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Nikola Tesla's Contributions to Radio Developments

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Abstract: Following research and inventions into the field of polyphase low frequency alternating current system of generation, transmission and utilization, Nikola Tesla, around 1890, entered into a new and unknown field of high frequency currents. After developing new generators capable of producing higher frequency alternating currents, he turned his attention to generating alternating currents by discharging condenser through a coil coupled to another coil – secondary of "Tesla transformer". In the three famous lectures between 1891 and 1893 he presented many new characteristics and possible uses of high frequency currents: for illumination, in medicine, industry and for wireless energy transmission. For wireless energy transmission, in 1891-1892 he developed connection of generator to antenna-ground through tuned Tesla transformer. In 1893 he disclosed the principle of wireless energy transmission system with already explained radio transmitter and receiver tuned to operating frequency of the transmitter. In 1897 Tesla submitted two patents on apparatus and system of electrical energy transmission, issued in 1900. These patents were used in the Supreme Court case brought by the Marconi Wireless Telegraph Company of America against the United States of America, alleging that they have used wireless devices that infringed on Marconi patent of June 28, 1904. After 25 years, the United States Supreme Court on June 21, 1943 invalidated the fundamental American radio patent of Marconi, as containing nothing which was not already contained in patents granted to Lodge, Tesla and Stone. However, in spite of this and many others who are recognizing Tesla as one of the radio pioneers, inventing basic radio principle of four tuned circuits, Tesla's name is still waiting the fool recognition of his role in the development of radio.

Keywords: High frequency currents, Tesla coil, illumination, medicine, radio.

1 Introduction

Scientific research of the most efficient frequency for alternating currents for industrial use is limited to the range between several tens to several hundreds

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of Hertz. During a practical experiment exploring the influence of frequency on the devices he constructed, Tesla could generate such currents by changing the rotation speed of the generator. That was probably enough for the first phase of research, but not for further efforts, when he focused attention on the construction of a generator of higher frequency currents. Higher frequency generators require a high pole number, combined with highest permitted rotor speed. Tesla's patents include two original constructions of these machines for the production of alternating currents up to 15 kHz. When he wanted even higher frequency he used oscillatory discharge of a condenser through a coil (already known at that time) but invented novel circuit by replacing simple coil with loose coupling transformer. This modification was so significant that a whole new field of research was created which ultimately led to radio and numerous other applications of high frequency alternating currents. The transformer used in this modification is known as "Tesla coil", and it is still widely used today.

2 Generators and Tesla Coil

Tesla probably constructed several higher frequency generators but two of them he patented.

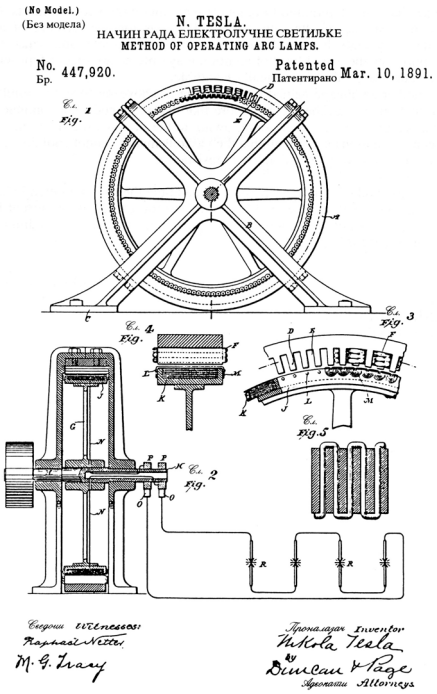


Fig. 1 – *Tesla's patents describing generator with 400 poles.*

One such machine had about 400 poles on the stator and was designed to operate inaudible arc lamps (Patent No. 447,920, [1]), see Fig.1. The rotor rotated with the speed of 1500 revolutions per minute. The other machine was made with a specially tailored flat disc rotor and toothed type stator (Patent No. 447,921, [2]), see Fig.2. This type was the base of later developed continuous current transmitter.

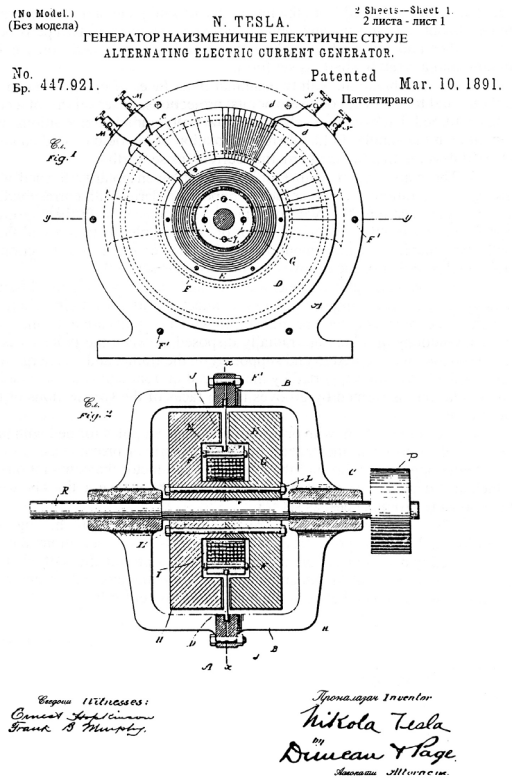


Fig. 2 – *Tesla's high frequency generator with flat disk rotor.*

3 Lectures

Experiments with high frequency machines revealed new and unknown properties of alternating currents, which were perfectly described by Tesla in his lecture before the American Institute of Electrical Engineers at Columbia College in New York, on 20 May 1891 [3]. Tesla prepared several exciting and new experiments with the assistance of Gano Dunn. The lecture was spectacular as his experiments revealed a new world of high frequency currents and high voltages. Tesla started the lecture by saying that nature is the most captivating

and most worthy subject of study and added: *"Nature has stored up in the universe infinite energy. The eternal recipient and transmitter of this energy is the ether…Of all forms of nature's energy, which ever and ever changing and moving, like a soul animates the inert universe, electricity and magnetism are perhaps the most fascinating…What is electricity, and what is magnetism?"*

In his lecture, Tesla considered the nature of electricity, trying to explain the essence of the phenomenon. He presented the assumption that electricity is connected to molecular activities; he stated his doubts about the existence of two electricities; he thought about ether as a medium that reacts differently to low and high frequency currents. He conducted experiments with a gradual increase of voltage at the ends of the transformer secondary coil and pointed to many phenomena he tried to explain through limited knowledge of the contemporary electrical science. He described the effects of heating of dielectric exposed to strong fields of high frequency currents, effects of luminescence, light effects in the vacuum and gases under pressure. He explained that the emission of light was: *"due to the air molecules coming bodily in contact with the point; they are attracted and repelled, charged and discharged, and, their atomic charges being thus disturbed, vibrate and emit light waves."* It is amazing how close he was to the modern theory of the emission of light photons from atoms stimulated by external source that is directly or indirectly caused by electricity. Tesla concluded that it would be possible to use high frequency currents to produce light and heat, as with an ordinary flame, but without consumption of material.

When entering the field of high frequency A.C. Tesla was in a completely new territory. In this case he discovered quickly that the iron core was disadvantage and he disposed of the iron and produced the air-core transformer, known since as the Tesla coil. Usually, this transformer was a part of high frequency generator and to produce the highest voltage in the secondary Tesla discovered that the length of wire in the secondary should be about quarter of the wavelength! The operating frequency of this generator is determined mainly by the primary resonant circuit and the secondary circuit is composed of inductance and self-capacitance of the secondary coil. It is interesting that Tesla coil secondary without extra capacitance is self resonating close to the condition disclosed by Tesla. Tesla never made full theoretical analysis of his transformer but in tuning for the maximum secondary voltage he certainly used "cut and try method". The coupling between the primary and secondary also plays important role and to these days this transformer is still studied with more or less approximate theory of its operation.

The best and most detailed Tesla's theory of his transformer can be found in his Colorado Springs Notes 1899-1900 [5], published by Nikola Tesla Museum in Belgrade in 1978 and also in several earlier patents and lectures.

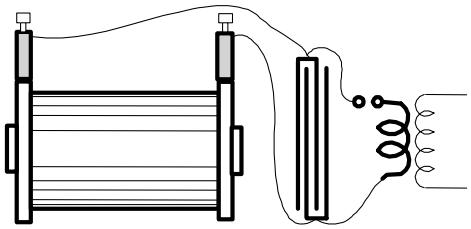


Fig. 3 – *First drawing of Tesla Coil presented in his 1891 lecture.*

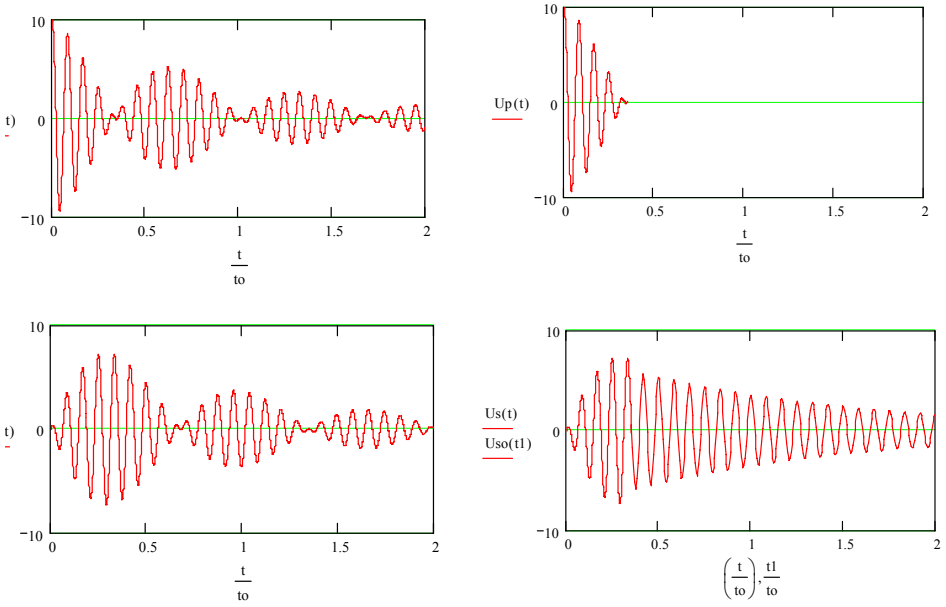
Tesla's oscillator is relatively easily outlined, although its detailed description is extremely complex. In the following analysis we will assume that primary and secondary circuits have been adjusted to the same resonant frequency which is determined by Thompson formulae

$$\omega_0 = 1/\sqrt{L_p C_p} = 1/\sqrt{L_s C_s} ,$$

which Tesla tried to achieve in his devices. In the formulae C_s is parasitic capacitance of the secondary coil of inductance L_s. We can assume that a source is charging the condenser of primary circuit C_p to a certain voltage V, while storing energy $C_p \mathrm{V}^2/2$ in it. A maximum voltage at the terminals of the condenser determines the striking voltage of a spark gap (made of two conducting electrodes separated by a gap). At the moment of achieving of a striking voltage for the selected spark gap, the gap breaks and condenser discharges energy through the primary coil of the Tesla transformer. The discharge is oscillatory, and the type of generated current depends on inductance and capacitance of the primary and secondary of the transformer and mutual coupling between primary and secondary circuit. A long spark (Fig. 3a) causes the transfer of energy from the primary into secondary and vice versa. In that case, the attained oscillations are two dampened sinusoids, one above and the other below selected frequency ω_0. As the coupling is stronger, the difference in frequencies is larger. If there is no new excitation – new discharge of energy from the external circuit of the condenser, oscillations stop when the initial energy is consumed and the spark quenches.

In a more convenient case, the spark in the primary would cease to conduct after the energy is transferred to the secondary (Fig. 3b). In this case, there would be no further losses in the primary and the secondary would continue to oscillate at the frequency of the secondary circuit ω_0. Strong coupling between the primary and the secondary shortens the time of transfer of the energy from the primary to the secondary and oscillations of the secondary are closer to the continual sinusoidal current, except in the interval of the energy transfer when the two

dampened sinusoidal currents are created, one below and the other above frequency ω_0. From the moment when the primary circuit is broken by the cessation of spark, the oscillations in the primary stop and condenser of the primary again charges with the energy from the network. When the voltage in the condenser of the primary again achieves striking voltage V, the oscillation process is repeated. In practice, for certain secondary circuit of the transformer Tesla changed capacitance and/or inductance of the primary until the sparks in the secondary attained a maximum intensity. He had an excellent feeling for the tuning of his devices regardless of the fact that he did not possess enough theoretical knowledge to fully understand and made the best use of all mentioned complex phenomena. When he invented the Tesla transformer in 1891, there was no theoretical analysis available for this device. A mathematical analysis appeared later in 1895 [6], but it was a simplified Tesla coil arrangement as the secondary circuit is not concentrated but distributed capacitance between coils.



(a) (b)

Fig. 3 – *Log spark (a), quenched spark (b).*

In a book [27], W.H. Eccles remarked about this coil that "*it was invented not for wireless but for making vacuum lamps glow without external electrodes, and it later played a principal part in other hands in the operation of big spark station*".

In his lecture, Tesla also proposed, as "*the ideal way of lighting a hall or room*", a system composed of high frequency alternator connected in series with a condenser and a primary of high frequency transformer. The secondary of transformer was connected to an insulated metal plate suspended on the ceiling and to the ground, "*their sizes being carefully determined*".

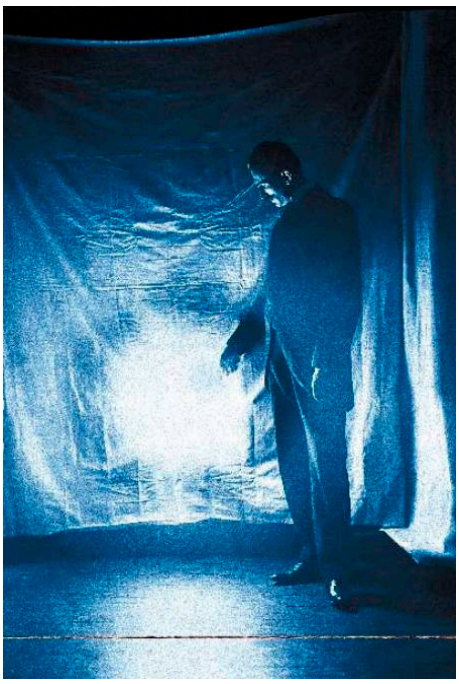


Fig. 4 – *Tesla and his wireless light.*

According to his explanation, an illuminating device could be moved and put anywhere, even beyond the plates. We are mentioning this because it seems to be the first use of generator driving transformer with resonant primary and secondary circuits and, in a way, indicate that he already started to think about wireless energy transmission. Here he mentioned electrostatic field effects and electromagnetic inductive effects, expecting that the latter may be more suitable as they diminish simply with the distance, as compared with the electrostatic effects that "*diminish nearly with the cube of the distance from the coil*". He also mentioned that by making use of resonance we might obtain the required electromotive force at a distance.

Discussing about the nature of electricity he said:

"I adhere to the idea that there is a thing which we have been in the habit of calling electricity. The question is, What is that thing? Or, What, of all things,

the existence of which we know, have we the best reason to call electricity? We know that it acts like an incompressible fluid; that there must be a constant quantity of it in nature; that it can be neither produced nor destroyed; ...”

The last words are the basis on which Tesla developed his hypothesis about possibility to transmit currents through the earth with diminished Hertz radiation.

At the beginning of 1892, Tesla visited London and Paris talking about his further experiments with alternate currents of high potential and high frequency [7]. He disclosed new achievements in obtaining better operation of his spark high frequency generator by producing rapid succession of sparks, either by employment of a magnet, air current, simple or multiple air gaps or various design of mechanical interrupters. Many of these inventions were later ‘reinvented’ by others without referring to Tesla. Another interesting hint on wireless energy transmission Tesla remarked in demonstrating high frequency driven motors through a single wire: “*It is quite possible, that such ‘no wire’ motors, as they might be called, could be operated by conduction through the rarefied air at considerable distances. Alternate currents, especially of high frequencies, pass with astonishing freedom through even slightly rarefied gases. The upper strata of air are rarefied. To reach a number of miles into space requires the overcoming of difficulties of a merely mechanical nature. There is no doubt that with the enormous potentials obtainable by the use of high frequencies and oil insulation luminous discharges might be passed through many miles of rarefied air, and that, by thus directing the energy of many hundreds or thousands of horse-power, motors or lamps might be operated at considerable distances from stationary sources”*.

As the main subject of the lecture was light production, he did not continue to talk about wireless transmission but turned to description of many types of single electrode bulbs [8, 9]. He produced many bulbs with buttons of carborundum and believed that they can produce even 20 times more light by means of currents of very high frequencies as compared with the light produced by the present incandescent light by the same expenditure of energy. At the end of the lecture Tesla again returned to transmission without wires and wondered why with the existing knowledge and experience gained, no attempt is being made to disturb the electrostatic or magnetic condition of the earth, to ”*transmit, if nothing else, intelligence”*.

The third Tesla's lecture “On light and other high frequency phenomena” before the Franklin Institute in Philadelphia, February 1893, is very important as in it Tesla disclosed the basis of modern radio [10]. In the introductory part Tesla expressed his admiration to eye, the organ which is *"the most precious, the most indispensable of our perceptive or directive organs, it is the great gateway through which all knowledge enters the mind. Of all our organs, it is the one,*

which is in the most intimate relation, that it is often said, the very souls shows itself in the eye".

Developing further his ideas about energy transmission, Tesla explained his numerous experiments with "single wire transmission". To the upper terminal of his generator, Tesla connected various coils coupled with incandescent lamps, h.f. motors driven through a single wire with no return. Describing many fascinating experiments with resonance effects Tesla said:

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

Tesla's assumption about electrical charge of the Earth, that if disturbed will oscillate and transmit energy, lead him to seek for the period of the Earth charge oscillation: *"One of the terminals of the source would be connected to earth as, for instance, to the city water mains, the other to an isolated body of large surface. It is possible that the outer conducting air strata, or free space, contain an opposite charge and that, together with the earth, they form a condenser of very large capacity. In such case the period of vibration may be very low...*"

The fire that destroyed Tesla's laboratory in New York on March 1895, postponed his further experiments not only on radio but also on electrical lighting and x-ray investigations. That is why he submitted two basic radio patents on 2nd September 1897 [11, 12], a year after Marconi submitted patent based on Hertz transmitter with Tesla's antenna-ground connection instead of connection to symmetrical dipole as in the original Hertz transmitter.

A year after Tesla's lecture in 1893, Oliver Lodge transmitted Hertzian waves over a distance to a receiver with a symmetrical dipole antenna connected to a coherer. Popov demonstrated in 1895 a somewhat improved taping coherer with vertical wire as antenna and earth connection instead of symmetrical dipole used by Hertz and Lodge. In 1896, Marconi came to England with his improved apparatus and continued experiments in 1896/97 with the transmitter shown in Fig.8, bottom, and with a coherer placed between the receiving antenna and ground. The coherer in each apparatus required to be taped (de-cohered) after receiving a pulse that made it conducting. In all these receivers no resonance was used at the receiving side and the operating frequency depended on the size and capacitive load of antenna.

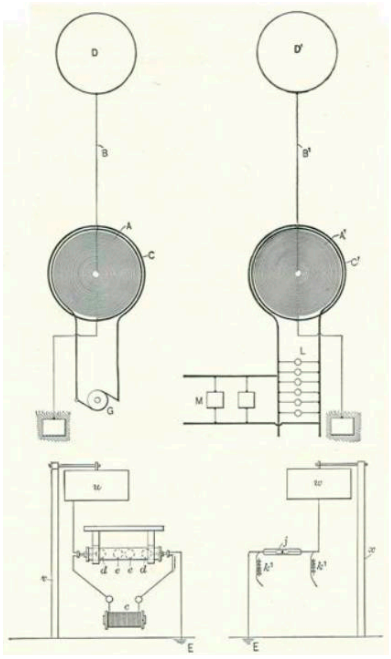


Fig. 5 – *Tesla's system of four tuned circuits [pat. 11,12] and Marcony's system [13]. Application to all these pattents are filed in 1897.*

During the years 1896 and 1897, researchers in all parts of the world discussed wavelengths appropriate to wireless telegraphy. It was known that Lodge and Righi oscillators produced damped waves of few centimeters that of Hertz waves of a few meters and waves several kilometers long by Tesla.

In explaining the operation of his radio system announced in 1893, Tesla came with his original theory, explaining that his system is not producing significant free-space radiation, but that it makes use of conduction by disturbing the electrostatic charge along the earth surface. In the early days of radio, some writers, misled by Tesla's theory, made distinction between the Tesla and Marcony systems [14]! Today we know that this was wrong view and that Tesla's experiments were early attempts to use ELF propagation mode [15].

4 Remote Control by Radio

Nikola Tesla invention of remote control by radio waves appeared in the early phase of radio development. It followed his work on "Tesla coil and oscillation transformer (1889-1892), researches and experiments with currents of high frequency (1889-1898) and Tesla Wireless System (1891-1893)".

On July 1, 1898 Tesla filed USA patent application and in just over four months, the patent on "Method of and Apparatus for Controlling Mechanism of

Moving Vessels" was granted to him [16]. In 1898, he was demonstrating wireless control of model ships and predicting the imminent completion of a system that could transmit both power and intelligence over long distance without wires [17]. The principle he was developing was applicable to "*any kind of machine that moves on land or in the water or in the air*", and to show this to an audience he constructed a boat.

Tesla performed some work on remote control in his laboratory in 35, South Fifth Avenue. When this laboratory burned down in March 1895, it was a terrible blow to him. Many experiments were stopped until the end of 1895, when he opened a new laboratory on 46, East Houston Street. In this laboratory he made, in his own words:

"Striking demonstrations, in many instances actually transmitting the whole motive energy to the devices instead of simply controlling the same from distance. In '97 I began the construction of a complete Automaton in the form of a boat, which is described in my original specification #613,809… This application was written during that year but the filing was delayed until July of the following year, long before which date the machine had been often exhibited to visitors who never seized to wonder at the performances… In that year I also constructed a larger boat, which I exhibited, among other things, in Chicago during a lecture before the Commercial Club. In this lecture I treated the whole field broadly, not limiting myself to mechanisms controlled from distance but to machine possessed of their own intelligence. Since that time I have advanced greatly in the evolution of the invention and think that the time is not distant when I shall show an automaton which, left to itself, will act as though possessed of reason and without any willful control from the outside. Whatever be the practical possibilities of such an achievement, it will mark the beginning of a new epoch in mechanics." [18].

After submitting USA patent on the apparatus and system for controlling moving objects, in the following 14 months Tesla submitted patents in 10 other countries, but it had to be many years before remote control became operative!

5 Colorado Springs Laboratory

Continuing his work on high frequency, very high voltages Tesla in 1899 moved to a new laboratory in Colorado Springs (see Fig.9). Tesla arrived on May 18, 1899, with the intention of carrying out intensive research in wireless telegraphy and properties of the upper atmosphere. In his article written upon his return to New York [19], he writes that he came to Colorado Springs with the following goals:

- To develop a transmitter of high power;
- To perfect means for individualizing and isolating the energy transmitted;

- To ascertain the laws of propagation of currents through the earth and the atmosphere.

The Notes[5] which Tesla kept at that time gives a detailed day-by-day description of the research in the period June 1, 1899 to Jan.7, 1900. Unlike many other records in the archives of Nikola Tesla Museum in Belgrade, the Colorado Springs diary is continuous and orderly. Since it was not intended for publications, Tesla probably kept it as a way of recording his research results. It could perhaps also have been a safety measure in case the laboratory gets destroyed, an eventuality by no means unlikely considering the dangerous experiments he was performing with powerful discharges.

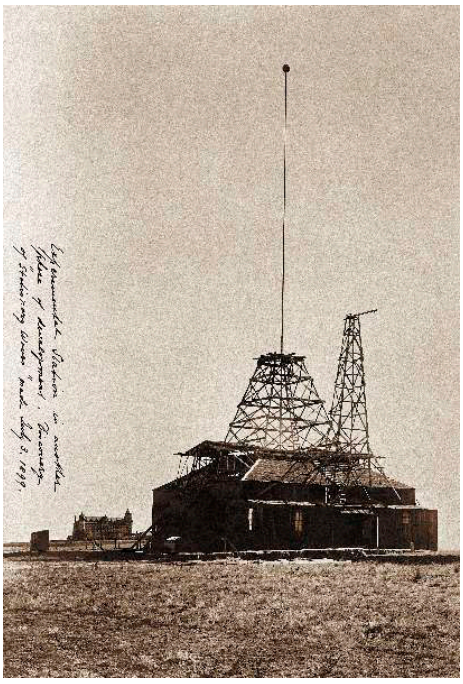


Fig. 6 – *Colorado Springs laboratory.*

Immediately after finishing work at Colorado Springs Tesla wrote a long article entitled "The problem of increasing human energy" [19] in which he often mentions his results from the Colorado Springs. The article really did create a sensation, and was reprinted many times. At the beginning of twentieth century Tesla believed that he is ahead of all others in developing wireless transmission not only for messages but also of energy in a more significant amount for other uses. While in Colorado Springs he invented multicarrier transmitter with a special receiver tuned to all carriers [20]. In his own words: "*this invention consists of generating two or more kinds or classes of*

disturbances or impulses of distinctive character with respect to their effect upon a receiving circuit and operating thereby a distant receiver which comprises two or more circuits, each of which is tuned to respond exclusively to the disturbances or impulses of one kind or class and so arranged that the operation of the receiver is dependent upon these conjoint or resultant action".

Tesla's double transmitter system is in a way a kind of spread spectrum system that are intended to protect message from intruders and at the same time decrease disturbing effect of noise in transmission. In Tesla's words this system "*improves individualization and isolation of messages".* Another interesting receiver is the one that rectify received signal and charge a capacitor periodically discharging it through a receiving device [21]. Today, we call this type of receiver 'integrate and damp receiver' and it is used to improve signal to noise ratio after detection of signal. Tesla used it to magnify input signal by integration. Around 1900 Tesla was already developing continuous radio systems at the time when others were developing the early spark telegraphy!

6 Long Island Plant

Immediately after returning to New York in 1900 Tesla took energetic steps to get backing for the implementation of a system of "World Telegraphy". He erected a building and an antenna in Wardenclyffe, Long Island, and started fitting out a new laboratory (see Fig.7).

In order to explain the purpose of his newest attempt, Tesla published a brochure of new "world telegraphy system." In the introduction, he said that "*the world system is the result of a combination of a couple different discoveries that the researcher came across in the course of his other investigations and numerous views.*" What is most interesting in the brochure is the description of technical possibilities of the system, which he summed up in twelve points:

1. Establishment of a connection between existing telegraph stations and centers all over the world;
2. Organizing of a secret state telegraph service without the possibility of jamming;
3. Establishment of a connection between existing telephone centers and stations on the Earth;
4. United diffusion of common gazette news by means of telegraph and telephone;
5. Organizing of a service with the principles of a "worldwide system" to transmit private information;
6. Establishment of interconnection of all telegraph systems in the world;
7. Creation of a service to record music;

8. Uniform timing clock, which marks seconds with astronomic accuracy;
9. Transmission of signs, words, sounds and so on, as well as typewritten and hand-written texts;
10. Organizing of a worldwide service for the needs of mercantile marine, which should help in navigation, in compassless voyages. It will help to determine location and speed, to prevent collisions, accidents and so forth;
11. Introduction of a worldwide printing system;
12. Reproduction of photos and all kinds of drawings or hand-written texts to send them over the world.

What Tesla foresaw in the twelve points, came to life in the next one hundred years, however, in those days, most of Tesla's ideas seemed like fantasies. When he told journalists that in the future every man will have a small transceiver, with which he will be in contact with all the users of the system and give and receive instructions wirelessly, journalists mocked him. In those days, the radio was known as a system of point-to-point communication, but Tesla already foresaw the expansion of the system for transmitting news, music, letters, checks, accurate time, etc. He did not skip the use of radios in navigation, distribution of correct time, for the trade-off of exchange information, etc. He thought about the exchange of movable pictures – television, but he never added that to his program because at that time he only thought about as we know from his unpublished Long Island Notes. From these subsequent notes we learned that he intended to verify his ideas about the resonance of the Earth's globe, referred to in a patent of 1900. The experiments he wanted to perform were not in fact carried out until the sixtieth of the last century, when it was found that the Earth resonates at 8, 14 and 20 Hz [22]. Tesla predicted that the resonance would be 6, 18 and 30 Hz.

After his financier J. P. Morgan refused to continue supporting Tesla's research, he wrote a letter to Morgan of January 9, 1902, in which he explained that he envisaged three "distinct steps to be made:

The transmission of minute amounts of energy and the production of feeble effects, barely perceptible by sensitive devices;

The transmission of notable amounts of energy dispensing with the necessity of sensitive devices and enabling the positive operation of any kind of apparatus requiring a small amount of power; and

The transmission of power in amounts of industrial significance. With the completion of my present undertaking the first step will be made".

For the experiments with transmission of large power he envisaged the construction of a plant at Niagara to generate about 100 million volts [23].

However, Tesla did not succeed in getting the necessary financial backing, and after three years of abortive effort to finish his Long Island Station he gave up his plans and turned to other fields of interest. He remained convinced to his death that the wireless transmission of energy would one day become reality. Today, when we have proof of the Earth's resonant modes (Schumann's resonance), and it is known that certain waves can propagate with very little attenuation, so little that standing wave can set up in the Earth-ionosphere system, we can judge how right was Tesla when he said that the mechanism of electromagnetic wave propagation in "his system" was not the same as in Hertz's system with collimated radiation. Naturally, Tesla could not have known that the phenomena he was talking about would only become pronounced at very low frequencies, because it seems he was never able to carry out the experiments which he had so brilliantly planned, as early as in 1893 [10]. It is gratifying that after so many years Tesla's name is rightfully reappearing in papers dealing with the propagation of radio waves and the resonance of the Earth. For example, Jackson [24] in his electromagnetic book stated that: "this remarkable genius clearly outlines the earth as a resonating circuit (he did not know of the ionosphere), estimates the lowest resonant frequency as 6 Hz (close to 6.6 Hz for a perfectly conducting sphere), and describes generation and detection of these waves. I thank V. L. Fitch for this fascinating piece of history".

The last patent in connection with radio transmitters Tesla submitted on Jan. 18, 1902 [25], renewed May 4, 1907 and issued Dec.1, 1914. This patent is extension of patents from 1897 [11, 12], with improvements that enable safe operation of apparatus for transmission of electrical energy with antenna charged to a high potential.

In Archives of Nikola Tesla Museum in Belgrade there are a number of various high voltage antenna designs that Tesla prepared in patent drawings form. Some of these were published in 1993 [26].

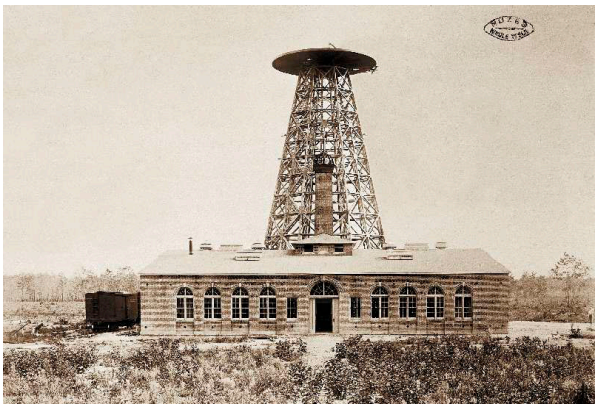


Fig. 7 – *Long Island Plant.*

His preoccupation with this great idea slowed down construction of his overseas station, and when radio transmission across the Atlantic was finally achieved by Marconi on December 1901 with a simpler apparatus, he had to admit that his plans included not only the transmission of signals over large distances but also an attempt to transmit power without wires.

Many omissions in connection with Tesla's research into the radio fundamentals are corrected by the decision of the United States Supreme Court [28] who gave priority to Tesla's patents applied in 1897 as a four-circuit system consisting of "an open antenna circuit coupled through a transformer, to a closed charging circuit at the transmitter, and an open antenna circuit at the receiver similarly coupled to a closed detector circuit". This judgment was delivered after the death of both Marconi and Tesla. It seems that this judgment did not alter much the views of many historians who neglect to mention the important role played by Tesla in the early development of radio. A striking example of distortion of historical facts is the report of the European Broadcast Union where in 1995 they did not mention Tesla among six pioneers of radio [29].

7 Conclusions

Investigations in the field of high frequency alternating currents and wireless energy transmission Tesla started in 1890-1891. In a short period of time Tesla delivered three famous lectures before scientists and experts in USA, England and France. From unexpected behaviour of these currents in comparisson to low frequency alternating currents, supported by many experiments, Tesla gradually increased his conviction that these currents can be used for efficient illumination, in medicine and in wireless taransmission of electrical energy. Tesla thought that the earth conductive properties and insulating properties of the atmosphere can be used for transmission of not only small amounts of energy required in message transmission, but also for larger amounts. His hypotetical assumption was that by using very high voltages and antenna of considerable height we can reach rarefied air, that is also conductive, and provide a system that can transmitt high power at any distance. In spite of many practical obstacles and dangers in operation of such a hypothetical system, Tesla's basic plan presented in 1893 and patented apparatus and transmission system, based on his four tuned circuit system from 1897 are, in fact, the base of modern radio in manu respects. In spite of that Tesla's contribution to the development of radio have been overlooked by many historian of radio.

History of radio has been subject of many researchers after historic Hertz's experiments in 1887. The work of Hertz proved the reasoning of Maxwell, who was the first who fully understood what is the nature of electromagnetic radiation. Early historian of science witnessed radio development and followed

research of Dolbear, Branly, Lodge, Tesla, Popoff, Marconi, Slaby, Fessenden, De Forest, etc.

At that time the theory of radio wave propagation was in infancy and that explains why some of them carefully presented Marconi's and Tesla's patents leaving readers to comment on priorities [30].

In a recent book on History of wireless [31], many authors presented facts about steps in the development of radio and it seems that after so many years Nikola Tesla will get his right place into the history of wireless as one of the pioneers who made the first important step with his four tuned-circuits and advanced ideas of multifrequency transmission and sophisticated receiver of the 'integrate and damp" type.

8 References

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