Microwave Musings

The Spherical Audion—The Gateway to the Golden Age of Radio

■ **Ed Godshalk**

One of the more colorful pioneers of early wireless was Lee de Forest, and his most noted invention is the Audion, more commonly referred to as the triode. Arguably, the triode was the gateway invention that allowed radio to become commercially viable.

De Forest was born in 1873 in Council Bluffs, Iowa, and received his Ph.D. in 1899 from Yale [1]; his thesis topic was "Reflections of Hertzian Waves from the Ends of Parallel Wires." His first job was with Western Electric in Chicago, where he became friends with Edwin Smythe. On their own time, these two entrepreneurial engineers worked together to develop improved methods of detecting wireless signals. In 1901, de Forest founded the Wireless Telegraph Company of America to make wireless transmitters and receivers.

At this time, it was becoming obvious that a significant impediment to reliable wireless communications was a reliable detector of adequate sensitivity. One of the more common detectors in use around 1900 was the coherer, which consisted of metal filings loosely packed in a glass cylinder between a metal electrode at each end (E1 and E2 in Figure 1). When a signal (Morse code, naturally) is received, an electric field appears across the electrodes, causing the metal filings to align themselves, creating a low dc resistance path between the electrodes. In effect, the coherer acts as a relay that closes when a signal is applied across the electrodes. By placing the coherer in series with a battery and a buzzer or galvanometer (an extremely sensitive ammeter), signals are detected.

The coherer was not foolproof, and it was not particularly sensitive. It is a miracle that Marconi was able to receive the first transatlantic transmission in 1901 using this device. Although, for the record, in eighth or ninth grade, I was able to make a simple coherer by placing slightly rusty steel wool in a small glass tube with electrodes formed by wrapping tin foil around the ends of two wires shoved into each end of the tube. Attaching one end of the coherer to a couple feet of wire served as an antenna, and ground consisted of shoving a wire into the dirt of one of my mother's flower pots. Mind you, there was no discrete coil or capacitor—the tuning was simply the self inductance and capacitance of the antenna to ground. My transmitter consisted of a spark coil from a Model T Ford with one end of the high-voltage secondary coil shoved into the same flower pot and a two-foot wire hanging off the other terminal. Amazingly, this simple transmitter-receiver system worked, sending signals about three feet. This was good enough to get an A in science class, although, I seem to recall that the flower in the pot mysteriously died.

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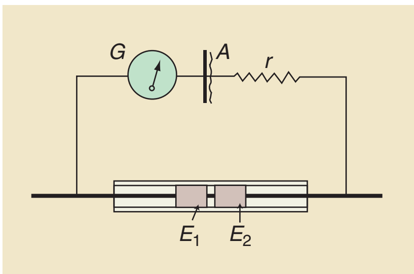

Figure 1. *A coherer detector in a simple receiver [2]. The galvanometer, G, shows current flow through the coherer electrodes E1 and E2 and battery A when a signal is detected.*

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3753B covers 3.5–12.4 GHz and provides 180° of phase shift at 3.5 GHz. It has insertion loss of 0.7 dB and maximum VSWR of 1.4:1. Both models can handle 200 W average and 1 kW peak power, have accuracy of ±0.5 dB/GHz, use Type N connectors, and have a digital dial display of phase shift. For more information, please visit the Web site at www.nardamicrowave.com/east.

Hand-Formable Cable Assemblies Perform Like Semirigid

Electronic Assembly Manufacturing, Inc., (EAM) an RF/microwave coaxial cable assembly supplier, has recently announced the availability of high-performance hand-formable cable assemblies. These cable assemblies provide typical insertion loss of 0.7 dB/ft at 20 GHz for a 0.141-in diameter cable. Typical VSWR is 1.13:1 at 18 GHz. These hand-formable cable assemblies minimize signal losses by means of a PTFE dielectric and they incorporate a copper-tin composite outer conductor to achieve excellent shielding effectiveness of more than 100 dB. They can be easily bent into a desired shape without tools and, once bent, will retain that form with minimal memory effects. In short, EAM's hand-formable cable assemblies provide greater ease of use than factory-formed semirigid cable assemblies, with little or no sacrifice in electrical performance and at a much lower cost. They are available in a wide range of

standard and custom lengths with the same connector choices as semirigid cable assemblies, including antitorque connectors, SMA, 7/16, BNC, N, and TNC connectors. Prices start at US$8.39 each for 2–12-in lengths with SMA connectors. For more information, please see the Web site at www.eamcableassemblies.com.

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Back to Dr. de Forest. In addition to the coherer, there were detectors based on electrolytic solutions, magnetized wires, etc., but they tended to be fussy and require tweaking to get decent sensitivity. One of the first discoveries de Forest and Smythe made was that the flame of a gaslight lamp flickered when their spark gap transmitter was operated. They filed three patents in early 1905 based on this concept [3]–[5].

Eventually, it was determined that acoustic waves were responsible for the flickering flame, but these experiments inspired de Forest to pursue a practical detector based on using a Bunsen burner (more correctly, a Welsbach burner) to create an ionized gas by heating various elements (metals and salts). The general idea was to heat salts in a palladium spoon, which released ions into the flame. A wire was placed a short distance from the spoon. Connecting this wire and the palladium spoon across an antenna and ground created the detector shown in Figure 2. According to the theory, when a signal was received, the ions formed a conduction path between the spoon and wire, causing a change in the resistance between them. Nothing really ever came of these detectors, and they were mostly a lab curiosity. However, they did inspire de Forest to think in terms of charged ions moving between electrodes as a possible foundation for a wireless detector.

About this time, John Ambrose Fleming successfully applied the Edison effect to make the first thermionic rectifier. In 1883, Edison had discovered that if a wire was inserted into an incandescent light bulb a

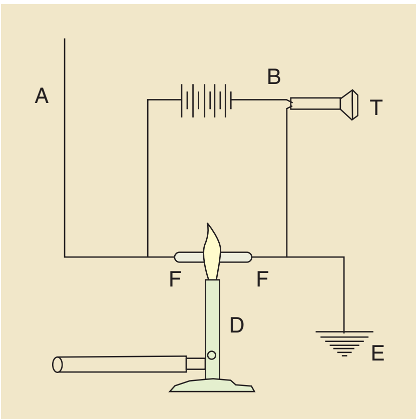

Figure 2. *A Bunsen burner detector circuit [6]. A is the antenna, B the battery, T a telephone receiver, E is ground, D is the Bunsen burner, and F are the two electrodes in the flame.*

current would flow if a positive bias was applied to the wire relative to the filament. In other words, Edison had discovered the thermionic diode [7].

Fleming joined Marconi's Wireless Telegraph Co., Ltd., in Britain in 1899 and was soon assigned to work on developing wireless equipment for transatlantic communications. As previously mentioned, a big impediment was a reliable detector to rectify high-frequency wireless signals. In October 1904, Fleming made the critical discovery that the Edison effect worked at high frequency (into the MHz range). In his own words, "The missing link in wireless was found—and it was an electric lamp." The greatness of his application of the Edison effect was well appreciated, earning him a knighthood and the title of Sir Fleming after he was knighted. He filed several patents in Europe and United States for what is commonly called the *Fleming valve* [8].

De Forest was a quick study, and soon he commissioned H.W. McCandless and Co., a manufacturer of small incandescent lamps, to make duplicates of the early Fleming valves

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(i.e., vacuum tube diodes). To make a long story short, De Forest went to great efforts to deny knowledge of Fleming's work and issued many patents of his own on variations on the Fleming valve that were of limited success [9]–[11].

De Forest saw his approach as different than Fleming's, since Fleming stated that thermionic emission was responsible for the operation and stressed the importance of having a complete vacuum, while de Forest claimed that too much vacuum resulted in poor performance, since ions of residual gas were essential for good performance. De Forest called his invention the Audion, and, in his early descriptions of the theory of operation, he began with a description of his Bunsen burner experiments [12]. He explained that the carbon filament of the incandescent lamp was analogous to the flame of the Bunsen burner in that it heated the gas in the glass bulb [13]. It has been stated that de Forest did not really understand the operation of his own inventions, but thanks to persistence and a bit of luck, he invented the triode [14]. His key innovation was to place an electrode between the filament and anode plate of his Audion, thus creating the world's first triode.

At this time (late 1906) de Forest was in serious financial and legal trouble that resulted in his resignation from the Wireless Telegraph Co. of America that he had founded in 1901. (In 1906, the U.S. Courts ruled the de Forest responder to be an infringement of Fessenden's electrolytic detector patent of 1900.) His consolation prize was US$1,000 (half was paid to his lawyer) and the patents to his Audion, since no experiments had been conducted yet and his creditors viewed them as useless.

After the dust settled, de Forest had his assistant, John Hogan, Jr., test the three-element Audion and immediately recognized that it could amplify signals and act as a detector, for which he was awarded U.S. Patent 879,532 on 18 February 1908. On 14 March 1907, de Forest disclosed the invention at the Brooklyn Institute of Arts and Sciences in his paper "The Wireless Transmission of Intelligence," and proceeded to form the De Forest Radio Telephone Co. to manufacture the triode. The rest is history, as they say, since the three-element Audion, better known as the triode, effectively opened the door to reliable and practical radio communication on a massive scale. By the mid-1920s, radio was a commercial success, and most homes owned one.

A genuine three-element spherical Audion is shown in Figure 3. It was owned by a long-time radio operator from circa World War I. Correspondence exists from the de Forest museum in the early 1960s, when they tried to purchase it from the owner. This tube has dual filaments dating it to about

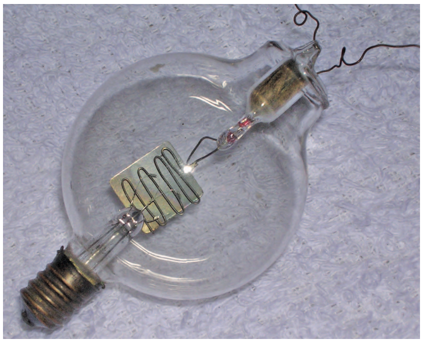

Figure 3. *A dual-filament three-element spherical Audion from 1908 made by H.W. McCandless & Co. for the De Forest Radio Telephone Company. At the lower left are the two filaments, in the middle is the grid (formed from copper wires wound back and forth around nails in a board) and in the background is the plate hand cut from a sheet of metal. The two wires on the top connect to the grid and plate, and the filaments connect to the screw-in lamp base.*

1908, since, prior to that, the Audions only had a single filament that only lasted about 35–100 hours. The 1908 version had two independent filaments, so when the first filament failed, the backup filament could be connected via an external wire to the base.

The three-element Audion is, without a doubt, one of the most significant inventions in the history of electrical engineering, or technology for that matter. As a collector item, they are highly sought after today. Since they can sell for US$1,000–2,000, there are many reproductions on the market. Some of the reproductions have been fabricated for purely historic reasons [15], but some have also been sold to unwary collectors as genuine. So "caveat emptor" if you are inclined to purchase one.

In conclusion, the story of the Audion is one of persistence and a bit of luck. Even through de Forest's understanding of its operation was a bit misguided from his experiments with the Bunsen burner detector, it was heuristically correct, which led to the critical innovation of adding a grid between the filament and plate. Both Edison and de Forest were great experimentalists and not easily thwarted by lack of a thorough theoretical background. This is perhaps an important lesson in today's world, where simulators are so dominant. There are often great discoveries to be made by spending time in the laboratory and simply following your instinct.

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