
An Examination of Tesla's Precedence in Discovering Radio

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Nikola Tesla's precedence in the discovery of radio has been asserted for many decades in numerous books of a biographical nature and more recently on a number of Internet sites. These assertions will surely continue to abound for some time to come, partly because Tesla failed to explain or document in any detail what he did or said he did, partly because he did not understand or accept the implications of Maxwellian theory, partly because Tesla morphed the description of his work over time, and partly because adherents have succumbed to conspiracy theories that the "establishment" has successfully suppressed Tesla's theories, technologies, and inventions for its own purposes. As a result, Tesla adherents often accept Tesla's unsupported theories, assertions, and distortions as fact, while mainstream science demands proof in the form of documentation and contemporaneous publication. But when it comes to the precedence in discovering radio, there should be no debate about Tesla's lack of precedence because Tesla repeatedly denied that he used Hertzian waves, a.k.a. electromagnetic radiation, for purposes of communicating intelligence (which is the definition of radio). Instead, Tesla made claims for his system such as, "the principles of transmission are the direct opposite of Hertzian wave transmission," and "the Hertz waves are practically suppressed and the entire energy of the current is transmitted through the ground exactly as though [it were] a big wire." The purpose of this paper is to explore and explain Tesla's role in wireless telegraphy and to separate fact from fiction about his precedence in discovering radio by exposing the red herrings and canards generated by authors who have attempted to secure for Tesla the title, "Father of Radio."

Nikola Tesla's precedence in discovering radio has been debated for many years in textbooks, history books, and bibliographies, and more recently in articles and blog posts on the Internet. There are two opposing camps—those who believe Tesla's precedence in radio is based on a well-received lecture he gave at both the Franklin Institute and National Electric Light Association (NELA) in 1893,¹ and those who believe that Tesla's approaches

to wireless communication did not utilize electromagnetic waves (a.k.a. Hertzian waves), which are fundamental to radio. The latter position is supported by Tesla's own words, in which he denied his approach used electromagnetic or Hertzian waves, a mantra that appeared in many of his writings. For example:

"Mr. Nikola Tesla has announced that as a result of experiments conducted

at Shoreham, Long Island, he has perfected a new system of wireless telegraphy and telephony in which the principles of transmission are the direct opposite of Hertzian wave transmission. In the latter, he says, the transmission is affected by rays akin to light, which pass through the air and cannot be transmitted through the ground, while in the former the Hertz waves are practically suppressed and the entire energy of the current is transmitted through the ground exactly as though a big wire.”²

This statement and others like it, all attributed to Tesla himself, would appear to be the final word on the subject. But alas, those who seem to be obsessed with making Tesla's legacy include “father of radio” have a different story to tell. So, the purpose of this article is to separate fact from fiction and documentary evidence from oral tradition by examining pertinent events that were reported in contemporaneous documents and literature.

It is impossible to address the issue of who has precedence in discovering radio without defining the term “radio.” When making claims that Tesla is the “father or radio,” many historians and overly enthusiastic Tesla supporters, characterized herein as Teslaphiles, fail to make a distinction between wireless telegraphy and Hertzian telegraphy, which meant then, and still means today, communicating intelligence by *electromagnetic radiation*.

One Teslaphile wrote, “Who invented radio and when largely depends on one's

definition of radio.”³ There is some truth to this statement, but only in the sense that many historians and Teslaphiles are obviously confused about the difference between the terms “wireless” and “radio.” This confusion is understandable because the term “radio” was virtually nonexistent in the last decade of the 1890s, the decade when wireless telegraphy by Hertzian waves was discovered. We now know that Hertzian waves are actually electromagnetic waves, and we also know that the term radio was reserved specifically for methods using Hertzian waves. The distinction between radio and wireless is important because there were many different concepts of wireless telegraphy that were proposed before the discovery of telegraphy by Hertzian waves, and they all have one thing in common—they were all limited to relatively short distances as compared to the method using Hertzian waves.

Tesla claimed that most, if not all of his approaches were capable of long-range communication of intelligence, but just because he claimed they were capable of long-range transmission does not mean that they utilized electromagnetic radiation—or that they actually worked. Prior to the discovery of electromagnetic radiation by Hertz in 1887, there were claims of both short- and long-range communication by means other than electromagnetic radiation. Part I of this paper contains a short review of the early methods of electronic wireless communication of intelligence, focusing on those that are similar to, or can be mistaken for, using electromagnetic radiation.

PART I. EARLY METHODS OF COMMUNICATION BY WIRELESS TELEGRAPHY

In 1898, one year after Guglielmo Marconi's achievements in communicating intelligence by Hertzian waves had been made public by William Preece on April 1897,⁴ Sylvanus P. Thompson, F.R.S., presented a paper to the Society of Arts on April 1, 1898, in which he described four distinctly different methods of wireless telegraphy: 1) conduction, 2) electric-field induction, 3) magnetic-field induction and 4) electric waves.⁵ By electric waves, Thompson was referring to Hertzian waves, or electromagnetic radiation. Most mainstream scientists today also follow this classification. It is interesting to note that Nikola Tesla also recognized the same four methods of communication in his automaton patent U.S. 613,809 for remote control of boats,⁶ which he filed on July 1, 1898, exactly three months after Thompson's lecture. While he allowed that there were four possible methods of communicating course corrections to the boat, he never specified which of the four methods he used in his 1898 demonstration to transmit correction signals to his boat.

Of the three methods of wireless communication that were known before the discovery of electromagnetic waves by Hertz, conduction and electric-field induction methods depended on ground currents that flowed between the receiver and transmitter. The third method, using magnetic field induction, consisted of two opposing loops of wire that did not require any attachments to

the ground, although in some applications the ground was used as one leg of the loop. Each of these four methods will be described in turn.

Conduction Methods

Karl A. Steinheil of Munich Germany was the first to discover that the earth could be used as the return leg of a two-wire telegraph system. In 1838 he proposed and demonstrated the concept of wireless telegraphy by using the earth to conduct electricity from a transmitter to a receiver. He found that the resistance of the earth was vanishingly small when compared to the resistance of the wires used in his telegraph system, and he then measured the ground current as a function of distance from the centerline to quantify how rapidly the currents dropped off with distance from the source (see Fig. 1). He determined that the current decreased in proportion to the square of the distance out to about 50 feet, the limit of the sensitivity of his measuring equipment. This was the first demonstration that signals could be detected at a location distant from the transmitter without connecting wires. Here is what Steinheil wrote:

"Appliances can indeed be constructed in which the indicator, having no metallic connection with the multiplier, generates currents in that multiplier, through the excitation of the ground alone, sufficient to cause

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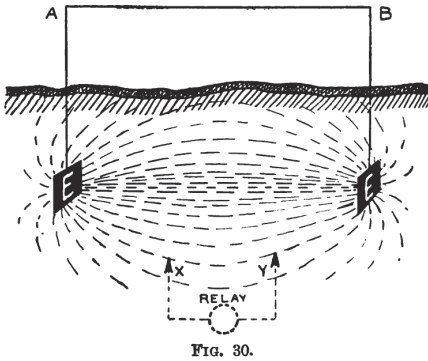


FIG. 30.

Fig. 1. Karl A. Steinheil of Munich Germany was the first to propose and demonstrate the concept of wireless telegraphy in 1838 by using the earth to conduct electricity from a transmitting wire to a remote receiver. He found that the current decreased in proportion to the square of the distance for distances out to about 50 feet, the limit of the sensitivity of his measuring equipment. (Image by W. J. White, *Wireless Telegraphy and Telephony*, 1912, p. 66)

visible deflections of the bar. This is a hitherto unobserved fact, and may be classed among the most extraordinary phenomena that science has revealed to us. It only holds good, however, for small distances, and **we must leave it to the future to decide whether it will ever be possible to telegraph to great distances entirely without metallic connection** [emphasis added].”⁷

After Steinheil’s disclosure, many different concepts for wireless communication were proposed using the method of conduction through the earth and water. The most notable examples were demonstrated by Samuel Morse,⁸ James Lindsay,⁹ and Nathan Stubblefield.¹⁰ The conduction methods described by these individuals were limited to a few miles

or less, and they are not particularly relevant to the subject at hand. However, a wireless method proposed by Mahlon Loomis in 1866 using the atmosphere for one half of a circuit and the earth as the other half of a circuit for long distance communication of intelligence is relevant.

Mahlon Loomis was the first to propose an approach for using the atmosphere as a source of electricity for transmitting messages and obtaining energy for industrial purposes.¹¹ His method of wireless telegraphy, depicted in Fig. 2, is described in his U.S. patent No. 129,971 dated July 30, 1872:

“As in dispensing with the double wire, which was first used in telegraphing, and making use of but one, substituting the earth instead of a wire to form one-half the circuit, so I now dispense with both wires, using the earth as one-half the circuit and the continuous electrical element far above the earth’s surface for the other part of the circuit. I also dispense with all artificial batteries, but use the free electricity of the atmosphere, co-operating with that of the earth, to supply the electrical dynamic force or current for telegraphing and for other useful purposes, such as light, heat, and motive power.”

Loomis’s proposal is of particular interest because Tesla described a similar method of transmitting energy to great distances in his second lecture of 1892, where he proposed to use the atmosphere for one leg of the circuit and the ground as the return circuit. It is clear from the

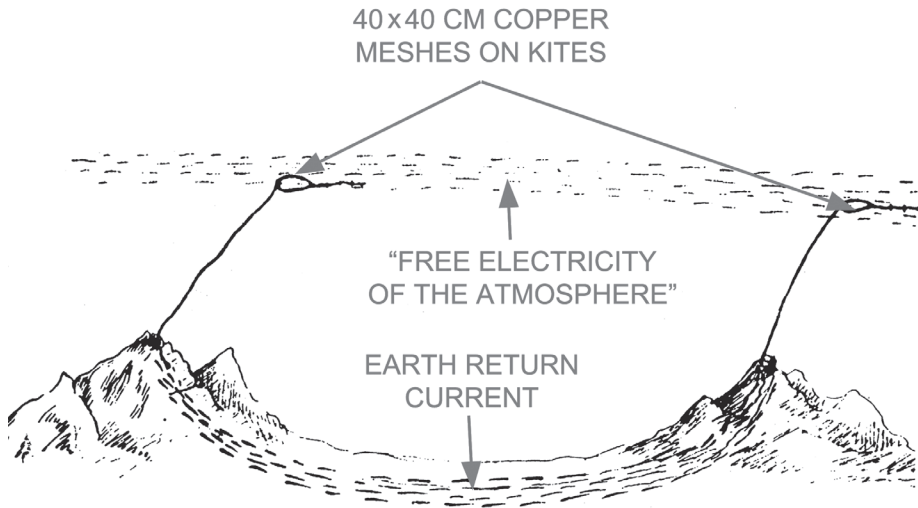


Fig. 2. Mahlon Loomis was the first to propose using the atmosphere as both a source of electricity for industrial purposes and a conducting medium for transmitting messages by using the atmosphere for one leg of a circuit and the ground as the return circuit. (Library of Congress)

similarity of Tesla's wording in his 1892 lecture to Loomis's wording in his earlier wireless proposal that Tesla had read Loomis's patent and perhaps his other published documents.

Loomis never claimed that he used electromagnetic radiation as the method for transmitting intelligence, and indeed the description of his experiment is inconsistent with the method of electromagnetic radiation. While Loomis claimed that he had transmitted and received signals at a distance of 20 miles, there is no documentation or named witnesses to support his claims, and no one has ever been able to reproduce his results. There is a sound theoretical basis, supported by experiments, to prove that he could not have transmitted intelligence to any distance with his approach.¹² Nevertheless, the following claims on behalf of Loomis for the following firsts in the

history of electronic communication appear to be valid:

- First to propose a technique for wireless transmission through the atmosphere,
- First to propose a vertical wire raised to substantial heights for telegraphy,
- First to use kites and balloons for holding vertical wires aloft,
- First to use a ground connection and vertical wires at both the transmitter and receiver,
- First to propose a technique for extracting energy from the atmosphere for use in telegraphy (and energy for "heat, light, and motive power"), and
- First to propose the use of a conducting surface at the top of a vertical wire in the form of a conducting patch on a kite or a conducting surface of a balloon.

Quasistatic Electric-Field Induction Methods

There were also a number of approaches proposed in the 1880s using the method of quasistatic electric-field induction. The three most notable examples of this approach were those of 1) W. W. Smith, who filed a patent application dated June 3, 1881, on electrostatic means of establishing communication on moving trains that was eventually demonstrated on a train (U.S. patent 247,127); 2) Thomas Edison, who filed a patent application dated May 23, 1885, on an quasistatic electric-field induction method to transmit signals over the horizon with raised conducting surfaces (U.S. patent 465,971); and 3) Amos Dolbear, who proposed and demonstrated a similar system to transmit telegraphic signals up to one-half a mile using an induction coil (U.S. patent 350,299). All three of these approaches were documented and successfully tested, although the reported distances of communication for all three were quite limited.

Of the three concepts, the one most relevant to the subject of this article is the proposal by Edison, who applied for a patent on a long-distance communication system dated May 23, 1885. In Edison's patent No. 465,971, he described an approach for communicating intelligence between ships, between ships and shore stations at over-the-horizon distances, and between ground stations separated by bodies of water where telegraph wires were not practical (see Fig. 3). Edison used a raised conducting surface at both the receiver and transmitter to form a capacitor through which displacement

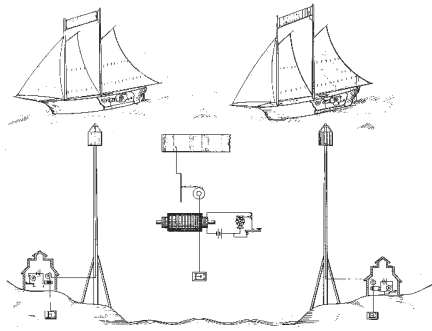


Fig. 3. Thomas Edison's patent application dated May 23, 1885, described a quasistatic electric-field induction method for wireless communication of intelligence between ships, between ships and shore stations at over-the-horizon distances, and between two ground stations separated by bodies of water where telegraph wires were not practical. (Edison's U.S. patent 465,971)

would flow. Edison claimed he sent signals to a distance of two and one-half miles with kites at a height of 580 feet,¹³ the longest distance reported for any electric-field induction technique.

A widely publicized schematic diagram for Edison's arrangement is shown in Fig. 4. The AC voltage generated by batteries in series with a current breaker was amplified by an induction coil with a secondary winding that was connected between a raised conducting surface and ground, which induced a voltage on another raised conducting surface at a distant receiving antenna by capacitive coupling. The induced change in voltage in the raised surface at the receiver was made audible by a telephone receiver connected between the raised surface and ground. The circuit was completed when the current flowing through the telephone receiver returned to the source

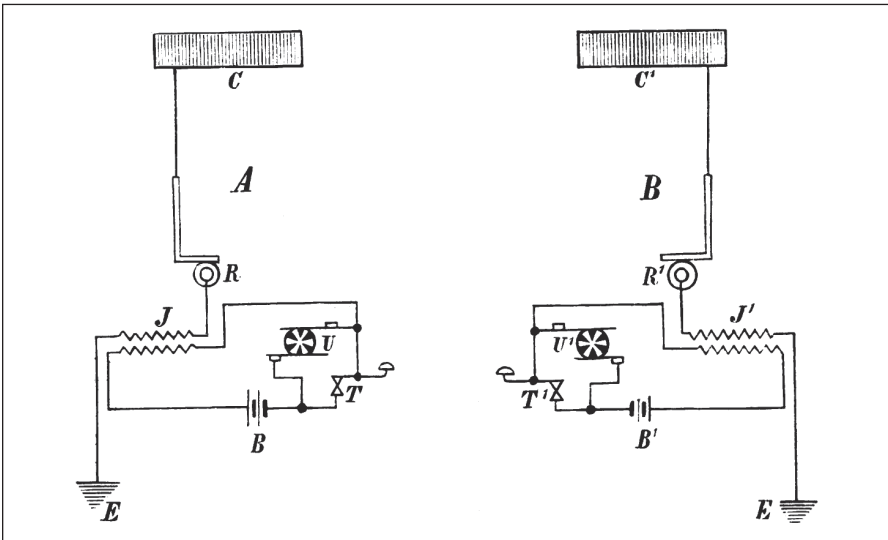


Fig. 4. The alternating voltage generated by the source at the transmitter in Edison's U.S. patent 465,971 was amplified by an induction coil that was connected to a raised conducting surface, which induced a voltage on another raised conducting surface at a distant receiving antenna by capacitive coupling. (A. Prasch, *Die Telegraphie ohne Draht*, 1902, p. 54)

through the conductive earth. The displacement current I flowing through air was proportional to the capacitance C between the two raised conducting surfaces and the rate of change of voltage dV/dt of the raised transmitting surface, $I = C \times dV/dt$, which means that sources with high voltages and high frequencies were most desirable.

Edison's source configuration is of particular interest because it is virtually identical to the source configuration that Tesla proposed for an experiment in his third lecture delivered in 1893, an equivalence that will be made clear later. Edison's source consisted of a DC source with a potential of 100 volts, which was connected to an induction coil by means of a motor-driven circuit breaker "with great rapidity" to develop a source of

alternating current with a voltage that was increased by the induction coil. The motor-drive, make-and-break circuit that Edison used, known as a rheotome, was a method that produced a continuous wave (CW) signal from a DC source, albeit not a pure sine wave. (A square wave is actually a sine wave with higher order harmonics that decrease in amplitude as $1/n$ where $n = 1, 3, 5, \dots$) The secondary of the induction coil was placed between the antenna wire attached to the large conducting surface and ground. The frequency was not specified in the patent, but the telephone Edison used, an electro-motograph, had a frequency response that allowed for reproduction of music, so the frequency produced by the breaker must have been somewhere between 500 Hz and 2 kHz, at

a minimum. In 1891, Edison proposed replacing the electro-motograph with one of his newer telephone receivers using an inductance coil.

Quasistatic Magnetic-Field Induction Methods

William Preece was the champion of the quasistatic magnetic-field induction method, in which large loops were placed on opposite banks of a body of water (see Fig. 5).¹⁴ The loops did not require ground currents, although Preece did use the earth in lieu of a wire for current flow in one side of the long rectangular loops he used on opposing banks. Wireless historian William White

states that it has always been difficult to determine whether Preece's technique was due to magnetic field induction alone or whether conduction also contributed.¹⁵ This subtlety is not particularly relevant here; the key point is that this method does not involve electromagnetic radiation. Preece's method was not used by either Tesla or Marconi, and it has not been confused with any of the methods that were proposed or used by either Marconi or Tesla. This method is mentioned primarily because it was the method used to transmit messages to the farthest distance of any wireless electrical method reported before the Hertzian method was demonstrated.

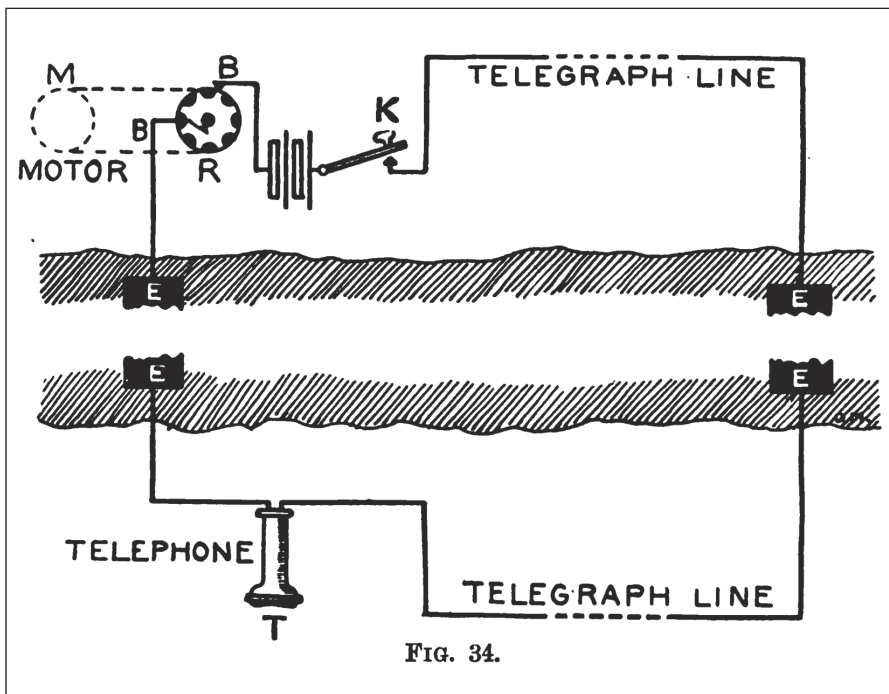


Fig. 5. This magnetic field induction technique was used by William Preece to transmit messages to a record distance of 3.3 miles across the Bristol Channel in May of 1897. (W. J. White, *Wireless Telegraphy and Telephony*, 1912, p. 76)

Electromagnetic Methods (A.K.A., Hertzian Waves or Radio)

During the decade of the 1890s and into the early 1900s, the term “wireless telegraphy” was applied to all four methods of communicating intelligence. The lines between the different methods were often blurred, and the primary word used to distinguish the method of electromagnetic radiation from the other three methods was “Hertzian,” as in Hertzian telegraphy, Hertzian waves, or Hertzian radiation. Because of this confusion, the term “radio” was introduced during the first decade of the 1900s specifically to distinguish the method of Hertzian waves from all other wireless methods. The term radio, with the root “radi” from radiation, was first adopted in 1906 at the International Radio-Telegraphic Conference of Berlin,¹⁶ and the U.S. Navy adopted the term circa 1912.¹⁷ The term radio was often subdivided into radiotelegraphy and radiotelephony, terms that were used extensively by many authorities of the day.

Definition of Radio

The terms “radio” and “wireless” coexisted from 1912 to 1921, particularly in the UK. It was not until 1922, when the broadcast era unfolded, that the word “radio” became the favored term for describing communication by electromagnetic radiation in the UK and most other countries. The terms radiotelegraphy and radiotelephony have appeared in many authoritative dictionaries and encyclopedias such as *Hawkins’ Electrical Dictionary*, published in 1910, and Sidney Gernsback’s classic, *G. Gernsback Radio*

Encyclopedia, first published in 1927, in which the following definition appears:

“The transmission of intelligence by means of electromagnetic waves through the ether. Radio falls under two general classifications: radio telephony and radio telegraphy.”¹⁸

This definition continued to appear for many years in venerable dictionaries such as Chambers’s Technical Dictionary published in 1948.¹⁹ The definition of radio today is basically the same, although the terms telegraphy and telephony have been dropped. The following definition appears in the current issue of the comprehensive *Webster’s New World Dictionary*—advertised as “the preferred reference of the Associated Press and newsrooms nationwide:”

“The practice or science of communicating over a distance by converting sounds or signals into electromagnetic waves [i.e., modulation] and transmitting these directly through space, without connecting wires, to a receiving set, which changes them back into sounds, signals, etc. [i.e., demodulation].”²⁰

There are two important concepts incorporated into the definition of radio. The first is the communication of intelligence or intelligible signals—as opposed to merely signaling. The primary difference between communication and signaling has to do with data rates. Communicating intelligence by wireless telegraphy requires data rates that allow communication of intelligence at

a reasonable data rate. A well-known example of *signaling* by electromagnetic waves was the “communication” system that the Navy developed to communicate with submarines, known as Project ELF, which was implemented in 1986 and abandoned in 2004.²¹ The data rate was so low that it could be used only to distinguish among predetermined messages—as opposed to communicating original orders. The data rate criterion is subjective, but without such a caveat, anyone who transmitted and detected Hertzian waves by any means for any purpose would be practicing radiotelegraphy—including both Heinrich Hertz and Édouard Branly. The equipments used by these two early pioneers were not capable of transmitting and receiving intelligence at any significant distance or speed by either code or voice, and neither claimed they conceived of or practiced wireless telegraphy.

The second concept in this definition, and the most important one, is the use of electromagnetic radiation transmitted through space—as opposed to non-radiating fields that are used in conduction and induction forms of wireless telegraphy. Many Teslaphiles tend to blur the distinction between non-radiating and radiating methods by believing that all of Tesla's long-distance wireless concepts of communicating intelligence are *radio* methods, whether or not they use electromagnetic radiation.

The principal characteristics of propagating electromagnetic waves in free space are as follows:

- Transverse electric and magnetic fields that are in phase, orthogonal

to each other, orthogonal to the direction of propagation, and have a constant ratio of 377 ohms (known as free-space impedance),

- Electric and magnetic field intensities that diminish as $1/r$ as they propagate in free space, and
- Electric and magnetic fields that have no DC component (the time integrals of the electric and magnetic fields are zero).

The method of communication using electromagnetic radiation is so different from all induction methods because electromagnetic radiation, with electromagnetic fields that diminish as $1/r$ in free space, has a long-range communication capability when compared to non-radiating, quasistatic fields, which diminish as $1/r^2$ and $1/r^3$, and have only a short-range capability. Conduction methods of communicating intelligence clearly do not use electromagnetic radiation. In the remainder of this paper, it will become clear how to distinguish between the Hertzian (radio) method, the conduction method, and the quasistatic electric- and magnetic-field induction methods.

The “Radio Definition” Canard

In an article entitled “Priority in the Invention of Radio, Tesla vs. Marconi” published in March 1980,²² Leland Anderson began well enough when he stated, “In the discussion of priority in the invention of radio, one must be very specific about definitions.” However, the discussion quickly went awry when Anderson claimed that a new definition of radio had evolved out of the litigation between Marconi Wireless Telegraph

Company of America and United States that ended up in the Supreme Court in 1942:²³

“The following definition of radio evolved out of the exhaustive depositions taken from the many technical experts in the field of radio and the physical sciences: A radio communication system requires two tuned circuits each at the transmitter and the receiver, all four tuned to the same frequency.”²⁴

Unfortunately, Anderson never provided the names of the experts, nor did he quote from any of the depositions to which he referred. Anderson may have been influenced by Tesla’s statement made to his attorney in 1915, which appeared in the book *Nikola Tesla on His Work in Alternating Currents* that Anderson edited and first published in 1992. Tesla said:

“If you take these two contemporaneous diagrams [of Marconi’s equipment appearing in his fundamental patent of 1896] and examine the subsequent developments, you will find that absolutely not a vestige, not a vestige of that apparatus of Marconi remains, and that in all the present systems [i.e., circa 1915] there is nothing but my four-tuned circuits. Everybody is using them.”²⁵

There is no record of any mainstream scientific organization or publication making claims that a radio is defined by a *specific circuit* or *set of circuits*—as opposed to the method of communication, namely by electromagnetic

radiation. Nevertheless this canard continues to swirl about on the Internet and in other publications.

This definition is incompatible with the mainstream definition, which is communication of intelligence by using electromagnetic (Hertzian) waves. It is incontestable that Marconi communicated messages (intelligence) at a rate of 12 words per minute to a distance of 9 miles in 1897 by Hertzian waves using a single-circuit transmitter and receiver, but by Anderson’s definition, Marconi’s communications were not by radio. On the other hand, Tesla’s first wireless patent U.S. 645,576 filed on September 2, 1897, would be defined as radio because it used two tuned circuits in the receiver and transmitter, all tuned to the same frequency. However, Tesla’s method described in this patent was based on breaking down the air between the transmitting and receiving station with “excessively high” voltages, which he believed would cause a *conduction current* to flow from the transmitting antenna to the receiving antenna and return to the transmitter by conduction currents through the ground. That is clearly not a method using propagating electromagnetic waves. So Anderson believes that a method of communication using Hertzian waves is not radio, but a method using conduction currents in lieu of Hertzian waves is radio.

And there are other problems with Anderson’s definition:

1. There were other methods of generating and radiating electromagnetic waves that did not require two tuned

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- circuits: a) arc sources; b) high-frequency alternators such as Alexander's 50 and 100 kW alternators; and c) vacuum tube oscillators that generated almost pure sine waves.
2. There was never a requirement to have single-circuit tuning in radio receivers. Both one-circuit and two-circuit tuning were common throughout the history of radio. A single-circuit autotransformer served virtually the same purpose as a two-circuit oscillation transformer for purposes of tuning the receiver to the transmitter frequency.
 3. The most common radio circuit, introduced to the public in the 1920s, is the superheterodyne, which requires only one circuit tuned to the transmitter frequency (see Fig. 6). The other tunable circuit is the local oscillator, which is tuned to the difference between the received signal frequency and the fixed intermediate frequency stages. By Anderson's definition the superheterodyne receiver is not a radio.

The truth is that many different radio circuits were developed in the early days of radio, and they became obsolete

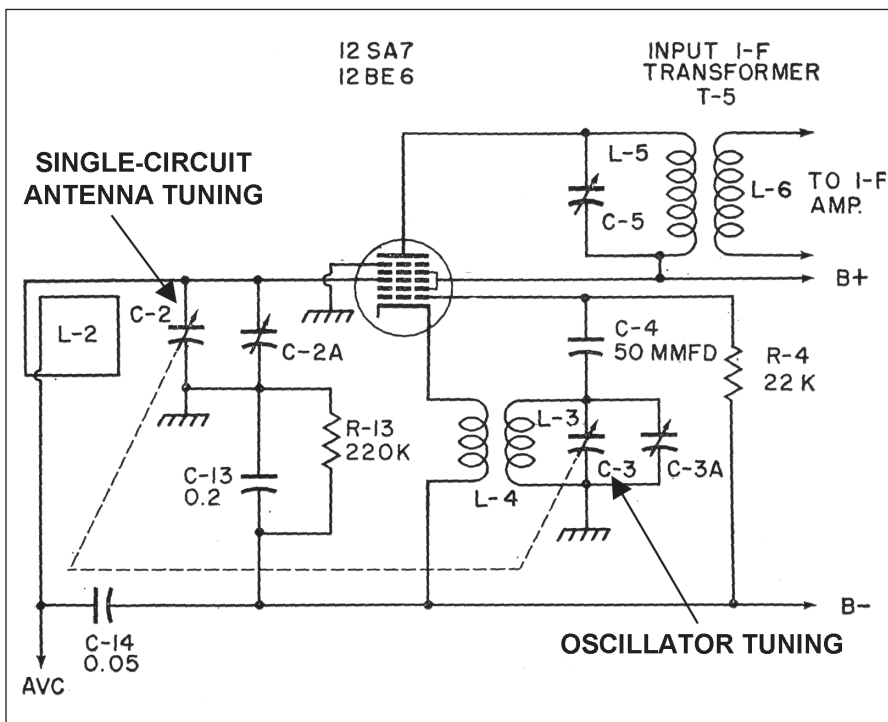


Fig. 6. The most common radio circuit, introduced to the public in the 1920s, is the superheterodyne, which requires only one circuit tuned to the transmitter frequency. (Marcus & Levy, *Practical Radio Servicing*, 1955, p. 472)

almost as fast they were developed. There were two basic circuits used in spark sources: single-circuit tuning and two-circuit tuning (see Fig. 7). The single-circuit transmitter that Marconi first used became obsolete in 1912 as a result of the Radio Act of 1912, which placed a limit on how short a damped oscillation could be (with the laudable goal of reducing interference in adjacent radio channels). Two-circuit tuning replaced single-circuit tuning in order to meet requirements of the Radio Act. However, eleven years later, the two-circuit tuners used in spark transmitters became obsolete when most spark sources were banned at the dawn of the broadcast radio era circa 1923.²⁶ The lifetime of two-circuit tuning in spark transmitter circuits was not significantly longer than the lifetime of single-circuit tuning.

There is another fundamental problem with using the concept of two-circuit tuning as the definition of radio. It turns out that two-circuit tuning, per se, will not significantly reduce the interference produced by spark transmitters. Two-circuit tuning must be combined with the separate concept of “loose coupling” in order to produce a single radiated frequency with a sufficiently narrow bandwidth to produce sharper tuning than that of a single-circuit transmitter. The requirement for loose coupling in producing sharp tuning has been ignored by most Teslaphiles, most likely because Tesla did not embrace the concept of loose coupling until 1900. The role of loose coupling in producing sharp tuning in spark transmitter circuits is described next.

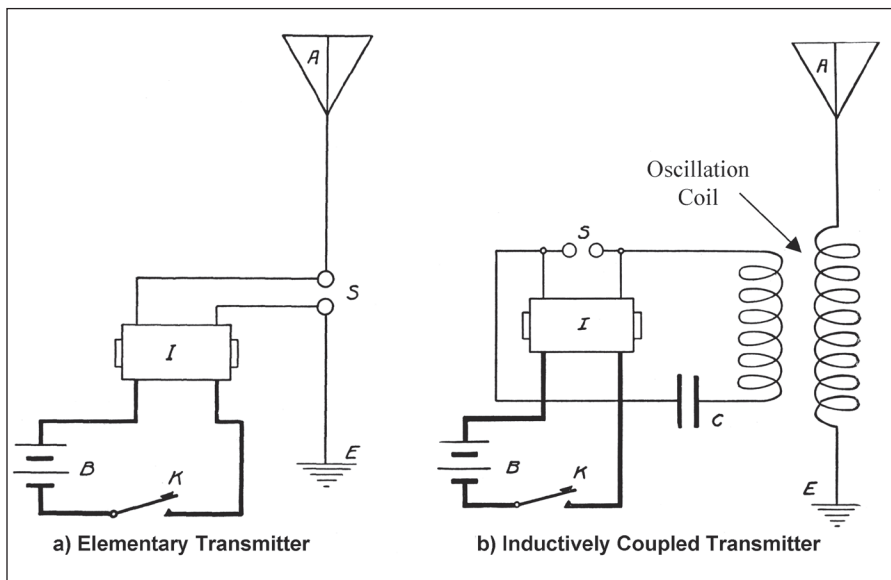


Fig. 7. There were two basic circuits used in spark sources: single circuit tuning (left) and two-circuit tuning (right). (C. Hayward, *How to Become a Wireless Operator*, 1918, pp.162–3)

Sharp Tuning of Spark Transmitter

Circuits

Single-Circuit Tuning: Without a doubt, the first circuit type to radiate electromagnetic pulses was the single-circuit spark source used by Hertz in 1887, and the first circuit to detect the electromagnetic pulse was a single “Hertz loop,” which Hertz tuned to match the transmitter. However, Hertz did not use his source or receiver for transmitting intelligence, and he did not connect one end of his radiator to a raised antenna and the other end to ground. And neither did Oliver Lodge in either of his 1894 lectures. In fact, Marconi was the first to use a single-circuit Hertz radiator as a source for transmitting and receiving messages, with one lead of his source attached to a monopole antenna and the other to ground, as shown in Fig. 7a. The single tuned circuit is formed by the secondary of the induction coil, the spark gap, and the antenna. At some point Marconi also used a large conducting surface in his antenna circuit. Marconi tuned the antenna circuits by adjusting the height of the antennas or the areas of the large surfaces. Marconi used this configuration circa 1895 in Italy, and beginning in early 1896 he also demonstrated the transmission and reception of messages in England with this configuration in the presence of independent observers.

Marconi's single-circuit spark source had a broad frequency spectrum, but the energy actually radiated was concentrated around the antenna's natural resonant frequency, supplemented by higher order harmonics. Marconi tuned his transmitter to his receiver system by

using a receiver antenna with the same resonant frequency as the transmitter. His single-circuit configuration was a very efficient radiator such that the radiated signals damped out after a few oscillations (see Fig. 8).

This configuration had two shortcomings. First, the total energy radiated by the antenna was determined by the capacity of the monopole antenna and the maximum allowable voltage. The voltage used in spark radio antenna circuits was limited to a maximum level of 50–100 kV to avoid lethal shocks and prevent brush discharges from the antenna. The antenna capacity was limited by the size of the antenna, and was not large for a simple monopole antenna consisting of a single wire. The available energy could be increased by using a two-circuit configuration, with or without tuning the two circuits, as explained in the next section. The capacity of the antenna could also be increased by using more complex antenna designs, such as an inverted cone monopole with a number of vertical wires, or top loading the antenna with a number of horizontal wires. So, the available energy was not the main reason for replacing the single circuit with two coupled circuits in spark transmitters.

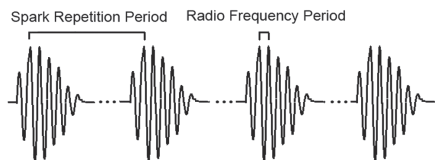


Fig. 8. The single-circuit configuration constitutes a very efficient radiator such that the radiated signals damp out after a few oscillations. (Author)

The second shortcoming was that the radiation from a simple monopole antenna with a single circuit fed by a spark source had a relatively large bandwidth, which often produced significant interference when two or more spark transmitters were operating in proximity to each other or to a nearby receiver. Reducing the interference produced by spark transmitters required two-circuit tuning with both circuits tuned to the same frequency, but it also required the primary and secondary circuits to be loosely coupled. Two-circuit tuning without loose coupling did not provide the sharp tuning needed to reduce the interference.

Two-Circuit Tuning: A representative two-circuit configuration for a radiating monopole is shown in Fig. 7b. The primary (non-radiating or closed) circuit has a charging capacitor C , a spark gap, and the primary winding of a second high-voltage induction coil, while the secondary (radiating or open) circuit has the secondary of the high-voltage induction coil and the antenna. The purpose of this improved circuit, as applied to spark radiotelegraphy, was primarily to provide sharper tuning by creating a radiated waveform with a narrower bandwidth. It also had the advantage of increasing the energy available for radiation when the capacitance of the charging capacitor C was made large relative to the capacity of the antenna. In this case, greater energy was available with or without tuning the primary circuit to the secondary circuit.

In order to reduce the bandwidth of the radiated signal, which was often approximated by a damped sinusoid, it

was necessary to reduce the damping factor (i.e., the decrement). The bandwidth is essentially inversely proportional to the pulse width. However, the reduction in bandwidth was not the result of tuning the primary and secondary circuits to the same frequency, per se. It was a result of decoupling the primary (non-radiating) circuit from the secondary (radiating) circuit so that a smaller fraction of the total energy was transferred to the radiating circuit in each cycle. It follows that if a smaller fraction of the energy is transferred from the non-radiating circuit to the radiating circuit during each cycle, it will take more cycles to radiate all the energy originally stored in the capacitor C .

The primary circuit was decoupled from the secondary circuit by reducing the flux from the primary windings that cross the secondary windings. In technical terms, the oscillation coil was designed to reduce the mutual inductance between the primary and secondary windings of the coil relative to the self-inductance of the primary and secondary windings. This could be accomplished by spacing the two windings at a distance apart in either a fixed or adjustable configuration.

If the coupling were not loose enough, the current generated in the primary circuit would couple into the secondary circuit until the spark extinguished in the primary circuit. A portion of the current in the secondary circuit would radiate and the remainder would couple back into the primary circuit, thereby reigniting the spark. The process would start all over again, resulting in the

An Examination of Tesla's Precedence in Discovering Radio

representative waveforms of the primary and secondary circuits shown in Fig. 9. While the resulting radiated pulses had an extended pulse length, which was desirable, two different frequencies were produced as the energy transferred back and forth between the two coupled circuits, thereby defeating the purpose of using two coupled circuits in the transmitter for sharp tuning.

The situation changed dramatically when the primary and secondary circuits were tuned to the same frequency *and* the two circuits were loosely coupled to a "critical degree of coupling," which according to Zenneck, every spark circuit had.²⁷ When the critical degree of loose coupling was reached, the energy coupled back to the primary circuit was not quite enough to reignite the spark, and the primary circuit was essentially an open circuit after the primary current

decayed to zero at the end of the first half cycle. The secondary circuit continued to oscillate at its resonant frequency and radiated a signal with a much longer pulse width (see Fig. 10), which resulted in a significant reduction in bandwidth, thus reducing the interference.

There is one disadvantage to the loose coupling scheme. The coefficient of coupling required to reach the point where the spark in the primary circuit was quenched at the end of the first cycle was less than 0.1.²⁸ The efficiency of a quenched-spark was less than optimal when using ordinary spherical spark gaps. In 1905, the efficiency of two-circuit tuning was increased when Max Wien demonstrated the efficacy of the quenched spark gap, which still required loose coupling, but not to the degree required with the ordinary spherical spark gap.²⁹ By the time the Radio Act

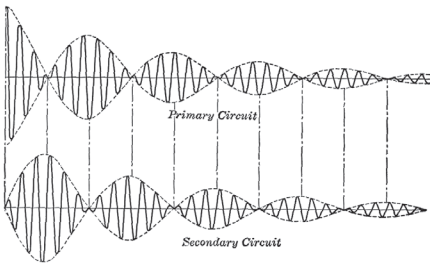


Fig. 9. The current generated in the primary circuit of a two-circuit tuned spark transmitter coupled into the secondary circuit until the spark extinguished in the primary circuit. If the coupling was not sufficiently loose, a portion of the current in the secondary would radiate and the remainder would couple back into the primary circuit, reigniting the spark to start the process all over again. (Zenneck, Seeling, *Wireless Telegraphy*, 1915, p. 94)

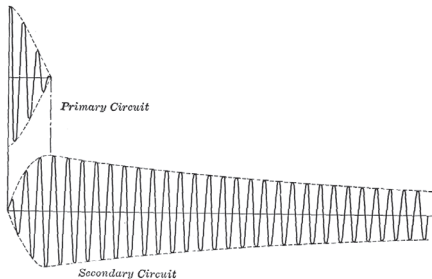


Fig. 10. When a critical degree of loose coupling was reached, the energy coupled back to the primary circuit was not quite enough to reignite the spark, and the primary circuit was essentially an open circuit after the current decayed to zero at the end of the first half cycle. The resulting radiated pulse from the secondary circuit became sharply tuned, thereby reducing the interference. (Zenneck, Seeling, *Wireless Telegraphy*, 1915, p. 94)

of 1912 was passed, most spark transmitters for wireless telegraphy used two tuned circuits with a degree of loose coupling, which was augmented by some form of quenched spark gap for sharp tuning *and* for better efficiency. This combination made single-circuit tuning obsolete.

It should be noted when the coupling was tight, the pulse would be very short, and two distinctly different frequencies would be radiated. In terms of producing interference, the two tightly coupled circuits in the transmitter could actually produce more interference than a single circuit. Two circuits, with or without tuning, were not used in spark radio transmitters to achieve sharp tuning without introducing the appropriate amount of loose coupling to quench the current in primary circuit after the first pulse.

The advantage of tight coupling is that less energy is wasted, and the peak voltage produced in the secondary circuit is greater. Tight coupling was ideal for applications that did not require sharp tuning—such as powering Tesla's lighting circuits. In fact, Tesla never mentioned loose coupling with regard to powering his lighting circuits, and it turns out that Tesla did not mention loose coupling in his wireless transmission patents until his application for U.S. patent 787,412 filed on May 16, 1900. By that time, John Stone Stone had worked out the mathematics of loose coupling

in both transmitter and receiver circuits and filed an application for his seminal patent U.S. 714,756, dated February 8, 1900, on the subject of loose coupling in radio circuits.³⁰

The key takeaway points from this section are as follows:

- Tuning two circuits to the same frequency without loose coupling is insufficient to produce sharp coupling.
- Two-circuit tuning without loose coupling was not used in radiotelegraphy.
- John Stone Stone was the first to document the advantage of loose coupling in radio circuits for sharp tuning.
- By the time the Radio Act of 1912 was enacted, which made single-circuit tuning obsolete in spark radio transmitters, virtually all spark radio transmitter circuits had two loosely coupled tuned circuits with a degree of loose coupling for sharp tuning, augmented by some type of quenched spark gap configuration for better efficiency. Neither loose coupling nor quenched spark gaps used in spark radio transmitter circuits were invented or discovered by Tesla or Marconi.
- Anderson's untenable definition of radio, consisting in part of two-circuit tuning in the transmitter, does not mention the requirement for loose coupling in the transmitter circuit to achieve the required sharp tuning.

PART II. WINDOW OF DISCOVERY: THE ACCOMPLISHMENTS OF MARCONI

If Tesla has precedence for the invention of radio, then it follows that he must have invented it before any of the other contenders—and in particular, before Guglielmo Marconi, who perhaps has the strongest credentials of all contenders. For purposes of this paper, Marconi will be considered as the gold standard for dates of discovery. Therefore, in order to claim precedence on behalf of Tesla in the discovery of radio, one must demonstrate that Tesla discovered radio before Marconi. This is a necessary but not sufficient condition to establish Tesla's precedence, since it is certainly possible that a third inventor has precedence over both Marconi and Tesla. This possibility is not addressed here.

Marconi's Accomplishments

Marconi is considered to be the gold standard because his accomplishments are so well documented. These accomplishments, which cover his descriptions and demonstrations using Hertzian waves (electromagnetic radiation) to communicate intelligence, include the following:

1. **Marconi's Documentation:** Marconi filed his application for UK patent No. 12,039 on June 2, 1896, which described a system of communicating intelligence by means of "electrical oscillations of high frequency." While the complete specification for Marconi's UK patent was not filed until March 2, 1897, his application for U.S. patent 586,193 filed on December 7, 1896, did contain the specification for a *complete system* to communicate intelligence, which specifically stated that his approach used "Hertzian" waves.³¹ This is the first known document claiming communication of intelligence by Hertzian waves (a.k.a. electromagnetic radiation), and the first known document describing a complete system for communicating intelligence by Hertzian waves. Claims that Tesla described a system for communicating intelligence in his 1893 lectures will be examined later in this paper.
2. **Marconi's Demonstrations:** Marconi demonstrated the transmission and reception of messages to distances of $1\frac{3}{4}$ to 4 miles on Salisbury Plain, beginning in July 1896, and a range of 7 miles by March 1897. These tests were observed and documented by representatives of the UK General Post Office (GPO). During the period May 10–13, 1897, Marconi successfully demonstrated the transmission and reception of messages across the Bristol Channel between Lavernock Point and Brean Down Fort in Somerset, with grounded transmitting and receiving antennas spaced at a distance of approximately 9 miles. These tests were observed and documented by William Preece,

Engineer-in-Chief of the UK GPO,³² the German professor Adolf Slaby,³³ and others.

Canards and Red Herrings Regarding Marconi's Early Accomplishments

There have been many attempts by Tesla-philites to marginalize or ignore Marconi's fundamental U.S. patent dated December 7, 1896, and the demonstration tests he began on Salisbury Plain on July 7, 1896, which continued until May 13, 1897, the date he demonstrated sending and receiving messages to a distance of 9 miles across the Bristol Channel. The attempts to marginalize Marconi's early work are a thinly disguised ploy to move the window of discovery to a later date to justify using Tesla's later accomplishments after May 13, 1897, to support arguments for his precedence. The repeated canards (untrue claims) and red herrings (claims intended to divert attention from the real issue) used to marginalize or ignore Marconi's accomplishments during this early period require a response, which follows.

Canard Alert: The Supreme Court Invalidated Marconi's Fundamental Patent

The boldest attempt to move the window of opportunity for Tesla's precedence in radio forward in time was the following assertion by Leland Anderson made in March 1980:

"Despite the fact that a U.S. Supreme Court decision in 1943 invalidated the fundamental radio patent of Marconi

there persists continuing argument asserting Marconi's priority."³⁴

Anderson was referring to the litigation at the U.S. Supreme Court in *Marconi vs. the United States*, (320 U.S. 1), where the Marconi Company sued the U.S. government for infringing on Marconi patents during WWI. The Marconi patent in question, which was indeed invalidated by the Supreme Court in 1943, was Marconi's U.S. tuning patent 763,772 with a filing date of November 10, 1900. This patent was an *improvement* in Marconi's fundamental U.S. patent filed on December 7, 1896. Surely, Leland Anderson did not believe that Marconi's *tuning patent* filed in November of 1900 was his *fundamental* patent for communicating intelligence by Hertzian waves. Marconi's fundamental or basic U.S. patent for communicating intelligence by Hertzian or radio waves is U.S. patent 586,193, which was filed on December 7, 1896, approximately four years earlier than the patent cited by Anderson. This patent was later reissued as No. 11,913 for a minor change in wording, but it retained the priority date of December 7, 1896.

Although the Supreme Court invalidated Marconi's later U.S. tuning patent 763,772 in 1943, it stated that Marconi's reputation as the man who first achieved successful radio transmission rests on his original patent, which became reissue patent No. 11,913:

"Four years before [the application date of the suit in question: 763,772], Marconi had applied for his original

and basic patent, which was granted as No. 586,193, July 13, 1897 and reissued June 4, 1901 as reissue No. 11,913. ... "Marconi's reputation as the man who first achieved successful radio transmission rests on his original patent, which became reissue No. 11,913, and which is not in question here. That reputation, however well-deserved, does not entitle him to a patent for every later improvement which he claims in the radio field."³⁵

So, the Supreme Court stated that Marconi's original patent, which became his reissue patent No. 11,913, was his "original and basic patent" and that the later Marconi patent 763,772 in the suit was an "improvement."³⁶ In short, Marconi's fundamental, original, basic patent was not invalidated by the U.S. Supreme Court, as Leland Anderson misrepresented.

Canard Alert: The Supreme Court Declared that Tesla Invented Radio

Many Teslaphiles and certain historians maintain that the Supreme Court declared that Tesla discovered radio. The issue of who discovered or invented radio was never before any U.S. court, and in particular, not before the Court of Claims or the U.S. Supreme Court in the case cited. Article III, Para. 1-2 of the U.S. Constitution, known as the "Cases and Controversies Clause," specifically limits the authority of U.S. courts to cases and controversies before the court, and it prohibits both rulings *and opinions* on controversies not before the court. Since the issue of who invented radio was

never before the Court of Claims or the Supreme Court, the constitution specifically prohibited the courts from issuing an opinion on who invented radio.

Does the Supreme Court itself agree with the interpretation that the U.S. Constitution prohibits both rulings *and opinions* on controversies not before the court? Citing the "Cases and Controversies Clause" of the U.S. Constitution, the Supreme Court made this ruling in 1793, and the court has abided by it ever since. Anyone who contemplates repeating this canard should read the 1793 Supreme Court ruling, in which the justices themselves ruled that federal courts may not render advisory opinions on cases in question not before them. Perhaps the best article on this topic was written by William R. Casto, an Allison Professor of Law at Texas Tech University.³⁷ Casto concludes his article with the following statement: "Following this textual analysis, Article III forbids the Court to use its judicial power to render an advisory opinion unless a request for an advisory opinion is a constitutional case or controversy."³⁸ The issue of who invented radio was clearly not before the Court of Claims and the Supreme Court in the case of Marconi vs. the United States, and they never rendered such an opinion. Teslaphiles who make this claim have never cited the language in the findings of this case to support this claim.

Canard Alert: The Supreme Court used Tesla's Patents to Invalidate Marconi's Tuning Patent

Teslaphiles have also asserted that the U.S. Supreme Court relied on a Tesla

patent to invalidate the Marconi patent. Nothing could be further from the truth. In its deliberations, the Supreme Court considered five patents that *may* have anticipated Marconi's tuning patent 763,772 for "improvements in apparatus for wireless telegraphy": Lodge U.S. patent 609,154, Stone U.S. patent 714,756, Tesla U.S. patent 645,576, Pupin U.S. patent 640,516, and Fessenden U.S. patent 706,735. The Supreme Court concluded that all of Marconi's claims were anticipated by Lodge and Stone, except for Claim 13. The Supreme Court found that Claim 13 was not anticipated by Lodge, Stone or Tesla:

"A feature of the Marconi combination not shown by Tesla was the use of a variable inductance as a means of adjusting the tuning of the antenna circuit of transmitter and receiver."³⁹

However, the Government (defendant) contended that Claim 16 was anticipated by both the Pupin and Fessenden patents. The Supreme Court agreed with the defendant's position and vacated the finding of the Court of Claims that Claim 13 of the Marconi patent was valid. The Supreme Court found that Marconi's Claim 16 was anticipated by the patents of Pupin and Fessenden—not Tesla. Claim 16 was remanded to the Court of the Claims so that they could reconsider its decision in the light of the Supreme Court's finding.

The findings of the Supreme Court, which were numbered 1 through 13 in the Syllabus,⁴⁰ identifies the patents of Lodge, Stone, Pupin, and Fessenden as

anticipating Marconi's claims (see Findings 1 and 7 reproduced below). Tesla was *not named* in the findings of the U.S. Supreme Court as being used for invalidating the Marconi tuning patent:

"1. The broad claims of the Marconi Patent No. 763,772, for improvements in apparatus for wireless telegraphy—briefly, for a structure and arrangement of four high-frequency circuits with means of independently adjusting each so that all four may be brought into electrical resonance with each other—held invalidated and anticipated. Marconi showed no invention over Stone (714,756) by making the tuning of his antenna circuit adjustable, or by using Lodge's (Patent No. 609,145) variable inductance for that purpose. Whether Stone's patent involved invention is not here determined. P. 38."⁴¹

"7. The judgment of the Court of Claims holding valid and infringed Claim 16 of Marconi Patent No. 763,772 is vacated and remanded in order that that court may determine whether to reconsider its decision in the light of the Government's present contention that Claim 16, as construed by the Court of Claims, was anticipated by the patents to Pupin, No. 640,516, and Fessenden, No. 706,735. P. 48."⁴²

Teslaphile claims that the Supreme Court relied on the Tesla patent to invalidate the Marconi tuning patent, or that *any* of Tesla's so-called "radio" patents predated Marconi's fundamental radio patent, are nothing but canards.

Canard Alert: Marconi Did Not Invent Anything New, and If He Did It Was Not Significant

In an article entitled "Reading the Supreme Court: Tesla's Invention of Radio,"⁴³ author Wallace Brand took the view that Marconi did not discover anything new, a view that is held by many Teslaphiles. Citing only the findings of the Court of Claims and the Supreme Court, he concluded: "The evidence available from historical documents simply does not support Marconi's claim of invention." Wallace Brand qualified this conclusion by stating that even if Marconi's fundamental patent represented invention, it "would be significant only if Marconi's combination of elements invented by others played an important role in the progress of radio. It did not, because the two-circuit system could transmit only a few miles."

Brand's conclusion is quite astonishing, and certainly contrary to the findings of the Court of Claims and the Supreme Court. Attorneys for the United States (defendant) argued before the Court of Claims that there was nothing new in Marconi's fundamental patent and that it should be invalidated because it did not constitute invention. On this issue, the Court of Claims found in favor of Marconi and validated his fundamental patent. Consequently, this issue was not in contention and was never before the Supreme Court. However, it was before the Court of Claims, and here is what the Court of Claims wrote about the Marconi fundamental patent filed in 1896. The bold letters in these citations are added for emphasis:

"Marconi applied for his first patent in 1896 and it was reissued under date of June 4, 1901. The reissue patent #11913 relates to a 'complete system or mechanism capable of artificially producing Hertz oscillations and forming the same into and propagating them as definite signals and capable of receiving and reproducing, telegraphically, such definite signals; * * *.' **The subject-matter of the reissue patent was extensively used until displaced by later improvements.**"⁴⁴

"When we consider the evidence it shows that there was nothing new in any of the individual elements of the apparatus described in claim 3 and while counsel for plaintiff in argument endeavor to show an infringement based on some one or more of these features **we are clear that the combination alone was patentable** and think a reading of the claim shows that nothing more was intended."⁴⁵

"As stated above, plaintiff's patent is on the combination. In *Loom Company v. Higgins*, 105 U.S. 580, it is said: **'If a new combination and arrangement of known elements produce a new and beneficial result, never attained before, it is evidence of invention.'** This quotation may sustain plaintiff's claim that the combination was patentable but it also shows that the patent thereon was not infringed."⁴⁶

"XXVI. No prior patent or publication discloses the combination of the claim in suit. The invention of the Marconi reissue patent made possible new results by permitting

the use of the Morse code for signalling with Hertz waves, and permitted signalling with Hertz waves to greater distances than was previously possible.”⁴⁷

Note that the Court of Claims found “the Marconi reissue patent made possible new results by permitting the use of the Morse code for signalling with **Hertz waves**, and permitted signalling with Hertz waves to **greater distances** than was previously possible.” To quantify this distance, the record shows that Marconi was able to transmit messages with Hertzian waves on May 13, 1897, across the Bristol Channel to a distance of approximately 9 miles with a 150 foot (46 meters) monopole antenna using the system described in his patent. This distance was three times the maximum distance achieved by the best non-Hertzian electronic system of wireless telegraphy reported up to May 13, 1897, which was the 3.3 miles reported by William Preece in May 1897 using his magnetic-field induction method.

The record also shows that by May 1897, Marconi had determined that the range of his system, as defined in his fundamental patent, was proportional to the square of the height of his antenna, which meant that his early system could have achieved a range of 36 miles for an antenna height of 300 feet. In fact, Marconi was able to communicate between England and France a year later without using two tuned circuits in either the transmitter or receiver. This was the first international communication of intelligence and attracted much attention

in both the popular and technical press. There was nothing in Marconi’s original patent that limited the height of the antenna or the power level, and with an antenna held aloft at 400 feet and a larger power source than Marconi used at the Bristol Channel, Marconi’s original system could have easily reached 1000 miles.

Mr. Brand was ill-advised to use the distance that Marconi actually demonstrated transmitting and receiving messages with his early system (9 to 36 miles) as a criterion for relevance. After all, there is no evidence whatsoever that Tesla transmitted any messages to any distance in his entire lifetime—much less to 9 miles by May of 1897, the date when Marconi clearly did so. If the criterion “demonstrated distance of message transmission” determines relevance of the system, then all of Tesla’s proposed systems are irrelevant.

Many historians believe that Marconi achieved long distance communications only because he began to use two tuned circuits in both his transmitter and receiver beginning in 1900. In fact, he achieved long distances after 1900 *in spite* of using two tuned circuits. The coherer he used in his original system is an extremely sensitive device and is triggered by the peak voltage at the coherer, not the energy in the pulse. The peak amplitude of the radiated signal during the first full oscillation emitted from a monopole radiator, as described in his original patent, is generally larger than the largest pulse produced by a loosely-coupled, two-circuit antenna configuration that has the capability of transmitting a single

frequency. The coherer responds within a nanosecond after the applied voltage exceeds the coherer's trigger voltage, so the range can actually be diminished when a two-circuit transmitting antenna is used *with a coherer* in lieu of the plain open aerial described in Marconi's patent. Wireless expert R. D. Bangay confirms that Marconi's original aerial circuit, which he illustrates in his text book *Elementary Principles of Wireless Telegraphy*, is an efficient long-range transmitter: "An aerial directly excited in this manner is usually called a "plain aerial," and is extremely efficient for obtaining a comparatively long range with the use of a small power."⁴⁸

The real relevance of Marconi's achievements is twofold. First, transmission of wireless messages was a dream of inventors since Karl Steinheil first proposed a wireless concept using conduction current in the earth circa 1836. In the intervening period between 1836 and May 1897, a conduction method and electric- and magnetic-field induction methods had been developed, but the longest recorded distance for transmitting wireless messages in the intervening 50 years was 3.3 miles by William Preece's quasi-magnetostatic approach.⁴⁹ Second, electromagnetic waves and the means for generating them were discovered by Hertz in 1887, but no one had defined and documented a system for transmitting and receiving messages by electromagnetic (Hertzian) waves in the intervening years until Marconi did on December 7, 1896—ten years later. And no one had demonstrated and documented transmitting and

receiving messages by electromagnetic waves to any distance until Marconi did so beginning in April 1896, which resulted in a documented demonstration of transmitting signals to a distance of approximately nine miles across the Bristol Channel on May 13, 1897. Marconi's accomplishments by mid-May of 1897 using his early system are chronicled in a number of well-known and often-referenced documents.⁵⁰ The more important accomplishments can be summarized as follows:

- He defined a system for communicating intelligence using Hertzian waves, now known as electromagnetic radiation, which he demonstrated was capable of transmitting messages to longer distances than had been achieved by any other electronic wireless communication method.
- He demonstrated that he could transmit messages at 12 words per minute to a minimum distance of nine miles with very modest and inexpensive equipment.
- Based on data he collected, he found that range was proportional to the square of the antenna height (which became known as Marconi's law).⁵¹
- He found that a line of sight between the transmit and receive antennas was not required to transmit and receive messages.
- He predicted the range of his system could be much longer using a combination of higher monopole antennas, antennas with more capacitance, and larger power sources (e.g., more batteries, rotating machinery).
- He found he could radiate energy

directionally with the aid of a curved reflector; these experiments would become the basis for directional beam transmission technology in the 1920s.

Red Herring Alert: Tesla's Four-Circuit System Made Marconi's Fundamental Patent Obsolete

As mentioned previously, Mr. Brand qualified his statement about Marconi's fundamental system by saying: "Furthermore, even if the two-circuit system [of Marconi] were found to be a viable system of radio communication, the four-circuit system made it obsolete." According to the Court of Claims and the Supreme Court, Marconi's two-circuit system was a viable system, and at some point it did become obsolete. The Court of Claims found: "The subject-matter of the reissue patent [Marconi's fundamental patent] was extensively used until displaced by later improvements."⁵² That two-circuit tuning was required in the transmitter antenna circuit is ironic, because it was mandated specifically because of the success of Marconi's system with single-circuit transmitter, which was replicated by others and became the cause of the interference that required two-circuit tuners (with loose coupling) in the transmitter.

So, where is the red herring in all of this? The red herring is in stating that the original Marconi system became obsolete, as if that fact were somehow relevant. It is axiomatic that most technologies covered by relevant patents become obsolete by subsequent technological developments, but that does not diminish the relevance of the seminal

patent or the precedence set by the invention described therein. In this regard, two-circuit tuners for spark transmitters described in the patents cited in the Supreme Court case became obsolete in mid-1922, when all amateur and most commercial spark transmitters were banned in favor of true continuous-wave systems. If one chooses to marginalize Marconi's fundamental spark transmitter patent with single-circuit tuning simply because it became obsolete in 1912, then one must equally marginalize the concept of two-circuit tuning used in spark transmitters, which became obsolete in the early 1920s, when most spark systems were banned. The fact that *later* discoveries by others improved the performance of the Hertzian telegraphy systems has no bearing on who has priority in discovery of Hertzian telegraphy.

Canard Alert: Tesla's Patent 645,576 Cited in the Supreme Court Case Was a "Radio" Patent

Many Teslaphiles and Tesla biographers refer to Tesla's patent 645,576 (see Fig. 11) as his first "radio patent." In fact, this is not a radio patent because the method of transferring energy is by breaking down the earth's atmosphere between a transmitter and receiver spaced at large distances, which presumably produces a highly conducting plasma that conducts the energy; consequently, Tesla's method did not transfer energy (or intelligence) by means of Hertzian waves. Tesla did use Hertzian frequencies, but only to generate the high voltages needed to break down the atmosphere at high altitudes—not for purposes of radiating

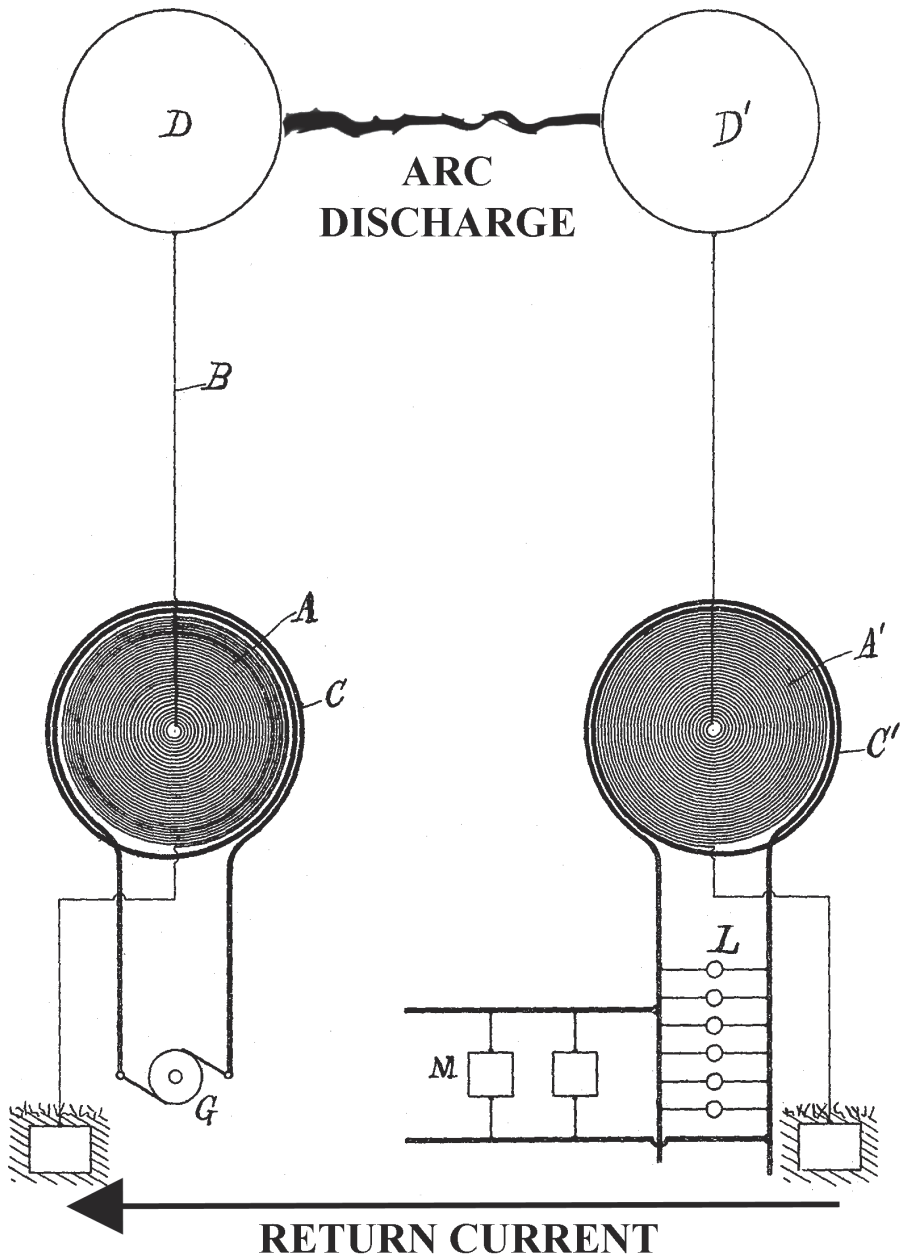


Fig. 11. Tesla's first wireless transmission patent was not a radio patent because the method of transferring energy was by breaking down the earth's atmosphere between a transmitter and receiver spaced at large distances, which was intended to produce a highly conducting plasma that conducted either energy or intelligence; the current returned to the source through the ground. (Tesla U.S. patent 645,576)

electromagnetic energy. Here is Tesla's first claim in this patent:

"What I now claim is—1. "The method herein before described of transmitting electrical energy through the natural media, which consists in producing at a generating-station a very high electrical pressure, causing thereby a propagation or flow of electrical energy, by conduction, through the earth and air strata, and collecting or receiving at a distant point the electrical energy so propagated or caused to flow."

The Supreme Court recognized that radio constituted wireless telegraphy by Hertzian waves:

"In wireless telegraphy, signals given by means of controlled electrical pulsations are transmitted through the ether by means of the so-called **Hertzian or radio waves**. Hertzian waves are electrical oscillations which travel with the speed of light and have varying wave lengths and consequent frequencies intermediate between the frequency ranges of light and sound waves."⁵³

Here is what the Supreme Court noted about Tesla's approach, which it never described as being radio. In fact, it specifically stated that Tesla did not use Hertzian waves, which by the mainstream definition of radio, which means Tesla's approach was not radio:

"Tesla in fact did not use Hertzian waves. His idea was to make the ether

a conductor for long distances by using extremely high voltage, 20,000,000 to 30,000,000 volts, and extremely high altitudes, 30,000 to 40,000 feet [5.7 to 7.6 miles] or more, to secure transmission from aerial to aerial. Balloons, with wires attached reaching to the ground, were his suggested aerials. His system was really one for transmitting power for motors, lighting, etc., to 'any terrestrial distance,' though he incidentally mentions 'intelligible messages.' As he did not use Hertzian waves, he had no such problem of selectivity as Marconi, Lodge, Stone and others were working on later."⁵⁴

Does anyone really believe that radio communication was—or ever could be—accomplished by breaking down the atmosphere to form a conducting path between two antennas 5.7 to 7.6 miles high spaced at "any terrestrial distance" (hundreds if not thousands of miles)? This method was described as a Jules Verne concept during this trial, and Tesla's patent was mocked by electrical journals of the day for several years after it was published in the *Electrical Review* on October 26, 1898. My favorite mock is the following snippet that appeared in the *Electrical World* on November 3, 1898, entitled "Boundless Space Busbar," which began with: "One of the American electrical journals has recently taken some of Mr. Tesla's patents undoubtedly more seriously than the inventor himself intended them." The editor went on to make the following comment on Tesla's new system of power transmission:

Snippet from the Electrical World on November 3, 1898

Boundless Space Busbar

“The system might, however give other results more valuable than those of power transmission. With transmitting and receiving stations at Niagara Falls and New York City, respectively, the State of New York would possibly be illuminated by a gigantic Geissler tube overhead that would turn night into day, put to shame the aurora borealis, and make the advocates of diffused illumination shout for joy.”*

*The writer reserves the rights to the use of interplanetary space as a vacuum tube for lighting purposes.”

This derision is well deserved because this patent is such nonsense on so many levels. First, Tesla's patent states:

“I conclude that with electromotive impulses not greatly exceeding fifteen or twenty million volts the energy of many thousands of horse-power may be transmitted over vast distances, measured by many hundreds and even thousands of miles, with terminals not more than thirty to thirty-five thousand feet the apparatus above the level of the sea.”

Thirty-five thousand feet is 6.6 miles or 10.6 km. He claims that “terminals can be safely maintained, as by the aid of captive balloons supplied continuously with gas from reservoirs and held in position securely by steel wires or by any other means, devices, or expedients, such as may be contrived and perfected by ingenious and skilled engineers.” There

is no way to have a tethered balloon at an altitude of 6 miles with a pipe for gas and the weight of tethers to maintain the balloon at altitude to withstand jet-stream winds of a hundred miles an hour or more—not to mention the problems of a light-weight, thin-wire feed (small radius) with 15–20 million volts applied that would discharge into the air along the entire length.

Second, even if Tesla's ingenious and skilled engineers could manage that feat, the isolated spherical surface will produce brush discharges that will extend out to some distance until the electric field drops to levels below the breakdown threshold of air at the balloon altitude. Tesla said he has observed brush discharges on his Tesla coil at sea level extend out to 60 feet, which he claimed covered a cylindrical or spherical area of hundreds if not thousands of square feet. However, there is no experimental or theoretical indication that these brush

discharges will propagate out to terrestrial distances of thousands of miles, as Tesla suggests. No one has reported a discharge emanating from a Tesla coil extending out to a mile, much less several thousand miles.

Last but not least, even if a brush discharge should turn into an arc discharge, the discharge will seek the nearest ground—which will not be an intended tower located at terrestrial distances. More likely the discharge will be the steel tether wire for the balloon, or perhaps a tall building with a lightning rod, or a structure atop a mountain somewhere—or most likely, the ground around the base of the Tesla transmit antenna where the image charge from the charge located in the transmitting tower resides. It turns out that most of the image charge in this configuration lies within a radius equal

to approximately two antenna heights of the base. Tesla confirmed that later at Colorado Springs, where he was able to transmit a “bolt of lightning” from a small sphere of 30 inches atop his 142 foot antenna to a distance of about 120 feet—a radius equal to slightly less than one antenna height.

In the end, whether or not anyone believes this is a radio patent is not particularly relevant in determining Tesla’s precedence in discovering radio because this patent was filed after the time frame that Marconi documented and demonstrated transmission and reception of radio by electromagnetic waves. This discussion is more relevant to make the point that the definition of radio is important, and that Tesla’s method described in the patent cited by the U.S. Supreme Court in 1942 does not fit that definition.

PART III. AN EXAMINATION OF TESLA’S ACCOMPLISHMENTS

Study Scope and Organization

Scope

The scope of this multiyear study was a comprehensive survey of virtually all pertinent documents that bear on the subject of Tesla’s contributions to the communication of intelligence and transmission of energy by wireless. The study included a review of both primary and secondary source documents, with a focus on primary source documents describing discoveries and events that occurred between 1891 and 1897. Examples of these documents include the following:

- Articles by and about Tesla’s contributions published in electrical journals and other periodicals, many of which are listed in the comprehensive “Tesla Collection,”⁵⁵
- Tesla’s patents on the development and application of disruptive discharge oscillators,
- Tesla’s patents on wireless transmission of energy and intelligence,
- Court documents reporting on decisions in litigation over Marconi’s fundamental patent in U.S. District Courts,
- Court documents reporting on decisions in litigation over Marconi’s

tuning patent in the U.S. Court of Claims and the U.S. Supreme Court.

Secondary documents reviewed include books, articles, and blogs by historians and Teslaphiles with arguments that support or oppose the proposition that Tesla has precedence in the discovery of radio.⁵⁶ There are two common themes espoused by those who believed Tesla has priority. The first is that Tesla's discovery of radio dates to one or more of the three lectures Tesla gave on high frequencies and high voltages in the years 1891, 1892 and 1893:

- Tesla's lecture to the AIEE at Columbia College (1891),
- Tesla's lecture to the Royal Institution of London (1892),
- Tesla's lecture to the Franklin Institute and the National Electric Light Association (1893).

The second common theme is that documents prepared by Tesla, or on behalf of Tesla, after Marconi's documented dates of discovery have been used to support Tesla's claim of precedence in the discovery of radio. A clear standard has been developed by the courts that dated documents cannot be used to support a priority date for invention when the date of the document is after the claimed priority date. A clear standard has also been developed that undated documents may not be used to establish priority date unless the author is available to testify under oath as to the date and circumstances of document preparation and is also available for cross examination under oath, subject to the court of jurisdiction. A similar standard of documented proof has also been used by the

scientific and engineering communities, although there is a distinction between the findings of the courts and the judgments of the scientific and engineering communities. The findings of priority by the courts are limited to the specific legal jurisdictions in which the dispute is adjudicated, whereas the judgments of the scientific and engineering communities transcend legal and political boundaries.

In this study, examples of such "after-the-fact" documents often cited by Tesla enthusiasts to support his precedence in discovering radio are the following, all of which were prepared and dated after Marconi's documented dates of discovery identified above:

- One or more of a series of so-called Tesla "radio patents," and in particular U.S. patent 645,576, which has the earliest filing date of all the patents in Tesla's series of wireless patents (September 2, 1897),
- Tesla U.S. patent 613,809 filed on July 1, 1898, for remote control of a boat's course,
- The book *Nikola Tesla on His Work with Alternating Currents* edited and first published by Leland Anderson in 1992,⁵⁷ which was based on conversations that Tesla had in private with his attorney circa 1915 during the course of a failed lawsuit against Marconi for patent infringement,
- *Nikola Tesla Colorado Springs Notes: 1899-1900*, (Nolit, Beograd, Yugoslavia, 1978). This book is a representation of Nikola Tesla's notes that was prepared for publication in 1978 by the Nikola Tesla Museum, Beograd,

Serbia with scientific commentaries by Aleksandar Marincic, and

- Tesla's publications and press releases to periodicals and newspapers after May 17, 1897, the date of Marconi's successful transmission and reception of messages across the Bristol Channel.

Organization

The only documents found with a date prior to May 13, 1897, that could possibly support a case for Tesla's precedence in discovering radio are Tesla's three demonstration lectures using alternating currents of high potential and high frequency in 1891, 1892, and 1893, and Tesla's nine patents covering descriptions of the high-frequency, disruptive discharge oscillators that Tesla filed prior to June 1897. Tesla did not mention the subject of transmitting intelligence or energy to any distance in his first lecture in 1891. He did demonstrate that he could excite light bulbs without wires at short distances, but he said this was possible only by using electrostatic effects, which he pointed out fell off as the cube of the distance. In Tesla's 1892 lecture, he disclosed, in passing, a general approach for transmitting energy to long distances, but without any detail.

In Tesla's 1893 lecture, he disclosed a different approach for transmitting energy or intelligence to long distances, which involved using the earth as a conductor and a source of excitation with a frequency to match the earth's resonant frequency. Tesla believed that by matching the source frequency to the resonant frequency of the earth,

the excitation would be amplified and propagated around the world through the earth. After his 1893 lecture, Tesla did not describe any new or different approaches for wireless transmission of energy or intelligence prior to his application for U.S. patent 645,576 dated September 2, 1897.

The remaining documents of potential interest are the Tesla oscillator patents, which were examined in detail because they play a central role in the claims made by many Teslaphiles who support the proposition that Tesla discovered radio. The Tesla oscillator patents are remarkable in that there is no mention of wireless transmission of energy or intelligence to any distance in any of these patents. This will be demonstrated, in part, by comparing and contrasting the Tesla oscillator patents prior to 1897 with a series of wireless transmission patent patents filed by Tesla, the first of which was filed on September 2, 1897.

Tesla's Lecture at the AIEE at Columbia College (1891)

Nikola Tesla's lecture to the American Institute of Electrical Engineers on May 20, 1891, entitled "Experiments with Alternate [sic] Currents of Very High Frequency and their Application to Methods of Artificial Illumination," was the first of three lectures given to various institutions in as many years.⁵⁸ These lectures thrilled audiences with spectacular electrical effects produced by high-frequency, high-voltage electrical currents. While many of these effects had been observed in scientific circles previously,⁵⁹ the higher frequencies and voltages that

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Tesla used produced much more intense effects, which captured the imagination of scientists and laymen alike.

Source of Excitation for Experiments

Tesla used his high-frequency dynamo (also referred to as an alternator), shown here in Fig. 12, as his electrical source for demonstrations at this lecture.⁶⁰ However, he was not forthcoming about the electrical characteristics of this source in this lecture. Tesla's dynamo used in this lecture was later described in a *Scientific American* article as operating at 3,000 revolutions per minute and producing a frequency of ninety-six hundred periods per second (approximately 10 kHz), which under full excitation "may reach 200 volts."⁶¹ This description is consistent with a later description by Tesla, who claimed, "I operated only at about "3,000

or 3,600 revolutions [per minute] and then I could get out of it approximately 4 kilowatts."⁶² Tesla also mentioned that he operated it at "5,000 cycles." At that time, it was customary to refer to each excursion from the zero baseline (positive or negative) as one cycle, and since there are two excursions per period, his source apparently had a frequency of approximately 10 kHz.

Tesla stepped up the voltage of his alternator by connecting its output to an ordinary induction coil in series with a capacitor (see Fig. 13). The purpose of the capacitor was to neutralize the reactive impedance of the inductance in the circuit, thereby minimizing the total reactive impedance of the circuit. He did not document the voltages he obtained from this configuration, but he did make several statements in the next two lectures that the voltage was at least 50 kV. In his 1892 lecture he said: "It is easy, for instance, to construct a transformer [induction coil] capable of

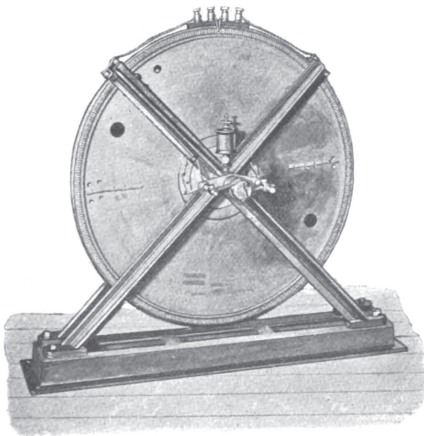


Fig. 12. Tesla's alternating current dynamo was described in a *Scientific American* article as operating at 3,000 revolutions per minute, producing a frequency of 9,600 hundred periods per second (approximately 10 kHz), which under full excitation might reach 200 volts. (*Trans. AIEE*, Vol. VIII, 1891, p. 275)

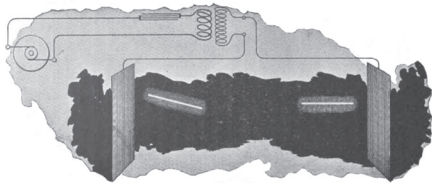


Fig. 13. Tesla connected the output of his alternating current dynamo to the primary winding of an ordinary oscillation coil that raised the voltage on the secondary winding, the output of which he attached to two parallel plates spaced about 3 meters apart; he performed his lighting demonstrations between these plates in his 1891 lecture to the AIEE. (*Trans. AIEE*, Vol. 8, 1891, p. 310)

giving, when operated from an ordinary alternate-current machine of low tension, say 50,000 volts.”⁶³

Overview of Experiments

Tesla’s demonstration experiments can be conveniently divided into three categories. The first category consisted of five different types of discharges in air, all of which were produced at the terminals of an ordinary induction coil. One of these was a brush discharge, shown in Fig. 14, which was produced at small isolated electrodes when the applied potential produced an electric field at the surface of the electrode that exceeded the breakdown threshold of air. Brush discharges were reported as early as 1854,⁶⁴ but the high voltages and frequencies used by Tesla produced more spectacular discharges. Unfortunately, Tesla’s experiments did not have much

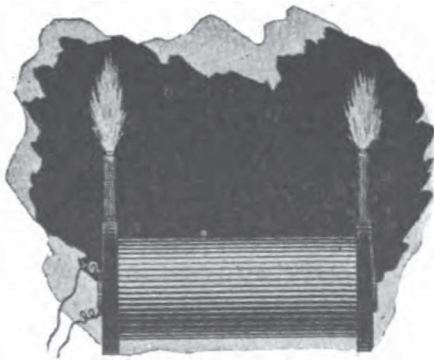


Fig. 14. Brush discharges were produced at small isolated electrodes when the applied potential produced an electric field at the surface of the electrode that exceeded the breakdown threshold of air. (*Trans. AIEE*, Vol. VIII, 1891, p. 287)

scientific value—in part because Tesla provided virtually no quantitative data on the effects he observed.⁶⁵ This type of discharge is relevant to his “rotating brush” vacuum tube that he introduced in his second lecture in 1892.

The second category of experiment consisted of lighting electric bulbs of various types (e.g., incandescent lamps, evacuated tubes, and phosphorescent bulbs) by attaching only a single conducting wire from one terminal of his induction coil to one terminal of the light bulb (see Fig. 15). This was in stark contrast to the common practice at that time of using two wires to deliver line voltages on the order of 100 volts with low frequencies (25 to 60 Hz) to both terminals of a light bulb. Without the wire and metal plate shown on the right of this figure, Tesla was able to light bulbs only rather dimly, but by attaching the wire and plate to the second terminal of the bulb, he was able to greatly increase the intensity of the light—clearly indicating that the circuit impedance was reduced by increasing the capacitive coupling between the plate and ground. These

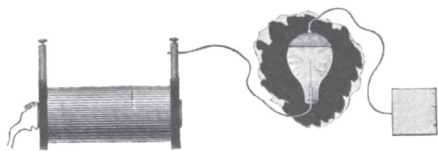


Fig. 15. Tesla was able to light both incandescent and phosphorescent bulbs by attaching a single conducting wire from the output of the induction coil to the tube; the circuit was actually completed by capacitive coupling, which was very effective when using high voltages and high frequencies. (*Trans. AIEE*, Vol. VIII, 1891, p. 306)

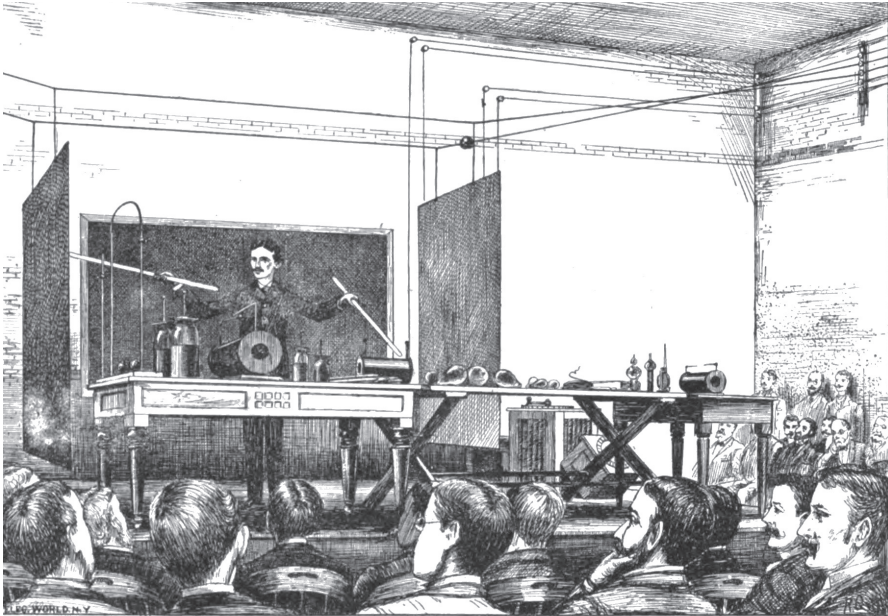
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experiments were very interesting to the audience, although they were not particularly relevant to the subject of *wireless* transmission of intelligence or energy to great distances.

The third category of experiments consisted of lighting bulbs without any connecting wires. Tesla contemplated using wireless configurations as a method of wireless transmission of energy to *very short* distances for purposes of illuminating halls and rooms, but not for long distance transmission:

“The ideal way of lighting a hall or room would, however, be to produce such a condition in it that an illuminating device could be moved and put

anywhere and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, rapidly alternating electrostatic field. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets as illustrated in Fig. [16], each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be *carried in the hand*



MR. NIKOLA TESLA'S LECTURE BEFORE THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Fig. 16. Tesla illuminates phosphorescent bulbs by holding them between two parallel plates attached to the output of an ordinary oscillation coil attached to his alternating current dynamo. (*Electrical World*, Vol. 18, May 20, 1891, p. 19)

[emphasis added] anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous. In such an electrostatic field interesting phenomena may be observed, especially if the alternations are kept low and the potentials excessively high.”⁶⁶

By all accounts the approximate distance between the two sheets was specified to be about 15 feet or approximately 5 meters. For a 5 meter spacing and an applied voltage of 50 kV, the electrostatic field strength between the plates would have been approximately 10 kV/m. Tesla said that the distance at which the light bulbs could be placed outside of the two sheets is actually very short because “the electrostatic effects diminish nearly with the cube of the distance from the coil, whereas the electromagnetic inductive effects diminish simply with the distance.”

Electrostatic Effects

Tesla went to great lengths in his lecture to point out that all of the effects he demonstrated were produced by electrostatic fields (quasistatic electric fields to be exact)—as opposed to true electromagnetic radiation. He claimed that, “powerful electrostatic effects are the *sine qua non* [essential condition] of light productions.” He said that incandescent bulbs with filaments were heated by capacitive coupling, and Geissler tubes with no attached wires were excited by electrostatic fields created by parallel conducting sheets. In the later case, he explains:

“Electromagnetic effects are primarily unavailable.... We could not affect by means of such waves, the static molecular or atomic charges of a gas, cause them to vibrate and to emit light. Long transverse waves (electromagnetic waves) cannot, apparently, produce such effects, since excessively small electromagnetic disturbances may pass readily through miles of air. Such dark waves, unless they are of the length of true light waves, cannot, it would seem, excite luminous radiation in a Geissler tube, and the luminous effect, which are producible by induction in a tube devoid of electrodes, I am inclined to consider as being of an electrostatic nature. To produce such luminous effects, straight electrostatic thrusts are required; these, whatever be their frequency, may disturb the molecular charges and produce light. Since current impulses of the required frequency cannot pass through a conductor of measurable dimensions, we must work with a gas and then the production of powerful electrostatic effects becomes an imperative necessity.”⁶⁷

Tesla gives a number of specific arguments to support his position, and then concludes by stating, “In all the cases, then, when we excite luminosity in exhausted tubes by means of such a coil [induction coil] the effect is due to the rapidly alternating electrostatic potential.”⁶⁸

Tesla concludes his remarks on electrostatic effects with these very important words:

"From these considerations, it would seem that if this ideal way of lighting is to be rendered practicable, it will be only by the use of electrostatic effects. In such a case, the most powerful electrostatic inductive effects are needed; the apparatus employed must, therefore, be capable of producing high electrostatic potentials changing in value with extreme rapidity. High frequencies are especially wanted, for practical considerations make it desirable to keep down the potential. By the employment of machines or, generally speaking, of any mechanical apparatus, but [i.e., only] low frequencies can be reached; recourse must, therefore, be had to some other means. The discharge of a condenser affords us a means of obtaining frequencies far higher than are obtainable mechanically, and I have accordingly employed condensers in the experiments to the above end."⁶⁹

Indeed, even before this lecture, where he used only a dynamo machine as a source, Tesla had already developed a disruptive discharge oscillator source for lighting purposes. Tesla described his oscillator source at his next lecture before the Royal Institution of London in 1892, where he used it for many of his demonstrations.

Key Takeaway from Tesla's 1891 Lecture

The main takeaway from Tesla's 1891 lecture is that Tesla explored the application of high-voltage, high-frequency currents to electrical lighting, and there was no mention of wireless transmission

of intelligence to any distance. The only mention of wireless transmission of energy was to short distances of a few meters from the terminals of his high-voltage oscillator coils. He despaired of sending energy to long distances by wireless means because he believed lighting of bulbs and running "no-wire motors" was accomplished by electrostatic effects, which he realized decreased as the cube of the distance from the source. There is nothing in this lecture that would constitute or support Tesla's precedence in the discovery of wireless communication of intelligence. Tesla's lecture was well received by both the public and the scientific community, and it secured a place for him in the history of high-voltage, high-frequency electricity.

Tesla's Lecture at the Royal Institution of London (1892)

Tesla's 1892 lecture entitled "Experiments with Alternate Currents with High Potential and High Frequency" was very similar to his lecture at Columbia the year before, but with several new concepts: 1) the introduction of a new disruptive discharge oscillator (Tesla oscillator) that produced higher voltages and frequencies than the low-frequency dynamo he used in the first demonstration lecture, 2) the presentation of a new concept for wireless transmission of energy to long distances by conduction through the rarefied portion of the atmosphere, and 3) the description of a new "rotating brush" bulb that Tesla thought might be useful as a detector for long-distance wireless telegraphy.

Tesla's Disruptive Discharge High-Frequency Oscillator

While Tesla filed two patents on his Tesla oscillator in early 1891, he did not use it in his 1891 lecture demonstration. It was not until his lecture to the Royal Institution in London in 1892 that he introduced it to the public, described it in some detail, and used it to produce even more spectacular lighting demonstrations than he did with the dynamo source. Tesla's oscillator produced a number of short damped sine-wave-like discharges with a nominal frequency of 250 kHz. In this lecture he stated: "By way of contrast [to the 10 kHz source used in the first lecture], here is a form of discharge of a coil the primary current of which is vibrating several hundred thousand times per second."⁷⁰ In his 1893 lecture, Tesla made this statement about the peak voltages and frequencies that could be produced by his new oscillator: "The streams of light, which you have observed issuing from my hand, are due to a potential of about 200,000 volts, alternating in rather irregular intervals, something like 1,000,000 times a second."⁷¹

A schematic diagram of the Tesla oscillator appearing in his 1892 lecture is reproduced in Fig. 17.⁷² The prime power source was a low-frequency alternator. Tesla later said that primary source he used to excite his Tesla coil was "a Siemens alternator whose frequency did not exceed 50 periods per second."⁷³ Tesla also claimed that the source he used for generating disruptive discharges in the mid-1890s was a 60 Hz source with an output of 60 horsepower.

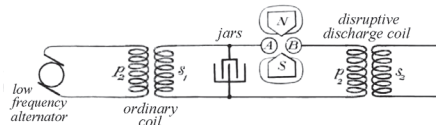


Fig. 17. In this schematic diagram of Tesla's oscillator, which appeared in his 1892 lecture, he has replaced a simple spherical spark gap with an improved discharge controller; note there are no adjustable inductances in either the primary or secondary circuits of this Tesla oscillator. (*J. IEE*, Vol. 21, 1892, p. 66)

The output of a low-voltage, low-frequency alternator was connected to an oscillation coil that transformed the voltage to perhaps 50 kV. The transformer charged a collection of Leyden jars to a voltage capable of producing a large spark. The spark was initiated at a spark gap or by his improved discharge controller, which produced a discharge at a preset voltage, usually just below the maximum voltage produced on the secondary of the low-voltage oscillation coil. The capacitor then discharged through the primary of the high-voltage "disruptive discharge coil," which consisted of a relatively few turns of a heavy wire. The secondary of the high-voltage oscillation coil has a relatively large number of turns that raised the voltage to even higher values—on the order of 200 kV.

Note the only adjustable component appearing in this circuit diagram is the charging capacitor, whose capacitance could be varied by adding or subtracting Leyden jars. Neither the primary nor the secondary windings of the disruptive discharge coil were adjustable. This can be confirmed by examining the design of the disruptive discharge coil Tesla described in his lecture (see

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Fig. 18). There are several important features that should be noted. The primary and secondary windings of the coil are housed in a hardwood box, which is covered on the outside with a zinc sheet that is "soldered all around." Before sealing, the box is filled with "boiled-out" oil. The secondary is wound over the

primary in a coaxial configuration in two parts, which are connected in series to separate low voltages from high voltages. Note that there is no way to vary or adjust the inductances of either the primary or secondary coils, and no way to adjust the mutual coupling. Also, this coaxial configuration produces very close

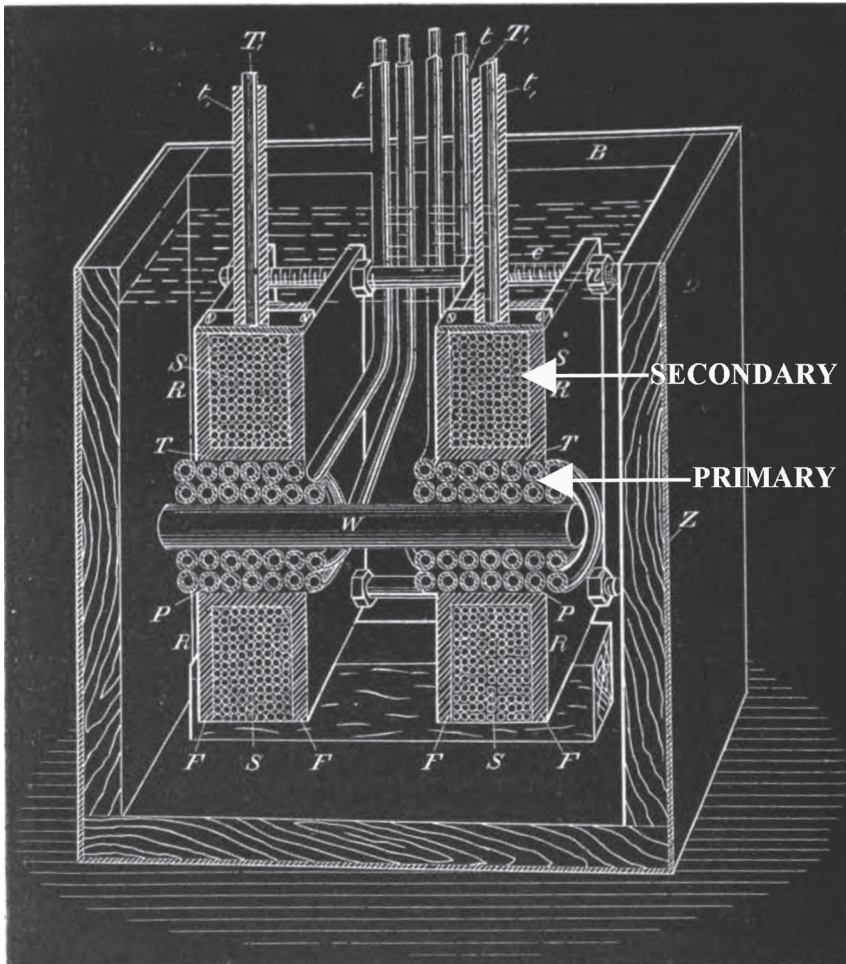


Fig. 18. The primary and secondary windings of Tesla's 1892 disruptive discharge coil, which was sealed in a box filled with oil, were tightly coupled and there was no means of adjusting the spacing between the two windings (i.e., the mutual inductance); also there was no means of adjusting the inductances of either winding. (*J. IEE*, Vol. 21, 1892, p. 62)

coupling between primary and secondary—unlike the loose coupling used later in radio circuits.

In fact, Tesla does not mention anywhere in his lecture that he intends to tune the primary and secondary circuits to each other. To tune the two circuits to the same frequency, it is necessary to have the product of the capacitance and inductance of the primary circuit equal to the capacity and inductance of the secondary circuit $L_p C_p = L_s C_s$. For a given Tesla oscillator, the inductance of the primary coil is fixed, so the frequency of the primary circuit is set by only the charging capacitor C_p . The frequency of the secondary circuit is set by the fixed inductance and capacitance of the secondary winding plus the capacitance and inductance of the load, which for Tesla's myriad of experiments was highly variable. Since he did many experiments with this coil, the resonant frequency of the secondary circuit would have been different for each experiment. In some experiments involving tubes that Tesla held between the parallel plates, the capacitance would have varied during the course of the experiment as he moved about.

It is clear that Tesla did not attempt to tune the Tesla oscillator to achieve resonance during the course of his lighting demonstrations. It also follows that Tesla did not try to change the frequency of his oscillator during the course of his experiments. Tesla confirms this by saying what had to be done to reach higher frequencies: "To reach this result [high frequencies] very small coils and jars of small capacity should be used."⁷⁴ That

means using a different oscillator coil, not adjusting the one he used in his lecture.

Tesla's Concept for Transmission of Energy to Long Distances

Like his first lecture in 1891, this lecture focused entirely on artificial lighting effects, and there is no need to review the experiments he performed in the first lecture using the alternator as a source. In this lecture, Tesla introduced his first idea for transmitting energy to large distances. He pointed out that "no-wire" motors were possible by situating an insulated plate or body within the vicinity of an alternating electrostatic field and connecting the other end to ground, but he said that it would not be practical to transmit energy to large distances by this means. Instead, he suggested "no-wire" motors could be operated by *conduction* through the rarefied air at considerable distances. He goes on to say that "luminous discharges" might be used to transmit energy:

"Alternate [alternating] currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of the air are rarefied. To reach a number of miles out into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation, luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horsepower,

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motors or lamps might be operated at considerable distances from stationary sources. But such schemes are mentioned merely as possibilities.”⁷⁵

The concept of transmitting energy by conduction through the rarefied atmosphere would become Tesla's first patent for wireless transmission of energy much later in September 1897—patent U.S. 645,576 for which he filed the patent application on September 2, 1897. (This is the patent that was mentioned in the Supreme Court opinion.) Tesla also stated in this lecture that there would soon be no reason to transmit power at all: “Ere many generations pass, our machinery will be driven by a power obtainable at any point in the universe. . . . It is a mere question of time when men will succeed in attaching their machinery to the very *wheelwork of nature* [emphasis added].”⁷⁶ Tesla's words “wheelwork of nature” are significant because Mahlon Loomis had made a similar suggestion about harvesting energy from the atmosphere in 1864 using the same unusual word in a similar phrase:

“So this great electrical ocean slumbering with giant power, untold wealth and willing aid, waits but the proper sluiceways or conducting channels to illuminate and to drive the *wheelwork of the world* [emphasis added].”⁷⁷

Loomis also used the phrase “to disturb the electrical equilibrium,” a concept that appears repeatedly in Tesla's writings. In an article dated January 7, 1872, Loomis wrote:

“Upon these mountaintops I erect suitable towers and apparatus to attract the electricity, or, in other words, *to disturb the electrical equilibrium* [emphasis added], and thus obtain a current of electricity, or shocks or pulsations, which traverse or disturb the positive electrical body of the atmosphere above and between two given points by communicating it to the negative electrical body in the earth below, to form the electrical circuit.”⁷⁸

Compare that to the phrase that appears at the end of Tesla's 1892 lecture:

“The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to *disturb the electrostatic or magnetic condition of the earth* [emphasis added], and transmit, if nothing else, intelligence.”⁷⁹

Loomis filed a patent on a technique to extract energy from the atmosphere for purposes of communicating of intelligence and for industrial uses of power. Loomis's U.S. patent 129,971 for wireless telegraphy dated July 30, 1872, contains the following words:

“I now dispense with both wires, using the earth as one-half the circuit and the continuous electrical element far above the earth's surface for the other part of the circuit. I also dispense with all artificial batteries, but use the free electricity of the atmosphere, co-operating with that of the earth, to supply the electrical dynamic force or current

for telegraphing *and for other useful purposes, such as light, heat, and motive power* [emphasis added].”

In Tesla’s 1892 lecture, he went on to say that soon intelligence would soon be transmitted without wires through the earth, but he did not say how:

“But such cables will not be constructed, for ere long intelligence—transmitted without wires—will throb through the earth like a pulse through a living organism. The wonder is that, with the present state of knowledge and the experiences gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, and transmit, if nothing else, intelligence.”⁸⁰

It is all but certain that Tesla read Loomis’s work and then become interested in the problem of transmitting intelligence without wires. He suggested the possibility that “luminous discharges might be passed through many miles of rarefied air” and that intelligence might be transmitted through the earth by “disturbing the electrostatic or magnetic condition of the earth.” In this lecture Tesla gave no concrete ideas on how to transmit energy or intelligence to large distances. He said, “such schemes are mentioned merely as possibilities.”⁸¹ There is nothing in this lecture that would support a claim on behalf of Tesla for precedence in discovering radio, or even wireless communication of intelligence. Tesla’s claims were not specific, and they were not really much different than the claims

that Loomis made decades earlier about using both the atmosphere and the earth for transmitting energy and intelligence.

Tesla’s Rotating Brush Bulb

In his 1892 lecture, Tesla described an evacuated bulb he had developed that presented a rotating brush discharge, which he claimed was a very sensitive detector of electric fields. This brush merits attention here because Tesla claimed that it might have some practical application as a detector in wireless telegraphy. Brush discharges in air (as opposed to within evacuated bulbs) were observed as early as 1853 by Faraday,⁸² and they were given this name because they have the appearance of a brush (see Fig. 19).⁸³ This type of discharge occurs when the charge on a smooth curved surface produces an electric field above the surface that exceeds the breakdown threshold of air and there is no nearby conducting surface that would produce a spark or corona discharge. Electrons emitted from the surface ionize the air, which produces the visible glow, and the electron currents in the air eventually find their way back to ground or the negative side of the high-voltage source.

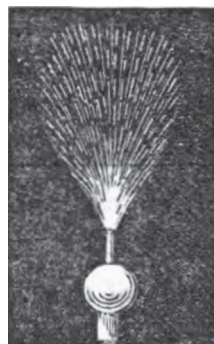


Fig. 19. Brush discharges produced by isolated high-voltage electrodes in air (as opposed to within evacuated bulbs) had been observed as early as 1853 by Faraday (W. S. Harris, *Rudimentary Electricity*, 1854 p. 150)

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Tesla introduced the brush bulb in his 1892 lecture by stating that it was more interesting than anything he was going to present during the lecture:

"I think it is best at this juncture to bring before you a phenomenon, observed by me some time ago, which to the pure scientific investigation may appear more interesting than any of the results which I have the privilege to present to you this evening. It may be quite properly ranked among the brush phenomena—in fact, it is a brush, formed at, or near, a single terminal in high vacuum."⁸⁴

Tesla said, albeit indirectly, that he did not actually demonstrate the rotating brush during his 1892 lecture. He stated that he had observed rotating brushes in bulbs with and without an internal conductor, but that rotating brushes were stable only in bulbs devoid of internal conductors. The rotating brush that Tesla described in his lecture was contained in the evacuated space between the two concentric spherical bulbs labeled *L* and *s* in Fig. 20, which was devoid of internal conductors.⁸⁵ To excite the bulb, Tesla said he connected a wire from the output of his high-voltage, high-frequency source to a thin sheet of aluminum foil fastened around the cylindrical base of the glass, and the bulb was suspended upside down by the wire (see Fig. 21):

"When the bulb is in use, the neck *n* is provided with a tin foil coating, which is connected to the generator [oscillator

coil terminal], and acts inductively on the moderately rarefied gas enclosed in the neck. From there the current passes through the tube *b* into the small sphere *s*, to act by induction upon the gas in the globe *L*."⁸⁶

Tesla described the difficulty in exciting a rotating brush bulb as follows:

"To excite it, it is usually sufficient to grasp the globe *L* with the hand. An intense phosphorescence then spreads at first over the globe, but soon gives place to a white, misty light. Shortly afterwards one may notice that the luminosity is unevenly distributed in the globe, and after passing the current for some time the bulb appears as in Fig. 15 [not shown here]. From this stage the phenomenon will gradually pass to that indicated in Fig. 16 [globe is reproduced here in Fig. 21], after some minutes, hours, days, or weeks, according to how the bulb is worked."⁸⁷

It becomes obvious why Tesla could not demonstrate the rotating brush bulb at his lecture. He said that it would reach its most sensitive state after "some minutes, hours, days, or weeks, according to how the bulb was worked." Tesla also said that he could not create the brush with a disruptive discharge—that is to say by his Tesla coil or by any electric field produced by a spark source:

"I have been unable to produce the phenomenon [the rotating brush] with the disruptive discharge coil, although every other of these phenomena [pre-

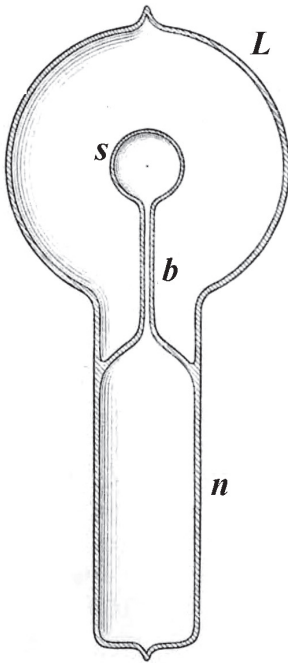


Fig. 20. The rotating brush that Tesla described in his lecture was contained in the evacuated space between the two concentric spherical bulbs labeled *L* and *s*. (*J. IEE*, Vol. 21, 1892, p. 84, Fig. 13)

sented in his demonstration lecture] can be well produced by it—many, in fact, much better than with coils operated from the alternator.”⁸⁸

Tesla said he was only able to create the brush with a continuous wave signal from his alternator, but that as frequency or amplitude of the alternator changed, the bulb lost sensitivity: “When it is in the state of highest sensitivity, and the potential or frequency be varied, the sensitiveness is rapidly diminished. Changing either of these but little will generally stop the rotation.”⁸⁹ That does not bode

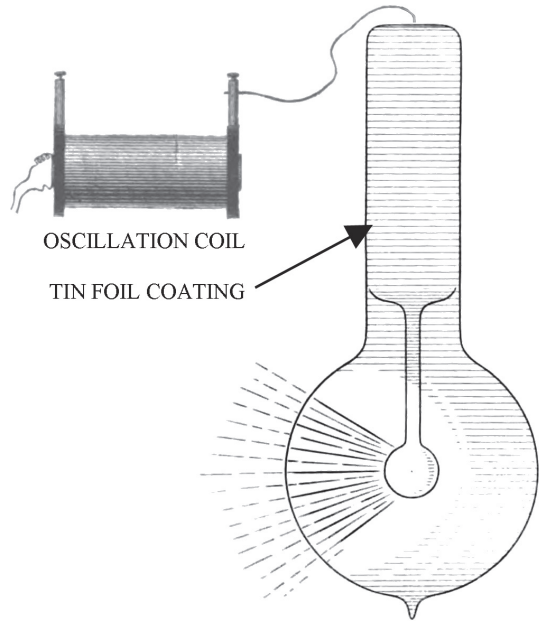


Fig. 21. To excite the rotating brush bulb, Tesla said he connected a wire from the output of his high-voltage, high-frequency source to a thin sheet of aluminum foil fastened around the cylindrical base of the glass, and the bulb was suspended upside down by the wire. (Composite of figures from *J. IEE*, Vol. 21, 1892)

well for an application to wireless telegraphy, where it would have been necessary to change the amplitude of a pure sine wave to encode intelligence (other forms of modulation had not been invented).

Tesla also claimed that the brush was extremely sensitive: “For example, when the experimenter may...approach the hand at a certain considerable distance to the bulb, and he may cause the brush to pass off by merely stiffening the muscle of his arm.”⁹⁰ What Tesla didn’t say was that the brush was caused by an electric field within the bulb near the breakdown threshold of the rarefied air within the

bulb, which was on the order of thousands of volts per meter—electric fields that are much higher than anything that was produced by a radio transmitter in the vicinity of a radio receiver. While the brush may have been sensitive to small changes in *large* electric fields caused by flexing a muscle near the signal source, it does not mean that it is sensitive to *small* electric fields characteristic of radio waves in the vicinity of a receiver located at a great distance from the signal source.

Tesla concluded his discussion of the rotating brush bulb with the following statement:

“I am firmly convinced that such a brush, *when we learn how to produce it properly*, will prove a valuable aid in the investigation of the nature of the forces acting in an electrostatic or magnetic field. *If there is any motion which is measurable* going on in the space, such a brush ought to reveal it. It is, so to speak, a beam of light, frictionless, devoid of inertia. *I think that it may find practical applications in telegraphy.* With such a brush it would be possible to send dispatches across the Atlantic, for instance, with any speed, since its sensitiveness *may be so great* that the slightest changes will affect it. *If it were possible to make the stream more intense and very narrow*, its deflections could be easily photographed.”⁹¹

The large number of qualifications and conjectures that Tesla made here are italicized for emphasis. Indeed, Tesla did not quantify the sensitivity of the brush, nor did he state how he would use the

brush in a telegraphic system, nor did he indicate how intelligible signals could be detected or extracted from the brush at a distant receiving station. Clearly, he did not know how to produce a workable bulb at the time of his lecture, and despite his claim to the contrary made in his rambling paper, “The True Wireless” published in the *Electrical Experimenter* in 1919, there is no evidence in the literature that he ever improved it or used it.⁹² Since a rotating brush cannot amplify a signal, rectify alternating current, or produce electrical oscillations, to say the rotating brush was a precursor to the radio tube—as some historians assert—is a stretch of epic proportion. The two are completely unrelated. And no one—including Tesla—has ever demonstrated that *messages* could be detected and received by a rotating brush bulb.

The Takeaways From Tesla's 1892 Lecture

- Tesla made no claims that the primary and secondary circuits of his high-voltage oscillator coil were tuned to each other or that the primary and secondary windings of the coil were loosely coupled.
- Tesla proposed a new approach to transmitting energy and intelligence to long distances, but it followed a plan that Loomis had set out in a patent decades before to transmit intelligence and energy to terrestrial distances by conduction of currents through both the air and the earth. And Tesla stated, “such schemes are mentioned merely as possibilities.”
- Tesla suggested his rotating brush

bulb might be used as a sensitive detector in wireless telegraphy—but only “*when we learn how to produce it properly.*” There is no evidence that Tesla ever learned how to produce it properly or that it could detect weak electric fields characteristic of radio waves at a receiver. More to the point, it has never been used for anything.

Tesla’s Disruptive Discharge Oscillator Patents

Purpose and Applications (1891–1896)

Tesla filed nine patents covering his disruptive discharge oscillator circuits

(utilizing spark gaps or circuit discharge controllers) for generating high-voltage, high-frequency currents between February 4, 1891, the date of his first disruptive discharge patent, and October 19, 1896, the date of his last oscillator circuit patent.⁹³ These nine patents are listed in Table 1. The first of these nine patents, U.S. 462,418, filed on February 2, 1891, is the seminal patent for the Tesla disruptive discharge oscillator, but it uses only one ordinary induction coil. The more familiar form of the Tesla oscillator with an additional high-voltage oscillator coil is described in his application for

Table 1. Tesla patents for Tesla’s disruptive discharge oscillator circuits for generating high-frequency, high-voltage currents, which were filed between February 4, 1891, and October 19, 1897.

Filing Date	Patent #	Patent Title	Stated Purposes Cited in Patent
1891-02-04	462,418	“Method of and Apparatus for Electrical Conversion and Distribution”	“a working circuit containing translating devices [loads], such as incandescent lamps or motors ”
1891-04-25	454,622	“System of Electric Lighting”	“a novel method of and apparatus for producing light by means of electricity.”
1893-08-02	514,168	“Means for Generating Electric Currents”	“into a working circuit containing translating devices [loads]”
1896-04-22	568,176	“Apparatus for Producing Currents of High Frequency and Potential”	“use with existing circuits..., such as the ordinary municipal incandescent-lighting circuits ”
1896-07-06	568,179	“Method of and Apparatus for Producing Currents of High Frequency”	“for the operation of vacuum tubes P, single-terminal lamps R , and other novel and useful purposes”
1896-06-20	568,178	“Method of Regulating Apparatus for Producing Currents of High Frequency”	“devised for use with...ordinary circuits used in municipal systems of incandescent lighting ”
1896-07-09	568,180	“Apparatus for Producing Electrical Currents of High Frequency”	“for the working circuit...containing the devices R [single-terminal lamps]”
1896-09-03	577,670	“Apparatus for Producing Currents of High Frequency”	for “a circuit containing vacuum-tubes M, single terminal lamps M’ , or other suitable devices”
1896-10-19	583,953	“Apparatus for Producing Currents of High Frequency”	“to supply current for any suitable devices ST [single terminal lamps and vacuum-tubes]”

An Examination of Tesla's Precedence in Discovering Radio

patent 454,622 dated April 25, 1891 (see Fig. 22). This version of his oscillator is identical to the version appearing in his 1892 lecture, with the exception that it uses a spark gap rather than the discharge controller that appeared in the lecture.

A number of historians and Tesla-philosophers assert that Tesla developed this disruptive discharge oscillator specifically for wireless transmission of energy or intelligence, but there is absolutely no evidence to support this contention. Not only does the figure in this patent show the application of the Tesla oscillator to lighting, but the patent specifically states:

"I have made the discovery that an electrical current of an excessively small period and very high potential may be utilized economically and practically

to great advantage for the production of light."

"The improvement in the art of electric lighting herein described, which consists in [sic] generating or producing for the operation of lighting devices[,] currents of enormous frequency and excessively high potential substantially as herein described."

There is not a single patent in this table that mentions wireless transmission of either energy or intelligence as an application, nor is there the slightest hint of wireless transmission even to laboratory distances. All these patents show lighting devices as loads (characterized by Tesla as "translation devices"), and there is no mention of an antenna, a raised conducting surface, or any type of transmitting device or circuit. The words describing Tesla's loads, characterized as either some type of artificial light or a "translating devices" for each of these patents is shown in the right-hand column of this table. In only one case—the earliest case—is a motor mentioned.

All bulbs or translating devices are directly connected to the oscillator output terminals, such as the circuit of U.S. patent 609,251 filed as late as April 3, 1897. This circuit shows two types of bulbs or translating devices attached to the output of the coil—a "vacuum-tube" bulb denoted by "X" with two connecting wires, and a "suitable lamp" denoted by "Y" with a single connecting wire (see Fig. 23). As in all of these patents, there is no bulb or other translating device excited by the oscillator without at least one direct wire connection.

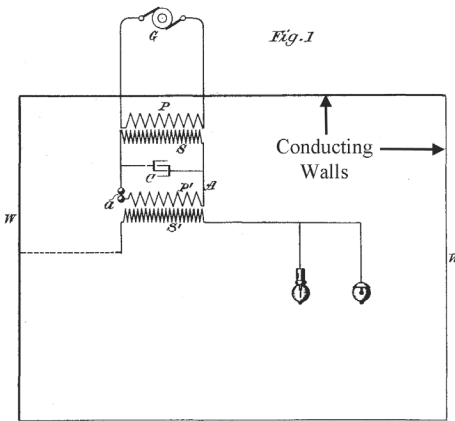


Fig. 22. The oscillator schematic that appeared in Tesla's patent for electric lighting (as applied to the interior of a room with four conducting walls) was identical to the one that appeared in his 1892 lecture, except that this schematic shows the original spherical spark gap, which he replaced with an improved spark discharger in his lecture. (Tesla patent U.S. 454,622)

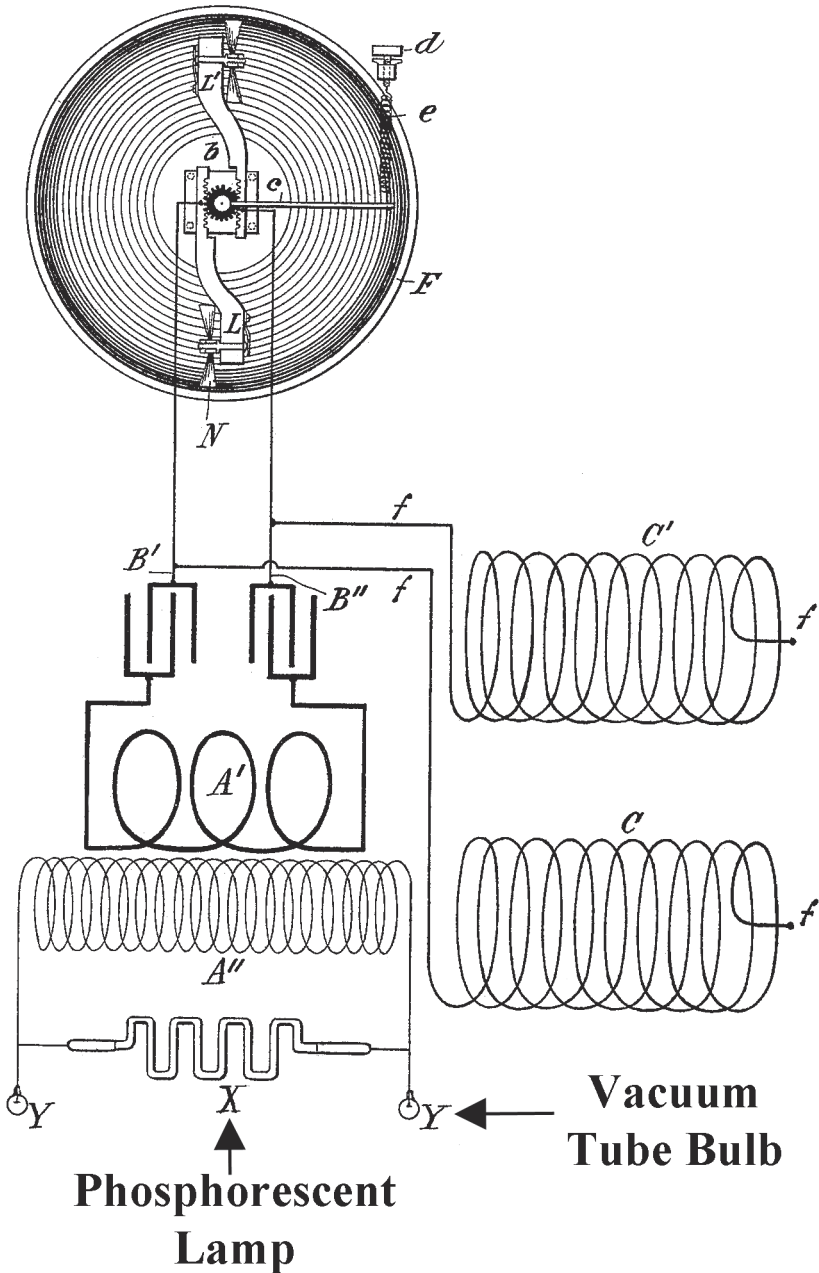


Fig. 23. The loads that appear in all of Tesla's oscillator patents, such as this one, show either one or two wire connections of bulbs to the oscillator output; not one shows *wireless* transmission of energy. In this patent, "X" (with two connecting wires) denotes a "vacuum-tube," and "Y" (with a single connecting wire) denotes a "suitable lamp." (Tesla patent U.S. 609,251)

Evolution of the Tesla Oscillator Design

Tesla's Early Oscillator design: Many people believe that the Tesla coil was designed from the outset with the primary and secondary circuits of the oscillation transformer tuned to the same frequency, but that is not the case. Nowhere in Tesla's first three lectures or in his patents prior to 1896 did Tesla refer to tuning the primary or secondary circuits—and he never mentioned loose coupling between the two circuits in any of these oscillator patents. Tesla's oscillation coil without tuning or loose coupled worked well for applications to lighting, where the key parameters were high voltage and high frequency. Larger capacitors in the primary circuit increased the energy available for each pulse, and tight coupling between the two circuits assured the maximum transfer of power and energy to the secondary circuit. Tuning the two circuits for resonance would have increased the voltage output of the secondary circuit, but not the energy or power transfer from the primary to the secondary circuit. And there was no need for sharp tuning in Tesla's lighting applications.

It is painfully obvious that Tesla did not tune his high-frequency oscillator in any of his lecture demonstration experiments dating to 1891–1893. First, his Tesla oscillator was enclosed in an oil tank and had no tunable elements. Second, the inductance and capacitance of his loads were variable and differed from experiment to experiment. Many of his experiments required him to hold bulbs, which depended on his body capacity to establish current flow through the bulbs.

Thus, the capacity was often highly variable, even during the course of a single experiment. There is no evidence in the description of his lecture experiments that he attempted to tune the primary and secondary circuits of his oscillator.

Tuning of Primary and Secondary Circuits Dates to 1896: The first document in which Tesla mentions tuning the primary and secondary circuits of his disruptive discharge oscillator is his application for U.S. patent No. 568,178 filed on June 20, 1896. Here is what Tesla wrote in this patent:

“When the conditions are such that the general law of harmonic vibrations is followed, the circuits are said to be in resonance or in electromagnetic synchronism, and this condition I have found in my system to be highly advantageous. Hence in practice I adjust the electrical constants of the circuits so that in normal operation this condition of resonance is approximately attained. To accomplish this, the number of impulses of current directed into the charging-circuit per unit time is made equal to the period of the charging circuit itself, or, generally, to a harmonic thereof, and the same relations are maintained between the charging and discharge circuit.”

While the patent filed on June 20, 1896, disclosed the efficacy of tuning the primary and secondary circuits of the oscillation coil to the same frequency, there is no reference in this patent to the use of his oscillator for wireless transmission of energy or intelligence. The application focused on lighting circuits.

The first time Tesla mentioned tuning his oscillator in conjunction with transmission of energy or intelligence was in his U.S. patent 645,576 filed on September 2, 1897, which was cited in the case of Marconi vs. the United States. The Supreme Court affirmed that Tesla's priority in using tuned circuits for transmission of energy or intelligence was the filing date of this patent, namely September 2, 1897, long after his 1893 lecture. Also, this date is later than May 13, 1897, the date by which Marconi had documented and demonstrated transmission and reception of intelligence to nine miles by Hertzian telegraphy.

Loose Coupling Dates to 1900: While Tesla's patent filed on June 20, 1896, disclosed the efficacy of tuning in producing higher voltages, it was silent on the subject of loose coupling, which was not relevant for lighting applications. In fact, loose coupling would have actually reduced the energy delivered to the load of Tesla's oscillator coil described in Tesla's 1896 patent. However, loose coupling was critical for wireless communication, since it was required to obtain the sharp tuning needed to reduce interference. Not only was Tesla's 1896 patent silent on loose coupling, so was Tesla's first wireless patent filed on September 2, 1897. In fact, the first publication in which Tesla referred to the subject of loose coupling was his U.S. patent 787,412 filed on May 16, 1900, with the title "Art of Transmitting Energy Through the Natural Mediums." Here is what Tesla wrote in this patent:

"In order to magnify the electrical movement in the secondary as much as

possible, it is essential that its inductive connection with the primary A should not be very intimate, as in ordinary transformers, but *loose*, so as to permit free oscillation that is to say, their **mutual induction should be small.**" (Emphasis added)

"I have found it practicable to produce in this manner an electrical movement thousands of times greater than the initial—that is, the one impressed upon the secondary by the primary A—and I have thus reached activities or rates of flow of electrical energy in the system E' C E measured by many tens of thousands of horsepower."

To the extent Tesla believed that loose coupling increased the energy or average power delivered to the secondary circuit, he was in error. Loose coupling can do nothing but decrease the energy and average power coupled from the primary to the secondary of an oscillation coil.

The U.S. Supreme Court actually focused on the issue of who discovered loose coupling as it applied to wireless communication. It is clear that they believed John S. Stone was the first one to introduce loose coupling into radio transmitter circuits. The U.S. Supreme Court found that Stone had described the advantages of loose coupling in his U.S. patent 714,756 filed on February 8, 1900, which was three months earlier than Tesla's patent filing date of May 16, 1900:

"That the closed circuit was intended to be a 'persistent oscillator' is also

brought out by Stone's emphasis on 'loose coupling.' Stone's application [for patent 714,756] explained in detail the fact that when two circuits are inductively coupled together there normally result 'two degrees of freedom,' that is to say, the superposition of two frequencies in the same circuit because of the effect on each of the magnetic lines of force set up by the other. He discussed in detail methods of eliminating this superposition, which interfered with accurate selectivity of tuning, by so constructing his circuits as to be 'loosely coupled.'⁹⁴

"... the testimony at the trial was in substantial agreement that the looser the coupling the slower is the transfer of energy from the closed charging circuit to the open antenna circuit. Hence the use of loose coupling presupposes a charging circuit that will store its energy for a considerable period, i.e., that will maintain persistent oscillations."⁹⁵

The Supreme Court also noted that Stone had documented his loose coupling approach in two letters to his young friend, Joseph B. Baker, dated June 30, 1899, and July 18, 1899—more than six months prior to the date of Stone's patent application. Baker and Stone had worked together in the mechanical department of the American Bell Telephone Company in Boston. The Court wrote:

"On July 18, 1899, Stone again wrote to Baker, mathematically demonstrating how to achieve the single frequency by means of forced vibrations. He

expressed as a trigonometric function the form taken by the forced wave 'if the period of the impressed force be the same as that of the fundamental of the vertical wire.' He also pointed out that the transmitting circuit which he had disclosed in his earlier letter to Baker, 'is practically the same as that employed by Tesla,' except that Stone added an inductance coil in the closed circuit 'to give additional means of tuning' and to 'swamp' the reactions from the coil of the oscillation transformer and thus loosen the coupling between the open and closed circuit of the transmitter."⁹⁶

The Supreme Court here stated that the tuning circuit was the same as Tesla's but that Stone added something that Tesla did not have—an inductance coil in the closed circuit to loosen the coupling between the open and closed circuit of the transmitter. The Supreme Court made no mention of Tesla using—or even referring to—loose coupling of the two circuits. A rather complete explanation of what was in these letters and how the U. S. Supreme Court interpreted the letters as well as Stone's patent is found in the book entitled *The Life of John Stone Stone* by historian George Clark.⁹⁷

Tesla Wireless Patent Applications Began in September 1897

Contrast the language in the Tesla's oscillator patents filed before September 2, 1897, with the language that appeared in Tesla's patents applications beginning with his September 2, 1897 patent application. Gone are all the words relating

to lighting applications. The words that appear beginning in September relate to the wireless transmission of signals, energy, or intelligible messages, as shown in the right-hand column of Table 2. These patents are often characterized, quite incorrectly, as “radio” patents; most if not all are wireless patents, but since they do not utilize electromagnetic energy, they are not radio patents.

Because all these patent applications were filed after the time frame of Marconi’s discoveries of communicating intelligence by Hertzian waves, none is relevant to the subject of Tesla’s precedence in the discovery of radio. By September 2, 1897, that ship had already sailed.

Key Takeaways from Tesla’s Disruptive Discharge Oscillator Patents

The key takeaway is that Tesla’s disruptive oscillator was not tuned or loosely coupled at the time of his 1893 lecture, and his oscillator design from the period 1891 to 1896 could not provide sharp tuning and was never used in radio.

- The first time Tesla ever disclosed an oscillator design with two tuned circuits was on **June 6, 1896**, when he filed an application for U.S. patent 568,178 for purposes of lighting. However, he did not mention the use of the two-tuned-circuit oscillator in any configuration for wireless transmission of intelligence or energy in

Table 2. Tesla patents for transmission of energy or intelligence to great distances.

Filing Date	Patent #	Title of Patent	Uses Cited in Patent
1897-09-02	645,576	System of Transmission of Electrical Energy	“transmit intelligible messages to great distances”
1899-06-24 Renewal: 1901-05-29	685,953	Method of Intensifying and Utilizing Effects Transmitted Through the Natural Media	“transmission of signals or intelligence is the main object of my present invention”
1899-08-01 Renewal: 1901-05-29	685,954	Method of Utilizing Effects Transmitted Through Natural Media	“My present invention is intended for the same general purposes.... “transmission of signals or intelligence...”
1899-09-08 Renewal: 1901-05-29	685,955	Apparatus for Utilizing Effects Transmitted from a Distance to a Receiving Device Through Natural Media	“When the apparatus I have described is used in connection with the transmission of signals or intelligence”
1899-11-02 Renewal: 1901-05-29	685,956	Apparatus for Utilizing Effects Transmitted Through Natural Media	“To over come limitations...in such systems of transmission of signals or intelligence...”
1900-02-19	649,621 Divisional	Apparatus for Transmission of Electrical Energy	“Improvements in apparatus for the transmission of electrical energy”
1900-03-21	685,012	Means for Increasing Intensity of Oscillations	“to greatly, extend the distance of transmission of signals”
1900-05-16	787,412	Art of Transmitting Electrical Energy Through the Natural Mediums	“the transmission of intelligible signals or messages between distant points”
1900-07-16	725,605	System of Signaling	“systems for transmitting intelligible messages”
1900-07-16 Divisional	723,188	Method of Signaling	“applications of such systems of signaling or intelligent transmission”
1902-01-18	1,119,732	Apparatus for Transmitting Electrical Energy	“Transmission of powerful disturbances to great distances”

this patent (or at any time prior to this date).

- The first time Tesla ever specified tuning his disruptive discharge oscillator for application to wireless transmission of energy or intelligence was on **September 2, 1897**, when he filed an application for U.S. patent 645,576 with the purpose of wireless transmitting electrical energy. However, he never mentioned in this patent (or in any document prior to this date) using his Tesla oscillator for any purpose with the two tuned circuits being loosely coupled.
- The first time Tesla ever disclosed a Tesla oscillator with two **loosely coupled**, tuned circuits, was on **May 16, 1900**, when he filed an application for U.S. patent 787,412 with the purpose of transmitting energy through the natural media.

Tesla's Lectures before the Franklin Institute and the National Electric Light Association (1893)

Much of the content of Tesla's lecture to the Franklin Institute and the National Electric Light Association was the same as his 1892 lecture, but there is one major exception. Tesla paused the demonstration portion of his 1893 lecture to introduce his thoughts on the transmission of intelligible signals and power to long distances without the use of wires. Tesla documented these thoughts in three paragraphs on pages 267–271 of the lecture he published in the *Journal of the Franklin Institute* dated July 1893—paragraphs which are almost universally

cited by those who contend that Tesla has precedence in the discovery of radio. These three paragraphs are important because they constitute the only description of a method of wireless transmission of energy or intelligence that Tesla documented before December 2, 1896, the date when Marconi filed his complete U.S. patent on using Hertzian waves for transmitting and receiving intelligence. Citing these three paragraphs from his 1893 lecture document as a source, many Teslaphiles and historians make one or more of the following claims on his behalf:

- Tesla described a complete system to transmit and receive radio signals.
- Tesla's description forms the basis for radio engineering.
- Tesla was the first to describe a radio system using grounded antennas in both the transmitter and receiver circuit.
- Tesla used a high-frequency source in the system he described.
- Tesla introduced the concept of capacitively loaded antennas.
- Tesla described the concept of two-circuit tuning.
- Tesla described the principle of adjusting for resonance to get the maximum sensitivity and selectivity in reception.

In the following paragraphs it will be shown none of these claims are supported by Tesla's description of his 1893 lecture. The relevant words from Tesla's 1893 lecture, which he published in the *Journal of the Franklin Institute*, are reproduced in italics below. Bold letters have been added for purposes of emphasis.

Tesla's Basic Approach to Transmission of Intelligible Signals

Tesla introduced his thoughts on the transmission of intelligible signals and power to any distance without wires by referring to resonance effects:

"In connection with resonance effects and the problem of transmission of energy over a single conductor which was previously considered, I would say a few words on a subject which constantly fills my thoughts and which concerns the welfare of all. I mean the transmission of intelligible signals or perhaps even power to any distance without the use of wires...."

"We now know that electric vibration may be transmitted through a single conductor. Why then not try to avail ourselves of the earth for this purpose? We need not be frightened by the idea of distance."
—Tesla's lecture (1893), p. 267–8.

Tesla's idea of transmitting intelligence or power to long distances was not new. As discussed previously, Mahlon Loomis filed a patent for transmitting intelligence to distant points, even to other continents, by using electric currents in the atmosphere as one path and the earth as a return path. However, Tesla added a new twist to the method, namely to use the resonant frequency of the earth to transmit signals more efficiently through the earth. The idea of using resonance was based on his observation that he could transmit signals more efficiently in his "one-wire" demonstration experiments when he adjusted the source frequency of his dynamo to match the resonant frequency of the RLC circuit

of the wire attached to his light bulbs. Tesla said that he did not believe that "telephony to any distance" is possible with induction methods through the air. Indeed, Tesla described a method by which he believed intelligence and energy could be "transmitted through a single conductor"—specifically, the earth.

Tesla Proposes to Measure the Resonant Frequency of the Earth

Tesla had a problem. He did not know the resonant frequency of the earth, and he could not describe a specific approach to a communication system until he knew the resonant frequency of the earth. So, he proposed an experiment to measure the earth's resonant period (i.e., frequency):

"If ever we can ascertain at what period the earth's charge, when disturbed, oscillates with respect to an oppositely electrified system or known circuit, we shall know a fact possibly of the greatest importance to the welfare of the human race...."

"I propose to seek for the period by means of an electrical oscillator, or a source of alternating electric current. One of the terminals of the source would be connected to earth, as, for instance, to the city water mains, the other to an insulated body of large surface. It is possible that...the period of vibration may be very low and an alternating dynamo machine might serve for the purpose of the experiment. I would then transform the current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the

ground and to the insulated body. By varying the frequency of the currents and carefully observing the potential of the insulated body and watching for the disturbance at various neighboring points of the earth's surface resonance might be detected." —Tesla's lecture (1893), p. 269.

Tesla Proposes a Dynamo Source for His Experiment

Tesla had developed two electrical oscillators for his lighting experiments—his low-frequency dynamo in conjunction with an ordinary oscillation coil and his high-frequency, disruptive-discharge oscillator using a spark source and a high-voltage oscillation coil. He proposed to use one of these oscillators in his experiment, but he did not know which one because he did not know the resonant frequency of the earth. Rather than guessing, he described how he would use each one in turn, beginning with his low-frequency dynamo, which was applicable in the event the resonant frequency was low. Because the earth's resonant frequency turned out to be very low, the experiment with the low-frequency source is most relevant to his proposed approach to communicating intelligence by conducting currents through the earth at the earth's resonant frequency.

In the context of describing his experiment, Tesla proposed to use his alternating dynamo and induction coil configuration in which the two primary windings of the oscillation coil were connected to the low-frequency dynamo, and the two terminals of the oscillation coil

secondary winding were connected to the raised conducting surface and ground electrode (see Fig. 24).⁹⁸ Tesla planned to vary the frequency of the dynamo source until it matched the resonant frequency of the earth, at which point the response of the earth at some unspecified distance from the source would presumably increase considerably. Note that he never mentioned tuning the secondary circuit with the raised surface and ground to match the variable source frequency. At the time of his lecture in 1893, Tesla was not aware that the frequency of the primary resonance mode that encircled the earth was 7.8 Hz, which is in a range known as the Extremely Low Frequency (ELF) band. The primary circumferential resonant modes of the earth are known as Schumann resonances, and the primary

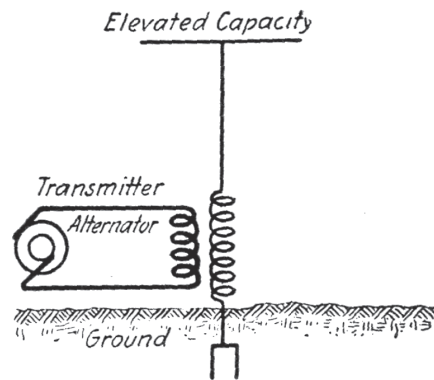


Fig. 24. If the earth's resonant frequency was low (it was), Tesla proposed to use this configuration with his alternating current dynamo attached to an induction coil for the experiment he proposed to determine the resonant frequency of the earth; Tesla said nothing about tuning the secondary circuit (antenna) to match the CW source frequency. (Adapted from Fig. 8, Tesla, *Electrical Experimenter*, Vol. 7, May 1919, p. 29)

resonance is at approximately 7.8 Hz, with measurable harmonics at 13.9, 20, 26, and 32 Hz.⁹⁹

It should be pointed out that there are also transverse earth resonances associated with the dimensions between the earth's surface and the sensible ionosphere. The primary transverse resonance is approximately 2 KHz, and there are a few measurable higher order harmonics as well. However, the transverse modes are highly localized and do not propagate around the earth like the Schumann resonances because the waves trapped between the earth the ionosphere are heavily attenuated with each reflection off the ionosphere.¹⁰⁰

Tesla reported that he had measured the wavelengths of earth resonances on July 3, 1899, when he was performing experiments in Colorado Springs.¹⁰¹ While he did not reveal the wavelengths in that announcement, he did reveal the wavelengths a year later:

"From data obtained in a large number of observations of the maxima and minima of these waves I found their length to vary approximately from twenty-five to seventy-five kilometers, and these results and theoretical deductions led me to the conclusion that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth."¹⁰²

The only known earth resonances in this range (75–25 km or 4–12 kHz),

are harmonics of the primary *transverse* mode at 2 kHz. These transverse modes do not travel far from the lightning strokes that produce them, so they would not be useful for communicating intelligence to a significant distance. They are generally observed in the vicinity of a lightning storm and at night when the ionosphere becomes more reflective.

Communication of Intelligence is Impractical at the Earth's Resonant Frequency

Communication of intelligence requires a channel bandwidth sufficient to carry the intelligence encoded on the carrier signal. The bandwidth required to reproduce voice and music is between 3 to 5 kHz, depending on the fidelity desired, and the bandwidth required for Morse code for bi-level signals (on and off) is on the order of 50–70 Hz for speeds that were commercially competitive with other methods in the day. The measured resonant frequency of the earth is 7.8 Hz, and the measured Q is approximately 5,¹⁰³ so the bandwidth of the earth's fundamental resonant frequency, Δf , is approximately equal to $f/Q = 1.6$ Hz. According to the Nyquist formula for a noise-free channel,¹⁰⁴ the upper bound to the bit rate (in bits per second) is $2B \times \log_2(M)$, where B is the bandwidth in Hz (1.6 Hz), and M is the number of signal levels, in this case 2 (on and off). The result for this case is $2B \times \log_2(2) = 2B = 3.2$ bps. At 3.2 bits per second, voice and music cannot be transmitted, and the *upper bound* to the word rate in Morse code would be about 4 words per minute *in a noiseless*

environment. A word rate of 4 words a minute would hardly be competitive with commercial telegraph wires and undersea cables, which could achieve word rates of 20 to 30 wpm. It should also be noted that since a communication system based on circumferential resonances would produce signals worldwide, only one system could operate worldwide at the resonant frequency of the earth without interfering with other systems. But more to the point, the electrical environment of the earth at the resonant frequency is anything but noiseless.

The upper bound to the word rate of four words per minute is predicated on a communication channel without any noise, and there is actually a great deal of noise from the earth's natural electrical environment in the ELF band, noise which is also amplified by the earth-ionosphere cavity at its resonant frequencies. Tesla believed that the earth would amplify the signals he generated at the earth's primary resonant frequency, but it apparently did not occur to him that the earth also amplified the natural electrical environment of the earth at its resonant frequencies. In fact, he never considered the noise at all in his communication scheme, and that turns out to be the limiting factor.

The two major sources of electrical noise at the resonant frequency of the earth are 1) the natural electric field at the earth's surface produced by a fluctuating current of positive charge from the ionosphere to the surface of the earth, and 2) lightning strokes, which occur worldwide at a rate of about 15–50 per second.¹⁰⁵ The natural electric field of the

earth has a magnitude of 100–200 V/m with a random rate of variation between zero and a few hundred mV/m/sec, which constitutes a relatively strong AC electric field in the ELF band.¹⁰⁶

Lightning strokes at the rate of 15 to 50 per second worldwide produce a background noise level in the ELF band such that individual strokes meld together so they are not distinguishable from each other. That does not bode well for a communication system in which each successive pulse must be distinguished, one from another, at a rate of more than a few pulses per second. The AC electric field background produced by multiple lightning strokes is on the order of a millivolt per meter.¹⁰⁷ In addition to the background electric field produced by multiple strokes, there are unusually large strokes, known as “sprites,” that produce Q-bursts that do not meld together. The Q-bursts occur at rate one every 10 seconds to a few minutes,¹⁰⁸ so they can actually be measured individually because they rise out of the noise background formed by the more common strokes. They have been reported to have peak electric fields on the order of 20–30 mV/m and pulse widths of 0.3–1.5 seconds.¹⁰⁹ Even these more occasional Q-bursts would be a significant source of noise for an ELF communication system.

In all cases of natural background noise in the environment, the actual noise reaching the detector in a communications receiver depends on the bandwidth of the bandpass filter used to reduce the noise. Theoretically, if the transmitted signal were a pure sine wave, and an infinitesimally narrow band-pass

filter were used at the receiver, noise from sources external to the receiver would not be a problem. However, intelligence cannot be communicated by a pure sine wave. A pure sine wave must be modulated to encode intelligence, and modulation causes the bandwidth of the transmitted signal to increase—and increase well beyond the 1.6 Hz bandwidth of the earth's primary resonant frequency. The bandwidth requirement for Morse code is about 50 to 75 Hz, and the minimum bandwidth requirements for voice and music are about 3–5 kHz, depending on fidelity required. For example, the bandwidth required today by AM radio is 10kHz.

There is no way Tesla's approach could support the transmission of voice or music, and telegraphy could be accomplished only by slowing down the data rate considerably. The actual data rate that could have been achieved with Morse code telegraphy depends on the signal to-noise-ratio at the detector, a calculation that is beyond the scope of this paper, particularly since Tesla did not describe a receiver. It should be noted in passing that the modulation bandwidth of the transmitted signals, the signal-to-noise ratio, and their use in designing bandpass filters are fundamental radio engineering principles for receivers, which Tesla never mentioned in his 1893 lecture.

So, an alternative way of looking at this problem is to review the U.S. Navy experience in Project ELF,¹¹⁰ which involved constructing a system to signal submarines from long distances using ELF signals centered at 76 Hz. It will be

shown that Project ELF also used ELF wavelengths, but with distinctly different system design parameters that greatly enhanced the radiated and received signals as compared to Tesla's concept. Nevertheless, the Navy system could signal only a few letters in a matter of many minutes, which allowed the submarine to select among predetermined message options, but not to transmit and receive intelligence in the form of new messages, because the maximum possible data rates were far too low. Tesla's proposed concept could not possibly have performed nearly as well as Project ELF.

U.S. Navy Experience with Project ELF

Project ELF was the third of three sequential Navy programs with the objective of implementing a system to communicate with submarines using an ELF carrier signal centered around 76 Hz.¹¹¹ This frequency was chosen because it was well above that of the noise produced by AC power lines and the earth's resonant frequencies (where the noise produced by natural electrical sources such as lightning was amplified by the earth's resonances). At the same time, it was also below 100 Hz, where there are no significant propagation losses due to atmospheric attenuation.¹¹² Project ELF immediately rejected the concept of using monopole antennas because of the inefficiency of transmitting ELF signals with antennas of any practical height at 76 Hz (much less at Tesla's choice of 7.8 Hz). Instead, Project ELF used several horizontal antennas 14 to 21 miles in length, one separated by over a hundred miles, with the antennas grounded at

An Examination of Tesla's Precedence in Discovering Radio

either end (see Fig. 25).¹¹³ The antennas were located in Wisconsin over a soil with an extremely low conductivity to increase the radiation from the horizontal antenna. The problem of broadening the transmitted frequency by amplitude modulation was eliminated by using frequency modulation in which the signal at 74 Hz represented one state and the signal at 78 Hz represented a second state.

CW sources with a power of approximately 1 MW centered at 76 Hz were connected at the midsections of these antennas, as shown in the figure, resulting in approximately 1 watt of radiated power. These design features considerably increased the radiated power over Tesla's approach, and yet the resulting data rates were still so low that it was possible to identify only among prearranged messages—but not to communicate new messages. The advertised (unclassified) message rate was on the order of 4 minutes to transmit three letters of code.¹¹⁴

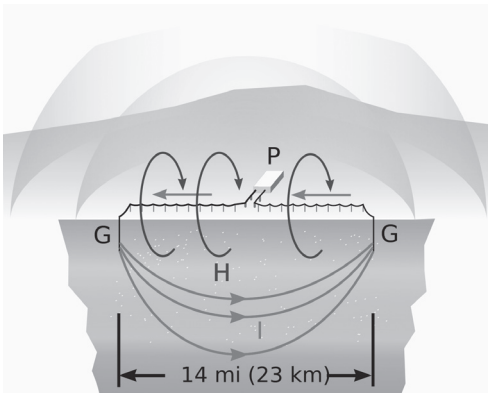


Fig. 25. Project ELF for signaling U.S. submarines at 76 Hz used several horizontal antennas 14 and 21 miles in length that were grounded at either end; monopole antennas were found to be completely impractical at ELF frequencies. ("Project Sanguine Revisited," p. 8)

Tesla's configuration for communicating intelligence in the ELF band was much worse than that for Project ELF in several respects. Tesla proposed to use 7.8 Hz as the source frequency in conjunction with a practical monopole antenna, a combination that is less efficient by many orders of magnitude in transmitting 7.8 Hz than Project ELF, which used 76 Hz and horizontal antennas 14 km long. And Project ELF used frequency modulation to avoid spreading the transmitted frequency spectrum that would have resulted from amplitude modulation by gating a CW signal on and off. Frequency modulation of the carrier allowed Project ELF to use narrower band-pass filters at the receiver. Tesla, on the other hand, never even considered a method of modulation. Tesla's approach of using the resonant frequency of the earth as a method of transmitting messages using a monopole antenna was a nonstarter based on bandwidth limitations, the inefficiency of transmitting signals through the air or ground with monopole antennas of any practical size, and the high level of noise at the earth's resonant frequency. The obvious conclusion is that Tesla's approach would have performed far worse than that of Project ELF. Tesla never attempted to demonstrate his approach using the resonant frequency of the earth.

Analysis of Low-Frequency Conduction Through the Earth: Tesla believed that the charge driven into the earth by his monopole antenna went to the far regions of

the earth, thereby exciting the primary resonant frequency of the earth. The purpose of this section is to show that most of the charge conducted into the earth by his dynamo source remained within a short distance from the base of the monopole antenna, which was equal to or less than a radius equal to several antenna heights. The exact solution for radiation and conduction of current from an electrically short monopole over a conducting ground plane is well known. The electrostatic and electromagnetic fields are equal at a distance of one wavelength divided by 2π or about $\frac{1}{6}$ of a wavelength. Conduction currents in the earth produced by exciting a monopole antenna are quasistatic out to a distance of approximately $\frac{1}{6}$ of a wavelength. The wavelength corresponding to 7.8 Hz is 38,000 km, and $\frac{1}{6}$ of that distance is about 6000 km. Thus, the quasistatic electric fields from a monopole antenna over a highly conducting earth can be computed to that distance by using image theory, where the actual monopole antenna is in the upper half quadrant and the image of the monopole in the lower half quadrant is produced by the conductive earth (see Fig. 26). The electric field E and surface charge density σ versus the distance r for this quasistatic dipole configuration is given by:

$$E = \frac{1}{4\pi\epsilon_0} \times \frac{2hq}{(h^2 + r^2)^{3/2}},$$

$$\sigma(r) = \epsilon_0 E(r) = \frac{1}{4\pi} \times \frac{2hq}{(h^2 + r^2)^{3/2}},$$

where q is the charge on the raised sur-

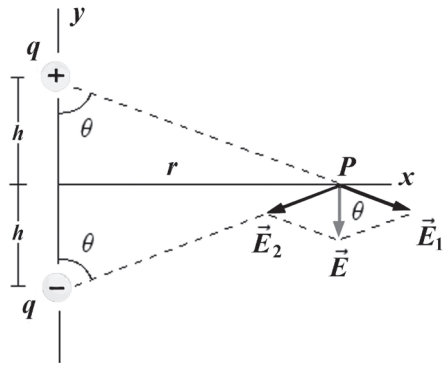


Fig. 26. The quasistatic electric fields from a monopole antenna over a perfectly conducting earth can be computed by using image theory, in which the physical monopole antenna is in the upper half quadrant and the image of the monopole in the lower half quadrant is the earth. (Author)

face when the electric field is maximum, h is the height of the raised surface, and r is the distance from the base of the monopole antenna.¹¹⁵ The electric field and charge density normalized to the values at the base of the monopole antenna ($r = 0$) is shown in Table 3. It is clear that the electric fields falls off as $1/r^3$ at large distances, and more to the point, the charge density at a distance of three antenna heights from the base ($r = 3h$) is about 3% of the value at $r = 0$, which means that most of the image charge to the charge on the raised surface resides within a distance of two or three antenna heights as measured from the base of the antenna.

The charge in the earth is attracted by the image charge of opposite sign in the raised surface, so the disturbance does not travel far from the base of the monopole antenna—and certainly not to terrestrial distances, as Tesla believed.

Table 3. Electric field and charge density versus r/h produced by a quasi-static dipole relative to levels at $r = 0$.

r/h	$E(r/h)$ $\sigma(r/h)$
0	1.0
.3	.88
.5	.71
1	.35
2	.089
3	.031
>3	$\approx (r/h)^{-3}$

Beyond a distance of three antenna heights, the magnitude of the electric field and charge density fall off as $1/r^3$ out to a distance where the electromagnetic fields dominate, which is on the order of 6000 km. This simple calculation shows why Tesla was able to throw “lightning bolts” (discharges from his Tesla coil) to a distance of only 120 feet in Colorado Springs, where his antenna had a small sphere that was raised to a height no greater than 142 feet.¹¹⁶

If one assumes the maximum height h of a practical monopole antenna is on the order of 1 km,¹¹⁷ the electric field E at 6000 km, (the maximum distance for which this approximation is still valid) is $E = E_0 \times (r/h)^{-3} = E_0 \times 5 \times 10^{-12}$, where E_0 is the electric field at the surface of the earth directly under the antenna. Assume the raised surface is a sphere with a radius R of 0.1 km that is located atop a 1 km antenna, and it is raised to a voltage that produces an electric field E_R at the surface of the sphere near the breakdown threshold of air, say 10^6

V/m. The maximum electric field on the earth at the base of the antenna E_0 would be 10^5 V/m,¹¹⁸ so the quasistatic electric field at the earth’s surface at a distance of 6000 km would be $0.5 \mu\text{V/m}$.

This is an incredibly small electric field as compared to natural electric fields of the earth in the frequency range of 7.8 Hz. It is beyond the scope of this paper to go into the effects of signal to noise ratio. Suffice it to say that that background noise from all natural electrical environments in the ELF range is at least several orders of magnitude greater than $0.5 \mu\text{V/m}$.

Low-Frequency Fields Radiated from a Monopole Antenna Using a Dynamo Source:

Some Teslaphiles claim that Tesla’s 1893 wireless configuration was capable of radiating electromagnetic energy, albeit at ELF frequencies. Not likely. At the primary resonant frequency, there is virtually no measurable electromagnetic energy radiated into the earth-ionosphere cavity by a monopole of any practical height, and the response of the earth is restricted to conduction currents flowing in the ground—just as Tesla originally envisioned. It is well known that the radiation efficiency of an ideal monopole antenna is maximum when the wavelength of the excitation source λ equals four times the height of the antenna h , and the radiation efficiency falls off as $(4h/\lambda)^2$ for longer wavelengths (lower frequencies). Many historians seem to believe the resonant frequency of a monopole antenna can be lowered by adding an inductance at the base of the antenna *without losing radiation efficiency*, but this not true. The resonant

frequency of an antenna can be lowered by adding inductance at the base, but the loss in radiation efficiency will still be proportional to $(4h/\lambda)^2$. In Tesla's case, the earth's primary resonant frequency of 7.8 Hz has a wavelength of 3.8×10^4 km. If the maximum practical height of a monopole antenna were on the order of 1 km, the radiation efficiency (power radiated divided by power applied) would be 2.7×10^{-9} . That means it would take an electrical source of almost one gigawatt operating at 7.8 Hz to radiate about 1 watt of electromagnetic energy from a 1 km high monopole antenna.

Tesla's CW Transmitter is Identical to That of Thomas Edison

A high-power CW dynamo operating at the earth's resonant frequency is something that Tesla did not have and that did not exist at that time. The maximum power output of Tesla's low-frequency dynamo was approximately 5 to 10 kW when operated at its maximum frequency, which was about 20 kHz. The output voltage and frequency of Tesla's dynamo was proportional to the rotational frequency of the dynamo, so the output at 7.8 Hz would have been negligible. The only way Tesla could have generated significant power centered around 7.8 Hz was with a high-voltage DC generator and a low-frequency circuit breaker, or rheotome—as Edison described in his application for U.S. patent 465,971 for wireless communication by an electrostatic induction method on May 23, 1885. In fact, the source Edison described using his rheotome source was exactly like the source Tesla

proposed—except the dynamo frequency of Tesla's source would have been even lower than that of Edison's source (see Fig. 27). Compare this figure with Tesla's source shown in Fig. 24. Clearly, the source configuration Tesla described in his lecture was the same quasistatic induction method that Edison had already disclosed.

Edison's method has been accepted by historians for decades as being the quintessential example of a quasistatic electric-field induction method. If Edison's method was electric-field induction, which it surely was, then Tesla's approach using a lower source frequency must

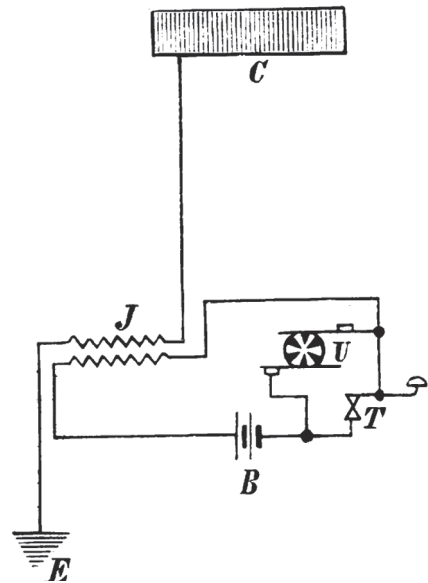


Fig. 27. The source and raised surface configuration for Edison's quasistatic electric-field induction technique shown here is virtually identical to that of Tesla's source and raised conducting surface configuration described in his 1893 lecture, which is shown in Fig 24. (Adapted from A. Prasch, *Die Telegraphie ohne Draht*, 1902, p. 54)

also have been an electric-field induction method—not an electromagnetic method. But no matter how one classifies Tesla's approach, the CW source configuration that Tesla described in his 1893 lecture is virtually identical to that described by Edison, and was by no means new.

Tesla Proposes a High-Frequency Tesla Oscillator Source for His Experiment

Tesla continued by saying that if the period of vibration should be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced:

"Should...the period be extremely small, then a dynamo machine would not do and a proper electrical oscillator would have to be produced and perhaps it might not be possible to obtain such rapid vibrations. But whether this be possible or not, and whether the earth contains a charge or not, and whatever may be its period of vibration, it certainly is possible—for of this we have daily evidence—to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface."——Tesla's lecture, 1893, p. 269.

Tesla wrote, "If the resonant frequency of the earth is high, a proper oscillator would have to be produced." There are two notable equivocations here that have been conveniently ignored by most Teslaphiles. The first equivocation is: "if the resonant frequency is high." However, the resonant frequency was

not high; it was 7.8 Hz—about as low as it could get. The second equivocation is that a proper oscillator "would have to be produced." Tesla does not say the oscillator he had in hand at the time of his 1893 lecture would be appropriate or that he intended to use it. He said he would have to produce a "proper oscillator." Yet Teslaphiles still claim that Tesla proposed a communication system to radiate high-frequency signals using his then existing Tesla coil. To repeat for emphasis, Tesla did not propose a communication system with a high frequency source. He proposed to use his high-frequency oscillator—but only for purposes of the experiment to determine the earth's resonant frequency, and only in the event that the resonant frequency was high. But it was not.

In any event, the circumferential resonant frequency of the earth was very low, and the high-frequency Tesla oscillator, which generates very little energy at 7.8 Hz, was singularly unsuitable for exciting resonant frequencies of the earth. Not only does any practical monopole antenna radiate little energy at 7.8 Hz, but a spark source generates very little energy within the very narrow bandwidth of a 7.8 Hz earth resonance (the earth's resonance at 7.8 Hz with a Q of 5 has a bandwidth of f/Q , or less than 2 Hz). Consequently, the inefficiencies of both factors must be multiplied together to arrive at the actual efficiency of radiating electromagnetic energy. For a given source power, the power radiated at or around 7.8 Hz by Tesla's high-frequency oscillator is far lower than that radiated by a dynamo source tuned to 7.8 Hz.

Canard Alert: Tesla's Oscillator Described in His 1893 Lecture Was Used in Radio Telegraphy

Teslaphiles claim that Tesla described an inductively coupled, two-circuit, high-frequency antenna configuration in his 1893 lecture that was the same as those used later in radiotelegraphy. However, the two coupled circuits in Tesla's 1893 oscillator configuration were not tuned to the same frequency, nor were the two circuits loosely coupled. As discussed previously, Tesla did not specify tuning the primary and secondary circuit of his oscillator until 1896, long after his 1893 lecture. Even then, he did not describe it for the application of wireless transmission of energy or intelligence until September 2, 1897. It was even later, in 1890, that Tesla mentioned the concept of loose coupling in conjunction with wireless transmissions. Since the only two-circuit transmitter configuration used in spark-source radio transmitters had two loosely-coupled circuits that were tuned to the same frequency, and since Tesla's oscillators dating from 1891 to 1896 had neither feature, the type of high-frequency oscillator design that Tesla had in hand at the time of his 1893 lecture was never used in radio.

Tesla Describes His Experimental Configuration

The two paragraphs in which Tesla described the experimental configuration he proposed to use to measure the resonant frequency of the earth are perhaps the most important two paragraphs in the entire lecture. The description of his experiment was accompanied by the only

diagram that appeared in this portion of the lecture describing wireless telegraphy, which was labeled Fig. 21 in his lecture and is reproduced here as Fig. 28. Referring to this figure, Tesla's description is quite clear and concise:

"Assume that a source of alternating currents S be connected, as in Fig. 21, with one of its terminals to earth (conveniently to the water mains) and with the other to a body of large surface P . When the electric oscillation is set up there will be a movement of electricity in and out of P , and alternating currents will pass through the earth, converging to, or diverging from the point C where the ground connection is made. In this manner neighboring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion.

"Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_1 , Fig. 21, similar to S , or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_1 if the same be of opposite phase to the source S ." —Tesla's lecture (1893), p. 270.

It is very clear from Tesla's language that both S and S_1 in this sketch are



FIG. 21.— Energy transmission to any distance

Fig. 28. Tesla's sketch of the experiment he proposed to measure the resonant frequency of the earth in his 1893 lecture contained two sources, S and S_1 , and no receivers; he stated "...another source S_1 , Fig. 21, similar to S or any number of sources can be set to work in synchronism with the latter..." (*J. Franklin Institute*, Vol. 136, No. 1, July 1893, p. 270)

sources of excitation. The second source S_1 (or any number of such sources) similar to S is intended to work in synchronism with S . Note that there is no description of a receiver or receive antenna in this sketch, and in fact there is no mention of a receiver, a receive antenna, or a detection device in Tesla's 1893 lecture, much less a description of one. This should be no surprise because Tesla was describing an experiment to measure the earth's resonant frequency—not a complete system of wireless telegraphy. So, how is it that many Teslaphiles claim that Tesla described a complete system of wireless telegraphy in this lecture? Most likely it is because Tesla actually morphed the description of his lecture in various publications over a period of time to make it appear that he had described a complete system in 1893, when in fact he had not.

Tesla Morphs His 1893 Lecture Configuration

Tesla morphed the description of the experiment he described in his 1893 lecture by claiming that the source S_1 was a receiver. Many Teslaphiles, following

Tesla's lead, have made the same claim. Tesla began his morph in a paper entitled "The problems of Increasing Human Energy,"¹¹⁹ dated June 1900, in which the figure reproduced here as Fig. 29 appeared. This figure is virtually identical to the one in his 1893 lecture, but the description in the text is markedly different. In his 1900 paper, Tesla begins by stating this figure appeared in his "scientific lectures in February and March 1893"—which it did. But then Tesla claims that the component S_1 in the circuit ES_1P_1 to the right of the figure represents a receiver, not a second source. In 1900 Tesla wrote:

"In the latter wire or circuit is included a **sensitive device or receiver S_1** , which is thus set in action and made to operate a relay or other appliance. Each station is, of course, provided both with a source of electrical oscillations S and a **sensitive receiver S_1** , and a simple provision is made for using each of the two wires alternatively to send and receive messages."¹²⁰

Incredibly, the source S_1 in his 1893 lecture is now a receiver S_1 in his 1900

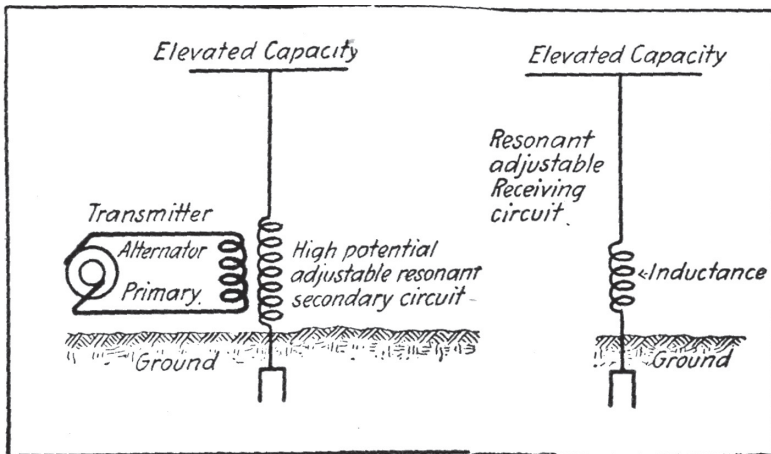


Fig. 29. Tesla morphed the description of his 1893 experimental configuration shown in Fig. 27 by claiming in 1900 that S_1 in circuit ES_1P_1 to the right of this figure represents a receiver, not a second source. (*Century Magazine*, Vol. 60, June 1900, p. 206)

article. Tesla followed this statement with one that is even more incredible. He wrote, "Since I described these simple principles of telegraphy without wires I have had frequent occasion to note that the identical features and elements have been used, in the evident belief that the signals are being transmitted to considerable distances by "Hertzian" radiations."¹²¹ What chutzpah! Tesla never described a receiver in his 1893 lecture, much less "a sensitive receiver S_r , which is thus set in action and made to operate a relay or other appliance"—an obvious allusion to Marconi's coherer receiver dating to 1895–6.

Tesla completed the metamorphosis in May 1919 when he published his article, "The True Wireless," where he

asserted that the image shown in Fig. 30 was from his 1893 lecture. Tesla explicitly wrote the following statement in the caption accompanying this figure: "Tesla's System of Wireless Transmission Thru the Earth as Actually Exposed in His Lectures Before the Franklin Institute and Electrical Light Association in February and March 1893." The circuit on the right, which was a second source S_r in his 1893 lecture, is now labeled "Resonant adjustable **receiving** circuit." And the circuit on the left, which in the 1893 lecture was a "source of alternating currents S , is now described as a "transmitter" with "a high potential adjustable resonant secondary circuit." There was no mention of an adjustable resonant secondary source in the 1893 lecture.



Tesla's System of Wireless Transmission Thru the Earth as Actually Exposed in His Lectures Before the Franklin Institute and Electric Light Association in February and March, 1893. Fig. 8.

Fig. 30. Tesla completed the metamorphosis of his 1893 experimental configuration (shown in Fig. 27) by stating in a 1919 article that this figure was the configuration he described in his 1893 lectures. (Tesla, *Electrical Experimenter*, Vol. 7, May 1919, p. 29)

An Examination of Tesla's Precedence in Discovering Radio

It has been noted before that the first time Tesla ever mentioned a resonant secondary circuit was in 1896. It should also be noted that the source he represents here is not his high-frequency oscillator—it is his low-frequency dynamo. This reinforces the statement made earlier that Tesla never proposed to use a *high-frequency* source for transmitting intelligence—he actually proposed to use a source that matched the resonant frequency of the earth.

Canard Alert: Tesla's Description is Often Taken to Be the Foundation of Radio Engineering

There is not one relevant radio principle that Tesla introduced in his 1893 lecture. The most basic principle of radio communication is that a communication system has both a transmitter and a receiver. Tesla did not describe a receiver, a detector, or even a receive antenna. Therefore, Tesla was missing all of the basic principles associated with receivers—receiver antenna size, impact of external noise and signal-to-noise, bandwidth filters to reduce external noise, receiver gain and noise, etc. Perhaps the most important receiver principle in the early days of radio was that some form of sensitive non-linear detector was required to demodulate intelligence impressed on transmitted signals with frequencies above the audio range. The suggestion that Tesla invented radio because he proposed to transmit high frequencies in 1893 is a nonstarter, since he provided no information on how to receive and detect signals of any frequency, much less, how to demodulate a high-frequency carrier

wave. Thus, he did not actually describe a system of transmitting and receiving intelligence by any means.

As for the transmitter, perhaps the most fundamental principle of radio engineering is that the natural resonant frequency of the transmit antenna should match the source frequency. In this lecture, Tesla states that the source frequency should match the earth's resonant frequency. And he gives no guidance on the size of the transmit antenna in relation to the desired source frequency. He also provides no guidance on how to change the resonant frequency of an antenna. Yet another important principle that Tesla did not mention is that the carrier frequency must be modulated to encode intelligence on the carrier. A CW signal or a repetitive pulse that does not vary from pulse-to-pulse or in spacing cannot convey intelligence. The sources that Tesla proposed to measure the resonant frequency of the earth were not modulated, and Tesla did not address modulation methods or bandwidth requirements for transmission (or reception) of signals with intelligence encoded.

Tesla's approach to communicating intelligence using a CW source was not new. Tesla's CW source configuration was identical to the source configuration that Thomas Edison used years earlier—including a raised conducting surface at the top of a vertical wire that consisted of a capacitive load. Both were using such low frequencies that they were quasistatic electric-field induction methods—not radio.

Finally, Tesla did not mention anything about tuning the transmitter and

receiver circuits to the same frequency, nor did he mention tuning the primary circuit of the transmitter to the secondary circuit in the transmitter. In fact, Tesla's did not tune the primary circuit and secondary circuit of his Tesla oscillator until 1896, and he did not apply that concept to transmitting energy or intelligence until September of 1897—well after the dates of Marconi's documented achievements.

Key Takeaways From Tesla's 1893

Lecture

There are eight important takeaways from Tesla's 1893 lecture:

1. Tesla proposed a concept of communicating intelligence using the resonant frequency of the earth to transmit intelligence through the earth to terrestrial distances.
2. Tesla did not know the resonant frequency of the earth, so he proposed an experiment to measure it.
3. Tesla never described a complete system of radiotelegraphy in his 1893 lecture—only an experiment to measure the resonant frequency of the earth; specifically, Tesla never mentioned or described a receive antenna, a receiver, or a detector, and certainly not a nonlinear detector, which was required to demodulate high-frequency signals.
4. Tesla did not propose to use a high-frequency source for communicating intelligence; he proposed to develop an appropriate high-frequency source for the experiment—but only if the resonant frequency of the earth was high. It was not.
5. Tesla's high-frequency oscillator source as it existed in 1893 was not suitable for radiotelegraphy because his two circuits were neither tuned nor loosely coupled; his 1893–1896 design of the Tesla coil was never used in radiotelegraphy.
6. Tesla did not introduce the concept of two-circuit tuning in either the transmitter circuit or receiver circuit in his 1893 lecture; he did so for the first time in his wireless transmission patent application dated September 2, 1897, more than four years later.
7. Tesla attempted to assert his precedence in the discovery of radio by morphing his 1893 lecture to make it appear that he had described a complete system of wireless communication in 1893, when in fact he did not.
8. One cannot claim precedence in the invention of a communication system without specifying both the transmitter and receiver.

PART IV. THE CASE AGAINST TESLA'S PRECEDENCE IN DISCOVERING RADIO

Summary

Methodology: To make the case for Tesla's precedence in the discovery of radio requires evidence in the form of documentation that proves Tesla discovered radio before any of the other leading contenders—and in particular, Guglielmo Marconi, whose accomplishments are well documented and dated. It has been said that who has precedence in the discovery of radio depends on the definition of radio. That may be true, but the standard definition for radio that has been accepted by the scientific community and those who have created and published dictionaries for over a century has two basic components—"communication of intelligence" and "by means of electromagnetic waves," originally known as Hertzian waves. Tesla-philosophers who have suggested significantly different definitions of radio have never provided any substantive evidence to support the validity of those definitions. The basic criterion used to determine if Tesla has precedence in the discovery of radio is that his documented accomplishments in discovering communication of intelligence by electromagnetic waves preceded those of Marconi.

Marconi's Dates of Discovery: There are two events that unequivocally mark Marconi's documented contribution to the discovery of radio. The first is Marconi's application for U.S. patent 586,193 filed on December 2, 1896 (reissued as U.S. 11,913 with the same priority date),

which contains a complete description of his wireless system that specifically states he was using Hertzian waves to communicate intelligence. This is the first patent ever describing a system of wireless communication using Hertzian waves, now known as electromagnetic radiation.

The second event date is May 13, 1897, when Marconi demonstrated that the system described in his patent was able to communicate messages to a distance of nine miles across the Bristol Channel. This distance exceeded the distance of the longest documented distance of any non-Hertzian method of electronic communication by a factor of almost three. The range of the longest documented communication of intelligence by non-Hertzian electronic means was achieved by William Prece in 1897 when he used a magnetic induction method to transmit messages to a distance of 3.3 miles, also across the Bristol Channel.

Attempts to Marginalize Marconi's Accomplishments: There have been many attempts to marginalize Marconi's contributions to the development of radio by asserting that he did not invent anything new, that his single-circuit tuning approach could not communicate intelligence to long distances, and that his single-circuit approach soon became obsolete when it was replaced by two coupled circuits tuned to the same frequency, which provided the sharper tuning needed to reduce interference. The

most egregious assertions are that the U.S. Supreme Court invalidated Marconi's fundamental patent and ruled Tesla invented radio.

In fact, the patent that the U.S. Supreme Court invalidated was Marconi's tuning patent U.S. 763,772 with a filing date of November 10, 1900—not Marconi's fundamental patent for discovering Hertzian telegraphy. Marconi's fundamental patent for communicating intelligence by Hertzian waves was never invalidated. The U.S. Supreme Court found that Marconi's original and fundamental U.S. patent was 586,193, which was filed on December 2, 1896:

*"Four years before [filing his tuning patent in question], Marconi had applied for his original and basic patent [filing on December 2, 1896], which was granted as No. 586,193, July 13, 1897 and reissued June 4, 1901 as reissue No. 11,913."*¹²²

*Marconi's reputation as the man who first achieved successful radio transmission rests on his original patent, which became reissue No. 11,913, and which is not here in question."*¹²³

Marconi's fundamental patent was not at issue before the Supreme Court because the U.S. Court of Claims, from which the case was appealed to the Supreme Court, had declared Marconi's fundamental patent to be valid. Specifically, the Court of Claims found:

"No prior patent of publication discloses the combination of the claim in suit. The invention of the Marconi

*reissue patent made possible new results by permitting the use of the Morse code for signalling with **Hertz waves**, and permitted signalling with Hertz waves to **greater distances** than was previously possible."*¹²⁴

This statement by the U.S. Court of Claims dispels Teslaphile claims that Marconi's patent did not describe anything new and that it did not transmit signals to significant distances. Indeed, Marconi was able to transmit to a distance of nine miles in 1897 with an antenna height of only 150 feet, while William Preece, who held the distance record for the longest non-Hertzian wireless method of communication, transmitted messages to a distance of only 3.3 miles—and with very long wires. Using his original equipment, Marconi had established Marconi's law, an empirical prediction that the distance transmitted was proportional to the square of the antenna height, which meant that Marconi could reach a distance of 36 miles with the same equipment using a 250 foot antenna. That distance would have been sufficient to bridge the English Channel, as well as most of the islands around England—and sufficient to make Hertzian telegraphy a commercial enterprise.

Many Teslaphiles also maintain that the Supreme Court declared Tesla discovered radio. The issue of who discovered or invented radio was never before any U.S. court, and in particular, not before the Court of Claims or the U.S. Supreme Court in the case cited. Article III, Para. 1-2 of the U.S. Constitution, known as the "Cases and Controversies

Clause,” specifically limits the authority of U.S. courts to cases and controversies before the court, and it prohibits both rulings *and opinions* on controversies not before the court. Since the issue of who invented radio was never before the Court of Claims or the Supreme Court, the U.S. Constitution specifically prohibited them from issuing an opinion on who invented radio.

Not only did the Supreme Court *not* claim that Tesla invented radio, they also did not cite any Tesla patents as the basis for invalidating Marconi's tuning patent, U.S. 763,772. In its findings, which were numbered 1 through 13 in the Syllabus, the Supreme Court invalidated Marconi's tuning patent on the basis that Marconi's claims had been anticipated by one or more the following four patents: Lodge's U.S. patent 609,154, Stone's U.S. patent 714,756, Pupin's U.S. patent 640,516, and Fessenden's U.S. patent 706,735. Neither Tesla nor any of his patents were mentioned in any of the findings, all of which were listed in the Syllabus.

The final Teslaphile objection to Marconi's patent was that it soon became obsolete. Indeed, the Court of Claims found: “The subject-matter of the reissue patent [Marconi's fundamental patent] was extensively used until displaced by later improvements.” Ironically, it was because Marconi's single-circuit design was so successful that it caused interference to the point that the sharper tuning was required by the Radio Act of 1912. The truth is that the inventive ideas described in most valuable patents are displaced or replaced by later

improvements, but that does not invalidate or diminish the original invention or patent. Even the two-circuit designs in transmitters that replaced Marconi's single-circuit design soon became obsolete themselves when spark transmitters were banned in the early 1920s and vacuum tube oscillators replaced spark dischargers.

It is clear that both the U.S. Court of Claims and the U.S. Supreme Court found that Marconi's contributions to radio between mid-1896 and mid-1897 were original and valuable. Teslaphile attempts to marginalize them are nothing more than canards that have no merit.

Tesla's Wireless Accomplishments prior to May 13, 1897: Documents that can be used to support claims on behalf of Tesla for discovering radio have been limited in time using the same rules that were adopted in patent infringement and interference cases by the courts—namely, to those documents that were *published* before the fact (e.g., date of alleged discoveries). Undated documents that were prepared but not published before the fact, such as laboratory notes, were also allowed into evidence for consideration, but only when the author was available to attest to the date of preparation and validity of the documents—and under oath, subject to cross-examination. Documents that were prepared after the fact, as a rule, were never allowed. Thus, the focus of this study has been on Tesla documents published before May 13, 1897, the date that Marconi demonstrated to a wide audience that he could communicate intelligence to a distance of nine miles

with the Hertzian telegraphy system he defined in his 1896 patent.

After searching through all relevant documents for Tesla's contributions to wireless telegraphy prior to May 13, 1896, it turns out that the only document published before that date in which Tesla described an approach to wireless communication of intelligence was in his 1893 lecture to the Franklin Institute and the National Electric Light Association, which was chronicled in the *Journal of the Franklin Institute* published in July 1893.

Tesla's Did Not Describe a Complete Wireless System in His 1893 Lecture: Virtually all claims of precedence made on behalf of Tesla begin with the assertion that Tesla described a complete wireless system in his 1893 lecture at the Franklin Institute and the National Electric Light Association. Many Teslaphiles add the dictum that this lecture should be considered the basis of radio engineering. In this lecture, Tesla described a concept for transmitting intelligence or energy to terrestrial distances (worldwide) by disturbing the "electrostatic equilibrium of the earth." He proposed sending currents through (within) the earth at the resonant frequency of the earth, thereby amplifying the signals much as he did in the lighting circuits he demonstrated in his lectures.

Tesla admitted he did not know the resonant frequency of the earth, and without that knowledge, he could not design a proper source. So instead of describing a system for transmitting intelligence, he described an experiment to measure the resonant frequency of the earth using one or more sources to excite

the resonant frequency of the earth. Tesla drew a sketch of the two sources he proposed to use to excite the earth in this experiment. The sketch, which appears as Fig. 21 in Tesla's lecture, is reproduced here as Fig. 31. The primary source S , (which appears on the left of this figure) was to be supplemented by a second source S_I (which appears on the right of this figure) in the event it was needed to obtain a measurable response. Tesla, referring to Fig. 21 from his 1893 lecture, describes these two sources in Fig. 31 as follows:

"Now it is quite certain that at any point within a certain radius of the source S a properly adjusted self-induction and capacity device can be set in action by resonance. But not only can this be done, but another source S_I , Fig. 21, similar to S , or any number of such sources can be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area, or a flow of electricity produced to or from the source S_I if the same be of opposite phase to the source S ."

Many Teslaphiles now claim that the source S_I was actually a receiver, and therefore this sketch constitutes a complete system. In fact, Tesla never described a receiver, receiving antenna, or a detector in his entire 1893 lecture. So what is the basis for this claim by Teslaphiles? The truth is that Tesla himself morphed this figure over time, most notably by transforming the source S_I on the right into a receiver in several steps. The first step occurred in Tesla's



FIG. 21.— Energy transmission to any distance

**“...another source S_1 , Fig. 21, similar to S
or any number of sources can be set to
work in synchronism with the latter...”**

—— Tesla's 1893 lecture

Fig. 31. Tesla described these two sources, S on the left and S_1 on the right, in his 1893 configuration for transmitting signals to excite the earth's resonant frequency. Compare this figure with the morphed figure he published in 1919 (see Fig. 32), in which he claimed he had described a complete system of wireless telegraphy in his 1893 lecture with a transmitter on the left and a receiver on the right. (*J. Franklin Institute*, Vol. 136, No. 1, July 1893, p. 270)

publication “Increasing Human Energy,” published in 1890, when he first referred to the structure P_1S_1E as a receiver (see previous Fig. 29). Apparently Tesla did not get any pushback on this substitution, so he continued with his morphing until 1919 when he completed the metamorphosis by producing his Fig. 8 (reproduced here as Fig. 32), which appeared in “The True Wireless,” an article he published in the May 1919 issue of *Electrical Experimenter*. Tesla states in his caption that this very figure appeared in his 1893 lecture: “Tesla's System of Wireless Telegraphy through the earth as Actually Exposed in His Lectures Before the Franklin Institute and the National

Electric Light Association in February and March, 1893.”

Tesla unabashedly claimed the antenna on the right is a receiver—but not just any receiver—a receiver with a “resonant adjustable receiving circuit.” This figure clearly conflicts with the image and language of his 1893 lecture. The figure in Tesla's “True Wireless” is a total fabrication, but Teslaphiles ignore this fact and continue to cite this figure as evidence that Tesla described a complete system in his 1893 lecture. It should be noted that his “receiver” does not even have detector, or receiving device. In Tesla's 1919 “True Wireless” article, Tesla admitted that he did not

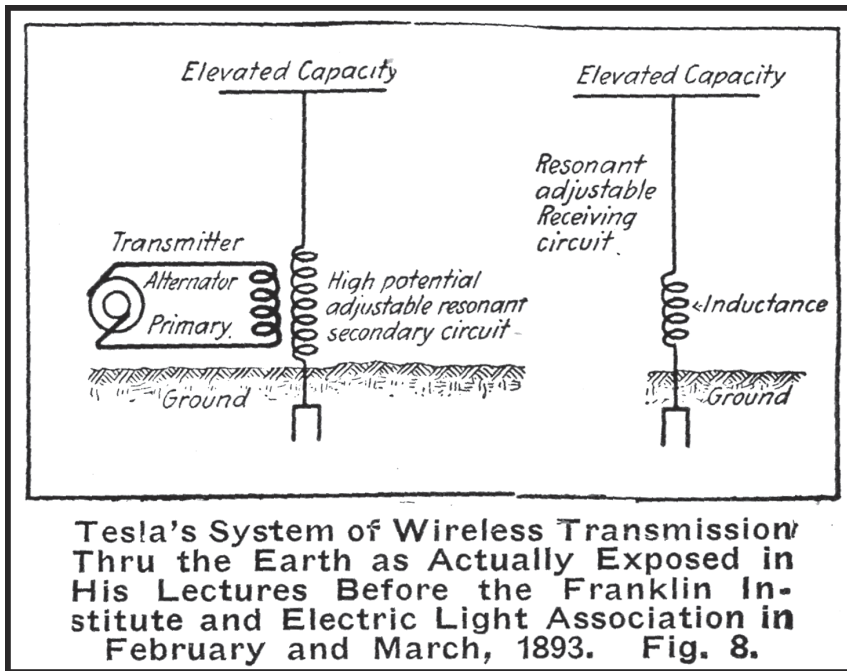


Fig. 32. Tesla published this morphed figure in 1919, claiming it was the one he “actually exposed” in his 1893 lecture, when in fact the figure he “actually exposed” in 1893 was the one reproduced in Fig. 31. (Tesla, *Electrical Experimenter*, Vol. 7, May 1919, p. 29)

mention a receiving device in his 1893 lecture:

“A specific form of receiving device was not mentioned, but I had in mind to transform the received currents and thus make their volume and tension suitable for any purpose.”

This is no small omission because Tesla would have required a nonlinear detector of some sort to receive and demodulate high-frequency emissions generated by his disruptive discharge oscillator if it were to be used for transmitting intelligence. Tesla’s description of a receiving device in 1919 is so

general as to be useless. This description covers every receiver that was invented or ever will be invented—and for any application. Without describing the basic elements of a receiver for a wireless communication system in his 1893 lecture—including the receiving antenna and receiving device, Tesla does not and cannot have precedence for inventing radio based on that lecture. Tesla’s deception in claiming that he described a receiver in his 1893 lecture is the “smoking gun” in the canard that Tesla has precedence in discovering radio.

One can only speculate as to why Tesla chose to morph his 1893 lecture. It is clear that as time passed following

his highly successful 1893 lectures, Tesla fell behind in the race for wireless telegraphy, and he chose to morph his 1893 lecture, beginning in 1900, in an attempt to establish precedence in the discovery of wireless telegraphy. Teslaphiles have picked up Tesla's gauntlet by asserting that he did have a receiver in his 1893 lecture, which made it appear that he had, in fact, described a complete system of wireless telegraphy as early as 1893—when in fact he did not. Tesla cannot claim precedence in the discovery of radio without describing both a transmitter and a receiver.

More Canards

The only description of a wireless telegraphy system that Tesla documented prior to May 13, 1897, was in his 1893 lecture. It is clear that Tesla did not describe a complete system of telegraphy in his 1893 lecture, and that finding alone is sufficient to make the case that Tesla does not have precedence in the discovery of radio. However, there are false claims still circulating today that the *source* Tesla described in his 1893 lectures was later used in radio—which, of course, is not sufficient to accord Tesla precedence in the discovery of radio, but it does suggest or imply that Tesla discovered the transmitter circuit or circuits used in Hertzian telegraphy before Marconi. This claim is a canard as well.

Canard: Tesla's High-Frequency Source Described in His 1893 Lecture Was Later Used in Radio

The Tesla oscillator as it was constituted and described at the time of Tesla's lecture

in 1893 was totally unsuitable for Hertzian telegraphy and was never used for communicating intelligence by radio. In 1893, the two circuits in Tesla's high-frequency oscillator were not tuned to the same frequency, nor were they loosely coupled. Without two-circuit tuning *and* loose coupling, Tesla's untuned high-frequency oscillator would have radiated two separate frequencies—the resonant frequency of the antenna circuit and the resonant frequency of the primary circuit with the spark source. Without loose coupling, Tesla's secondary circuit would have radiated two short (i.e., broadband) signals centered around two different resonant frequencies. While Marconi's source also radiated a broadband signal, it was centered around only one frequency—the natural resonant frequency of his antenna. Tesla's disruptive discharge source as constituted in 1893 could have produced more interference than Marconi's single-circuit source—not less. Tesla's oscillator was suitable for generating high voltages and high frequencies for lighting purposes—but it was not suitable for producing the sharp tuning that was required by the 1912 Radio Act to minimize interference between multiple transmitters.

The time evolution of Tesla's disruptive discharge oscillator development is summarized in Table 4. Tesla did not recognize the value of tuning circuits until 1896, and even then, he applied his oscillator with two-circuit tuning only to lighting circuits. It was not until September 2, 1897, that he proposed to use his oscillator with two-circuit tuning for wireless applications, but even then, he did not recognize the principle

Table 4. Tesla's High-Frequency Oscillator Evolution and Application

First Disclosure	Application	Date of 1 st Disclosure	Documentation
Two coupled circuits	Lighting	Feb. 4, 1891	Tesla Patent U.S. 462,418
Two coupled circuits tuned to the same frequency	Lighting	June 6, 1896	Tesla Patent U.S. 568,178
Two coupled circuits tuned to the same frequency	Wireless Transmission	Sept. 2, 1897	Tesla Patent U.S. 645,576
Two loosely coupled circuits tuned to the same frequency	Wireless Transmission	May 16, 1900	Tesla Patent U.S. 787,412

of loose coupling. Loose coupling was not needed for the conduction method of wireless transmission that he described in the application for his first wireless transmission patent, U.S. 645,576, dated September 2, 1897. The first time he described the principle of loose coupling was in his wireless patent application dated May 16, 1900. By that time, John S. Stone had already described the requirement for loose coupling to achieve sharp tuning needed in radiotelegraphy in his application for U.S. patent 714,756 dated February 8, 1900, and he had also documented the loose coupling principle in two letters to Joseph B. Baker dated June 30, 1899, and July 18, 1899—almost a year before Tesla's disclosure in his patent application.

To summarize, Tesla's 1893–1899 versions of his high-frequency disruptive discharge oscillator source were never used in radiotelegraphy. Sharp tuning in spark telegraphy sources was obtained only with two tuned circuits *in conjunction with loose coupling*. Tesla did not disclose the concept of loose coupling for wireless telegraphy until he filed his patent application dated May 16, 1900—well after John S. Stone

made his disclosures of the importance of loose coupling for sharp tuning in radiotelegraphy.

Canard: Tesla's Continuous Wave Source was Later Used in Radio

Many Teslaphiles claim that Tesla was the first one to propose using a continuous wave source for wireless telegraphy in his 1893 lecture. Tesla said that if the resonant frequency of the earth was low, “an alternating dynamo machine might serve for the purpose of the experiment. I would then transform current to a potential as high as it would be found possible and connect the ends of the high tension secondary to the ground and to the insulated body.” Since the earth's resonant frequency was 7.8 Hz, which is indeed low, Tesla proposed to use a dynamo machine for the wireless system he had in mind in 1893. For short monopole antennas, electrostatic fields dominate the electromagnetic fields out to a distance of $\lambda/2\pi$, which for 7.8 Hz amounts to a distance of 6120 km. The radiation efficiency of a monopole antenna (power radiated divided by power applied) with a height on the order of, say a kilometer,

and a source frequency of 7.8 Hz is vanishingly small: 2.7×10^{-9} .

It is clear that Tesla's configuration using a source frequency of 7.8 Hz and a monopole antenna of any practical height was not capable of radiating measurable electromagnetic energy. Tesla's method is actually a quasistatic electrical-field induction method, just like Edison's electric-field induction method proposed in his application for U.S. patent 465,971 dated May 3, 1885. In fact, Tesla's source configuration is virtually identical to Edison's source configuration (compare Figs. 24 and 27). The main difference was that Edison had a telegraph key that he used to modulate the power applied to the raised surface, whereas Tesla did not consider a means of modulation. Also, Edison used a DC source with a breaker operating at a frequency on the order of 1–5 kHz, whereas Tesla proposed a dynamo/alternator operating at the earth's resonant frequency of 7.8 Hz.

Do not be fooled into thinking that Tesla's CW source was any different than Edison's breaker circuit. In order to transmit intelligence, Tesla would have had to modulate the sine wave using some type of breaker, thereby introducing higher frequencies comparable to Edison's approach. Also, since Tesla's alternator output and frequency are both proportional to the rotation speed of the dynamo, the power output of Tesla's dynamo at 7.8 Hz would have been nil, and the only high power source available to Tesla in 1893 would have been a DC source in conjunction with a current breaker similar to the rheotome used by Edison. The takeaway here is that Tesla's approach was not new. It was

no different from Edison's approach—and both were a method of electric-field induction, not Hertzian radiation.

The second problem with Tesla's approach using the resonant frequency of the earth is that bandwidth of the resonance is too narrow for carrying Morse code, which required about 50–70 Hz bandwidth, and far too narrow for transmitting voice and music, which requires at least 3–5 kHz bandwidth. The bandwidth of the earth's primary resonance is equal to the resonant frequency (7.8 Hz) divided by the Q of the resonance (~5), or about 1.6 Hz. In Project ELF, the U.S. Navy found that it was not possible to communicate intelligence or even select among prerecorded messages using a monopole antenna and ELF frequencies. The Navy did find that using a frequency of 76 Hz and several very long horizontal antennas grounded at either end, they could select among prerecorded messages, but because of the low data rates, they could not convey intelligence in the form of new messages.

Tesla's approach using 7.8 Hz and a monopole antenna would have required orders of magnitude more source energy than Project ELF, which required multiple sources of a few megawatts. Also the earth's resonant frequency is one of the worst possible frequencies because of the noise produced by lightning, which excites the earth's resonances. In fact, it would have been impossible for Tesla to detect any signals from his CW source at 7.8 Hz, much less an amplitude modulated signal, which would have introduced higher frequencies outside the bandwidth of the earth's resonance.

Concluding Remarks

Throughout Tesla's entire life, he believed that communication of intelligence to long distances was accomplished by currents flowing through the earth, and that Hertzian radiation into the earth-ionosphere cavity was a waste of energy. To that end, he proposed wireless methods that used monopole antennas in conjunction with low-frequency sources (just above the audio frequency range), which in fact did minimize Hertzian radiation. This is just opposite of the fundamental principle of radio engineering, which is to use frequencies at or near the natural resonant frequency of the antenna wherever possible to maximize Hertzian radiation efficiency.

As wireless communication systems using the method of Hertzian radiation became successful, Tesla's theories were increasingly rejected by radio engineers. Nevertheless, Tesla maintained that the underlying theory of Hertzian telegraphy was incorrect. He maintained that the method of communicating intelligence using Hertzian waves did not actually use Hertzian waves; instead, Tesla claimed that the "Hertzian method" actually communicated by using earth currents as a means of conveying intelligence from transmitter to receiver, and radiated Hertzian waves were just a waste of energy. Here is what Tesla said in his 1919 paper, "The True Wireless":

"The Hertz wave theory of wireless transmission may be kept up for a while, but I do not hesitate to say that in a short time it will be recognized as one of the most remarkable and inexplicable aberrations

of the scientific mind which has ever been recorded in history." — Nikola Tesla, *Electrical Experimenter*, May 1919, p. 87.

One only has to look around the world today to see that earth currents do not convey information by flowing from the transmitter to the receiver. The following types of radio receivers do not require a ground connection of any kind: cell phones, hand-held, two-way radios, battery operated AM-FM radios, car radios, radios on airplanes, radios on spacecraft, etc. While they do not require grounds, they all require antennas. The only role of ground currents in radio transmission and reception is to increase the efficiency of monopole antennas by extending the effective height. This is accomplished by ground currents that flow only in the vicinity of the antenna itself—not to great distances. Ground currents are not needed at all when using dipole antennas.

It should be noted that Tesla never built and successfully tested any of the wireless communication systems that he described in his lectures or patents, and there are no documents that confirm or prove that he sent and received a wireless message using Hertzian waves to any distance in his entire life, much less in the time frame prior to Marconi's demonstrations that culminated in transmitting and receiving messages at a distance of nine miles across the Bristol Channel on May 13, 1897. It truly can be said that Tesla did not believe in communicating intelligence with Hertzian radiation, that is to say radio, and he does not have precedence in discovering radio.

Endnotes

The following documents are referenced often, and the following abbreviated notation in bold print below will be used for each respective reference:

Tesla lecture (1891): Nikola Tesla, "Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination," *Trans. AIEE*, Vol. 8, May 20, 1891. Lecture delivered before the AIAA at Columbia College, New York City on May 20, 1891.

Tesla lecture (1892): Nikola Tesla, "Experiments with Alternate Currents of High Potential and High Frequency," *J. of the IEE*, Vol. 21, No. 97, 1892. Lecture delivered to the IEE at the Royal Institution on Feb. 3, 1892.

Tesla lecture (1893): Nikola Tesla, "On Light and Other High Frequency Phenomena," *J. Franklin Institute*, Vol. 136, No. 1, July 1893. Lecture delivered before the Franklin Institute at Philadelphia on Feb. 24, 1893, and the National Electric Light Association at St. Louis on March 1, 1893.

Supreme Court Opinion: *United States Reports* Vol. 320, "Cases Adjudged in the Supreme Court of the United States at October Term, 1944, Marconi Wireless Telegraphy Company of America v. United States," Decided June 21, 1943, pp. 1–80; see <https://babel.hathitrust.org/cgi/pt?id=uc1.b3692172;view=lup;seq=73>. In legal circles, this reference is often expressed as "320 U.S. 1."

Court of Claims Opinion: *Cases Decided in the U.S. Court of Claims of the United States, March 5, 1935 to December 1, 1935*,

reported by C. F. Kincheloe, Vol. 81, 1938. "Marconi Wireless Telegraphy Company of America v. the United States, Decided Dec. 4, 1935, pp. 671–785; see: <https://babel.hathitrust.org/cgi/pt?id=mdp.39015074203467;view=lup;seq=701>

1. Tesla lecture (1893).
2. "New Tesla Wireless System," *Electrical World*, Vol. 54, Dec. 2, 1909, p. 1335.
3. For example see: Jim Glenn, ed., *The Complete Patents of Nikola Tesla*, (Barnes & Noble Books, 1994) p. 305.
4. W. H. Preece, "Signalling Through Space Without Wires," *The Electrician* (London), Vol. 39, June 11, 1897, pp. 216–218.
5. Sivlanus P. Thompson, "Telegraphing Across Space," *J. Soc. of Arts*, Vol. 46, Apr. 1, 1898, pp. 453–460.
6. Citation to Tesla's boat patent 613, 809 filed on July 1, 1898. Tesla states: "I accomplish, nevertheless, similar results and in a much more practicable manner by producing waves, impulses, or radiations which are received through the earth, water, or atmosphere by suitable apparatus on the moving body and cause the desired actions so long as the body remains within the active region or effective range of such currents, waves, impulses, or radiations." He then describes four methods: 1) electro-magnetic (magnetic field) induction, p. 1, lines 90–95; 2) electric field induction, p. 2, lines 12–30; 3) conductions currents through the ground, p. 2, lines 30–40; and 4) electromagnetic radiation: "electrical oscillations which do not follow any particular conducting-path but propagate in straight lines through space," p. 2, lines 55–63.
7. A. T. Story, *The Story of Wireless Telegraphy*, (D. Appleton and Company, New York, 1904) pp. 20–21.
8. Alfred Vail, "The American Electro Magnetic Telegraph: with the Reports of Congress, and a Description of All Telegraphs Known, Employing Electricity or Galvanism," (Lea and Blanchard, Philadelphia, 1845) pp. 60–66; "Mode of Crossing Broad Rivers or Other Bodies of Water Without Wires," *Electrical World*, Vol. 25, No. 26, June 29, 1895.
9. A rather complete story of James Bowman and his telegraphic experiments and patent are

- covered in a book by A. H. Millard published in 1925, which contains a foreword written by Guglielmo Marconi: A. H. Millard, *James Bowman Lindsay and other Pioneers of Invention*, (M.C. Macleod, Dundee, 1925); The salient points of his telegraphic system are also described by John Fahie: J. J. Fahie, *A History of Wireless Telegraphy Including Some Bare-Wire Proposals for Subaqueous Telegraphs*, (Dodd, Mead and Co., Edinburgh and London, 1902, 3rd edition) pp. 13–32.
10. See for example: Thomas Olin Morgan, "The Contribution of Nathan B. Stubblefield to the Invention of Wireless Voice Communication," Dissertation submitted to Department of Communication, Florida State University, 1971; James P. Rybak, "'Forgotten' Pioneers of Wireless," Part I—Nathan Stubblefield, *The Old Timers Bulletin* (now the *AWA Journal*), May 1997, pp. 32–34.
 11. While Loomis was not the first to file a patent for obtaining electricity from the atmosphere for telegraphic purposes, he documented his approach eight years before the date of his patent in a sketch dated July 21, 1864, which is in the Mahlon Loomis Collection at the Library of Congress.
 12. Eric P. Wenaas, "Did Mahlon Loomis Really Invent Radio," *AWA Review*, Vol. 31, 2018, pp. 211–258.
 13. F. Dyer, T. Martin, and W. Meadowcroft, *Edison His Life and Inventions*, Vol. II, (Harper & Bros, New York, 1929) p. 578.
 14. W. J. White, *Wireless Telegraphy and Telephony*, (Whittaker & Co. London, 1912) p. 76.
 15. Ibid.
 16. C. C. F. Monckton, *Radio-Telegraphy*, (D. Van Nostrand Co., New York, 1908) p. viii: "The conference of 1906 not only regulated the service; it fixed the name of the new method of intercommunication, which previously had been called 'Wireless Telegraphy' in England and 'Spark Telegraphy' in Germany. It had been proposed to call it 'Hertz Telegraphy' (after the discoverer), but it has now been definitely named 'Radio-telegraphy;' and the message received is to be called a 'Radio-telegram,' a word which before long will probably be shortened to 'Radiogram.' " Soon there were two major subdivisions of radio communication—radio telegraphy for communication by Morse code and radiotelephony for communication by voice, music, and sound effects.
 17. The publication *Annual Reports of the Navy Department* for the year 1912 (published by the Government Printing Office in 1913) was the first such annual report to use the term radio. Previous editions used the term "wireless."
 18. Sidney Gernsback, *S. Gernsback's Radio Encyclopedia*, (Vintage Press, 1927) p. 130.
 19. N. Hawkins, *Hawkins' Electrical Dictionary*, (Theodore Audel & Co. London, 1910, 1915, 1925) p. 355; Sidney Gernsback, *S. Gernsback's Radio Encyclopedia* (S. Gernsback Publishers, New York, 2nd ed. 1931) p. 217; C. F. Tweney and L. E. C. Hughes, ed., *Chambers's Technical Dictionary*, (Macmillan Co., New York, 1948) p. 698.
 20. *Webster's New World College Dictionary*, (Houghton Mifflin Harcourt, New York, 2016 5th ed.).
 21. "Project Sanguine revisited: Why the US Navy once wanted to turn Wisconsin into the world's largest antenna," *Defense News*, April 11, 2015; <http://osnetdaily.com/2015/04/why-the-us-navy-once-wanted-to-turn-wisconsin-into-the-worlds-largest-antenna/>.
 22. Leland Anderson, "Priority in the Invention of Radio, Tesla vs. Marconi," *AWA Monograph*, No. 4 (New Series), March 1980; reset and reprinted October 1983.
 23. Supreme Court Opinion, known in legal circles as 320 U.S. 1.
 24. Ibid., p. 3.
 25. Leland Anderson, Ed., "Nikola Tesla on His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power," (Twenty First Century Books, Denver, 1992) p. 105.
 26. Most spark sources were banned circa 1923, with the notable exception of legacy systems used by the government and military transmitters, which were banned circa WWII.
 27. J. Zenneck, *Wireless Telegraphy*, (McGraw Hill, New York, 1915) p. 96.
 28. Rupert Stanley, *Text Book on Wireless Telegraphy*, Vol. 1, (Longmans, Green & Co., London, 1919) pp. 149–150.
 29. J. Zenneck, pp. 93, 182, 208. The quenched spark gap actually consisted of a series of short disk-like gaps such that each gap had a much smaller breakdown voltage than one or two large gaps. The desired breakdown voltage was adjusted by choosing the number of gaps, and the degree of loose coupling was adjusted to cause the spark to extinguish at the end of the first half cycle.

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30. Supreme Court Opinion, p. 34. The Supreme Court found that Stone had disclosed loose coupling in his patent dated February 8, 1900, and also in two letters to his friend Joseph Baker dated June 30, 1899, and July 18, 1899, both of which were included as exhibits produced during the litigation at the U.S. Court of Claims (see Court of Claims Opinion, p. 11).
31. Many historians and scientists cite the date June 2, 1896, the date on Marconi's "Provisional Specification" for his British patent No. 12,039, as the priority date for his discovery. However, the provisional specification did not contain the complete description that appeared in filing of the "Complete Specification," which has a filing date of March 2, 1897. The later date of December 7, 1896, is used here because it is the date of his U.S. patent filing, which did contain the complete specification of his system.
32. W. H. Preece, *The Electrician* (London), 1897, pp. 216–218.
33. A. Slaby, "The New Telegraphy," *The Century*, Vol. 55, No. 6, April, 1898, pp. 867–874.
34. Anderson, AWA Monograph, 1980, p. 1.
35. Supreme Court Opinion, p. 1.
36. These two statements are not interpreted here as having a bearing on the issue of priority of invention—they show that the Supreme Court stated that Marconi's U.S. patent 586,193 dated July 13, 1897, and reissued as U.S. patent 11,913, was his *fundamental* patent, not his later *tuning* patent 763,772.
37. William R. Casto, "The Early Supreme Court Justices' Most Significant Opinion," *29 Ohio Northern Law Review*, (2002) pp. 173–207; <https://www.yumpu.com/en/document/read/19301857/the-early-supreme-court-justices-most-significant-opinion>.
38. *Ibid.*, p. 203.
39. Supreme Court Opinion, p. 16.
40. Supreme Court Opinion, pp. 1–3. The Syllabus in a Supreme Court ruling lists the findings of the Court in short form, in this case with 13 numbered findings. Each numbered finding ends with a page number where the finding is discussed.
41. Supreme Court Opinion, p. 1.
42. Supreme Court Opinion, p. 2.
43. W. E. Brand, "Reading the Supreme Court: Tesla's Invention of Radio," *Antenna Magazine*, Vol. 11, No. 2, May 1999.
44. Court of Claims Opinion, p. 744.
45. *Ibid.*, p. 746.
46. *Ibid.*, p. 751.
47. *Ibid.*, p. 687.
48. R. D. Bangay, *Elementary Principles of Wireless Telegraphy, Part I*, (Wireless Press Ltd., London, 1917) p. 89.
49. J. J. Fahie, p. 1899.
50. G. Marconi, "Wireless Telegraphy," *J. IEE*, Vol. 28, March 2, 1899, pp. 273–297; Cleveland Moffett, "Signor Marconi and Wireless Telegraphy," *Windsor Magazine*, Vol. 10, June 1899, pp. 141–152; G. Marconi, "Wireless Telegraphy," Notices of the Proc. at Meetings of the Royal Institution of G.B., Vol. 16, 1899–1901, pp. 247–256; speech delivered on Feb. 2, 1900; G. Marconi, "Syntonic Wireless telegraphy," *J. Soc. Arts*, vol. 49, May 17, 1901, pp. 506–517; J. A. Fleming, "The Principles of Electric Wave Telegraphy and Telephony," (Longmans, Green & Co., London, 1910, 2nd ed.) Chapter VII, "The Evolution of Electric Wave Telegraphy."
51. *Ibid.*, J. A. Fleming, 1910, p. 717.
52. Court of Claims Opinion, p. 744.
53. Supreme Court Opinion, p. 4.
54. Supreme Court Opinion, p. 68.
55. *The Tesla Collection* is claimed to be "the most comprehensive compilation of newspaper and periodical material ever assembled by or about Nikola Tesla. The Collection begins on August 14, 1886 and continues through December 11, 1920. See "<http://www.teslcollection.com/>."
56. For example, many arguments in favor of Tesla's precedence appear in the writings of Leyland Anderson, a long-time proponent of Tesla's priority. Many of these sources are identified on the Twentieth Century Books website; <http://www.tfcbooks.com/mainpage/links.htm>.
57. Leland Anderson, Ed., "*Nikola Tesla on His Work With Alternating Currents and Their Application to Wireless Telegraphy, Telephony, and Transmission of Power*," (Twenty First Century Books, Denver, 1992).
58. Tesla lecture (1891), pp. 267–319.
59. Laurence A. Hawkins, "Nikola Tesla, His Work and Unfulfilled Promises," *Electrical Age*, Vol. 30, Feb. 1903, p. 103.
60. Tesla lecture (1891), p. 274.
61. Mr. Tesla's Experiments on Alternating Currents of Great Frequency, *Sci. Amer.*, Mar. 20, 1892, p. 195.
62. Leland I. Anderson, Editor, *Nikola Tesla on His Work with Alternating Currents and their application to Wireless Telegraphy and Transmission of Power*, (Twenty First Century Books, Breckenridge, Colorado, 2002) p. 6.

63. Tesla lecture (1891), p. 126.
64. Sir W. Snow Harris, F.R.S., *Rudimentary Electricity*, (John Weal, London, 1854) p. 150.
65. "Notes," *Electrician*, Vol. 31, June 9, 1893, p. 139: "Mr. Nikola Tesla's lecture...before the Franklin Institute...is a disappointment. If a few quantitative determinations of current, voltage, or even frequency, had been given in the lecture it would have had a definite scientific value. To reduce even one out of the 50 experiments to a complete research would be worth all the other 49 brilliant and suggestive demonstrations."
66. Tesla lecture (1891), pp. 310–311.
67. *Ibid.*, p. 297.
68. *Ibid.*, p. 309.
69. *Ibid.*, p. 313.
70. Tesla lecture (1892), p. 56.
71. Tesla lecture (1893), p. 93.
72. Tesla lecture (1892), p. 66.
73. "Mr. Tesla's Experiments of Alternating Currents of Great Frequency," *Scientific American*, Vol. 66, Mar. 26, 1892, p. 195.
74. Tesla lecture (1892), p. 74.
75. *Ibid.*, p. 95.
76. Tesla lecture (1892), p. 95.
77. S. R. Winters, "The Story of Mahlon Loomis, Pioneer of Radio," *Radio News*, Vol. 4, No. 5, Nov. 1922, pp. 836–7, 966–982. The cited phrase appears in a hand-written article dated Jan. 7, 1892, which was signed by Mahlon Loomis. The citation appears on page 974 of the *Radio News* article.
78. *Ibid.*
79. Tesla lecture (1892), p. 162.
80. *Ibid.*
81. *Ibid.*, p. 95.
82. Michael Faraday, "Experimental Researches in Electricity," *Phil. Trans. Royal Society*, London, Part I, Feb. 8, 1838, p. 113.
83. Harris, 1854, p. 150.
84. Tesla lecture (1892), p. 84.
85. *Ibid.*, p. 86.
86. *Ibid.*, p. 85.
87. *Ibid.*, p. 87.
88. *Ibid.*, 89–90.
89. *Ibid.*, p. 88.
90. *Ibid.*
91. *Ibid.*, p. 89.
92. Nikola Tesla, "The True Wireless," *Electrical Experimenter*, "This is undoubtedly the most delicate wireless detector known, but for a long time it was hard to produce and to maintain in that sensitive state. These difficulties do not exist now and I am looking to valuable applications of this device, particularly in connection with the high-speed photographic method, which I suggested, in wireless, as well as in wire, transmission."
93. Tesla filed another five patents on *circuit controllers* for his oscillators between June 3, 1897, and April 19, 1898; these circuit controllers do not describe oscillator *circuits* and are not relevant to the issues involved here.
94. Supreme Court Opinion, footnote, p. 20.
95. *Ibid.*, footnote, p. 21.
96. *Ibid.*, p. 33.
97. George H. Clark, *The Life of John Stone Stone*, (Frye & Smith, Ltd., 1947) p. 59. An excerpt from the book: "Going back for a moment to the Stone-Baker letters, the first letter clearly outlines the basic feature of the invention, which was 'four-circuit tuning,' that is, at the transmitter, two circuits tuned to each other, one the primary or power circuit, the other the antenna or radiating circuit; at the receiver, likewise two circuits tuned to each other, one the antenna or pick-up circuit, the other the secondary or detector circuit. Finally, both transmitter and receiver were of the same tune, or frequency-adjustment, as of course they had to be if they were to work with each other. But there was more to it than this; if perfect tuning were to be had, that is, if the transmitter were to send out its own specific frequency and that alone, and if the receiver were adapted to receive that specific frequency and it alone, there had to be at both ends of the wireless circuit a loose coupling between the two circuits at each such end, so that there would be no reaction on the exciting circuit by the circuit excited. Such reaction would have resulted in a broad tuning; an emanation of several rather than one frequency at the sending end, a picking-up of more than one frequency at the receiving end. Thus the full designation of the patent's intent was 'selective four-circuit tuning.'" See: <https://babel.hathitrust.org/cgi/pt?id=mdp.39015063598414;view=1up;seq=7>.
98. Note that in 1919, Tesla confirmed that this configuration was the one he used in his 1893 lecture, but he erroneously claimed the secondary circuit is an adjustable tuned circuit. In fact, there is no mention of a tunable circuit anywhere in his 1893 lecture: N. Tesla, "The True Wireless" *Electrical Experimenter*, Vol. 7, No. 1, May 1919, p. 29, Fig. 8.
99. A. P. Nickolaenko and M. Hayakawa, *Resonances*

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- in the Earth-Ionosphere Cavity*, (Kluwer Academic Publishers, Dordrecht/Boston/London, 2002) p. 25.
100. *Ibid.*, p. 4.
 101. Nikola Tesla, "The Transmission of Electric Energy without Wires," *Electrical World and Engineer*, Vol. 43, No. 10, March 5, 1904, p. 429.
 102. Nikola Tesla letter dated June 30, 1905 to the *New York World*, July 2, 1905.
 103. Colin Price, "ELF Electromagnetic Waves from Lightning: The Schumann Resonances, *Atmosphere*," Vol. 7, 1916, p. 3. https://www.researchgate.net/publication/308181528_ELF_Electromagnetic_Waves_from_Lightning_The_Schumann_Resonances.
 104. Riki Morikawa, *Fundamentals of Telecommunications and Networking for IT*, (Kendall Hunt Publishing, 2018); see: http://mason.gmu.edu/~rmorika2/Noise__Data_Rate_and_Frequency_Bandwidth.htm.
 105. *Ibid.* p. 6.
 106. A. J. Bennett and R. G. Harrison, "A Simple Atmospheric Electrical Instrument for Educational Use" *Advances in Geosciences*, Vol. 13, p. 14, Fig. 3.
 107. *Ibid.* p. 4.
 108. Price, p. 7.
 109. T. Ogawa and M. Komatsu, *Analysis of Q Burst Waveforms*, Radio Science, Vol. 42, RS2S18, 2007.
 110. "Project Sanguine Revisited;" see also: Carlos A. Altgelt, The Broadcasters' Desktop Resource, (www.theBDR.net); <https://www.hep.wisc.edu/~prepost/ELF.pdf>.
 111. Carlos A. Altgelt, p. 5.
 112. Price, p. 2. The attenuation of electromagnetic radiation below 100 Hz is less than 0.5 dB per megameter.
 113. "Project Sanguine Revisited," p. 8.
 114. *Ibid.*
 115. R. P. Feynman, *The Feynman Lectures on Physics, Vol. II*, (Addison-Wesley, Menlo Park, 1964) pp. 6-8–6-10.
 116. *Nikola Tesla Colorado Springs Notes: 1899-1900*, (Nolit, Beograd, Yugoslavia, 1978) pp 226–227.
 117. A practical monopole antenna can easily be taller than 0.1 km, but 10 km is too tall to be practical.
 118. $E_0 = E_R \times h/R$, where the electric field E_0 at the earth under a conducting sphere with a radius R located at a distance h above the earth with an electric field E_R at the surface of the sphere. It is assumed that $h \gg R$.
 119. Nikola Tesla, "The Problems of Increasing Human Energy," *The Century Magazine*, Vol. 60, June 1900,
 120. *Ibid.*, p. 206.
 121. *Ibid.*, p. 207.
 122. Supreme Court Opinion, p. 5
 123. *Ibid.*, p. 37.
 124. Court of Claims Opinion, p. 687.

About the Author

Eric P. Wenaas has had a lifelong passion for antique radios beginning with his first Radiola and crystal set given to him as a young man growing up in Chicago by family friends. He experimented with radio devices and repaired radios and televisions as a hobby while in high school, and went on to study electrical engineering at Purdue University, graduating with B.S. and M.S. degrees in Electrical Engineering. He then went to the State University of New York (SUNY) at Buffalo where he earned a Ph.D. degree in Interdisciplinary Studies in the School of Engineering. After graduating, he spent most of his career at Jaycor, a defense company in Southern California—first as an engineer and later as the President and Chief Executive Officer.

Upon his retirement in 2002, he set out to research the early days of wireless and document interesting historical vignettes based on original documents of the era. He has assembled an extensive collection of Radiolas from the 1920s and wrote an award-winning book on the subject. He has also assembled a large collection of French and American crystal sets, and he is now gathering original document collections of well-known inventors and historians that recorded

the history of the wireless and early broadcast era. He has recently become interested in repeating experiments of early wireless pioneers to compare what they could have observed with what they said they observed.



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