Tesla Laboratory Colorado Springs 1899-1900
IEEE Milestone Docket 2025-01

Citation

In 1899, Nikola Tesla built a full scale Magnifying Transmitter and high sensitivity Receiver in Colorado Springs which received stationary waves at long distance and demonstrated high power wireless telegraphy and wireless power transmission based upon his Tesla Coil that he had first described in 1891.

Summary

In 1889, Tesla was introduced to the experiments of Heinrich Hertz and his discovery of electromagnetic waves. Building on Hertz's Ruhmkorff Coil experiment, Tesla modified the circuit, placing a capacitor and spark gap in the primary and driving it with his patented higher frequency AC generator. This created an AC oscillator with frequency determined by capacitance and inductance of primary circuit. This induced an high frequency AC signal in the secondary with higher voltage and lower current than the primary. This was the Tesla Coil. He invented variable capacitors and variable inductors to tune the oscillator to higher frequencies at resonance achieving 30KHz AC.

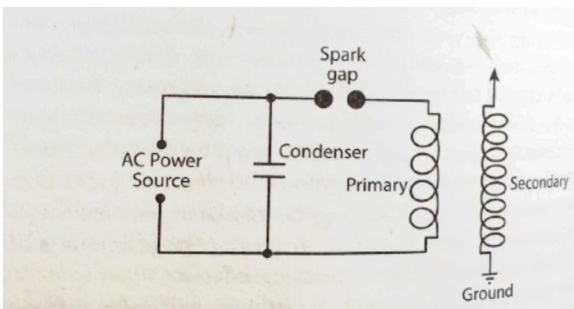


FIGURE 6.2. Diagram of a Tesla coil.

In 1891, he demonstrated this Tesla coil in an AIEE lecture at Columbia College using it's high frequency AC to wirelessly power lighting. Later in 1891, he modified this circuit by grounding the secondary and connected to the top of the secondary to a capacitor mounted on the roof creating an antenna.

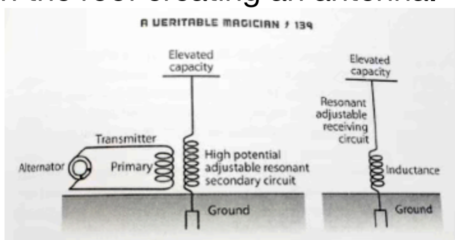


FIGURE 7.3. Diagram showing how Tesla grounded his transmitter and receiver. In his 1916 testimony, Tesla reported that he used arrangements like this as early as 1891. Tesla used a large metal can for the elevated capacity in the transmitter. Redrawn from NT, "The True Wireless," *Electrical Experimenter*, May 1919, 28–30 ff., on p. 29.

By 1893, he transmited energy 1.3 miles from his Liberty Street Lab using his Tesla coil transmitter and a receiver antenna tuned to the same frequency. During the next 6 years, he refined his transmitter and receiver and patented his wireless transmission system.

On May 18, 1899, he arrived in Colorado Springs to build a laboratory which demonstrated that a high sensitivity receiver could receive stationary waves over 100 miles away and demonstrated both wireless telegraphy and wireless power transmission with very high voltage & high power.

Detailed Description

In 1882 while working for the Edison Works in Paris, Nikola Tesla described his idea for a 3 phase AC Induction Motor to Edison employees. No one was interested.

"While Tesla acquired engineering know-how from the Edison organization, he also made his own contribution to the company. Most of the Edison men had learned about electrical machines by working either in the telegraph industry or in machine shops, and few had any formal schooling in science or mathematics. In contrast, Tesla had received a thorough education in physics and mathematics at Graz, and the French manager of SE Edison, R. W. Picou, recognized Tesla's ability to apply theory and make calculations. Shortly after joining the company, Tesla was put to work designing dynamos for incandescent lighting installations and was paid three hundred francs a month."[12]

"While at the Edison works at Ivry, Tesla continued to think about his ideas for a motor. "We were together almost constantly in Paris in the year 1882," Szigeti later testified, and "Mr. Tesla was much excited over the ideas which he then had of operating motors."[13] One evening, he outlined his plans for an AC motor to Szigeti and four or five Edison men by drawing diagrams in the dirt with a stick. Picking up on his insight in Budapest that several alternating currents should be able to produce a rotating magnetic field, Tesla described to his Edison colleagues an elaborate system in which the generator produce three separate alternating currents that were delivered to the motor over six different wires (see Figure 3-3)."

"In his subsequent patents and lectures, Tesla explained that these three alternating currents would have to be out of phase with each other by 120° in order to create a rotating magnetic field, but there is nothing to indicate that he understood in 1882 the significance of having the currents out of phase. "My idea," Tesla explained, "was that the more wires I used the more perfect would be the action of the motor."[14]

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 3 p. 64
[12] NT: Motor Testimony, 187-88, 195, 306
[13] Szigeti, 1889 deposition, A398.
[14] Tesla described his invention to David F. Cunningham, Milton F. Adams, Charles M. Hennis, and James F. Hipple; see NT, Motor Testimony, 189-90, 274-75.

In April 1887, the Tesla Electric Company is formed. Tesla's first laboratory is located at 89 Liberty Street in New York City.

"Intrigued by Tesla's thermomagnetic motor and several other ideas, Peck proposed in the fall of 1886 that he and Brown underwrite Tesla's efforts to develop these inventions into practical devices. To permit Tesla to get started on perfecting his inventions, Peck and Brown rented a laboratory for him in lower Manhattan in the fall of 1886."

"They agreed to share any profits, with Tesla receiving a third, Peck and Brown splitting a third, and a third to be reinvested to develop future inventions. Peck and Brown covered all expenses related to securing patents and paid Tesla a monthly salary of $250. In April 1887, Tesla, Peck and Brown formed the Tesla Electric Company. And in 1887, Szigeti came to New York to serve as Tesla's assistant.[4]"

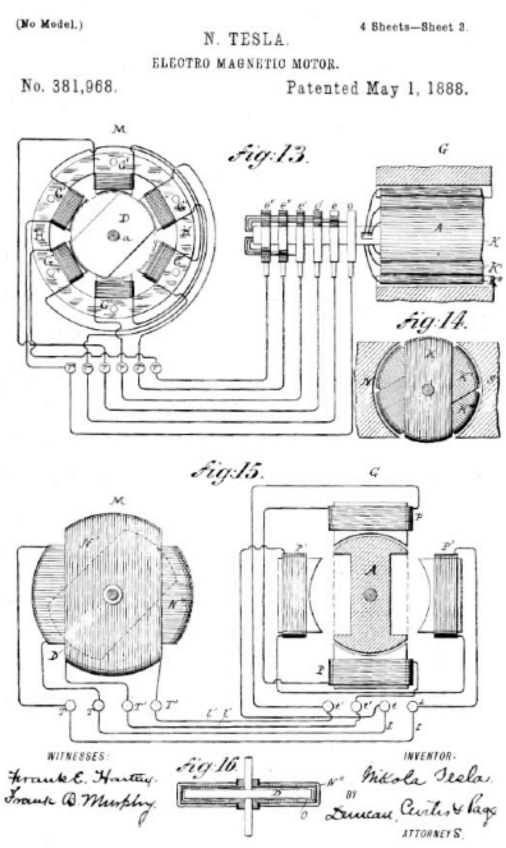
"Tesla's first laboratory was located in New York's financial district. The laboratory was at 89 Liberty Street, just around the corner from the offices of Mutual Union at 120 Broadway. On the ground floor was the Globe Stationery & Printing Company, and Tesla occupied a room upstairs. The lab was furnished with only a workbench, a stove, and a dynamo manufactured by Edward Weston. To provide power for the dynamo, Peck and Brown struck a deal with the printing company. Because Globe used its steam engine to run the presses during the day, the company could provide power at night to Tesla. As a result, Tesla got into the habit of working on his inventions at night.[5]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 4 p. 80-81
[4] John B. Taltavall, comp., *Telegraphers of To-Day: Descriptive, Historical, Biographical* (New York: John B. Taltavall, 1893), 19-20.

[5] Norvin Green to A. S. Hewitt, 1 September 1887, Western Union Collection, Series 4, Box 204A, National Museum of American History Archives, Washington, DC. I am grateful to Joshua Wolff for sharing this item with me. See also Arthur J. Beckhard, *Electrical Genius Nikola Tesla* (New York: Julian Messner, 1959), 120, 125.

On May 1, 1888, Nikola Tesla received a US Patent “Electric Magnetic Motor” describing his AC induction motor powered by 3 phase AC power.

US Patent 381,968 - Patented May 1, 1988



https://patents.google.com/patent/US381968

May 16, 1888. Tesla's first lecture to AIEE (American Institute of Electrical Engineers) - *A New System of Alternating Current Motors and Transformers*.

"The centerpiece of the promotional campaign was Tesla's lecture to the American Institute of Electrical Engineers (ALEE) on 16 May 1888. Since Anthony was a vice president and Martin a former president of the institute, they encouraged Tesla to give a paper on his polyphase inventions. Exhausted and ill from overwork, Tesla initially declined to give the lecture. However, Anthony and Martin persisted, and Tesla wrote the lecture hastily the night before he gave it. As props for the lecture, Tesla displayed the two motors that Anthony had tested. In order that he could participate in the discussion following the paper, Martin arranged not to chair the session (as he frequently did but instead asked Francis R. Upton, AIEE vice president and treasurer of the Edison Lamp Company, to preside."

"Tesla titled his AIEE lecture "A New System of Alternate Current Motors and Transformers." Though his title was modest, he immediately made bold claims for polyphase AC: "I now have the pleasure bringing to your notice... a novel system of electric distribution transmission of power by means of alternate currents... which I confident will at once establish the superior adaptability of these currents to the transmission of power."[16]"

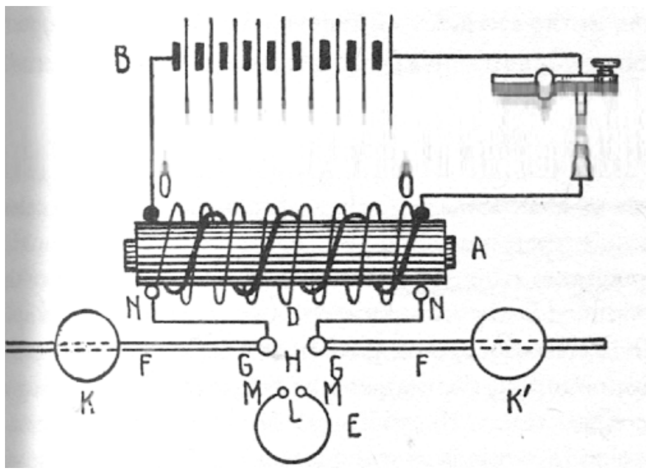
Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 5 p. 105-106
[16] NT, "*A New System of Alternate Current Motors and Transformers*," AIEE Transactions 5 (September 1887-October 1888): 307-27 and reprinted in TCM, *Invention Researches, and Writings*, 9-25.

July 7, 1888. Tesla sold his patents to Westinghouse Electric for about $75K.

"Peck kept up the pressure on Westinghouse, telling Stanley that he was just about to sell the parents to another party. With that news, Westinghouse decided that they should not wait any longer, and Kerr, Byllesby, and Shallenberger negotiated an agreement with Peck and Brown.[41] On 7 July 1888, Peck and Brown agreed to sell the Tesla patents to Westinghouse for $25,000 in cash, $50,000 in notes, and a royalty of $2.50 per horsepower for each motor. Westinghouse guaranteed that the royalties would be at least $5,000 in the first year, $10,000 in the second year, and $15,000 in each succeeding year. In addition, Peck and Brown were reimbursed by the Westinghouse Company for all of the expenses they incurred during the development of the motor.[42] "

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 5 p. 113
[41] Kerr testimony, NT, Motor Testimony, 449-51.
[42] "Agreement of July 7, 1888," in NT 74, 584-87; NT, Motor Testimony, 327.

In 1889 during a trip to Europe, Vilhelm Bjerknes introduces Tesla to Heinrich Hertz's discovery of electromagnetic waves. His Ruhmkoff Coil Experiment Was Used By Hertz to Demonstrate Electromagnetic Waves



"Living off what he had earned at Westinghouse, Tesla traveled to Europe that summer as a member of the delegation from the American Institute of Electrical Engineers to the Congrès International des Electriciens. This congress was being held in conjunction with the Exposition Universelle in Paris, and so Tesla was able to review the numerous electrical exhibits as well as the unveiling of the Eiffel Tower.[1] While there, Tesla witnessed a demonstration lecture of vibrating diaphragms by the young Norwegian physicist Vilhelm Bjerknes. It is likely that Bjerknes introduced Tesla to the discovery of electromagnetic waves by Heinrich Hertz. In 1887, Hertz reported that he had detected the electromagnetic waves that James Clerk Maxwell had predicted in his theoretical work on electricity and magnetism. Bjerknes had come to Paris to attend Henri Poincaré's lectures on electrodynamics and subsequently spent two years at the University of Bonn as Hertz's assistant. Together, Hertz and Bjerknes studied resonance in oscillatory circuits.?[2]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 6 p. 117
[1]Ralph W. Pope to NT, 15 August 1889, Notecards, KSP: Jill Jonnes, *Eiffel's Tower:And the World's Fair Where Buffalo Bill Beguiled Paris, the Artists Quarreled, and Thomas Edison Became a Count* (New York: Viking, 2009).
2. O'Neill, *Prodigal Genius*, 99; NT, "On the Dissipation of the Electrical Energy of the Hertz Resonator," *Electrical Engineer* 14 (21 December 1892): 587-88 in

Ratzlaff, *Tesla Said*, 22-23; entry for Bjerknes, *Dictionary of Scientific Biography*, 16 vols., ed. C. C.Gillespie (New York: Scribner, 1970-80), 2:167-69.

In 1890, Tesla duplicates Hertz experiments in America for the first time. He proceeds to modify Hertz design. He moves the capacitor & spark gap to the primary side of the circuit. He develops a variable inductor (with moving iron core) to change inductance. He develops a variable capacitor to vary capacitance. Tuning capacitor and inductor to generate higher frequencies of oscillation. Observes the Resonance Effect for the first time. This becomes the Tesla Coil

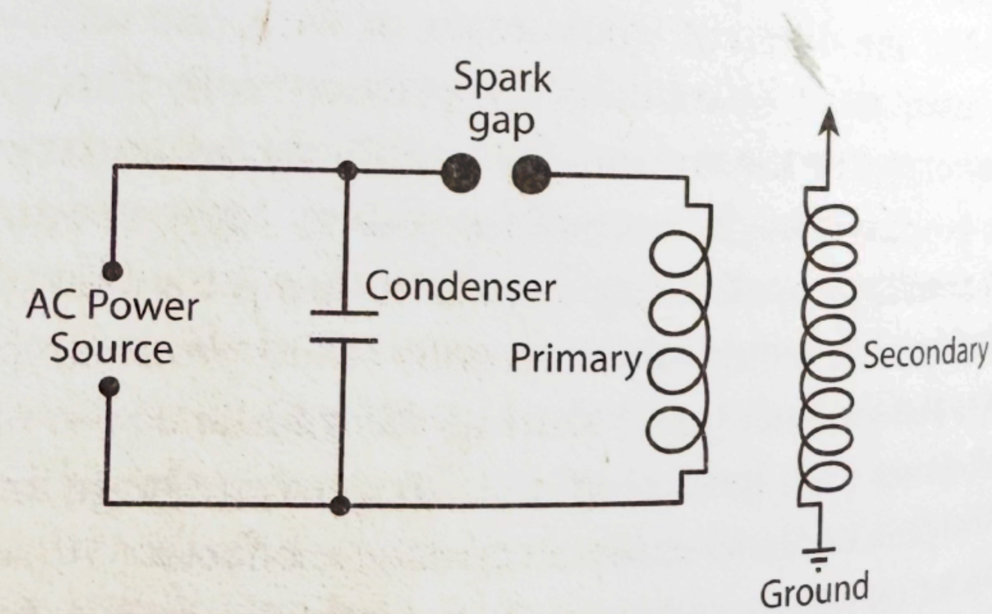


FIGURE 6.2. Diagram of a Tesla coil.

"In 1890, Tesla repeated Hertz's experiments and may well have been the first researcher in America to do so. Not satisfied with the apparatus Hertz had used, Tesla altered the experimental setup (Figure 6.2).[18] An obvious step was to replace the mechanical current interrupter with his high-frequency generator. Rather than have the apparatus use the few hundred cycles per second produced by the mechanical interrupter, why not use 10,000 to 20,000 cycles from his alternator? Tesla soon discovered that as the frequency increased, so did the amount of heat generated that melted the paraffin or gutta-percha insulation between the primary and secondary inside the induction. coil. To address this problem, Tesla made two changes. First, he got rid of the insulation and instead wound his induction coils with an air gap between the primary and the secondary. Second, because thin core in the induction coil became so hot, he redesigned his versions so that the iron core could be moved in and out of the primary coil. By moving the core, Tesla found that he could also adjust the inductance of the primary.[19] "

"Tesla also encountered problems with the condenser or capacitor that was frequently used with induction coils. To increase the strength of the spark produced by the secondary, investigators (beginning with Armand Hippolyte Fizeau in 1853) typically placed a Leyden jar or capacitor in a shunt around the spark gap of the secondary. With the rapid alternations from his high-frequency generator, Tesla found that this capacitor often counteracted the self-inductance of the secondary coil and burned out the coll. In response, Tesla moved the capacitor in his apparatus between the generator and the primary. He also made this capacitor adjustable.[20] Tinkering with the arrangement of the capacitor and coils was quite natural for Tesla; in developing his split-phase motors, he had used combinations of induction coils, resistors, and capacitors to split and give the incoming current different phases.[21]"

"Tesla now realized that by carefully adjusting the capacitor and induction coil it was possible to boost the frequency to even higher levels. Electrical scientists had initially assumed that when the capacitor discharged, the electricity simply flowed from one plate to the other, much like water running out of a reservoir. However, in 1856, the British physicist Sir William Thomson proved mathematically that capacitor discharge was instead vibratory. Just as a vertical weighted spring bobs up and down when released, the electrical charge surges back and forth between the plates in the capacitor until the stored-up energy is dissipated and flows through the circuit in the form of a high-frequency current.[23]"

"In order to take full advantage of the vibratory character of the capacitor discharge, Tesla next carefully adjusted the induction coil.
Just as the capacitor can be thought of as the electrical equivalent of a weighted spring, an induction coil can be seen as the equivalent of a pendulum. As an alternating current flows through the primary, the current induced in the secondary coil oscillates between a maximum and a minimum value, much like the bob on a mechanical pendulum swings to and fro. Tesla now realized that if he could match each electrostatic discharge or "thrust" so that it coincided with each maximum if the induced current, he could increase the voltage of the current produced by the induction coil. Just as one can keep a mechanical pendulum going longer by giving it a little nudge just as it reaches one end of its swing, Tesla adjusted his capacitor and induction coil so that each "thrust"

came just as the current in the induction coil reached its maximum. In doing so, Tesla was taking advantage of the another portion of the circuit and thus boost the output. By creating resonance by adjusting the capacitor and the induction coil, Tesla was soon able to produce a current that alternated up to thirty thousand times per second? Fascinated with how resonance could create such powerful effects, Tesla looked for other places where he could take advantage of resonance, and it quickly became the new ideal guiding his efforts with high-frequency phenomena."

"By combining his understanding of the vibratory nature of capacitor discharge with the principle of resonance, Tesla now had an invention that produced currents whose voltage and frequency were higher than those generated by other machines. Tesla called this invention his oscillating transformer, but as it came to be widely employed by other investigators, it became known as the Tesla coil. The oscillating transformer was fundamental for much of Tesla's subsequent work on wireless power, and he felt that it was one of his great discoveries. A he recalled later, "When in 1900 I obtained powerful discharges 100 feet and flashed a current around the globe, I was reminded the first tiny spark I observed in my Grand Street laboratory and was thrilled by sensations akin to those I felt when I discovered the rotating magnetic field."[25]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 6 p. 122-23

[18] NT, "The True Wireless," 28

[19] NT, "Alternating Currents of Short Period," 128 and NT, "Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination," a lecture delivered before the ATEE at Columbia College, 21 May 1891 in TCM, *Inventions, Researches, and Writings*, 145-97, on 170-71 (hereafter cited as NT, 1891 Columbia lecture).

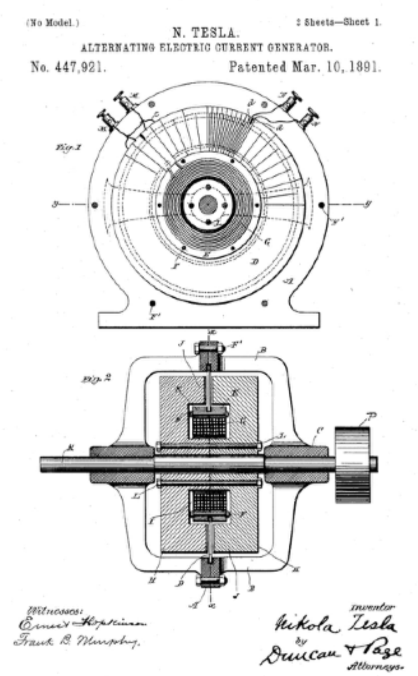
[21] In 1868, James Clerk Maxwell published a mathematical analysis of the interaction of capacitors and induction coils in circuits, but there is no indication that Tesla was aware of this prior work; see Julian Blanchard, The History of Electrical Resonance," *Bell System Technical Journal* 20(1941): 415-33, on 419-20, http://www .http://www .alcatel-lucent.com/bstj/vol20-1941/articles bstj20-4-415.pdf

[23] NT, Radio Testimony, 48-50; O'Neill, *Prodigal Genius*, 90. Tesla also filed a patent for the idea of using the vibratory discharge of capacitors; see "Method of and Apparatus for Electrical Conversion and Distribution," U.S. Patent 462,418 (filed 4 February 1891, granted 3 November 1891).

[25] NT, *My Inventions*, 75.

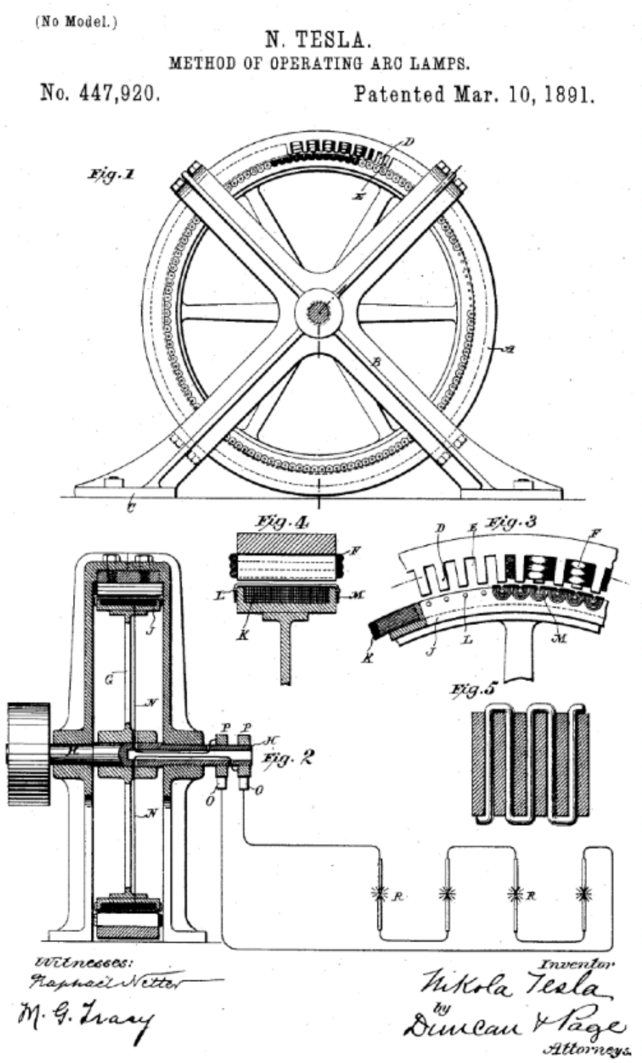
Tesla decided to focus his efforts on applications of high frequency AC. He develops a new AC generator with 24 poles capable of generating AC at 2 KHz.

US Patent 447,921 - March 10, 1891
https://patents.google.com/patent/US447921



Tesla applies a new 10 KHz high frequency AC generator to power Arc Lamps that did not flicker and received US Patent 477,920 “Method of Operating Arc Lamps” on March 10, 1891.

US Patent - 477,920
https://patents.google.com/patent/US447920



Tesla applies the new Tesla Coil to demonstrate wireless lighting.

In 1891, he does a lecture to the AIEE at Columbia University where he demonstrates his Tesla Coil driven by a high frequency alternator at 10KHz and demonstrates wireless lighting.

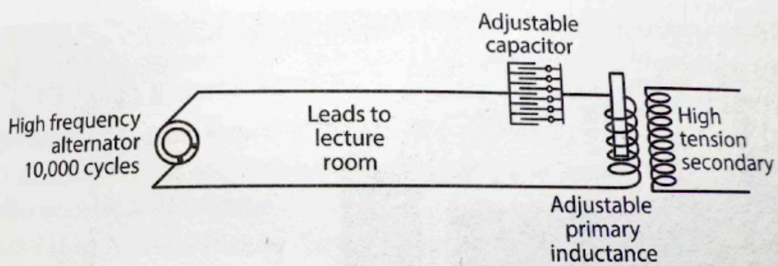


FIGURE 7.1. Circuit used by Tesla for his 1891 lecture at Columbia College. The capacitor, inductance, and transformer on the right constituted his oscillating transformer or Tesla Coil. Redrawn from NT, "The True Wireless," *Electrical Experimenter,* May 1919, 28–30 ff., on p. 29.

“Tesla spoke on the evening of 20 May 1891 at Columbia College in New York in the lecture hall of Theodore W. Dwight, Dean of the Law School. Although an electrical engineering department had been established in 1889 in the Columbia School of Mines, the department lacked its own classroom, but the two electrical engineering professors, Francis B. Crocker and Michael Pupin, were probably anxious to attract attention to their new department by hosting Tesla's lecture. To provide power, Tesla installed his high-frequency alternator in the college's electrical workshop (a modest brick building nicknamed the "cowshed") and powered it by an electric motor; using a switch on-stage, Tesla could adjust the speed of the motor and hence control the frequency produced by his alternator(Figure 7.1)[15]”

“To help the audience appreciate the full potential of high-frequency AC for electric lighting, Tesla offered a breathtaking demonstration. Two large zine sheets were suspended from the ceiling about fifteen feet from each other and connected to the oscillating transformer. With the auditorium lights dimmed, Tesla took a long gas-filled tube in each hand and stepped between the two sheets. As he waved the slender tubes, they glowed, charged by an electrostatic field set up between the plates. As Tesla explained, high-frequency current now made it possible to have electric lighting without wires, to have lamps that could be moved freely around a room[19]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 7 p. 134-35
[15]In 1891, Columbia College had its campus on 49th Street between Madison and Fourth avenues. From 1857 to 1891, while the Law School was nominally part of Columbia, it was single-handedly run by Dwight as a proprietary school; hence, in all descriptions of Tesla's lecture, the location is given as Professor Dwight's room. See Robert A. McCaughey, *Stand, Columbia: A History of Columbia University in the City of New York, 1754-2004* (New York: Columbia University Press, 2003), 138-40, 182-83. On the history of electrical engineering at Columbia, see Michael Pupin, *From Immigrant to Inventor* (New York: Charles Scribner's Sons, 1922), 276-85 and James Kip Finch, *A History of the School of Engineering, Columbia University* (New York: Columbia University Press, 1954), 68-70.

[19]NT, 1891 Columbia lecture, 187-90. Tesla covered the basic idea behind this demonstration in the patent application he filed prior to the lecture; see "System of Electric Lighting," U.S. Patent 454,622 (filed 25 April 1891, granted 23 June 1891).

In the summer of 1891, Tesla modifies his design to include plate capacitor on the roof of his lab and a ground connection for the secondary coil. The grounded coil was first demonstrated by August von Steinheil in 1838 who showed a one wire telegraph with ground return. Amos E Dolbear patented a circuit with a elevated capacitor and grounded secondary induction coil in 1886.

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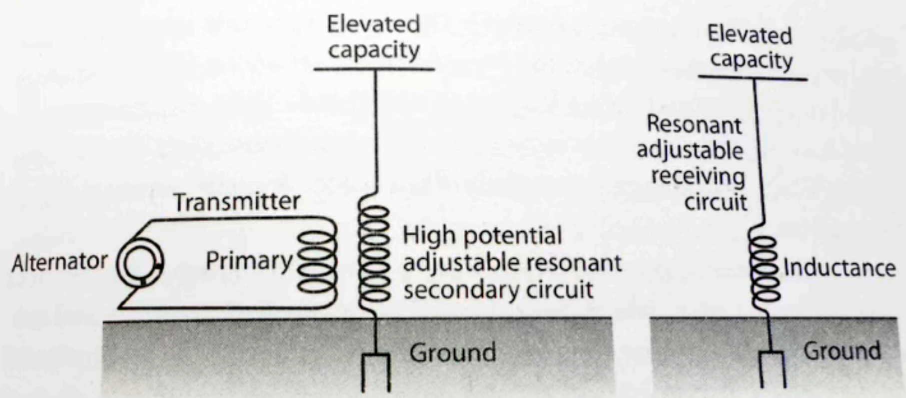


FIGURE 7.3. Diagram showing how Tesla grounded his transmitter and receiver.
In his 1916 testimony, Tesla reported that he used arrangements like this as early as 1891. Tesla used a large metal can for the elevated capacity in the transmitter.
Redrawn from NT, "The True Wireless," *Electrical Experimenter,* May 1919, 28–30 ff., on p. 29.

"Through the summer and fall of 1891, Tesla began to scale up his demonstration apparatus. Onstage he had used his high-frequency alternator and oscillating transformer to transmit energy between two plates separated by fifteen feet; how much farther might he be able to convey energy without wires? To find out, Tesla substituted a large metal can for one plate and placed it on the roof of his Grand Street lab (figure 7•3). In lieu of the other plate, Tesla connected his apparatus to the building's water pipe system to ground it. In configuring his system in this manner, Tesla may have been influenced by a circuit patented in 1886 by Amos E. Dolbear of Tufts College; by connecting one terminal of an induction coil to a large capacitor and grounding the other terminal, Dolbear found that he was able to transmit telephone signals from the college laboratory to his home nearby.[31]"

"In grounding the circuit, Dolbear was using a technique already in common practice in telegraphy and telephony. First discovered by Carl August von Steinheil in 1838, electricians had discovered that it was possible to operate a telegraph circuit with one wire running between the transmitter and receiver and then connecting both devices to plates buried in the ground since the current could move through the Earth and hence complete the circuit.[32]"

“With the can and Earth connected to the terminals of his high-frequency apparatus, Tesla's idea "was that I would disturb the electrical equilibrium in the nearby portions of the earth, and the equilibrium being disturbed, this could then be utilized to bring into operation in any way some instrument.[33]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 7 p. 138-39

[31]A. E. Dolbear, "Mode of Electric Communication," U.S. Patent 350,299 (filed 24 March 1882, granted 5 October 1886).
[32] Hawkins Electrical Guide (New York: Theo. Audel, 1915), 9:2264-65.
[33] NT, Radio Testimony, 9.

1892 - Westinghouse uses Tesla’s single phase AC generator, transmission line, and AC motors to create the Ames Hydroelectric Power Plant and drive the Gold King Mine several km away near Telluride CO. The First US AC Transmission of Power - Pikes Peak Milestone

https://ethw.org/Milestones:Ames_Hydroelectric_Generating_Plant,_1891

Dedication #14
Location Ames, CO, U.S.A.
IEEE Regions5d
IEEE sections Pikes Peak
Achievement date range 1891

Ames Hydroelectric Generating Plant, 1891

Ames, CO Dedicated July 1988 - IEEE Pikes Peak Section

Electricity produced here in the spring of 1891 was transmitted 2.6 miles over rugged and at times inaccessible terrain to provide power for operating the motor-driven mill at the Gold King Mine. This pioneering demonstration of the practical value of transmitting electrical power was a significant precedent in the United States for much larger plants at Niagara Falls (in 1895) and elsewhere. Electricity at Ames was generated at 3000 volts, 133 Hertz, single-phase AC, by a 100-hp Westinghouse alternator.

1893 - Tesla's Tesla coil transmitter transmits energy 1.3 miles from Liberty Street Lab

"Using resonance, Tesla now set out to study how high-frequency currents traveled through the ground, and he returned to the apparatus he had put together in the fall of 1891 (see Figure 7-3). Again his high-frequency generator and oscillating transformer served as the to the water mains, he connected the other terminal to "an insulated body of large surfaces what we would call an antenna on the roof of his laboratory downtown on South Fifth Avenue. The receiver consisted of several capacitors and an electromagnetic relay. When the capacitors were adjusted to the frequency of the transmitted signal, the relay caused a tightly stretched wire to vibrate and produce an audible hum. Tesla arranged these components into a wooden box so that he could carry the receiver tucked under his arm.[10]"

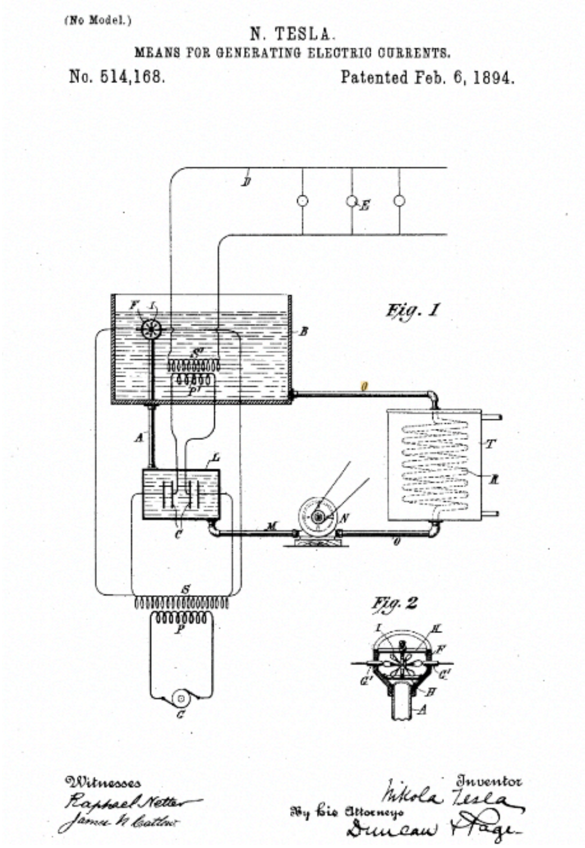
"With the transmitter running in his lab, Tesla carried the receiver throughout Manhattan, stopping periodically to ground the receiver and see if it would hum and detect the oscillating current produced by the transmitter. He would often take the receiver uptown to the Gerlach Hotel and found that he could detect the current there, about 1.3 miles (2.09 kilometers) from his lab.[11]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 10 p. 180

[10] Ibid., 347, NT, Radio Testimony, 23-26

[11] NT, Radio Testimony, 23

1893 - Tesla built an oscillator using turbine blade between spark gap which increases the frequency of oscillation, covers spark gap with oil to reduce arcing. This resulting oscillator operated over a 30-80KHz range with close to continuous wave output. US Patent 514,168 issued Feb 6, 1894

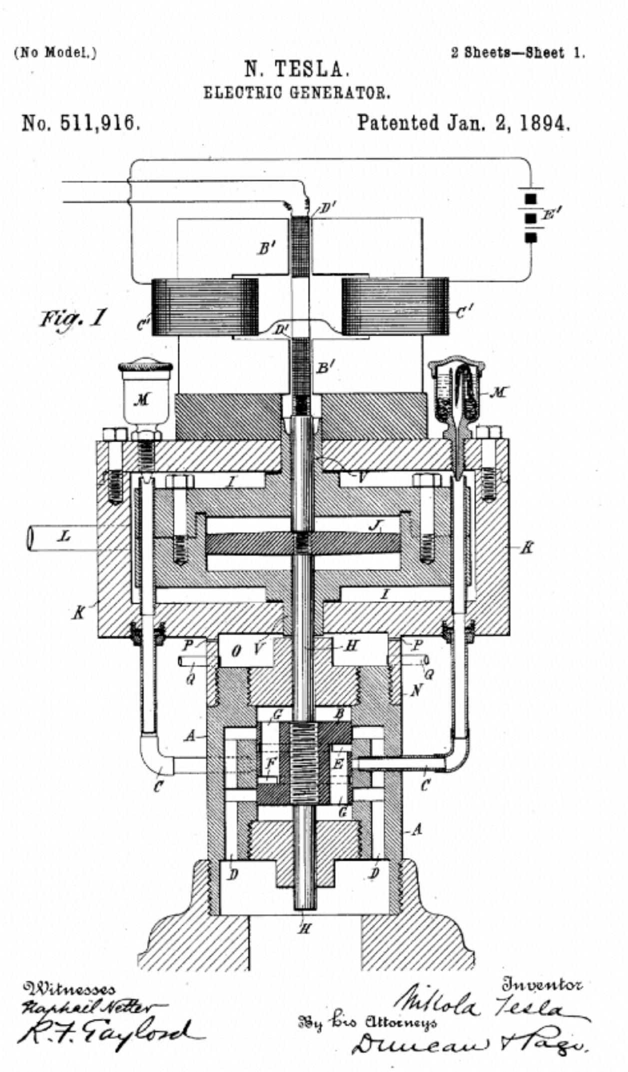


But while it was fun to play with the mechanical oscillator, it was not the solution that Tesla needed in order to perfect his wireless lighting system. Consequently, in 1893, he devised yet another substitute for the spark gap by inserting a fan or turbine spinning between the terminals of the spark gap; sparks would jump between the stationary terminals and the turbine blades, and the sparks would be shorter and quicker as a result of the turbine spinning rapidly. To minimize any chance of arcing between the blades and the terminals, Tesla immersed the entire spark gap in an oil tank; by pumping oil through the tank, the flow of the oil turned the turbine blades that interrupted the sparks. Using this circuit controller, Tesla was able to produce frequencies in the range of 30,000 to 80,000 cycles per second.[27]

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 10 p. 187

[27] NT, Radio Testimony, 48-60; NT, "Means for Generating Electric Currents," U.S. Patent 514,168 (filed 2 August 1893, granted 6 February 1894). In terms of controlllers, Tesla's efforts culminated in a series of mercury interrupters "in which a thin centrifugal ribbon of mercury whirls a three-vaned spindle into rapid contact with itself"; for one Tesla expert, these interrupters combined "fine adjustment and high speed with absolute economy of moving parts." See NT, "Electric Circuit Controller," U.S. Patent 609,247 (filed 14 March 1898, granted 16 August 1898) and Jim Glenn, ed., *The Complete Patents of Nikola Tesla* (New York: Barnes & Noble, 1994), 231.

1894 - US Patent 511,916 "Electric Generator" Issued on January 1894. Reciprocating Steam Generator increases the frequency accuracy for improved communications between transmitter and receiver. Tesla observed that it was difficult to tune a receiver for reception of signal that did not have precise frequency regulation. This new generator ran at higher frequency and was isochronous.



"However, in transmitting between his lab and the Gerlach, Tesla became frustrated because he often detected no signal at his hotel even though the generator was running just fine at the lab. Tesla found that the generator did not produce waves at a single frequency but instead at several frequencies. In particular, it did not produce oscillations with the same time period, and this made it difficult to tune the receiver to the right frequency. This variation in frequency was caused by slight changes in the speed of the steam engine that drove the alternator.[11]"

“To overcome this problem, Tesla designed a new AC generator. Rather than generate a current by having coils rotate through a magnetic field (as in typical electric generators), Tesla instead built a generator using the reciprocating (or to-and-fro motion) of a piston. His inspiration for this new generator dated back to 1884. Shortly after arriving in America, Tesla had visited the International Electrical Exhibition organized by the Franklin Institute in Philadelphia. At the exhibition, he had played with a thick copper washer with handles so that visitors could move the washer within a strong magnetic field; because the field would induce eddy currents in the washer as it was moved, the visitors would feel mechanical resistance to the way they were manipulating the washer. In moving the washer through the field, Tesla realized that it would be possible to create a generator just by moving a conductor using reciprocating motion.[12]”

“To do so, Tesla combined a piston engine with generating coils and a magnetic field. As steam or compressed air drove the piston back and forth, a shaft connected to the piston moved the generating coils through the magnetic field. By using high pressure and keeping the stroke of the piston short, Tesla was able to move the coils far more quickly than in a traditional rotating generator and hence produce currents with higher frequencies than were previously possible. Moreover, the oscillations produced were completely isochronous, so much so that Tesla boasted that they could be used to run a clock.[13] Tesla called this new machine his oscillator and he filed patent applications covering several versions in August and December 1893. He unveiled this new invention in a lecture he gave at the Chicago’s World Fair.[14]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 10 p. 181-2

[11] NT, Radio Testimony, 23.
[12] "Nikola Tesla's Lecture," *Electrical Industries*, 31 October 1893, Pp. 5-6 in TC 8:92-3.
[13] NT, Radio Testimony, 36-47; TCM, "Tesla's Oscillator and Other Inventions," *The Century Magazine* 46 (April 1895): 916-33, on 920 in TC 9:143-59.
[14] NT, "Reciprocating Engine," U.S. Patent 514,169 (filed 13 August 1893, granted 6 February 1894); "Electrical Generator," U.S. Patent 511,916 (filed 19 August 1893, granted 2 January 1894); "Steam Engine," U.S. Patent 517,900 (filed 29 December 1893, granted 10 April 1894); "Stages and Types of the Tesla Oscillator," Electrical Engineer 19(3 April 1895): 301-4 in TC 10:165-68; "Mr. Tesla's Lecture on Mechanical and Electrical Oscillators," *Electrical Engineer 41* (30 August 1893): 208 in TC 8:59.

1894 - South 5th Street Lab - Tesla builds a prototype of his magnifying transmitter. Primary coil circles the room, secondary has 3-foot tall secondary coil adjusted to resonate with primary frequency.

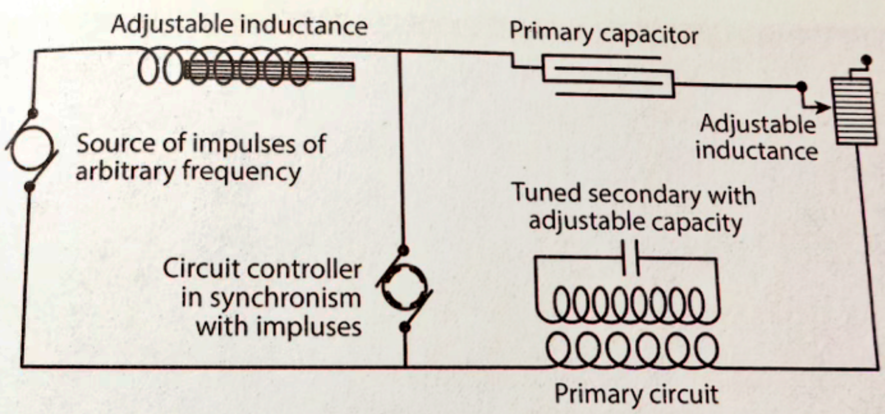


FIGURE 10.3. Circuit used by Tesla to deliver wireless power to his lamps in his South Fifth Avenue laboratory circa 1894.

In practice, the primary shown above was a thick cable around the perimeter of the main room and the secondary was the moveable coil shown in Figure 10.4.

Redrawn from NT, "True History of the Wireless," p. 29.

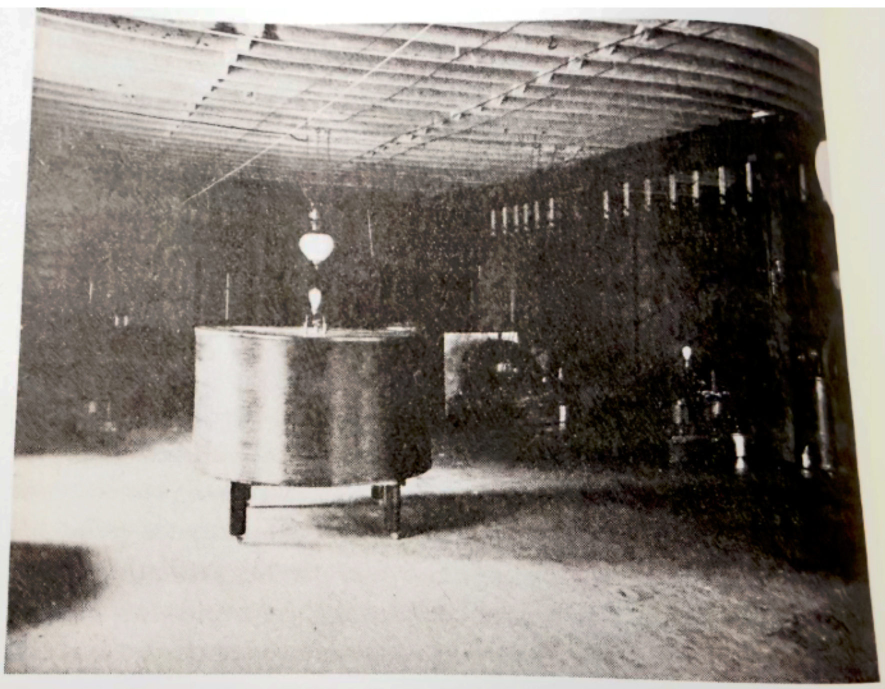


FIGURE 10.4. The receiving coil for Tesla's resonant transformer, as used in the South Fifth Avenue laboratory circa 1894.

From TCM, "Tesla's Oscillator and Other Inventions," *The Century Magazine* 49:916–33 (April 1895), Fig. 10.

“As Tesla came to appreciate how he could use his oscillating transformer to concentrate power, he realized that he could now modify his distribution circuits in order to transmit power across a room and light lamps without any wires. In his previous patents, Tesla had connected his oscillating transformer to a second transformer that in turn distributed the power to his lights. But now thanks to the increased concentration of power, he could separate the two windings in this second transformer and transmit power between them even if they were separated by ten or twenty feet (Figure 10.3).”

“On the transmitting side of this new wireless lighting system, Tesla now used his oscillator to charge a bank of capacitors that in turn were connected to a large cable that ran around the perimeter of the main hall (which was 40 × 80 feet) of the lab. Effectively a coil with just one turn of wire, this large cable took the place of the primary winding of the old second transformer. On the receiving end, Tesla used a three-foot-tall coil in place of the secondary winding of the old second transformer (Figure 10.4). Mounted on casters, this receiving coil could be rolled about the main hall to see where it worked best. Even more important, it could be adjusted so as to resonate to the frequency generated by the transmitter. Instead of the energy being transmitted between two plates—as in his lectures at Columbia and the Royal Institution—the energy now moved wirelessly between two coils.[31]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 10 p. 189

[31]TCM, “Tesla’s Oscillator,” 927

March 15, 1895 - Fire at South 5th Street Lab destroys everything. Tesla needs larger lab outside New York City to fully test his Magnifying Transmitter design

“In visiting Tesla's lab, White would have seen that the Wizard was engaged in four main lines of research. One was his oscillator (i.e., the combination steam engine and electric generator), which Tesla regarded as a practically perfected machine, but which of course, suggests many new lines of thought every day." A second was his new wireless lighting system while a third "was the transmission of intelligence any distance without wires. A fourth, which is an ever present problem for every thinking electrician touches on the nature of electricity.”[4]"

“It was in this manic state that Tesla received a terrible emotional
in blow. At 2:30 A.M. on 13 March 1895, a fire broke out in the building re
containing his laboratory. The fire gutted 33-35 South Fifth and Tesla lost everything. "In a single night," reported the New York Herald, the fruits of ten years of toil and research were swept away. The web of a thousand wires which at his bidding thrilled with life had been twisted by fire into a tangled skein. Machines, to the perfection of which he gave all that was best of a master mind

are now shapeless things, and vessels which contained the results of patient experiment are heaps of pot sherds." Along with his apparatus, Tesla lost all his notes and papers, as he had just brought them to the laboratory to start organizing them. Tesla estimated that he had invested $80,000 to $100,000 in the laboratory, and, regrettably, he had no fire insurance.[6]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 215-6
[4]"Tesla's Laboratory Burned," *Electrical Review*, 20 March 1895, p. 145 in TC 9:127.
[6]"Fruits of Genius Were Swept Away," *New York Herald*, 14 March 1895 and TCM,"The Burning of Tesla's Laboratory," *Engineering Magazine*, April 1895, pp. 101-4 in TC 9:119, 162-64.

July 1895 - New Tesla Lab built at 46 East Houston Street

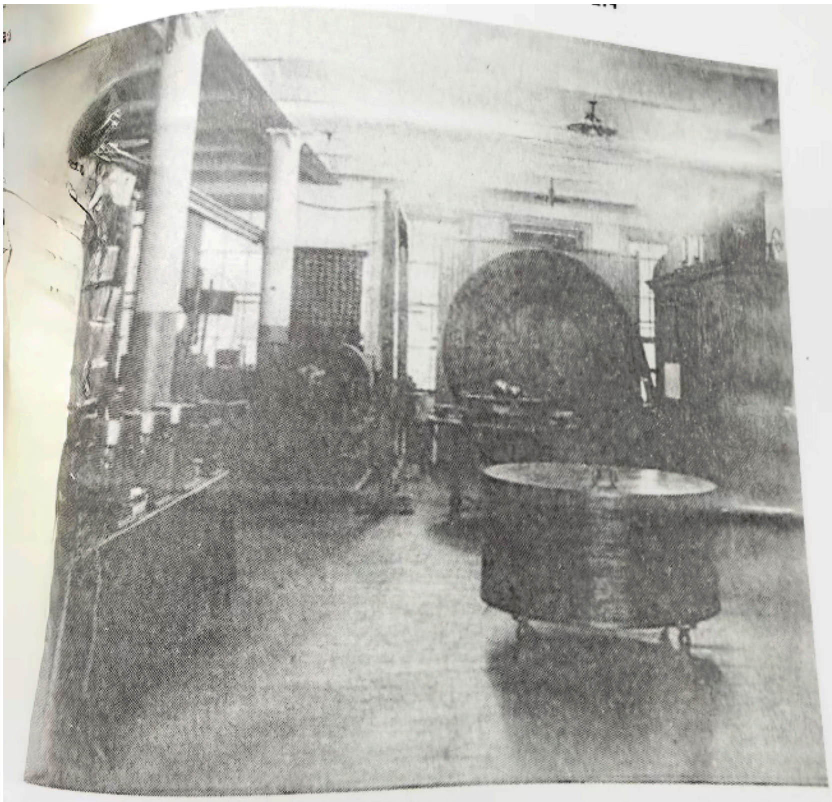


FIGURE 12.1. Tesla's laboratory at East Houston Street. Note that the large spiral coil is visible in the back of the room. From NTM.

“With his depression finally waning, Tesla rented a new laboratory on two floors of a building at 46 East Houston Street in July 1895 (Figure 12.1). There he employed "a clerk who attends to visitors, keep away cranks, keeps a scrapbook, and sees that everybody who has real business with the inventor is provided with the latest copy of some scientific paper until Mr. Tesla is disengaged. He also has a dozen or more mechanics who are as loyal to him as Edison's men are to him; but the nature of his work and the magnitude of the problems he sets for himself to solve do not permit their rendering him the same sort of assistance that the Wizard's [i.e., Edison's] men furnish to their employer.[16]”

“Realizing that investors and manufacturers were not interested in licensing or buying the patents for his system of wireless lighting (see Chapter 11), Tesla shifted from promoting an entire system to emphasizing components. Through 1895 and 1896, he redesigned his oscillating transformer (what others were now calling a Tesla coil) into a compact device that could take power from existing electrical circuits and step it up to a high voltage and high frequency. Tesla then used this improved oscillating transformer to power a new vacuum tube lamp, which he claimed gave out more light and was more efficient than Edison's incandescent lamps or the gas-filled tubes then being touted by D. McFarlane Moore.[17]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 218-9

[16]O'Neill, *Prodigal Genius*, 123; "Nikola Tesla's Work."
[17]On this redesigned Tesla coil, see NT, NY Academy of Sciences Lecture, 41-45.For a photograph of this device, see http://www.electrotherapymuseum.com/2007/ Oscillator/images/Tesla%20Oscillator%202.jpg. See also "Tesla's Electric Oscillator,"13 September 1896, *New York Tribune* in TC 11:120. On the portrait, see "Tesla's Important Advances," *Electrical Review,* 20 May 1896, p. 263 in TC 11:68.

In 1898, Tesla develops and patents a Radio Controlled Boat demonstrating wireless remote control using his Tesla coil transmitter and new coherers developed by Branly & Lodge as receiver.

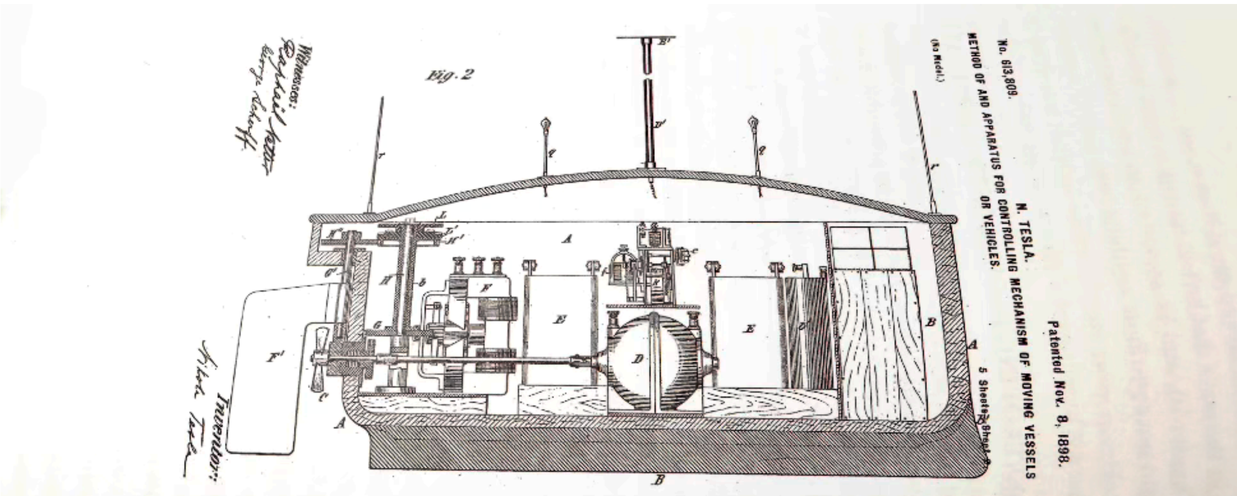


FIGURE 12.4. Diagram showing interior of Tesla's first radio-controlled boat in 1898.

The boat received signals via the antenna (E') that were delivered to the coherer (c) just below the antenna. The signals were then processed by the disk mechanism in the stern, marked by (L). Depending on the number of times the signal was interrupted, the disk (L) advanced a certain number of "clicks" which in turn regulated the current delivered to the motor (F) that controlled the rudder (F'). The boat was propelled by another motor (D) and the current to the motors was provided by storage batteries (E). The signal lamps are marked by q and the space marked B was where an explosive charge could be carried.

From NT, "Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles," US Patent 613,809 (filed 1 July 1898, granted 8 Nov. 1898), Figure 2.

"In 1897 Tesla began building a test model with the help of one of his assistants, Raphael Netter. While he anticipated that his control mechanisms could be used in any kind of vehicle or flying machine, he chose to build the model in the form of a boat in response to the naval armaments race then under way.[33] In 1889 the dominant naval power, Britain, had decided that it should build a new fleet of battleships superior to the combined fleets of its rivals, France and Russia. As these three powers raced to build new ships, the United States, Germany, Spain, and Japan followed suit in order to protect themselves.[34] Powered by new triple-expansion steam engines and protected by hardened steel armor, this new generation of battleships carried main batteries of twelve-inch guns in turrets supported by additional batteries of smaller guns. Fast, well-protected, and bristling with weapons, these new warships looked as if they were invincible.[35]"

"To attack these new battleships, Tesla designed an unmanned torpedo boat that could carry an explosive charge and be directed by electromagnetic signals (Figures 12.4 and 125). One visitor to the Houston Street laboratory offered the following description of the boat and how Tesla demonstrated it:"

"Elevated on stocks on a table in the centre of the laboratory stood a model of a screw-propelled craft, about four feet long and somewhat disproportionately wide and deep.

Mr. Tesla explained that it was merely a working model which he had made in order to exhibit to President McKinley, and that no attempt had been made to follow the usual sharp lines of a torpedo boat. The deck was slightly arched and surmounted by three slender standards, the centre one being considerably higher than the other two, which carried small incandescent bulbs, a third bulb being fixed at the bow. The keel consisted of a massive copper plate, the propeller and rudder being in their usual positions. Mr. Tesla explained that the boat contained the propelling machinery, consisting of an electric motor actuated by a storage battery in the hold, another motor to actuate the rudder and the delicate mechanism which performs the function of receiving through the central standard the electric impulses sent through the atmosphere from the distant operating station, which set in motion the propelling and steering motors, and through them light or extinguish the electric bulbs and fire the exploding charge in the chamber of the bow in response to signals sent by the operator."

"Now watch," said the inventor, and going to a table on the other side of the room on which lay a little switchbox, about five inches square, he gave the lever a sharp turn. Instantly the little bronze propeller began to revolve at a furious rate. "Now I will send the boat to starboard," he said, and another quick movement of the lever sent the helm sharp over, and another movement turned it as rapidly back again. At another signal the screw stopped and reversed.[36]"

"To control this boat, Tesla had the transmitter generate a continous electromagnetic wave at one frequency, which the boat detected using a coherer that had been invented in 1890 by the French physicist Edouard Branly and subsequently improved by Oliver Lodge. At the transmitter, Tesla could rotate the lever, touching from one d four contacts; in doing so, he would interrupt the signal being sent to the boat. Inside the boat, these interruptions caused a special disk to rotate and engage different contacts on the surface of the disk, thus. activating the rudder and the motor to the propeller (Figure 12.4). For instance, rotating the transmitter's lever to a first contact might cause the rudder to turn right, moving it to the next contact would stop the rudder turning and start the propeller, and shifting the lever to the third contact would turn the propeller to the left. Because the contacts controlling the rudder and propeller were placed in a specific sequence on the disk, Tesla could not pick one function and directly execute it; instead, he had to move the lever from contact to contact in order to get the boat to do what he wanted. Hence, in the modern technical sense, Tesla's first boat was not "remote-controlled" but "radio-controlled," as the former term describes situations in which different signals are sent to execute different functions.[37]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 227-29

[33] NT to Miessner, 29 September 1915.
[34] Tesla may have become aware of the naval armaments race from Theodore Roosevelt who was then assistant secretary of the navy. In November 1897,

Roosevelt gave a speech at Delmonico's before the Society of Naval Architects calling for a stronger U.S. Navy. Moreover, Tesla was a friend of Roosevelt's sister, Corinne Robinson, and we know Tesla met Roosevelt at least once in 1899; as he told Corinne, "It was a great privilege to meet your brother and to listen to his enlightening conversation." See "Roosevelt on the Navy," *New York Times*, 13 November 1897 and NT to Mrs. Robinson, 6 March 1899, Corinne (Roosevelt) Robinson Papers, MS Am 1785 (1362), Houghton Library, Harvard University, Cambridge, MA.

[35] “Pre-dreadnought Battleship," http://en.wikipedia.org/wiki/Pre-dreadnought.

[36] "Tesla Declares He Will Abolish War," *New York Herald*, 8 November 1898 in TC 13:138-40, on 139.

[37] I am grateful to Antonio Pérez Yuste for calling this distinction to my attention. According to Yuste, the key pioneer in remote control was the Spanish engineer Leonardo Torres y Quevedo; see Yuste, "Early Developments of Wireless Remote Control:The Telekino of Torres Quevedo," *Proceedings of the IEEE*, 96 (January 2008): 186-89.

1897 - Two years before Colorado Springs, Tesla filed US Patent 645,576 "System of Transmission of Electrical Energy" documenting the use of his Tesla coil connected to a high antenna and a ground connection at transmitter and receiver. Patent granted in March 1900. He concluded he needs a pilot facility outside of New York City and at high altitude.

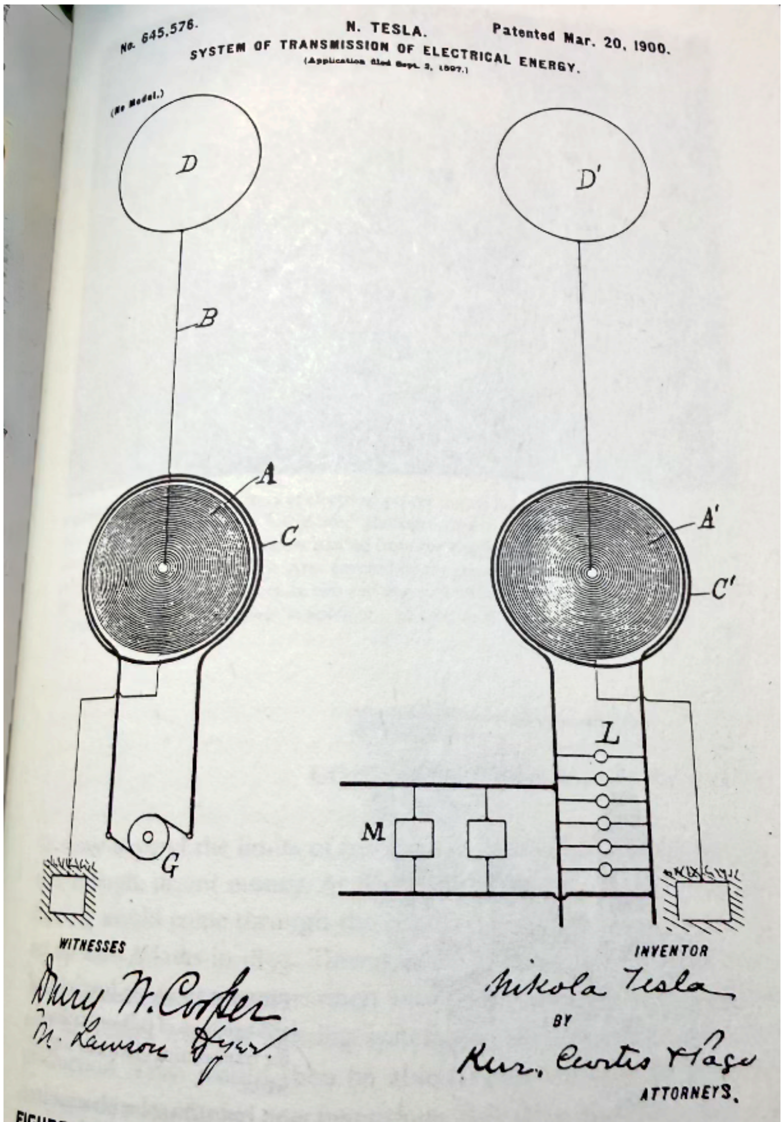


FIGURE 12.11. NT, "System of Transmission of Electrical Energy," US Patent 645,675 (filed 2 September 1897; granted 20 March 1900). D and D' are balloons attached to the transmitter and receiver.

"If he could set up a return circuit in a nearly evacuated tube, Tesla now reasoned that he could then do the same at high altitudes where. the air was thinner. All that was now needed was to connect the spiral coils in the transmitter and receiver to balloons with a large metallic surface area (Figure

12.11). Floating high in the air, these balloons would allow a current to pass from the receiver back to the transmitter. To depict Tesla's new wireless system, Pearson's Magazine ran an illustration showing balloons floating over the skyline of a city (Figure 12.12)."

"To avoid having balloons on mile-long tethers, Tesla believed that he could take two steps: first, raise the power of his system to millions of volts, and second, locate his transmitter and receivers on mountaintops. With regard to the first, Tesla began experimenting with increasing the power of his transmitter in the Houston Street laboratory. Using a primary consisting of two turns of heavy cable around the perimeter of the main workroom and his favorite spiral coil, Tesla was able to push the voltage up to 2.5 million volts and generate sixteen-foot sparks (Figure 12.13). He further tested the power of the system by taking a receiver out of the lab and traveling by boat up he Hudson River to West Point to see if he could pick up oscillations from his lab. Tesla found that he was able to detect oscillations thirty miles from the lab. During this test, Tesla concentrated on seeing it could detect the continuous waves generated by his transmitter and he did not use the signal to send a message by Morse Code or voice.[85]"

"Although revealing, these experiments did not tell him where to best to locate his transmitter; at what voltages and what altitudes would his system work? What would it take to create "a transmitter of adequate power" that might "bridge the greatest terrestrial distances* To answer these questions, Tesla realized that he would have to move. beyond the confines of his New York laboratory and build a pilot plant."

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 252

85 On transmitter tests at Houston Street, see "A Wonderful Possibility in Electric Power Transmission," *Electrical Review*, 26 October 1898, p. 262 in TC 13:127-28; "Tesla Would Use Air as Conductor," *New York Herald*, 27 October 1897 in TC 13:129. On the West Point distance test, which Tesla recalled occurred in 1897, see NT, Radio Testimony, 27-28, 67, 108.

1898 - Tesla does an experiment at Houston Street to validate RF transmission efficiency in near vacuum using a tube 55 feet long. He observes good RF conduction at high altitude. Envisions a very tall antenna suspended by a balloon to reach high altitude to couple with the atmosphere.

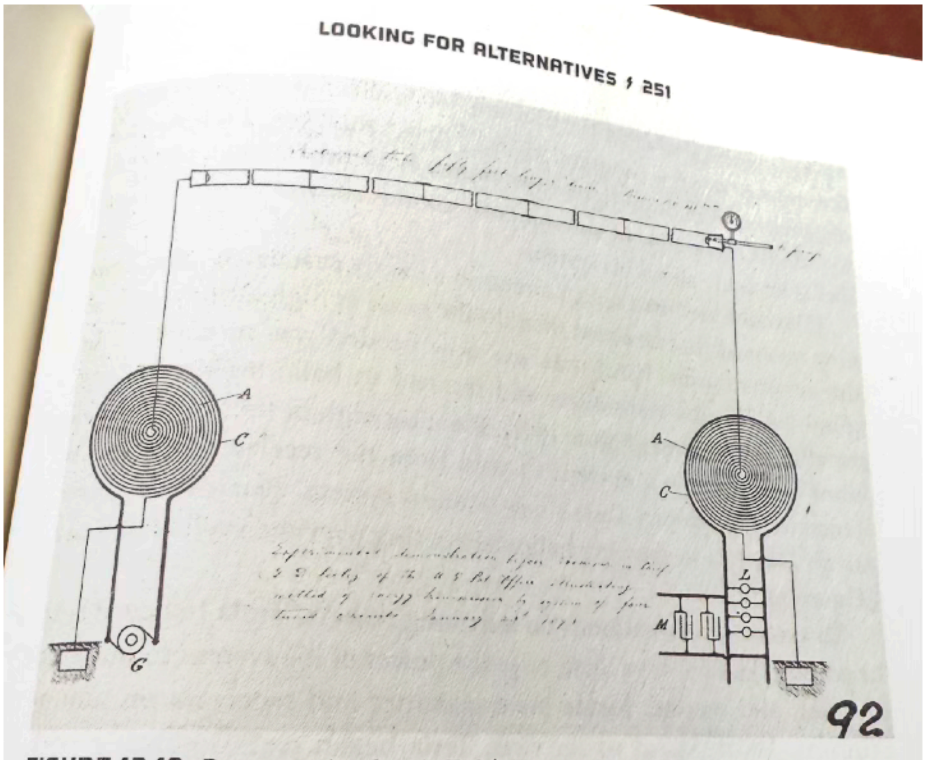


FIGURE 12.10. Demonstration done in Tesla's Houston Street laboratory to show the feasibility of conducting high-frequency currents through a low-pressure gas, 1898. On the left is Tesla's transmitter and on the right is his receiver. Across the top is the fifty-foot glass pipe with reduced pressure. From NTM.

"With the system configured in this manner, Tesla again took up the puzzle of the return circuit. How could he eliminate the wire connecting the transmitter and the receiver to create a true wireless power system? To solve this puzzle, Tesla went back to thinking about why Crookes and Geissler tubes produce light when connected to an electrical source. While at atmospheric pressure, most gases oppose the passage of electricity and function as an insulator; however, to make his tubes light up, Crookes had evacuated most of the gas from the glass tubes. At low pressures, the gas glows when it is traversed by a high-voltage current. Reasoning by analogy, Tesla replaced the wire between the transmitter and receiver with what was effectively a giant Crookes tube. In his Houston Street laboratory, he erected a fifty-foot glass pipe between his transmitter and receiver (Figure 12.10). Using a vacuum pump, Tesla lowered the pressure to 120-150 mm of mercury (the pressure of the atmosphere at an altitude of five miles) and discovered that he could create a return circuit from the receiver back to the transmitter. While power moved from the transmitter to the receiver through the ground, Tesla hypothesized that a return circuit created in the evacuated pipe since the rarefied air allowed the passage of a current from the receiver back to the transmitter. Hence for Tesla, the secret to wireless transmission lay not with electromagnetic waves (i.e., radiation) passing through the atmosphere but that an oscillating current could be conducted through a gas at low pressure. "[T]he transmission of electrical energy," declared Tesla in October 1898, "is one of true conduction, and is not to be confounded with the phenomena of induction or of electrical radiation which have heretofore been observed and experimented with."[82] In emphasizing that electrical oscillations moved through the atmosphere via conduction, Tesla was again distancing himself from most other inventors and scientists who felt that Hertzian waves were a form of radiation moving through the ether."

"What really excited Tesla about this experiment showing how oscillating currents could move through gases at low pressures was that the process was so efficient; if the voltage and frequency were high enough and the atmospheric pressure low enough, a great deal of power could be transmitted. For Tesla,"the discovery of these new properties of the atmosphere not only opened up the possibility of transmitting, without wires, energy in large amounts, but, what was still more significant, it afforded the certitude that energy could be transmitted in this manner economically. In this new system it matters little - in fact, almost nothing - whether the transmission is effected at a distance of a few miles or of a thousand miles.[83]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 249-52

[82]"Tesla's System of Electric Power Transmission through Natural Media, *Electrical Review*, 26 October 1898 in TC 13:124-26, on 126.

[83] NT, "Problem of Increasing Human Energy," 209-10.

January 1899 - Tesla send letter to John Jacob Astor seeking funding for full scale development of this transmitter. Tesla receives a commitment for $100K and $30K up front.

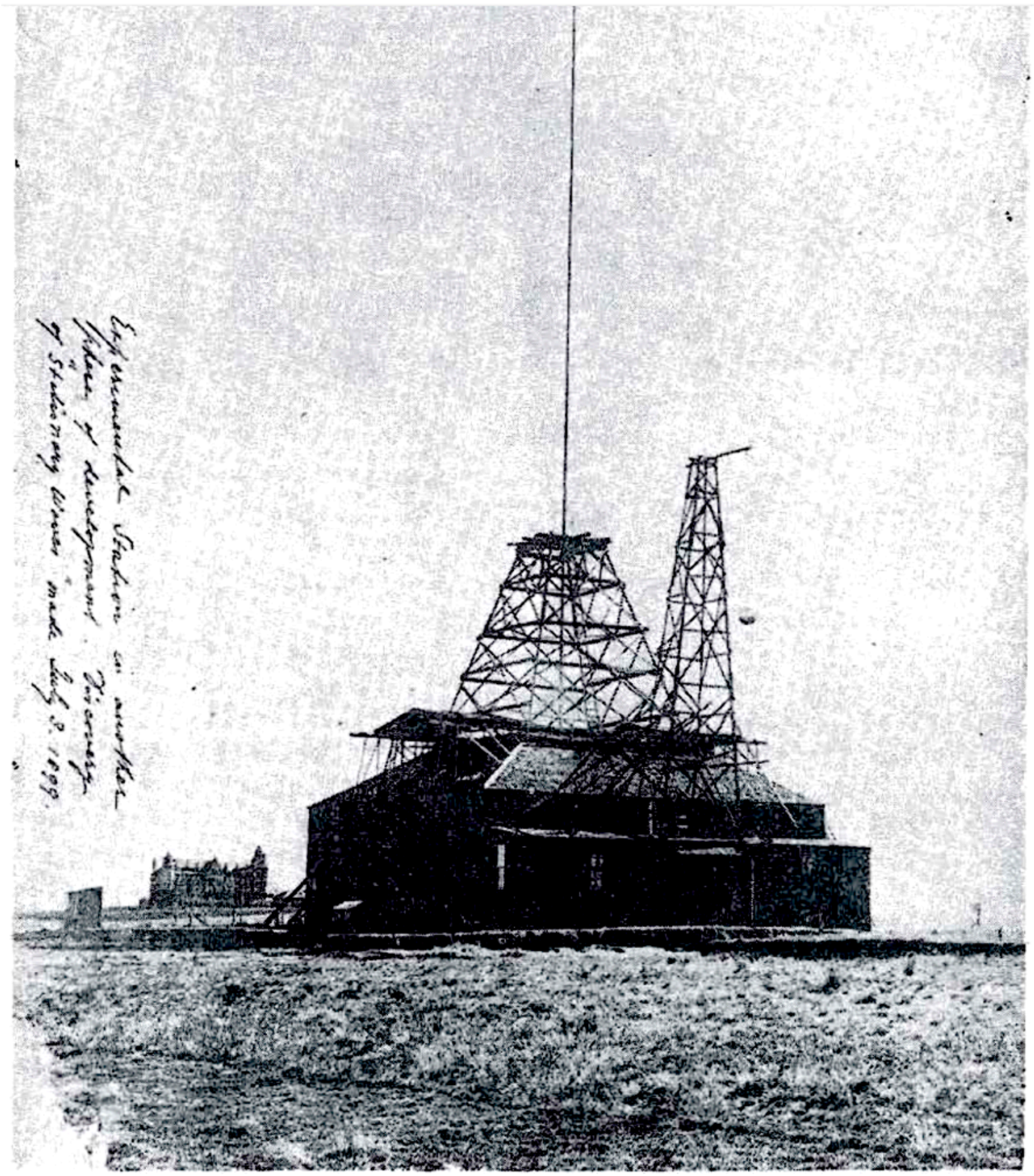
“Within a few days of receiving this carefully crafted sales pitch, Astor signed an agreement with Tesla. Having "placed faith" in Astor, Tesla had bought up enough shares in the Nikola Tesla Company so as to have majority control, leaving Adams, Rankine, Brown, and Coaney with minority interests.[93] In return for five hundred shares, Astor promised to invest $100,000 and was made a director of the company. When all of the shares were transferred to Astor, the colonel gave Tesla an initial payment of $30,000 and then promptly left on a trip to Europe.[94]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 12 p. 259

93 See NT to JJA, 6 January 1899. Correspondence between NT and Scherff indicates that these men continued to be involved in the Nikola Tesla Company; see NT to Scherff, 30 May 1899; Scherff to NT, 29 June 1899; NT to Scherff, 13 July 1899; and Scherff to NT, 15 July 1899, in John T. Ratzlaff and Fred A. Jost, eds., Dr. Nikola Tesla...Tesla/Scherff Colorado Springs Correspondence, 1899-1900 (Millbrae, CA: Tesla Book Com-pany, 1979), 30, 86, 91-92.

94 Seifer, *Wizard*, 211; "Appraisement of Estate Reveals Astor's Personality"; O'Neill, *Prodigal Genius*, 176.

May 18, 1899 - Tesla arrives in Colorado Springs to develop his Experimental Lab. Patent Attorney Leonard Curtis has arranged for land and free electricity from the local utility. He constructs a larger magnifying transmitter and a sensitive receiver in a building in open area right outside of downtown.



Phot. I. Front view of Laboratory from Pike's Peak side.

From Nikola Tesla Colorado Springs Notes, p. 322

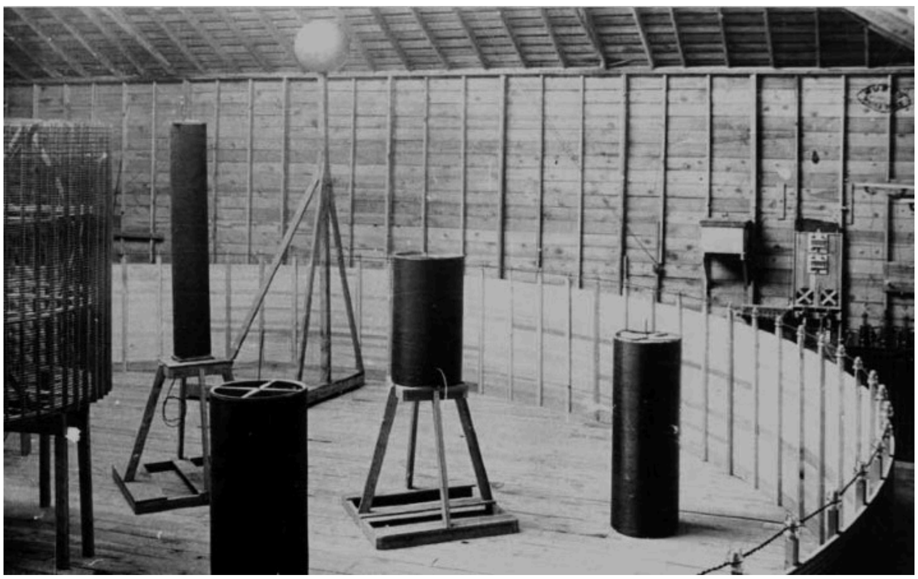
“One newspaper report suggests that Tesla had made a brief visit to Colorado Springs in 1896 to conduct a few wireless experiments; the 1899 move came at the recommendation of Leonard E. Curtis, who had been a partner of Parker Page, Tesla's patent attorney. Curtis had moved to Colorado Springs to regain his health and invited Tesla to come and conduct experiments there. In rural Colorado Springs, Tesla could erect a larger system than the one he had in his New York laboratory and safely conduct experiments with higher voltages. "My coils [in New York] are producing 4,000,000 volts," Tesla told Curtis and "sparks jumping from walls to ceilings are a fire hazard." Moreover, by being in the mountains, Tesla could study how currents were conducted through both the earth's crust and the atmosphere at high altitude.
Attracted by the chance to work away from the press, Tesla accepted Curtis's invitation to relocate temporarily and outlined his needs: "This is a secret test. I must have electrical power, water, and my own laboratory. I will need a good carpenter who will follow instructions. I am being financed for this by Astor, and also Crawford and Simpson. My work will be done late at night when the power load will be least”. Delighted to have Tesla visiting, Curtis arranged for Tesla to get free power from the local electrical utility, the El Paso Power Company.[4]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 264

[4] NT to Leonard Curtis, n.d., quoted in Aleksandar Marincic, foreword to Nikola Tesla, *The Problem of Increasing Human Energy, with Special Reference to the Harnessing of the Sun's Energy* (Belgrade: NTM, 2006), 6; Hunt and Draper, *Lightning in His Hand*, 105-6.

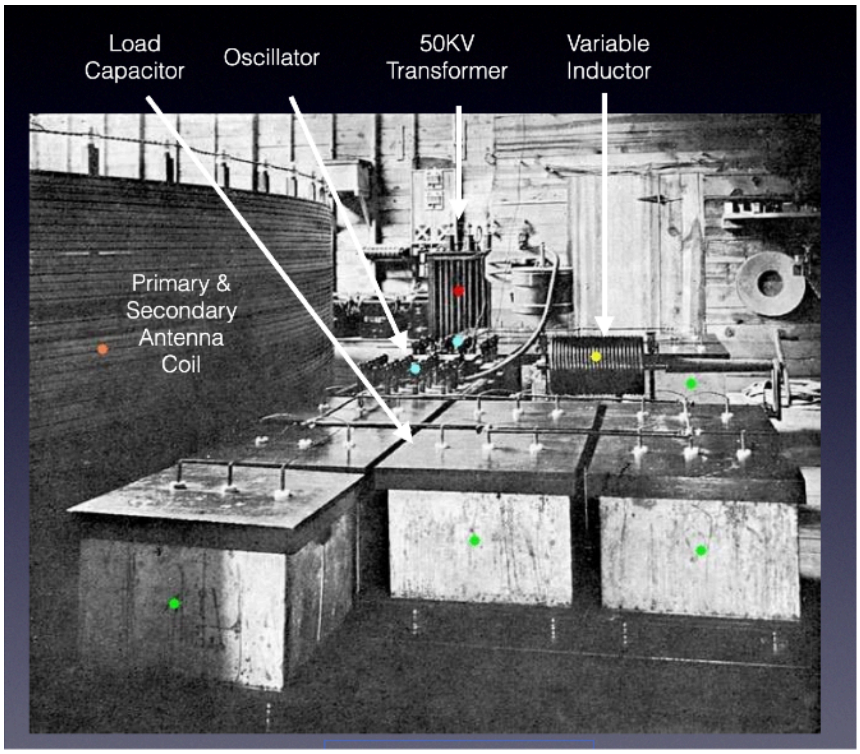
“Under Tesla's direction, Lowenstein and Gregg built an enormous magnifying transmitter. In the station's main room, they constructed a circular wooden wall about six feet high and 49.25 feet in diameter (see Figure 13-7). Around the top of this wall they wound two turns of thick cable in order to create the primary winding of the transmitter.”

“In the center of the room they built the secondary coil using a hundred turns of finer wire.[9] One end of this secondary coil could be connected to either a spherical terminal inside the laboratory or the copper ball atop the mast while the other end was grounded.“



From Phot. II: Nikola Tesla Colorado Springs Notes 1899-1900, p. 323.

“To provide AC to the transmitter, Tesla tapped into the streetcar line that stopped just at the edge of the Knob Hill prairie. He stepped up this 500-volt current by employing a 50-kilowatt Westinghouse transformer that he rewound so that it converted the incoming current to 20,000 or 40,000 volts. The transformer was connected to a large bank of capacitors that were automatically interrupted and hence discharged by a motorized breakwheel (Figure 13-3). Rounding out the equipment were several large coils that could be moved around the space between the secondary and the primary.[11]”



From Phot. III: Nikola Tesla Colorado Springs Notes 1899-1900, p. 324.

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 267-8
[9] Hull, *Coil Builder's Guide to the Colorado Springs Notes*, A28; Cheney and Uth, *Tesla: Master of Lightning*, 87
ary 1901 in TC 15:115.
[11] Gregg to Hunt, 9 October 1962; "Tesla's Call from Mars?" *New York Sun*, 3 January 1901 in TC 15:115

Tesla’s goals for his Colorado Springs Laboratory

1. **To develop a transmitter of high power**
2. **To perfect means for individualizing and isolating the energy transmitted**
3. **To ascertain the laws of propagation of currents through the earth and the atmosphere.**

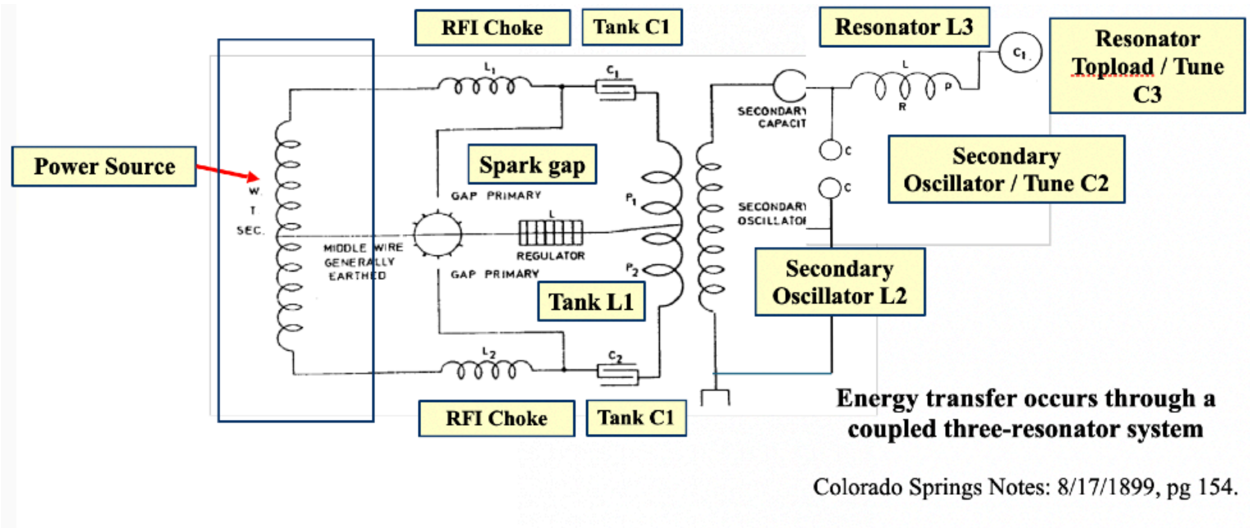
“By the spring of 1899, all the elements needed to realize his ideal wireless power system were falling into place for Tesla: he had perfected the circuitry needed to create a powerful high-voltage, high-frequency transmitter, he had discovered how is tune his transmitter and receivers by adjusting the capacitance and inductance, and he had become convinced that the atmosphere could serve as the return circuit for his system.”

“Yet to make this system practical, several areas required further investigation. First he had "to ascertain the laws of propagation of currents through the earth and the atmosphere" to ensure that his system could send power or messages from one point to another. Next Tesla sought "to develop a transmitter of great power," meaning that he had to figure out how to build coils and capacitors capable of working at millions of volts. And finally, knowing that he would need to deliver power or messages to specific users, Tesla sought to improve his methods of tuning, or as he put it, "to perfect means for individualizing and isolating the energy transmitted.”[1]

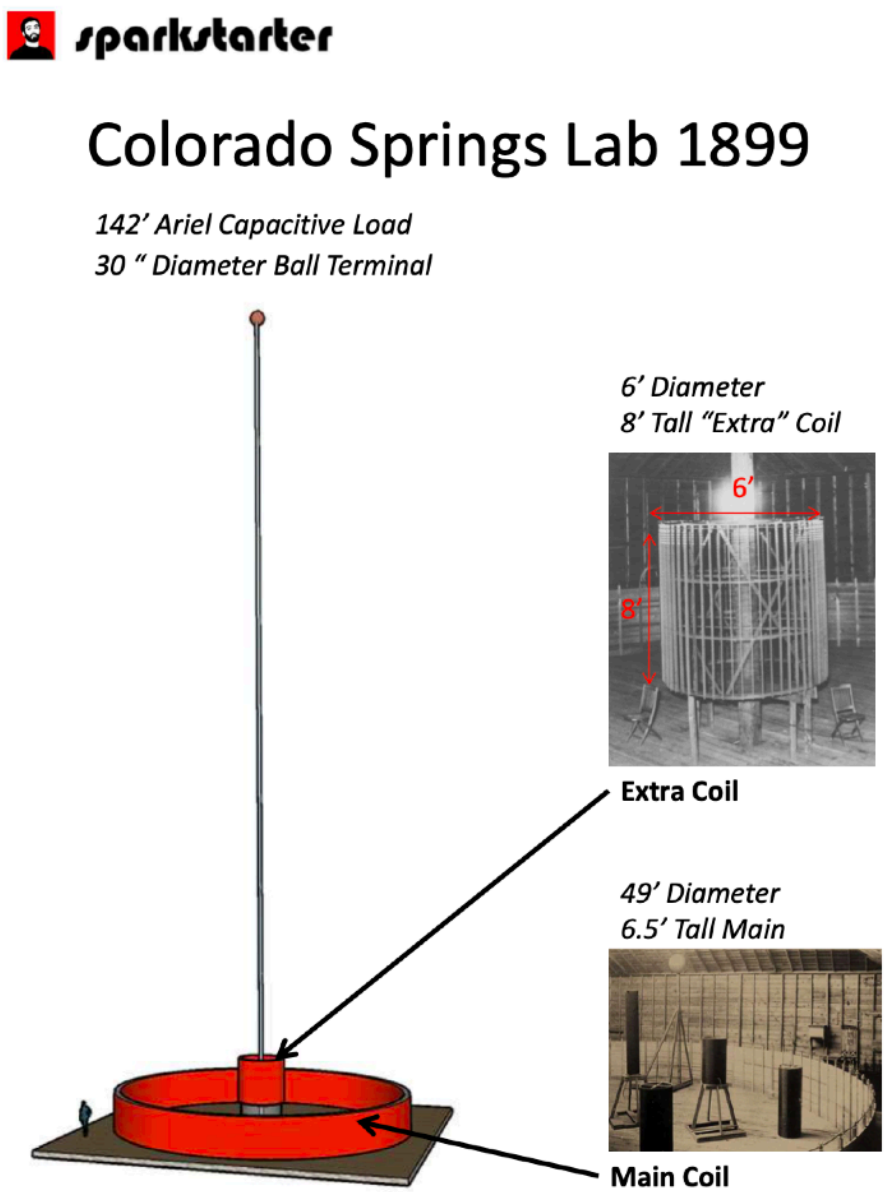
Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 262

[1] 1904 Essay, 429

Goal 1: Develop a transmitter of high power



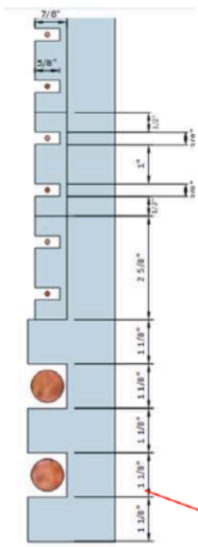
“Tesla built a Magnifying Transmitter with 2 coil secondary winding connected to ground and a 142 Foot antenna topped with a ball capacitor using an optimized Tesla coil design first described in an AIEE Presentation at Columbia University in 1891 and continuously refined during the 1890s. This Magnifying Transmitter achieved output voltage of >4 million volts and >100KW AC power at frequencies from 30-150KHz using an inductively tuned primary oscillator. The basic design patent was applied for prior to the construction of the Colorado Springs Laboratory (September 1897) and received March 20, 1900. This design pre-dates high power AC transmission designs of other wireless telegraphy competitors.”

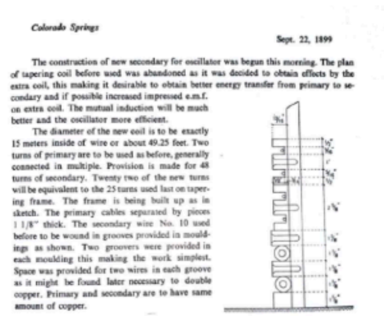


This graphic from Sparkstarter (https://static1.squarespace.com/static/5f98b0d4c9b0f23d525e4434/t/622638e761684548c31ede36/1646672104821/CO+Tesla+Power+System+Design+Notes+pdf.pdf) graphically describes the Colorado Springs Experimental Lab modifications made by Nikola Tesla based upon Nikola Tesla Colorado Springs Notes 1899-1900, September 21, 23 showing the antenna and extra coil which was part of the final Magnifying Transmitter.

sparkstarter

Tesla Coil : Colorado Springs Notes 1899 -1900
See Notes : Sept. 21, 23, 1899



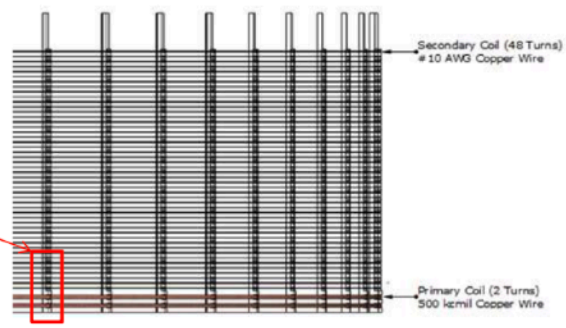


Colorado Springs

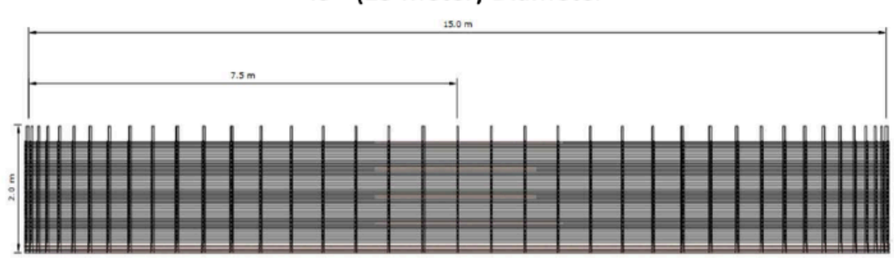
Sept. 22, 1899

The construction of new secondary for oscillator was begun this morning. The plan of tapering coil before used was abandoned as it was decided to obtain effects by the extra coil, this making it desirable to obtain better energy transfer from primary to secondary and if possible increased impressed e.m.f. on extra coil. The mutual induction will be much better and the oscillator more efficient.

The diameter of the new coil is to be exactly 15 meters inside of wire or about 49.25 feet. Two turns of primary are to be used as before, generally connected in multiple. Provision is made for 48 turns of secondary. Twenty two of the new turns will be equivalent to the 25 turns used last on tapering frame. The frame is being built up as in sketch. The primary cables separated by pieces 1 1/8" thick. The secondary wire No. 10 used before to be wound in grooves provided in mouldings as shown. Two groovers were provided in each moulding this making the work simplest. Space was provided for two wires in each groove as it might be found later necessary to double copper. Primary and secondary are to have same amount of copper.



49' (15 meter) Diameter



Here are details of the primary and secondary coil redesign also documented in Nikola Tesla Colorado Springs Notes 1899-1900, September 21, 23

“Rather than having people witness the performance of the magnifying transmitter, Tesla instead chose to rely on photography to document his work at Colorado Springs; photographs were the illusion of choice. In the late fall, Tesla telegraphed Richard Watson Gilder, the editor-in-chief at The Century Magazine (and Robert Underwood Johnson's boss): "Friendly motives prompt me to inquire would it pay you to send [a] photographer here with [the] object of obtaining material for illustrations to appear at your pleasure in Century my rights subsequently reserved(?) If so would like very much getting Mr Alley of Tonnele because of familiarity skill and discretion[.] Would join you in expense as he may do some work for me?] Kindly answer experimental station."[72] Gilder and Johnson readily agreed to share the costs and sent the art photographer Dickenson Alley out from New York. Alley had helped test Tesla's lighting tubes in 1894 (see Chapter 12) and had taken the photographs that appeared in the *Electrical Review* in the spring of 1899. Over the last two weeks of December 1899, Tesla and Alley created a remarkable series of sixty-eight photographs.[73]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 295

[72] NT to Richard Watson Gilder, n.d., Box 100, *Century Collection*, Manuscript and Archives Division, New York Public Library; NT to RUJ, 28 November 1899, MSS 001452 A, Dibner Library, NMAH.

[73] Aleksandar Marincic, foreword to *The Problem of Increasing Human Energy*, 17.

Nikola Tesla demonstrated wireless signal transmission from the Magnifying Transmitter

“Over the next few months, Tesla conducted additional tests to verify that his magnifying transmitter was sending currents into the ground and that they could be detected. In August he tried "arrangements for telegraphy," finding that "the apparatus responded freely to a small pocket coil at a distance of several feet with no capacity attached and no adjusted circuit. Consequently will go at great distance." A few weeks later, he took a receiver outside and connected it to an underground water pipe; at 250 feet from the station, he drew one-inch sparks, and at 400 feet he got half-inch sparks. On 11 September 1900, Tesia carried a receiver a mile away from the station, to nearby Prospect Lake, where he was able to measure that the magnifying transmitter was operating with a wavelength of about 4,000 feet.[53]”

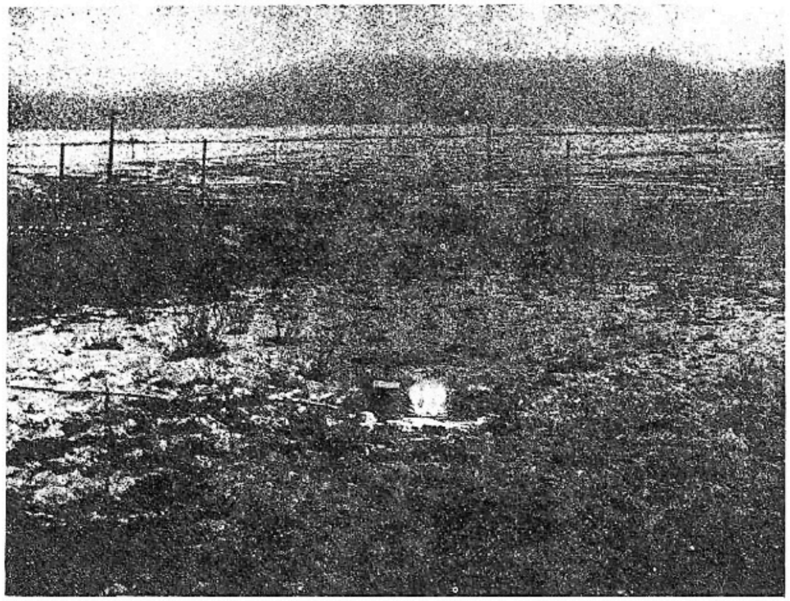
“Mr. Tesla would at first go with the receiving apparatus in his room and experiment there, while I was handling the oscillator. Then he would take, after certain accomplishments in the room, the whole set in portable boxes and go outside of the building, leaving me instruction for continuously switching on and off in certain intervals. In these instances, I often ran to the door to see him for a moment, and I saw that he went as far as, say, a thousand or two thousand feet. I could not watch him closely, as I had to stick to my switch, and so it came that sometimes when just looking out to see him for a moment I couldn't see him, and then I don't know how far he went, but by the time he came back again, being to my recollection not more than the forenoon or the afternoon, you may easily build an idea how far Mr. Tesla could have gone at the time I was standing at the switch.[68]”

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 288-89

[53] L. S. Howeth, *History of Communications-Electronics in the United States Navy* (Washington, DC: Bureau of Ships and Office of Naval History, 1963), chap. 4, http:// carlyradiohistory.us/1963hw04.htm.

[68] Lowenstein testimony in Anderson, *Guided Weapons & Computer Technology*, 121,

Nikola Tesla demonstrated wireless power transmission to a photographer



Phot. XVII (?) Experiment to illustrate an inductive effect of an electrical oscillator of great power. The photograph shown is reproduced from Tesla's article[41] in which somewhat different circuit dimensions and position are quoted.

Nikola Tesla Colorado Springs Notes 1899-1900, p. 344

"In mid-December, as he was completing his experiments in Colorado, Tesla arranged for the photographer Dickenson Alley to come out from New York and photograph his magnifying transmitter in action. (These photographs are discussed more fully later.) As part of this series, Tesla had Alley make several images of lamps lit by the oscillator outside the experimental station. For one image, Tesla placed three lamps on the ground and connected them to a square of wire that was sixty-two feet on each side; this huge square picked up the ground and connected them to a square of wire that was sixty-two feet on each side; this huge square picked up the ground current from the oscillator and caused the bulbs to glow (Figure 13.8)."

"Tesla reported that the bulbs were sixty feet from the secondary coil inside the station. In a second photograph taken outside, Tesla connected an incandescent lamp between a large coil and the ground and again the lamp glowed (Figure 13•9). For this second image, Tesla did not indicate how far away the coil was from the transmitter.[64]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 289-90

[64] NT, CSN, 2 January 1900, 341, 343.

Goal 2: To perfect means for individualizing and isolating the energy transmitted

Tesla recognized that multiple spark transmissions in an area would interfere with each other. He wanted to develop a system to transmit signals with secrecy, immunity, and selectivity. Tesla built on a transmission system demonstrated in New York using two transmission frequencies to control his second radio controlled boat. This is an early form of spread spectrum communications. He used an oscillator which drove two separate tuned primary circuits and a then had two separate tuned secondary circuits. Transmitting on two different frequencies. At the receiver, Tesla had two tuned coils and receiver circuits with sounder that only responded when both signals were present. Tesla attended an America's Cup Race in New York in September 1899 where Marconi's transmissions were purposely jammed by Greenleaf Whitter Packard to show the limitations of spark transmission.

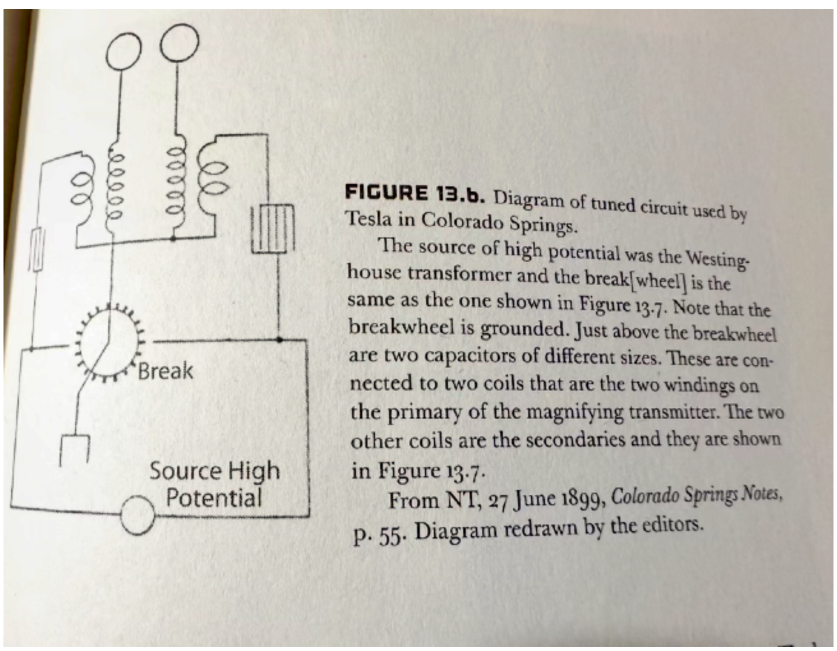


FIGURE 13.6. Diagram of tuned circuit used by Tesla in Colorado Springs.

The source of high potential was the Westinghouse transformer and the break[wheel] is the same as the one shown in Figure 13.7. Note that the breakwheel is grounded. Just above the breakwheel are two capacitors of different sizes. These are connected to two coils that are the two windings on the primary of the magnifying transmitter. The two other coils are the secondaries and they are shown in Figure 13.7.

From NT, 27 June 1899, *Colorado Springs Notes*, p. 55. Diagram redrawn by the editors.

"In running the magnifying transmitter at Colorado Springs, Tesla devoted a great deal of effort to perfecting techniques for tuning that would provide "secrecy, immunity, and selectivity"[54]. To develop a large-scale, capital-intensive communications system, Tesla reasoned that it would be necessary to make messages secure and private. As he explained a few years later, while in Colorado he thought about sending messages across the ocean, "and the greater the distance the more important and the more essential... it was to secure privacy and non-interference of messages; at small distance it does not matter so much whether the operation of a device is interfered with, but when costly apparatus, such as was necessary to employ in my contemplated undertaking was used to produce effects at great distances, the value of a plant and of the whole investment would be destroyed if the messages could not be kept private."[55]

"[ZZ]Though Marconi could send messages from his transmitter to a receiver in 1899, he could not protect his messages from interference from other transmitters operating in the vicinity, For instance, during the 1901 America's Cup race off New York, Greenleaf Whittier Pickard of the American Wireless Telephone & Telegraph Company sent a series of ten-second transmissions that jammed the signals being sent by Marconi and Lee de Forest as they tried to cover the race.[56]"

"Now in Colorado, Tesla was ready to test this idea and see if he could send and receive signals employing a number of distinctive elements. For the transmitter, Tesla used the Westinghouse transformer and breakwheel to supply power not to a single bank of capacitors but instead to two separate banks, each of which was then connected to one turn of the primary loop that ran around the fifty-foot circle in the station (Figure 13.6). Inside the circle, Tesla then had two separate secondary coils. Since each secondary coil was wound with a different length of wire, each generated oscillations at a different frequency. Since the entire transmitter was grounded, both oscillations were sent through the Earth (Figure 13-7).[59]"

"On the receiving end, Tesla used a variety of arrangements involving one, two, or even more receivers. However, to test for security, he often used a receiver with two separate circuits, each of which was tuned to detect one of the two frequencies sent by his transmitter. In this arrangement, the telegraph sounder responded only when it received signals from both detection circuits. By sending and receiving two frequencies in this way, Tesla believed that his messages would be secure and private.[60]"

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 284-86
[55]NT, Fessenden Testimony, 80-81.
[56] Howeth, *History of Communications-Electronics in the United States Navy*, 38-39.
[59] NT, Fessenden Testimony, 24.
[60]Ibid., 30 and NT, CSN, 27 June 1899, 49-50. Leland Anderson has suggested that in developing these techniques for using two frequencies, Tesla should be regarded as the inventor of the AND gate used in the logic circuits of computers; see Anderson, *Guided Weapons & Computer Technology*, 150-51.

Goal 3: To ascertain the laws of propagation of currents through the earth and the atmosphere.

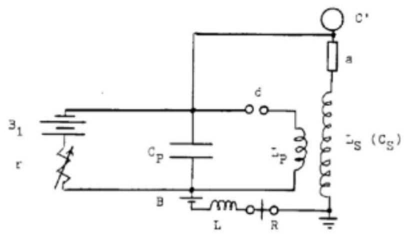


Fig. 3. Redrawn version of Tesla's Sept. 1, 1899 receiver.

Tesla built a unique receiver with 4 different receive circuits based upon designs by himself, Branley, Lodge, and Bose. His Tesla mode was particularly sensitive. Using this receiver and his tuned receive antenna, he observed stationary waves propagated from long distances from a lightning storm as it approached Colorado Springs from the West and receded into the distance in the East. He observed the strength of signal vary with distance. He concluded that transmissions were possible over long distances.

“A significant segment of Nikola Tesla's 1899 Colorado Springs research effort encompassed the detection and monitoring of VLF radio waves emitted from atmospheric electrical storms. (Twenty-nine years later, Karl Jansky was conducting much the same research, at short-wave, when he observed thunderstorms and discovered radio noise emanating from the galactic plane.) Indeed, this branch of radio science may be traced directly to Tesla. Tesla also reported detecting a peculiar extra-terrestrial signal, which he subsequently concluded was from the planet Mars. How did the 1899 receivers of Tesla’s work?”

“Using Tesla's patent applications, correspondence, and Colorado Springs laboratory notes (abbreviated as CSN), about 15 years ago we conducted a study of his novel coherer techniques and reconstructed models of his receiving apparatus. The results were surprising to us, for they revealed an unanticipated level of sophistication not initially apparent in the simple circuit diagrams. His 1899 coherer operation was nothing like the coherer circuits of Branly, Lodge, or Bose. Not only did Tesla's detector circuits include high Q tuned resonators, but also oscillator injected negative resistance [similar to the peak (or "boost") operation of the shunt type Q-multipliers of the 1950s, which raised the effective Q and increased the resonant rise of voltage. This has the same effect as making the detector stage regenerative. A detailed technical discussion of Tesla's 1899 receivers was published in 1994 [2], and an analysis of the "radio telescope" system parameters associated with his Colorado Springs observatory was presented in 1994.[3]"

Tesla's Colorado Springs Receivers (A Short Introduction), Kenneth L. Corum and James F. Corum, PhD. https://teslasociety.com/teslarec.pdf

[2] Corum, K.L., J.F. Corum, and A.H. Aidinejad, "*Atmospheric Fields, Tesla's Receivers and Regenerative Detectors*," Proceedings of the 1994 International Tesla Symposium, International Tesla Society, Colorado Springs, Colorado, 1994. This paper, and others, are available through PV Scientific, http://www.arcsandsparks.com.

[3]Corum, K.L. and J.F. Corum, "*Nikola Tesla and the Electrical Signals of Planetary Origin*," presented at the 1996 International Tesla Symposium, Colorado Springs, Colorado, and at the Fifth International Tesla Conference: "T*esla III Millennium*", Serbian Academy of Sciences and Arts, October 15-19, 1996, Belgrade, Yugoslavia. (The complete eighty-one page report is available through PV 22. Scientific, http://www.arcsandsparks.com. An abbreviated synopsis, including audio clips of the receiver output, can be examined at http://teslasociety.com.)

"In late June and early July, as Lowenstein and Gregg continued to fit out the station, Tesla began making observations in the clear, crisp environment. Since he intended to have his transmitter send current through the Earth to a receiver some distance away, an immediate task was to study the earth's electrical potential and note how it varied. Because the numerous systems in New York for telegraphy, telephony, lighting, and transportation produced too much electrical interference, Tesia had not been able to make any reliable measurements of whether the Earth possessed a natural electrical potential or charge. If the Earth were uncharged, then Tesla would have to use his magnifying transmitter to introduce a tremendous amount of power in order to make the Earth vibrate electrically and transmit power over distances. To use the metaphor of a football (discussed in Chapter 11), an uncharged Earth would be the same as a football with little or no air inside it. However, if the Earth already possessed an electric potential, then Tesla would only need to add a small amount of electricity in order to transmit power; a charged Earth would be the equivalent of a fully inflated football.[13]"

"To increase the sensitivity of his coherer, Tesla placed it in the secondary circuit of a transformer, while the primary of the transformer that was connected to the ground and an elevated terminal of adjustable capacity. This meant that any variations of the electrical potential in was the Earth would give rise to electric surgings in the primary winding, and hence in the instrument. Using this arrangement, Tesla found that the "[t)he earth was ... literally, alive with electrical vibrations, and soon I was deeply absorbed in the interesting investigation."[15]"

"Tesla confirmed his hunch by trackirg a spectacular thunderstorm on 3 July 1899. That evening, a violent storm broke loose in the mountains to the west, passed over

Colorado Springs, and then moved quickly east onto the plain According to Tesla, the storm produced an extraordinary display of lightning, no less than 10-12 thousand discharges being witnessed in two hours. The flashing was almost continuous and even later in the night when the storm had abated 15-20 discharges per minute were witnessed. Some of the discharges were of a wonderful brilliancy and showed often 10 or twice as many branches."

"To measure these lightning discharges, Tesla connected his rotating coherer to the ground and an elevated plate. To magnify any electrical effects transmitted through the ground, he inserted a capacitor between the coherer and the ground. And in order to record each lightning discharge, the coherer caused a telegraph relay to sound. As he reported in his notes, "The relay was not adjusted very sensitively but it began to play, nevertheless, when the storm was still at a distance of about 80-100 miles, that is judging the distance by the velocity of sound. As the storm got nearer the adjustment had to be rendered less and less sensitive until the limit of the strength of the spring was reached, but even then it played at every discharge."[20]

"But "as the storm receded," noted Tesla, "the most valuable observation was made." As the storm continued east over the plains, Tesla turned back to using his rotating coherer and relay. As he recorded in his notes:"

"the instrument was again adjusted so as to be more sensitive and to respond readily to every discharge which was seen or heard. It did so for a while, when it stopped. It was thought that the lightning was now too far and it may have been about 50 miles away. All of a sudden the instrument began again to play, continuously increasing in strength, although the storm was moving away rapidly. After some time the indications again ceased but half an hour later the instrument began to record again. When it once more ceased the adjustment was rendered more delicate, in fact very considerably so, still the instrument failed to respond, but half an hour or so it again began to play and now the spring was tightened on the relay very much and still it indicated the discharges. By this time the storm had moved away far out of sight. By readjusting the instrument and setting it again so as to be very sensitive, after some time it again began to play periodically. The storm was now at a distance of greater than 200 miles at least. Later in the evening repeatedly the instrument played and ceased to play in intervals of nearly a half an hour although most of the horizon was clear by that time."[22]

To explain why the signals started and stopped every half hour, Tesla concluded that he was observing stationary electromagnetic waves. He reasoned that the lightning strokes set off an electromagnetic wave in the earth's crust that then reflected back on itself to create the stationary wave. Tesla was not certain where the waves were reflected. "It would be difficult to believe that they were reflected from the opposite point of the Earth's surface, though it may be possible," he observed. "But I rather think that they are reflected from the point of the cloud where the conducting path began; in this case. the point where the lightning struck the ground would be a nodal point."[23] Since this nodal point would change as the storm continued to move while

Tesla's receiver stayed in one place, the receiver would respond periodically as a peak of the stationary wave passed through the ground underneath the receiver."[24]

Tesla: Inventor of the Electrical Age, W. Bernard Carlson, 2013, Chapter 13 p. 269-72

[13] O'Neill, Prodigal Genius, 179.

[15] 1904 Essay, 429.

[20] NT, CSN, 4 July 1899, 69.

[23] Ibid., 70

[24] Leland Anderson suggested that Tesla detected these periodic signals as a result of the waves being reflected of the mountains west of Colorado Springs. See Seifer, *Wizard,* 471