

NIKOLA TESLA ON HIS WORK WITH ALTERNATING CURRENTS
and Their Application to Wireless Telegraphy, Telephony and Transmission of Power : An Extended Interview
Leland I. Anderson, Editor
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PREFACE

The surfacing of the transcript for this pre-hearing interview with Nikola Tesla by his legal counsel in 1916 resulted from an intensive search in archives of legal firms, some now defunct and others later acquired by contemporary interests. The interview was precipitated by numerous pending court cases as the fledgling radio industry entered a period of fierce competition. Tesla's counsel believed the interview necessary not only in order to prepare for the pressing of his own claims against the Marconi Company, but also to protect his own patent interests when called to give expert-witness testimony in the upcoming litigation foray pitting as adversaries a plethora of new communication companies and their captive radio pioneers.

A case prompting this interview, one of dozens to reach judicial review, was "Marconi Wireless Telegraph Company of America v. Atlantic Communication Company, *et al.*" Atlantic owned and operated the large radio station at Sayville, Long Island. The proceedings opened in 1915 with the calling of expert witnesses including Ferdinand Braun and Nikola Tesla. The specter of war had cast its shadow over Europe, and Count George von Arco, who had also been called, was detained because of services to the German Army in the use of asphyxiating gases and other deadly inventions perfected by him.

The text of this interview was, of course, never intended for publication. Counsel, concerned primarily with the protection of Tesla's patent interests, ask questions almost exclusively relating to the priority of his patents and their application. Tesla candidly discusses his contenders while presenting a thorough history of his work with alternating currents as applied to wireless transmission. In this document, he describes experimental methods, techniques, and apparatus used in his laboratories at New York City, Colorado Springs, and Long Island.

Most of the photographs accompanying this interview are in good condition, but those of schematic and mechanical drawings have suffered some decay with time. These may be the only form of the drawings extant and are reproduced with as much fidelity as possible. For better clarity, five illustrations are reprinted from the February and May, 1913 issues of the *Electrical Experimenter* magazine, Copyright Gernsback Publications, where they subsequently appeared. These are Figures 66, 67, 79, 81 and 82.

Although the interview spanned several days, it is presented in this work as though it was given at one time; all references to interruptions and resumptions have been removed. The text is printed in standard typewriter pica type, unjustified, in the style of hearing proceedings of that period. No alterations have been made in Tesla's remarks except for 'clean-up' additions, typically references to photographs and diagrams, and fill-in words necessitated by occasional rambling and incomplete sentence structure. These additions are provided in brackets []. Helpful notes are also cued to the text in brackets.

INTRODUCTION

What I am going to show you, step by step, is how I proceeded until I finally realized my dream.

Nikola Tesla

You are holding in your hands one of the most remarkable documents in the history of electrical science. Seldom, in technical research, has such a treasure of descriptive commentary and historical documentation been discovered. This book is a veritable Rosetta stone for deciphering and tracing the technical thoughts of one of the world's most distinguished engineering scientists since Archimedes. It describes electrical experiments which took place nearly 100 years ago—but have yet to be replicated.

So astonishing are its contents that it takes one's breath away!

Here, in Tesla's own words, are interpretations (couched in the language of 19th century physics) for electrical phenomena which even today lack satisfactory explanations in the language of modern technical analysis. Oh, it won't tell you how to wire up "the magnifying transmitter" (that arcane instrument for global wireless power transmission),* but it will tell you what instruments Tesla was employing, what his thoughts were, how he conceptualized things, how he proceeded, where he performed his historic experiments, when key results were obtained, and how he reached his conclusions.

* It may just be that there is enough information present to solve the puzzle of the magnifying transmitter. The reader will have to dig for himself.

Tesla, himself, was awe-struck with the results of his scientific endeavor. He expressed astonishment then at what he later asserts is experimentally demonstrable. Listen to the words he uses in this interview to describe the electrical phenomena to his attorney: "magnificent," "it was a marvelous sight," "a wonderful thing," "practically the lamp of Aladdin," "a tremendous display," "glorious," "so marvelous that one would be almost afraid to talk about them. . . ." An Edmund Spenser or a John Milton could be no more eloquent. One of Shakespeare's characters once said, "Bid me discourse, and I will enchant thine ear." Tesla does no less, even in a legal briefing. He weaves the gossamer web of enchantment—which yet thrills our technical imagination and lures us in, nearly 80 years after a stenographer recorded these spoken words!

Who was Nikola Tesla?

In 1896, at the Franklin Institute in Philadelphia, Lord Kelvin said, "Tesla has contributed more to electrical science than any man up to his time." After showering words of praise upon the inventor before a meeting of the Royal Society in London in 1892, Lord Rayleigh declared that Tesla possessed a great gift for electrical discovery. Fortunately, the text of Tesla's speech has been preserved and republished.^{1,2,3} He was one of the earliest scientists to understand the distinction between lumped and distributed resonance and the first to patent voltage magnification by standing waves.

The unit of magnetic induction is named in honor of Tesla. It is commonly understood by power engineers that he was the inventor of the induction motor utilizing the rotating magnetic field and the AC polyphase power distribution system currently used throughout the civilized world.* However, most electrical engineers are unaware that, as late as 1943, he (not Marconi**) was recognized by the U.S. Supreme Court as having priority in the invention of "radio." Even fewer computer scientists are aware that, when certain computer manufacturers attempted to patent digital logic gates after World War II, the U.S. Patent Office asserted Tesla's turn-of-the-century priority in the electrical implementation of logic gates for secure communications, control systems, and robotics. As a result, a monopoly on digital logic gates in general was unable to be secured in the 1950s.

* Charles E. Scott, past president of the AIEE has said, "The evolution of electric power from the discovery of Faraday in 1831 to the initial great installation of the Tesla polyphase system in 1896 [at Niagara Falls] is undoubtedly the most tremendous event in all engineering history. [*Electrical Engineering*, August, 1943 (Vol. 62, No. 8), pp. 351-355.]

** Although it took the courts several decades to figure this out, the facts were well understood by impartial technical men of the day. Robert H. Marriott, the first president of the IRE, once said that Marconi had ". . . played the part of a demonstrator and sales engineer. A money getting company was formed, which in attempting to obtain a monopoly, set out to advertise to everybody that Marconi was the inventor and that they owned that patent on wireless which entitled them to a monopoly." [*Radio Broadcast*, December, 1925 (Vol. 8, No. 2), pp. 159-162.]

Tesla served the electrical engineering profession in its highest offices. In the early 1890s, he was elected as vice-president of the American Institute of Electrical Engineers, now the Institute of Electrical and Electronics Engineers. At the time of his election, Alexander Graham Bell was its president. Tesla served two years as vice-president of the AIEE and, a decade later, one of his laboratory technicians at the Colorado Springs experiments served as the first vice-president of the Institute of Radio Engineers when it was formed in 1903. This was the now, famous consulting engineer Fritz Lowenstein. Lowenstein was the inventor of the grid biased Class A amplifier (for which he received the sum of \$150,000 from AT&T in 1918),⁴ the shaped plate capacitor, and other electrical and mechanical devices. His two IRE papers, with comments on the propagation of ground waves by Ze-neck and sky waves by Austin, appeared in February and June issues of the IRE Proceedings, the year of this interview. It should also be noted that Tesla was a fellow of the AIEE, the American Association for the Advancement of Science, and a dozen other professional societies. He received over 13 honorary degrees from such diverse institutions as Columbia, Yale, and the Universities of Paris, Vienna, Prague, and Sofia.

Recently, another fascinating fact about Tesla has come to light. After all these years, it is now known that he was nominated for an *undivided* Nobel prize in physics in 1937.⁵ Tesla's nominator, Felix Ehernhaft, of Vienna, had previously nominated Albert Einstein for the Nobel prize.

Tesla had the remarkable talent of charming and astonishing his admirers while at the same time enraging his enemies—the phenomenon continues to the present day. It is unfortunate that, despite several current popular biographies, there still exists no definitive technical authority, other than his own scattered publications, to consult on the scientific issues of his intriguing and colorful scientific career. Consider the adulation bestowed upon him by Lord Kelvin, Hermann von Helmholtz, Sir William Crookes, Lord Rayleigh, Sir James Dewar, Robert Millikan, Sir James Fleming, B.A. Behrend, A.E. Kennally, L.W. Austin, W.H. Bragg, Ferdinand Braun, Jonathan Ze-neck, E.W.E Alexanderson, J.S. Stone, Vannevar Bush, W.H. Eccles, Edwin H. Armstrong (who served as a pallbearer at Tesla's funeral, as did Alexanderson), and notably Albert Einstein, Ernest Rutherford, Arthur Compton, and Neils Bohr. There are a number of Nobel laureates, Royal Society fellows, IEEE presidents and fellows, and university presidents in that collection. No one, since Franklin, had so stirred the scientific and engineering world.

In 1893, Thomas Commerford Martin, the third president of the AIEE (1888-1889), edited and published a remarkable collection of Tesla's contemporary lectures. It is in print today, and a century from now it will still be considered an unparalleled classic in scientific literature to be read along with Franklin's *letters*, Priestly's *history*, Faraday's *researches in electricity*, Maxwell's *treatise*, Hertz's *electric waves*, and Heaviside's *electrical papers*. In 1919, 26 years after publishing the work on Tesla, Martin wrote,

"Tesla's influence may truly be said to have marked an epoch in the progress of electrical science. Very little data, however, has been procurable that is descriptive of his later researches, and more is the pity from the historical standpoint. Tesla has not finished. The world waits expectantly for each fresh touch of his vitalizing thought upon the big electrical problem of the age."⁶

Unlike most of the aforementioned scientists, Dr. Tesla—for so it is appropriate to call him—had no financial support to fall back on from a faculty position or research institute. His ideas had to support themselves and him in the technical marketplace. It is not surprising, therefore, that he felt no compulsion to share further technical details in the open scientific literature of his day. For these you must dig (and dig, and dig) through the patent literature, where only enough is disclosed to make it clear to one "skilled in the art.

Readers will also be struck with Tesla's lighter side. His sense of humor and his quick wit shine through when he describes his 1893 RF demonstration before the public at the Sixteenth Convention of the National Electric Light Association in St. Louis, where he was distinguished as honorary member: "There was a stampede in the two upper galleries and they all rushed out. They thought it was some part of the devil's work." (p. 87) His humor is also evident in his description of the influence that his demonstrations had upon the Royal Institution in London in 1892: "The scientists simply did not know where they were when they saw it." (p. 95)

Tesla could also be sarcastic: "The greatest men of science have told me [the Tesla coil] was my best achievement. . . . For instance, a man fills this space with hydrogen; he employs all my instrumentalities, everything that is necessary, but calls it a new wireless system—I *cannot stop it*. Another man puts in here a kind of gap. *He gets a Nobel prize for it*. . . . The inventive effort involved is about the same as that of which a 30-year old mule is capable." (p. 48)

Electrical History

For those deeply active in the technical evaluation of historic electrical research, it is a source of intense frustration and shattering disappointment to find "a new book" (or even to have a TV "documentary") appear, only to discover that the authors (a) didn't penetrate the technical aspects of their subject sufficiently to understand what the real issues were, and (b) continue to perpetuate

unsubstantiated popularized assertions, myths, and historical errors 'generated at victory balls' and not at the scene of the battle. This is especially true of authors addressing topics in the realm of RF, antennas, and distributed circuits (i.e., radio) where merely an academic knowledge of electronics or Maxwell's theory is insufficient to guarantee professional livelihood in those disciplines. It leads one to conclude that no reliable history of this research can be written until those with adequate technical training and experience devote their time and effort to the subject.

But this document is a breath of fresh air. It sets straight a region of the radio history puzzle which has been incongruous for over nine decades. When we saw these pages, our first impulse was to start an immediate technical evaluation: replicate apparatus, search for partially disclosed concepts and missing pieces, clarify issues, and execute a technical analysis.

We believe that this document will initiate considerable activity along these lines, performed as well by a broad spectrum of investigators. This introduction is not an appropriate medium to discuss such pursuits. Instead, we invite the reader to consider the wonderful personal narrative which will be placed before him.

Feel the pathos in Tesla's voice as he describes the famous system of four-tuned circuits: Every wireless message that has ever been transmitted to any distance has been transmitted by this apparatus; there is no other way. Twenty-seven more years would pass before the highest courts of the land would echo in agreement. From those legal proceedings would emerge the acid test for any radio system. For this reason, Tesla, not Hertz, Marconi, or De Forest has been given the title inventor of radio. The courts clearly exercise a distinction between "innovated" and "invention." How strange that, even at this late date, there are those that still don't understand what happened.

Fresh Surprises from Tesla

Tesla has never lost the magical touch. Even today, exactly 100 years after his lecture at the Royal Institution (London), his careful engineering skill still has power to surprise and delight a technical audience. But what was unexpected from Tesla—today, in 1992, is a fresh glimpse of his life's work. Those of us that have toiled with RF technology, and electromagnetic radiation and propagation owe a great debt to Anderson, one of the world's leading authorities on Tesla, for publishing this remarkable document. It is absolutely unique. We have no doubt that it is destined to join *My Inventions; Lectures, Patents, and Articles; Und Sein Werk; Invention, Researches and Writings*, and *Colorado Springs Notes* as a member of the historic "canonical Tesla publications." Anyone doing a serious technical evaluation of Tesla's research must turn to these works.

Return to 1916

It is important to grasp the pulse of society at the time of this interview. In your mind's eye, return to the era of 1916. A Princeton history professor named Woodrow Wilson, the same age as Tesla, will be re-elected to lead the country. War has been raging in Europe for the past 18 months. The Lusitania has been sunk. Within a year, the U.S. would declare war on Germany and more than 100,000 young Americans would go "over there" never to return home to their loved ones. Irving Berlin is writing songs, 24 states have voted-in prohibition, and Ford has produced his millionth automobile. Motorized taxis have just appeared on the streets of New York, and electricity has made possible the new skyscrapers that now begin to dominate the city's skyline.

On Mount Wilson, in California, the new 100-inch telescope is nearing completion. In Europe, Albert Einstein has just introduced the general theory of relativity, and astronomer Arthur Stanley Eddington is quietly preparing expeditions to islands off the coast of Africa and Brazil to test the theory during a solar eclipse. Consultant John Stone Stone has just completed his term as president of the IRE, and Harvard Professor A.E. Kennelly has stepped into the position—he had previously served as president of the AIEE in 1898. The IRE now has almost 1,000 members. Dr. Ze-neck's treatise on wireless telegraphy has just appeared, and he will soon be held "under arrest" at Ellis Island for the duration of WWI. Ze-neck would later serve as vice-president of the IRE during 1933.

At Bell Labs, John R. Carson has just shown that single-sideband transmission is mathematically possible. The first transcontinental telephone link has just been demonstrated between Alexander Graham Bell in New York and Thomas A. Watson in San Francisco, and wireless service between the U.S. and Japan has been inaugurated. In 1916 the electromagnetic spectrum is populated only by amateurs and commercial telegraph stations. There is yet no commercial AM broadcasting, although Frank Conrad, who would be vice-president of the IRE 11 years later, has just built an amateur station. It would become Westinghouse's KDKA in November, 1920.

Tesla has recently published "Some Personal Recollections" in the *Scientific American*. He has proposed that the Secretary of Defense create a Defense Science Board. Looking toward the future, he publishes an essay called, "The Wonder World to be Created by Electricity." E. Taylor Jones and W.M. Jones have published, in the *Philosophical Magazine* (London), erroneous lumped-circuit analyses of Tesla coils. Nineteen years later, one of E.O. Lawrence's proteges at Berkeley would declare, in pages of

the *Physical Review*, that Tesla coils "cannot be treated usefully by mathematics."

Tesla prophesies that radio-controlled torpedoes and missiles will soon expose the general population, not just the military, to the horrors of war. In 1916, the *Scientific American* discusses Tesla's new automobile speedometer, the tower at Shoreham (Long Island) will pass from his hands, and Hugo Gernsback's magazine, the *Electrical Experimenter* will contemplate his Colorado Springs experiments. Princes Lwoff-Parlaghy entertains Tesla among New York socialites, and her painting of Tesla appears in *The New York Times*. It will later appear on the cover of *Time* (July 20, 1931).

A Visit to a Law Office

As an unseen guest, you have been ushered into an oak-decorated law office in New York City. Before you sits Nikola Tesla, now 60 years old, still with bushy black hair, slight wrinkles beginning to form around his piercing light blue-grey eyes. He possesses a winning smile and a firm handshake. He wears no jewelry or watch fob. He has a somewhat high-pitched, reedy voice, and speaks quickly and convincingly. He is still very much the cosmopolitan New Yorker in his speech, manner, and demeanor. He has brought with him numerous drawings, papers, and photographs for reference.

Across a wooden table sits his attorney. His demeanor is professional and serious, his questions are penetrating, his manner is deliberate. He is well aware of the professional reputation and international regard of the esteemed gentleman that sits before him, and he is intent upon understanding every detail that he can turn to his client's advantage in the dramatic contests at law which will soon occur. Also present is a stenographer, intent upon providing the attorney with an accurate written transcription of every thought which will soon unfold. The formalities being over, the counselor begins to speak. . . .

K.L. Corum* and J.F. Corum, Ph.D.**
April 4, 1992

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- (3) Tesla, Nikola, *Experiments with Alternate Currents of High Potential and High Frequency*, McGraw Publishing Co., New York, 1304, 162 pp.
- (4) Discussion of "A History of Some Foundations of Modern Radio-Electronic Technology," Comments by Lloyd Espenschied, *Proceedings of the IRE*, July, 1959 (Vol. 47, No. 7), pp. 1254, 1256.
- (5) Crawford, E., Heilbron, J.L., and Ullrich, R., University of California, 1987.
- (6) Martin, T.C., and Goles, S.L., *The Story of Electricity*, The Story of Electricity Co., Vol. 2, 1919, p. 107.

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** Battelle, Columbus, Ohio

IV. Apparatus for Transformation by Condenser Discharges; Damped Waves

Tesla

This work [Fig. 31] was begun already in 1889. This type of apparatus is identified with my name as certain as the law of gravitation is with that of Newton. I know that some have claimed that Professor Thomson also invented the so-called Tesla coil, but those feeble chirps ne'er went beyond Swampscott. Professor Thomson is an odd sort of man; very ingenious, but he never was a wireless expert; he never could be. Moreover, it is important to realize that this principle is universally employed everywhere. The greatest

men of science have told me that this was my best achievement and, in connection with this apparatus [referring to schematics of Fig. 31], I may say that a lot of liberties have been taken. For instance, a man fills this space [break D] with hydrogen; he employs all my instrumentalities, everything that is necessary, but calls it a new wireless system—the Poulsen arc. I cannot stop it. Another man puts in here [referring to space between self-inductive lines L L] a kind of gap—he gets a Nobel prize for doing it. My name is not mentioned. Still another man inserts here [conductor B] a mercury[-arc] rectifier. That is my friend Cooper Hewitt. But, as a matter of fact, those devices have nothing to do with the performance.

(No Model.)

N. TESLA.

METHOD OF AND APPARATUS FOR ELECTRICAL CONVERSION AND DISTRIBUTION.

No. 462,418.

Patented Nov. 3, 1891.

Fig. 1

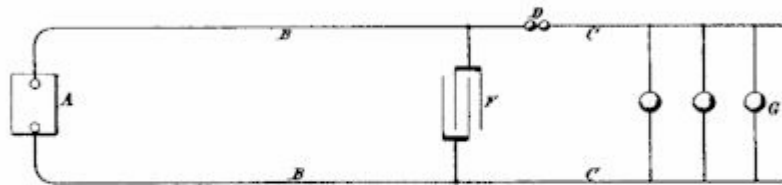
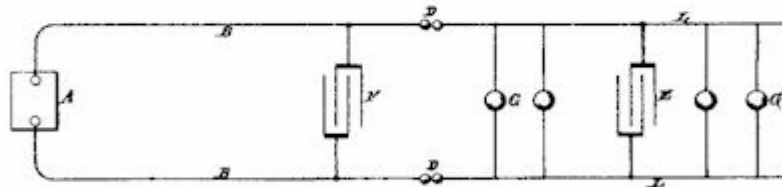


Fig. 2



Witnesses:

Raphael Nelson
Frank B. Murphy.

Inventor

Nikola Tesla
by Duncan Hage.
Attorneys.

Figure 31.

Method of Transformation of electrical energy by oscillatory condenser discharges described in U.S. Patent No. 462,418 of November 3, 1891. Application filed February 4, 1891. Announcement of this invention was made in Tesla's lecture before the American Institute of Electrical Engineers at Columbia College, May 20, 1891, where it was predicted that this apparatus afforded vast possibilities and would play an important part in the future. Illustrated and described in T.C Martin book, Figs. 126 and 127, pp. 191-194.

If these men knew what I do, they would not touch my arrangements; they would leave my apparatus as it is. Marconi puts in here [break D] two wheels. I showed only one wheel; he shows two. And he says, "See what happens when the wheels are rotated; a

wonderful thing happens!" What is the wonderful thing? Why, when the teeth of the wheels pass one another, the currents are broken and interrupted. That is the wonderful thing that happens? The Lord himself could not make anything else happen unless he broke his own laws. So, in this way, invention has been degraded, debased, prostituted, more in connection with my apparatus than in anything else. Not a vestige of invention as a creative effort is in the thousands of arrangements that you see under the name of other people—not a vestige of invention. It is exactly like in car couplings on which 6,000 patents have been taken out; but all the couplings are constructed and operated exactly the same way. The inventive effort involved is about the same as that of which a 30-year-old mule is capable. This is a fact.

This is one of most beautiful things ever produced in the way of apparatus: I take a generator of any kind. With the generator I charge a condenser. Then I discharge the condenser under conditions which result in the production of vibrations. Now, it was known since Lord Kelvin that the condenser discharge would give this vibration, but I perfected my apparatus to such a degree that it became an instrument utilizable in the arts, in a much broader way than Lord Kelvin had contemplated as possible. In fact, years afterwards when Lord Kelvin honored me by presenting to the British Association one of my oscillators of a perfected form, he said that it was "a wonderful development and destined to be of great importance."

[Returning to a discussion of Fig. 31], [E] is supposed to be a condenser. That [A] is the generator. Now then, supposing that this is a generator of steady pressure. I can obtain oscillations of any frequency I desire. I can make them damped or undamped. I can make them of one direction or alternating in direction as I choose. At G are devices which operate—lamps, or anything else. Some experimenters who have gone after me have found a difficulty. They said,

"No, we cannot produce a constant train of oscillations."

Well, it is not my fault. I never have had the slightest difficulty. I produced constant oscillations and I have described how I produced them. Anyone who has no more than my own skill can do it.

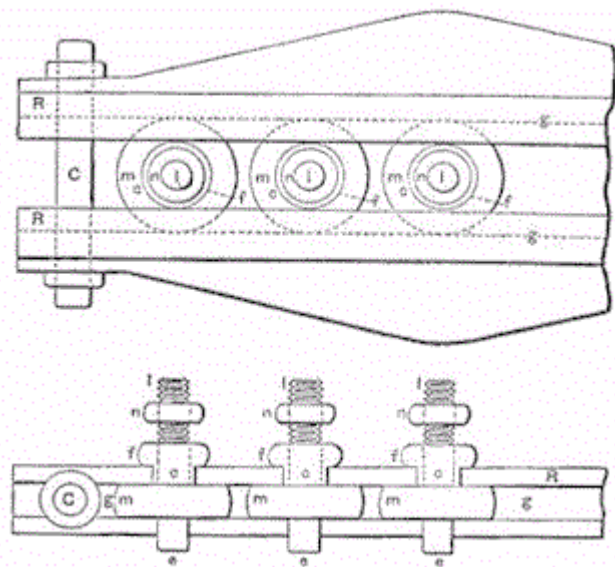


Figure 32.

Quenched spark gap. (Tesla at that time pointed out the future of quenching and showed that oscillations can be maintained without a spark being visible to the naked eye between the knobs.) Illustrated in T.C. Martin book, Figs. 135 and 136, p. 211.

This [Fig. 32] is another improvement in that particular device, which was the weakness of the invention and which I tried to eliminate. This device incorporated many spark gaps in series. It had a peculiar feature; namely, through the great number of gaps, I was able, as I have pointed out in my writings, to produce oscillations without even a spark being visible between the knobs. This device is now known in the art as the "quenched spark gap." Professor Wein has formulated a beautiful theory about it, which I understand has netted him the Nobel prize. Wein's theories are admirable. The only trouble is that he has overlooked one very important fact. It is this: If the apparatus is properly designed and operated, there is no use for the quenched gap, for the oscillations are continuous anyway. The radio men who came after me had the problem before them of making a bell sound, and they immersed it in mercury. Now, you know mercury is heavy. When they struck their bell, the mercury did not permit it to vibrate long because it took away all the energy. I put my bell in a vacuum and make it vibrate for hours. I have designed circuits in connection with an enterprise in 1898 for transmission of energy which, once started, would vibrate three years, and even after that the oscillations could

still be detected. Professor Wein's theory is very beautiful, but it really has no practical meaning. It will become useless as soon as the inefficient apparatus of the day, with antennae that radiate energy rapidly, [are] replaced by a scientifically designed oscillator which does not give out energy except when it gets up to a tremendous electromagnetic momentum.

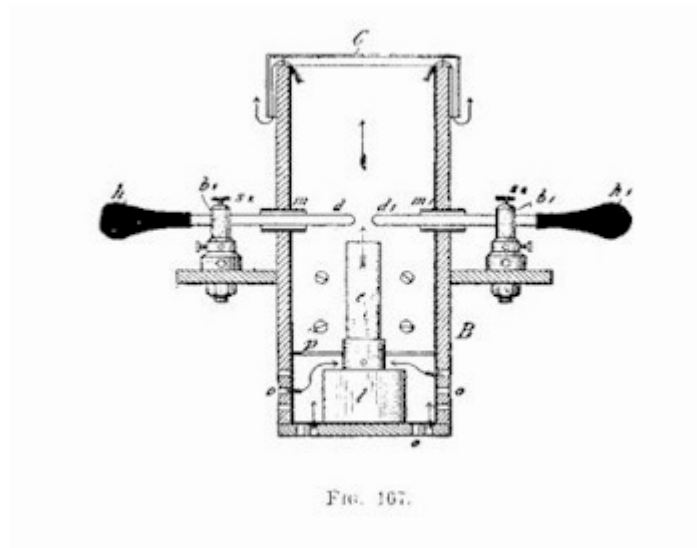
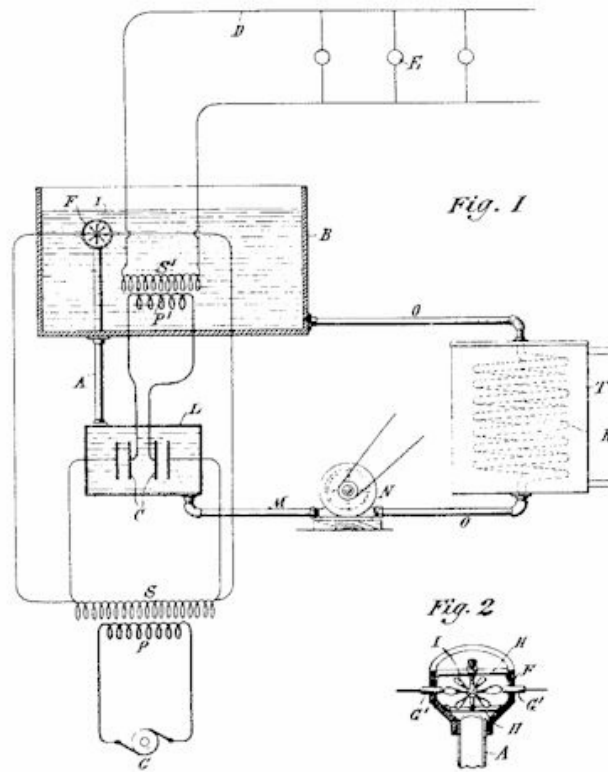


Figure 33.

The discharger working in an atmosphere, chiefly consisting of hydrogen, still further weakened by heat. The use of hydrogen in this connection has been claimed as a discovery and patented. Presented in Tesla's lectures before the Franklin Institute and the National Electric Light Association. T.C. Martin book, Fig. 167. pp. 307-308.

In this form of break [Fig. 33], I changed the atmosphere in which the arc was operating. The atmosphere was mostly hydrogen, and with this device I performed my experiments before the Franklin Institute in Philadelphia and the National Electric Light Association in St. Louis. This has been used by Poulsen and it is now called the "Poulsen arc" and "Poulsen system." But, of course, there is no invention in it. I am on record with prior publications, and besides, the hydrogen does not have any other effect except that it lowers the tension under which the device can operate. It has the disadvantage of producing asymmetrical or distorted waves, and the impulses obtained are not best suited for tuning.



Witnesses
Raphael Netter
James W. Cottler

Inventor
Nikola Tesla
 By *Geo. S. Atteridge*
Duncan Page

Figure 34.

Oscillatory apparatus with interrupter in oil. Exhibited in the Chicago Exposition of 1893 before Helmholtz. Described in U.S. Patent No. 514,168 of February 6, 1894. Application filed August 2, 1893.

This [Fig. 34] is the apparatus used in the Chicago Exposition of 1893, at which time I explained for the first time to Professor Helmholtz my plan for transmitting energy. After I had shown Professor Helmholtz and other scientific men there certain phenomena, he asked me,

"Now, what is all this intended for?"

I told him I was trying to develop an apparatus for transmitting energy without wire for telegraphy, telephony, and other purposes. When I explained to Professor Helmholtz the whole idea, I said,

"Excellency, do you think that my plan is realizable?"

He replied,

"Why, certainly it is, but first you must produce the apparatus."

I started then and there to produce the apparatus.

Counsel

Was that conversation at the the Chicago Exposition?

Tesla

Yes. It took place in a pavilion which was built especially for exhibiting my inventions and discoveries. I believe Professor Wedding was there and some other scientists whom I cannot remember now. I showed Professor Helmholtz my vacuum tubes and performed many other experiments.

Counsel

Will you describe this apparatus in a little more detail?

Tesla

The apparatus [Fig. 34], as you see, comprised primary and secondary coils immersed in a large tank of oil. The break was automatically effected by means of a turbine. The oil was circulated by a pump, and the current [i.e., stream flow] of oil drove the turbine which effected the make and break. Owing to the fact that the oil used was a very good insulator, rapidly flowing and of great dielectric strength, these make-and-break points were very close together, and the arcs extremely short. The effects were accordingly more intense. Here [T in Diag. 1 of Fig. 34] is a cooler through which the oil was circulated. The oil was forced through the gaps at great speed, and as it flowed out it was supplied again to the tank and the current driving the turbine.

Counsel

That device [Diag. 2 of Fig. 34] you call a turbine?

Tesla

Yes. It had vanes like those of a propeller and constituted a rotary break in the circuit.

Counsel

What was your prime source [of power]?

Tesla

The primary source was an alternator with a frequency of 133 cycles and, if I recollect rightly, the pressure [at the secondary] was about 20,000 volts. I may have had 10,000 volts. I am not sure what it was, but it must have been certainly from 10,000 to 20,000 volts—within that range.

Counsel

I notice you have two sets of transformers in there marked S and S', have you not?

Tesla

This [S'] is my oscillatory circuit. That [S] is the transformer from which the condenser was charged. Here [at S] we had 20,000 volts, or whatever it was, from the commercial transformer and here [at S'] is my secondary which generated the high frequency currents. The rotary gap is shown in detail [Diag. 2 of Fig. 34].

I had a special reason for showing this. To meet that great man Helmholtz and other scientific men, and to bring before them for the first time the results of years of previous labor, was an important moment in my life—particularly because Professor Helmholtz gave me the assurance himself that what I explained to him was realizable, provided that I could produce the apparatus. I was very much

encouraged.

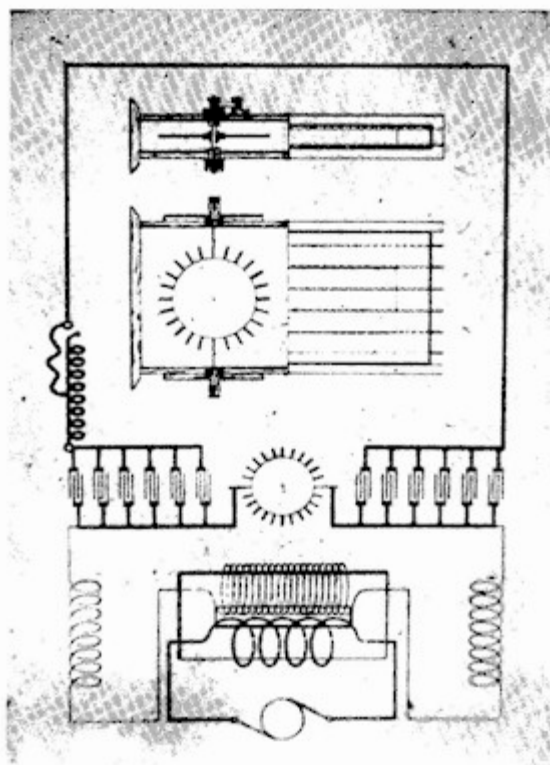


Figure 35.

Apparatus with mechanical break as installed on a large scale in the laboratory at South Fifth Avenue and subsequently at 46 East Houston Street. Described in U.S. Patent No. 645,576 of March 20, 1900. Application filed September 2, 1897.

This [Fig. 35] is the apparatus I had at 35 South Fifth Avenue and also Houston Street. It shows the whole arrangement as I had it for the demonstration of effects which I investigated.[*] This cable you see [square loop in top half of Fig. 35] is stretched around the hall. These are my condensers. There is the mechanically operated break, and that is a transformer charged from the generator. That is the way I had it for the production of current effects which were rather of damped character because, at that period, I used circuits of great activity which radiated rapidly. In the Houston Street laboratory, I could take in my hands a coil tuned to my body and collect $3/4$ horsepower anywhere in the room without tangible connection, and I have often disillusioned my visitors in regard to such wonderful effects. Sometimes, I would produce flames shooting out from my head and run a motor in my hands, or light six or eight lamps. They could not understand these manifestations of energy and thought that it was a genuine transmission of power. I told them that these phenomena were wonderful, but that a system of transmission, based on the same principle, was absolutely worthless. It was a transmission by electromagnetic waves. The solution lay in a different direction. I am showing you this [diagram] simply as a typical form of apparatus of that period, and if you go over the literature of the present day you will find that the newest arrangements have nothing better to show.

Counsel

What was the make and break frequency that you got from that apparatus?

Tesla

It was 5,000, 6,000—sometimes higher still. I had two oppositely rotating discs which I will show you and with which I could have reached, probably, 15,000 or 18,000.

Counsel

What wave frequencies did you develop?

Tesla

I could operate from a few thousand up to a million per second, if I wanted.

Counsel

What did you actually use?

Tesla

In these demonstrations, which I showed these effects, these most powerful effects that were the sight of New York at that time, I operated with frequencies from 30,000 to 80,000. At that time I could pick up a wire, coil it up, and tell what the vibration would be, without any test, because I was experimenting day and night.

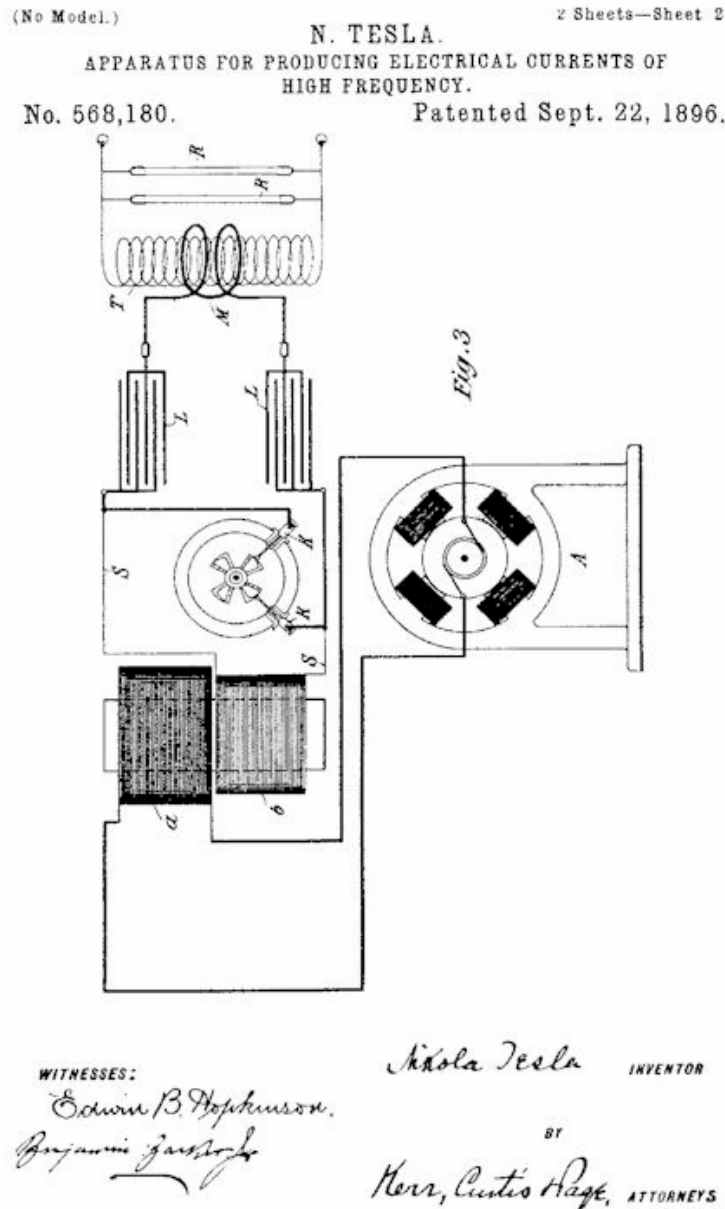


Figure 36.

Isosynchronous mechanical break used in the laboratory at 35 South Fifth Avenue. Described in U.S. Patent Nos. 568,179 and 568,180 of September 22, 1896. Applications filed July 6 and 9, 1896. (Diagram taken from Patent No. 568,180.)

This [Fig. 36] is a form of break which I developed in working with alternators. I recognized that it was of tremendous advantage to break at the peak of the wave. If I used just an ordinary break, it would make and break the current at low as well as high points of the wave. Of this apparatus I had two forms; one in which I drove the break right from the shaft of the dynamo and the other in which I drove it with an isochronous motor. Then, by a movement of these knobs (K K), I would make the adjustments so that the makes would occur exactly at the top of the wave. That is a form of break which is embodied in hundreds of patents and used now extensively.

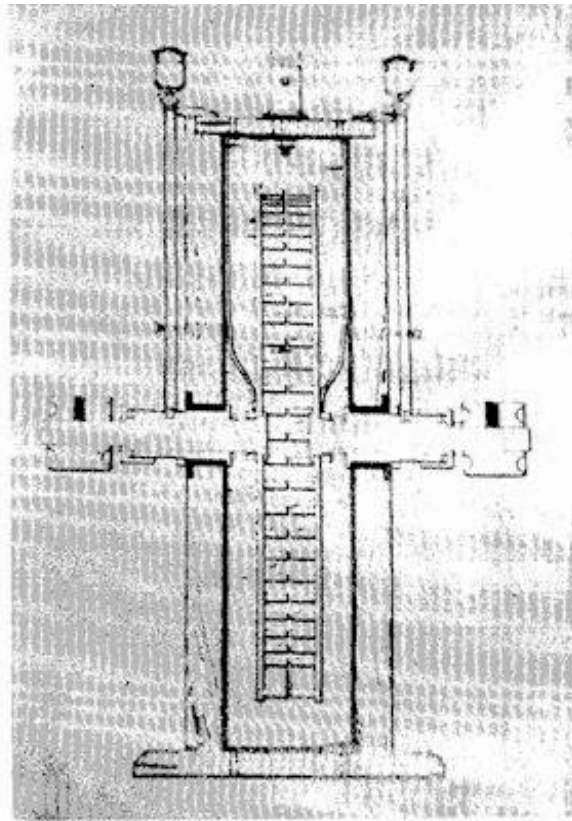


Figure 37.

Mechanical break with two oppositely rotating discs used for the purpose of increasing the number of breaks and alternating oscillations practically undamped. (Subsequently patented by others.)

Here [Fig. 37] I show an apparatus that was installed in the Houston Street laboratory prior to the other break because I wanted to get as high a number of impulses as possible. The drawing dates from the spring of 1896. It is a break with which I could reach from 15,000 to 18,000 interruptions per second. I used it very much until later I found it was not necessary. That is the innocent device which Marconi thought a great invention.

Counsel

This is also a rotary gap?

Tesla

Yes, and it consists of two discs of aluminum, with teeth of aluminum on the side. They were rotated by two motors in opposite directions, and as they rotated they alternately closed and opened the circuit. In some instances I used an uneven number of teeth on one and an even number on the other so that I could produce as many breaks as I desired. I will show you later an apparatus more perfect than this one, and of a different kind, in which I have 24 stationary contacts, and 25 rotating elements that established the contact and broke it, so that by one revolution I obtained 24 times 25, or 600 interruptions [per revolution].

Counsel

Whenever you say "the break", you mean "a spark gap"?

Tesla Yes; otherwise I use the term "circuit controller," preferably.

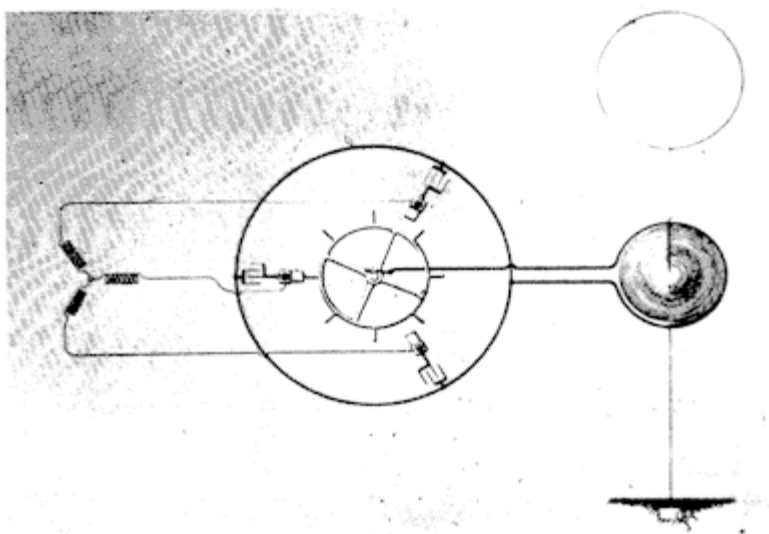


Figure 38.

Use of multi-phase generator with mechanical break. Experiments in the laboratory at 35 South Fifth Avenue and subsequently.

This [Fig. 38] illustrates another development in a different direction. In order to increase the number of breaks, I employed currents of different phase. I had in my laboratory, permanently, a two-phase dynamo and could get phases between; that is, from two phases, 90 apart, I could obtain four phases, 45 apart. Here is an arrangement shown as I had it, working with three phases [60 apart, and could obtain six phases, 30 apart], and later on I had one with four phases [45 apart, and could obtain eight phases 22 1/2 apart]. You see, as I multiplied the number of the phases, I increased the number of the fundamental discharges.

Counsel

What is the date of this apparatus?

Tesla

This I employed already in the 35 South Fifth Avenue laboratory, because I remember that I gave entertainments to several scientific societies and it was then present there. I know on one occasion there was the Society of Architects, and another, the Electrotherapeutic Society, and then I had distinguished men like Mark Twain and Joseph Jefferson—I gave them a demonstration which was published in Martin's article in the Century Magazine of April 1895, and I know that on these occasions I used a two-phase arrangement. Later on I made it four phase. That apparatus existed, therefore, prior to the destruction of my laboratory in 1895.

Counsel

Do you recall any publication in which this diagram was illustrated?

Tesla

I made no publication, and I vividly remember that when I installed my apparatus on Long Island I had an arrangement with four transformers and four phases 45 apart. After I had been using this apparatus there, several years afterwards, I ran across a patent, I believe held by the General Electric Company, describing precisely the same arrangement.[*] It was a similar experience as with that patent of Fessenden on the compressed air condenser. Any time I want to use these improvements all I need to do is to produce my records and that will settle the patents.

Counsel

When was that drawing [Fig. 38]?

Tesla

This is from an old patent drawing which was made by Mr. Netter.

Counsel

But that did not go to patent?

Tesla

No. I have hundreds of inventions that were to be patented but side-stepped. The expense was too great and I could not do it. This form of apparatus with two and four phases was used prior to the destruction of my laboratory in 1895, and it was installed on a large scale with four phases in my plant on Long Island with which I was to telephone around the world, but that is a long story.

Counsel

In that use you made of it at your laboratory, was that connected up as shown there [Fig. 38], to an antenna?

Tesla

I used the apparatus, yes, in connection with the antenna too, but this is from a patent drawing in which an antenna is shown; I mean, I used it in every connection. [Fig. 38] illustrates an antenna with my transmitting circuit, but the apparatus was used in all my work, in all my investigations.

Counsel

And when this was connected in and used in an antenna, did you use it as in other instances—go off and listen to the notes which you received?

Tesla

Oh, certainly. But I remember that, besides this, I had different kinds of apparatus. Then I had a sensibly damped wave because at that time I still was laboring under the same difficulties as some do this day—I had not learned how to produce a circuit which would give me, with very few fundamental impulses, a perfectly continuous wave. That came with the perfection of the devices. When I came to my experiments in Colorado, I could take my apparatus like that and get a continuous or undamped wave, almost without exception, between individual discharges.

Counsel

Speaking of your not having perfectly undamped waves at that time, you were referring to that character of circuit?

Tesla

Yes, but with another kind of circuit I could, of course. The advantage of this apparatus was the delivering of energy at short intervals whereby one could increase activity, and with this scheme I was able to perform all of those wonderful experiments which have been reprinted from time to time in the technical papers. I would take energy out of a circuit at rates of hundreds or thousands of horsepower. In Colorado, I reached 18 million horsepower activities, but that was always by this device: Energy stored in the condenser and discharged in an inconceivably small interval of time. You could not produce that activity with an undamped wave. The damped wave is of advantage because it gives you, with a generator of 1 kilowatt, an activity of 2,000, 3,000, 4,000, or 5,000 kilowatts; whereas, if you have a continuous or undamped wave, 1 kilowatt gives you only wave energy at the rate of 1 kilowatt and nothing more. That is the reason why the system with a quenched gap has become popular.

I have refined this so that I have been able to take energy out of engines by drawing on their momentum. For instance, if the engine is

of 200 horsepower, I take the energy out for a minute interval of time, at a rate of 5,000 or 6,000 horsepower, then I store [it] in a condenser and discharge the same at the rate of several millions of horsepower. That is how these wonderful effects are produced. The condenser is the most wonderful instrument, as I have stated in my writings, because it enables us to attain greater activities than are practical with explosives. There is no limit to the energy which you can develop with a condenser. There is a limit to the energy which you can develop with an explosive.

A common experiment, for instance, in my laboratory on Houston Street, was to pass through a coil energy at a rate of several thousand horsepower, put a piece of thick tinfoil on a stick, and approach it to that coil. The tinfoil would melt, and would not only melt, but while it was still in that form, it would be evaporated and the whole process took place in so small an interval of time that it was like a cannon shot. Instantly I put it there, there was an explosion. That was a striking experiment. It simply showed the power of the condenser, and at that time I was so reckless that in order to demonstrate to my visitors that my theories were correct, I would stick my head into that coil and I was not hurt; but, I would not do it now.

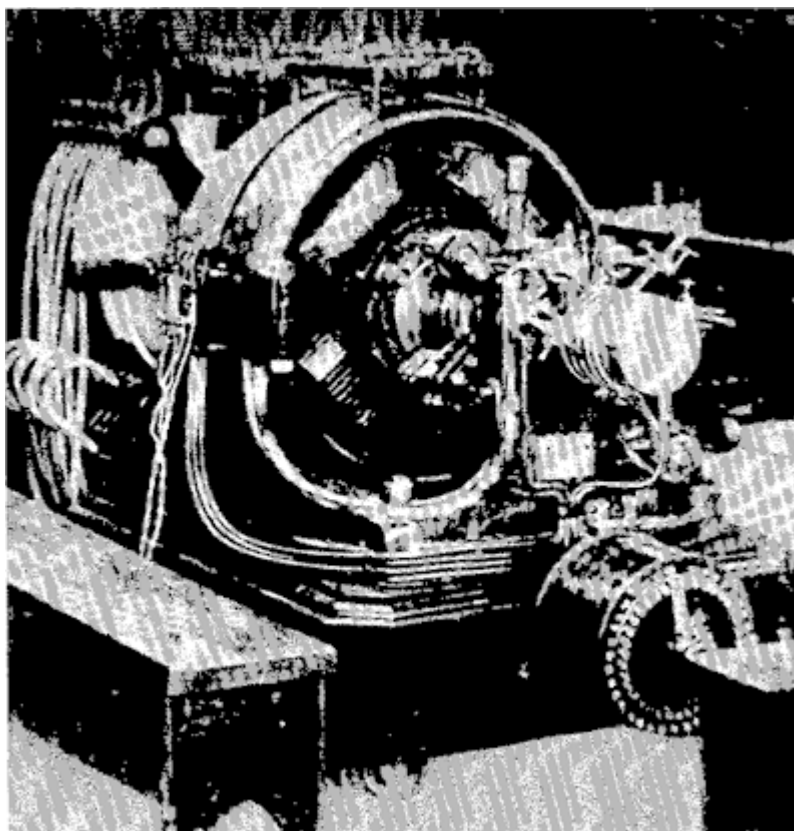


Figure 39

Apparatus furnishing direct currents of high tension, producing undamped electrical oscillations of high frequency. (This is also shown in [Fig. 27]). Apparatus built in 1895.

[Fig. 39] shows a four-phase machine which was furnished me by the Westinghouse Electric Company at the close of 1895. My laboratory burned out in May, and I urged my friend, Mr. Albert Schmidt, who was the Superintendent, to give me this alternator as soon as possible. He worked day and night until he got it out, and he certainly did notable work because while the machine was rated at 30 horsepower, I have run it at 150 horsepower.

By the way, and this is a painful reflection, it was Schmidt and I who developed this type of frame and this general arrangement which is universally adopted now—a base, with the magnets cast below, split at the center line, and a corresponding upper part. That is now used everywhere. I remember years ago, some of my friends, Messrs. Crocker and Wheeler, started with those long magnets and I told them, "The sooner you throw these away and adopt this construction, the better it will be for you." They have got it now; it is all right.

Counsel

How is this machine [Fig. 39] shown in connection with that?

Tesla

This dynamo [Fig. 39], you see, is a two-phase machine; that is, I develop from it currents of two-phase. Now, there are four transformers. You see them down here [lower left of Fig. 39] that furnish the primary energy. From these two phases I develop four phases. [However,] this involves something else which I have referred to before; namely, an arrangement which enables me to produce from these alternating currents direct currents and undamped—absolutely undamped—isochronous oscillations of any period I like.

This is accomplished in the following manner: The secondaries of the four transformers could each develop 44,000 volts. They were specially built for me by the Westinghouse Company. They could, however, be connected in such a way that each would give 11,000 volts, and then I would take these 11,000 volts and these four phases and commutate them by a commutator consisting of aluminum plates, or aluminum segments, which were rotated in synchronism with the alternator. Then I obtained a continuous pressure; that is, direct current of a tension of 44,000 volts, and with these 44,000 volts I charged my condensers. Then by discharging the condensers, either through a stationary gap or through a gap with a mechanical interrupter, I obtained any frequency I desired, and perfectly undamped waves. This arrangement was installed in 1901 in my wireless plant at Long Island, with which I was to telephone around the world.

Counsel

Who built that machine?

Tesla

The Westinghouse Company, [under direction of] Mr. Albert Schmidt, Superintendent. It was especially built for me and furnished to my laboratory on Houston Street.

While I was with the Westinghouse Company, I did two things in addition to bringing my motors to them. I had discovered that Bessemer steel was a much better material for transformers and motors than the soft iron which was previously used. When I came to Pittsburgh, my motors gave results which their motors could not at first produce, and I told them that I had used Bessemer steel. I discovered, in following up the analysis of the steels which were used, that the Bessemer was not steel but really soft iron. The Westinghouse people then adopted my suggestion. At first, Mr. Shallenberger and other electricians there objected very much, but I persuaded them and when the transformers were built we found that we could get 2 1/2 times the output we got before.

The Westinghouse people kept it a secret for a long time and no one understood how they could make such fine transformers, but all they did was to use the Bessemer steel, on my suggestion, instead of the soft iron the General Electric and other people used. Mr. Westinghouse especially requested me to join efforts with Mr. Schmidt and improve the design of his machines, and we did so. We evolved this design, introduced the ready-made coils, which are pressed on the armature, and other improvements. I took a couple of patents out with Mr. Schmidt, and Mr. Westinghouse was very nice about it. I think he compensated me with \$10,000, or something like that, for my suggestions.

Counsel

You have spoken of the use of that machine at Houston Street. In what way was it used?

Tesla

I used this machine, as I said, either to produce alternating currents and then interrupt them with a mechanical break at the high peaks of the wave; or, I used alternating currents and interrupted them with an independent rotating break having a great number of teeth. Or, I generated continuous currents by commutating the high tension alternating currents of the transformer. At that time I had two transformers from which I obtained a constant pressure, charged the condenser, and produced undamped waves of any frequency I wanted. As to the machine here [Fig. 39], that is the way it was arranged. It was for the generation of continuous electromotive force and production of undamped waves—from 1895 and on.

Counsel

What sort of apparatus was it connected up to for the purpose of absorbing these waves?

Tesla

It was the same as shown here [Fig. 38]. It was connected to the condensers, and these condensers were discharged through a primary which excited the secondary; the antenna was included in the secondary. At other times we discharged the condensers directly so that I could use the antenna without the secondary.

Counsel

In the same way did you note the operation of these waves?

Tesla

We did, of course, only in most cases the instrument of reception was different. When I operated with these continuous, or undamped, waves, generated in this way, I usually went to high frequencies. I did operate [at] a very few thousand, but that gave me a smaller output. Such a machine you have to operate at high frequencies to get power.

Counsel

What do you mean by high frequencies?

Tesla

I mean frequencies of 30,000, 40,000, 50,000, or something like that.

Counsel

And by means of that machine, you put undamped waves of frequency about 50,000 into that antenna at Houston Street in 1895?

Tesla

No, not in 1895. Late in 1895 the machine was furnished and I began to operate in early 1896. That is when I began to operate.

Counsel

Then you did this, that I speak of, in 1896?

Tesla

Yes, from 1896 to 1899, right along.

Counsel

When you used frequencies like that in your antenna, was your antenna tuned or untuned?

Tesla

I could not use it untuned. That would be absurd.

Counsel

What form of device did you use, and where did you use it, for noting the generation of these oscillations or waves in the antenna?

Tesla

I suppose I had hundreds of devices, but the first device that I used, and it was very successful, was an improvement on the bolometer. I met Professor Langley in 1892 at the Royal Institution. He said to me, after I had delivered a lecture, that they were all

proud of me. I spoke to him of the bolometer, and remarked that it was a beautiful instrument. I then said,

"Professor Langley, I have a suggestion for making an improvement in the bolometer, if you will embody it in the principle."

I explained to him how the bolometer could be improved. Professor Langley was very much interested and wrote in his notebook what I suggested. I used what I have termed a small-mass resistance, but of much smaller mass than in the bolometer of Langley, and of much smaller mass than that of any of the devices which have been recorded in patents issued since. Those are clumsy things. I used masses that were not a millionth of the smallest mass described in any of the patents, or in the publications. With such an instrument, I operated, for instance, in West Point—I received signals from my laboratory on Houston Street in West Point.

Counsel

This was then the machine that you used when working with West Point?

Tesla

I operated once or twice with it at that distance, but usually as I was investigating in the city. My work at that time was to prepare for the development of a commercial plant, and with me the question was not to transmit signals, but to see what intensity I could get to put me in position to calculate out my apparatus, the dimensions and the forms, before I began the undertaking. It was nothing but preparatory work for the construction of a commercial plant, and I demonstrated its practicability through my experiments, a plant which was to accomplish much more than all others.

Counsel

What was the horsepower activity in the oscillating circuits when you used this machine?

Tesla

Usually something like 50 horsepower, and I would get, I should say, approximately 30 horsepower in the antenna; that is, I would get 30 horsepower in the oscillating circuit.

Counsel

I understood a little while ago when you made the statement of using several thousand horsepower put into a condenser, you could take out of the condenser a million horsepower. I wondered if you got the same condition with this machine.

Tesla

Yes; I charged the condenser with 40,000 volts. When it was charged full, I discharged it suddenly, through a short circuit which gave me a very rapid rate of oscillation. Let us suppose that I had stored in the condenser 10 watts. Then, for such a wave there is a flux of energy of $(4 \times 10^4)^2$, and this is multiplied by the frequency of 100,000. You see, it may go into thousands or millions of horsepower.

Counsel

What I wanted to get at was, did that depend upon the suddenness of the discharge?

Tesla

Yes. It is merely the electrical analogue of a pile driver or a hammer. You accumulate energy through a long distance and then you deliver it with a tremendous suddenness. The distance through which the mass moves is small—the pressure immense.

Counsel

Did you find that that was the best condition for transmitting energy without the use of wire?

Tesla

No, I did not use that method when I was transmitting energy. I used it only in the production of those freaks for which I have been called a magician. If I had used merely undamped waves, I would have been an ordinary electrician like everybody else.

Counsel

You have referred to some delicate receiving instruments. Did you have any trouble with those burning out on account of static?

Tesla

My dear sir, I burned out so many instruments before I discovered what was the matter with them! They burned out instantly until I learned how to make them so that they could not burn out. Yes, that was a great trouble in the beginning.

Counsel

Did you succeed in getting them so they would not burn out?

Tesla

Yes. If lightning struck close by, it would not burn out my instrument that has a millionth of the smallest mass used in the instruments of others.

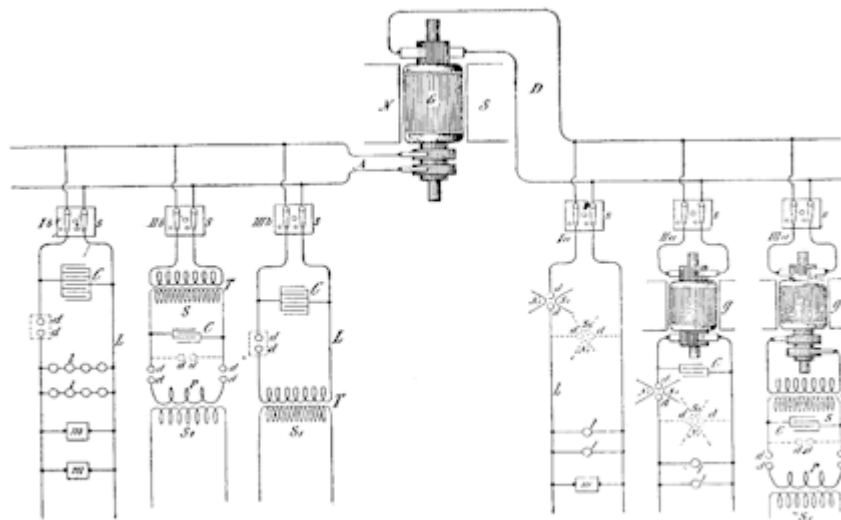


FIG. 163.

Figure 40.

Apparatus and method of conversion by condenser discharges applicable to both alternating and direct currents. Described in lectures before the Franklin Institute and the National Electric Light Association early in 1893. Illustrated in T.C. Martin book, Fig. 165, pp. 302-317.

This [Fig. 40] is a systematic representation of the various ways which I gave in my lecture before the Franklin Institute and the National Electric Light Association, embodying the general arrangements for the obtainment of continuous waves, undamped or damped waves, from direct and alternating current supply. On the one side [right] you have direct, on the other side alternating current supply. Some electricians have had difficulties in operating some of this apparatus. I had none. I can take an ordinary circuit of 50 volts and produce from it absolutely undamped oscillations and never have the slightest difficulty about it.

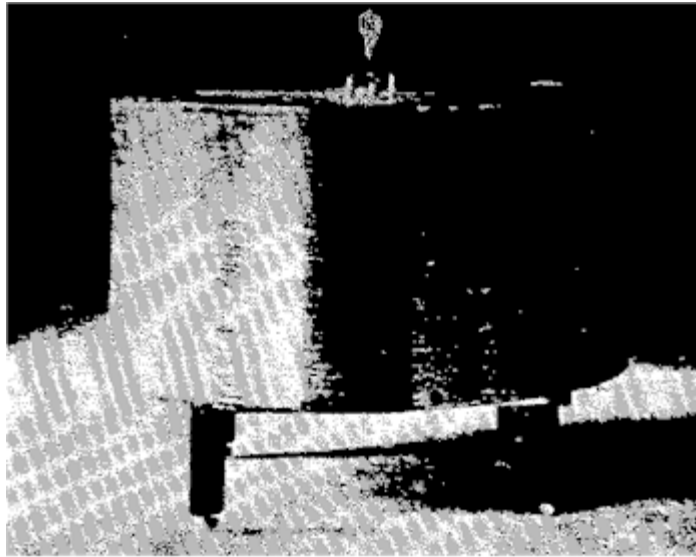


Figure 41.
Illustrating one of the early experiments with a tuned transformer in the laboratory at South Fifth Avenue.

Now I come to a few pieces of apparatus which I used in the Houston Street laboratory and the South Fifth Avenue laboratory. I have here [Fig. 41] what you might call a tuning coil. I employed usually another secondary and had my condensers on the table. You see one of the coils in action. This is a tuned circuit which responds to electromagnetic waves which are sent through the room.

Counsel

This is being used as a receiver of waves?

Tesla

Yes.

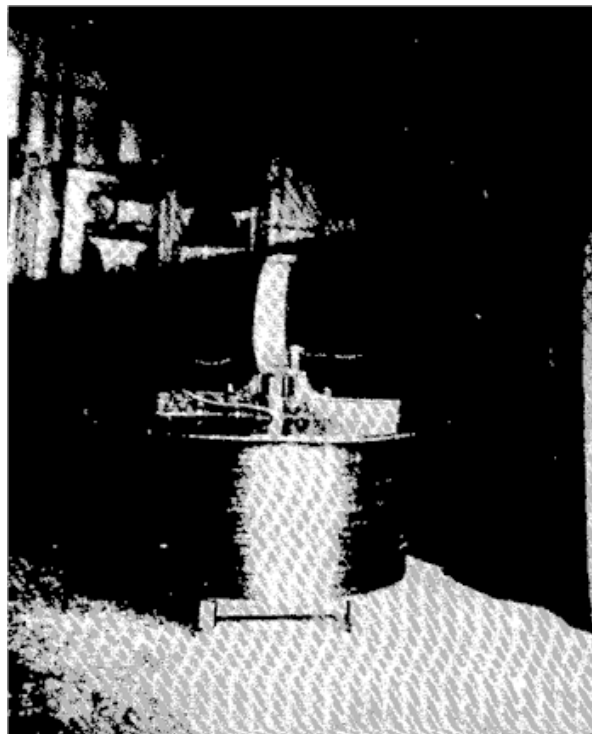


Figure 42.

Another illustration of one of the early experiments with a tuned transformer in the laboratory at South Fifth Avenue. (Article by T.C. Martin ["Tesla's Oscillator and Other Inventions"], Century Magazine, April 1895, Fig. 9, p. 926.)

This [instrument shown in Fig. 42] was used in the laboratory on South Fifth Avenue. Here [large circular disc lying on top of coil] is the tuning table with the condensers, a thick primary, and another secondary wire. Sometimes I would operate with two vibrations and I would tune the first circuit to one and the second to the other. Here [referring to cabinets in back of room] you see some of my historical apparatus. Professor Fairfield Osborn[*] came once to my laboratory and said to me, "Why on earth do you keep it in this laboratory?" I had all of this apparatus, 400 pieces, absolutely priceless, and he offered to take it over to the Museum. But I did not heed his advice, and it is gone.

Counsel

Where were the waves sent from?

Tesla

The whole room was energized by electromagnetic waves and the receiver responded at any place in the hall. The hall was bigger than this room [shown in Fig. 42], twice as long, and anywhere the intensity of action was the same. These discs [vertical, on top of tuning table] were, I think, about 14 or 15 inches in diameter, and you could see the streamers [shown as white between the discs] anywhere in the room. In a hall twice as long as this, wherever I placed the instrument, it would respond to the electromagnetic waves.

Counsel

In this particular instance you are speaking of, the waves were generated right there at 35 South Fifth Avenue?

Tesla

Yes.

Counsel

Was that the apparatus in which you had the primaries running entirely around the room?

Tesla

Yes. This was shown to many people and societies.

This [Fig. 43] shows the first single step I made toward the evolution of an apparatus which, given primary oscillations, will transform them into oscillations capable of penetrating the medium. That experiment, which was marvelous at the time it was performed, was shown for the first time in 1894. I remember the incident perfectly. I called Mr. Edward Adams, the banker, to come and see it, and he was the first man to observe it and to hear my explanation of what it meant.

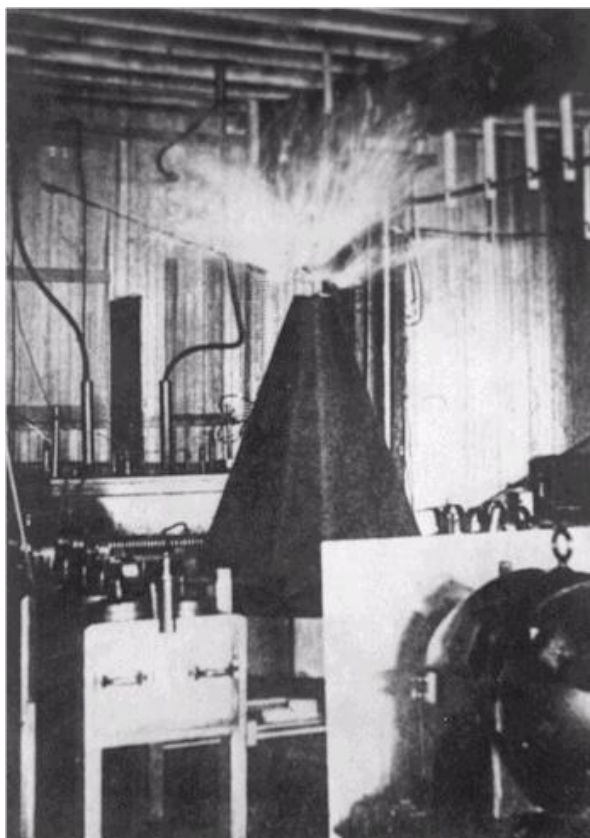


Figure 43.

Apparatus in action illustrating the first step in the evolution of the magnifying transmitter in the laboratory at 35 South Fifth Avenue. (Article by T.C. Martin ["Tesla's Oscillator and Other Inventions"], Century Magazine, April 1895, Fig. 15, p. 932.)

This coil, which I have subsequently shown in my patents Nos. 645,576 and 649,621, in the form of a spiral, was, as you see, [earlier] in the form of a cone. The idea was to put the coil, with reference to the primary, in an inductive connection which was not close—we call it now a loose coupling—but free to permit a great resonant rise. That was the first single step, as I say, toward the evolution of an invention which I have called my "magnifying transmitter." That means, a circuit connected to ground and to the antenna, of a tremendous electromagnetic momentum and small damping factor, with all the conditions so determined that an immense accumulation of electrical energy can take place.

It was along this line that I finally arrived at the results described in my article in the Century Magazine of June 1900. [Fig. 43] shows an alternator; not the alternator that was furnished for my laboratory on Houston Street—that was another one, [but] at 35 South Fifth Avenue [and] operated on the same principle. Here [lower left] are the condensers, primary, and all the rest. The discharge there was 5 or 6 feet, comparatively small to what I subsequently obtained. I have produced discharges of 100 feet, and could produce some of 1,000 feet if necessary, with the greatest facility.

Counsel

Mr. Tesla, at that point, what did you mean by electro-magnetic momentum?

Tesla

I mean that you have to have in the circuit, inertia. You have to have a large self-inductance in order that you may accomplish two things: First, a comparatively low frequency, which will reduce the radiation of the electromagnetic waves to a comparatively small value, and second, a great resonant effect. That is not possible in an antenna, for instance, of large capacity and small self-inductance. A large capacity and small self-inductance is the poorest kind of circuit which can be constructed; it gives a very small resonant effect. That was the reason why in my experiments in Colorado the energies were 1,000 times greater than in the present antennae.

Counsel

You say the energy was 1,000 times greater. Do you mean that the voltage was increased, or the current, or both?

Tesla

Yes [both]. To be more explicit, I take a very large self-inductance and a comparatively small capacity, which I have constructed in a certain way so that the electricity cannot leak out. I thus obtain a low frequency; but, as you know, the electromagnetic radiation is proportionate to the square root of the capacity divided by the self-induction. I do not permit the energy to go out; I accumulate in that circuit a tremendous energy. When the high potential is attained, if I want to give off electromagnetic waves, I do so, but I prefer to reduce those waves in quantity and pass a current into the earth, because electromagnetic wave energy is not recoverable while that [earth] current is entirely recoverable, being the energy stored in an elastic system.

Counsel

What elastic system do you refer to?

Tesla

I mean this: If you pass a current into a circuit with large self-induction, and no radiation takes place, and you have a low resistance, there is no possibility of this energy getting out into space; therefore, the impressed impulses accumulate.

Counsel

Let's see if I understand this correctly. If you have radiation or electromagnetic waves going from your system, the energy is wasted?

Tesla

Absolutely wasted. From my circuit you can get either electromagnetic waves, 90 percent of electromagnetic waves if you like, and 10 percent in the current energy that passes through the earth. Or, you can reverse the process and get 10 percent of the energy in electromagnetic waves and 90 percent in energy of the current that passes through the earth.

It is just like this: I have invented a knife. The knife can cut with the sharp edge. I tell the man who applies my invention, you must cut with the sharp edge. I know perfectly well you can cut butter with the blunt edge, but my knife is not intended for this. You must not make the antenna give off 90 percent in electromagnetic and 10 percent in current waves, because the electromagnetic waves are lost by the time you are a few arcs around the planet, while the current travels to the uttermost distance of the globe and can be recovered.

This view, by the way, is now confirmed. Note, for instance, the mathematical treatise of Sommerfeld,[*] who shows that my theory is correct, that I was right in my explanations of the phenomena, and that the profession was completely misled. This is the reason why these followers of mine in high frequency currents have made a mistake. They wanted to make high frequency alternators of 200,000 cycles with the idea that they would produce electromagnetic waves, 90 percent in electromagnetic waves and the rest in current energy. I only used low alternations, and I produced 90 percent in current energy and only 10 percent in electromagnetic waves, which are wasted, and that is why I got my results. . . .

You see, the apparatus which I have devised was an apparatus enabling one to produce tremendous differences of potential and currents in an antenna circuit. These requirements must be fulfilled, whether you transmit by currents of conduction, or whether you transmit by electromagnetic waves. You want high potential currents, you want a great amount of vibratory energy; but you can graduate this vibratory energy. By proper design and choice of wave lengths, you can arrange it so that you get, for instance, 5 percent in these electromagnetic waves and 95 percent in the current that goes through the earth. That is what I am doing. Or you can get, as these radio men, 95 percent in the energy of electromagnetic waves and only 5 percent in the energy of the current. . . . The apparatus is suitable for one or the other method. I am not producing radiation with my system; I am suppressing electromagnetic waves. . . . In my system, you should free yourself of the idea that there is radiation, that the energy is radiated. It is not radiated; it is conserved. . . .