both change monotonically with the distance to the reader antenna) and can be directly linked to control the sounds (volume and pitch). As an alternative, tag location can be calculated using RFID spatial identification methods [33] and mapped to a virtual piano keyboard space in front of the player. Note that unlike some well known wireless controls for computer, such as Wii Music [39], these batons can be purely passive devices without any batteries. Of course, playing such an analog instrument will require a certain skill, like a certain skill is required to play a thereminvox. In thereminvox, one's body and hands strongly interact with the near field of thereminvox antennas and affect the way the instrument responds to the player. In RFID-vox, the interaction happens in the far field, and if the tags are detached from the hands (like in baton sticks), they are not affected by one's body as much. However, the complexity of the propagation channel (including reflections, polarization mismatch, and other effects) will probably make the task of learning how to play RFID-vox equally challenging.

A simple digital version of RFID-vox was realized based on a single bit tilt sensor called the α–WISP [40]. The α–WISP devices were affixed to two cups. When the cups were tilted, musical sounds were triggered by the reader. Because each cup was uniquely identified, each made its own characteristic sound. Digital RFID-vox instruments could be implemented in other ways. The digital identification capability of RFID suggests using different physical objects as input devices, each of which could be associated with a unique sound or instrument. Rather than implementing the sensing in an analog fashion, one could build sensors into the RFID tags, and communicate the sensor data as well as the ID digitally. Sensor data can come, for example, from UHF RFID powered and read continuous accelerometer devices, such as WISPs [41]. These could be mapped to pitch and volume, by analogy with the thereminvox, but these controllers could also be used in countless other ways as well.

The relatively low cost of RFID tags could enable many collectible input devices (which might even look like toys rather than musical instruments, like it has been described in [42]), each of which could trigger unique musical behaviors. RFID-vox devices could enable new types of musical input devices that could find many applications. For example, novel musical controllers, such as the guitar controller used in the music game *Guitar Hero* [43], combined with proper music mapping algorithms, can also allow non-skilled musicians to enjoy the experience of playing music or used for children musical education [44].

4 Conclusions

This book chapter was written as a tribute to Leon Theremin, a great inventor and an extraordinary person who lived an amazing life and stood at the roots of electronic musical instruments and passive RFID technology. It is exciting to see that new technologies (such as Gen2 UHF RFID) combined with old principles

(such as the ones used in thereminvox) can open up a window for novel applications, such as wireless contactless musical instruments. As an example of such application, we described an RFID-vox (both analog and digital versions) which can be readily built with existing technology.

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