TESLINI IZUMI U FIZICI I NJEGOV INŽENJERSKI DUH

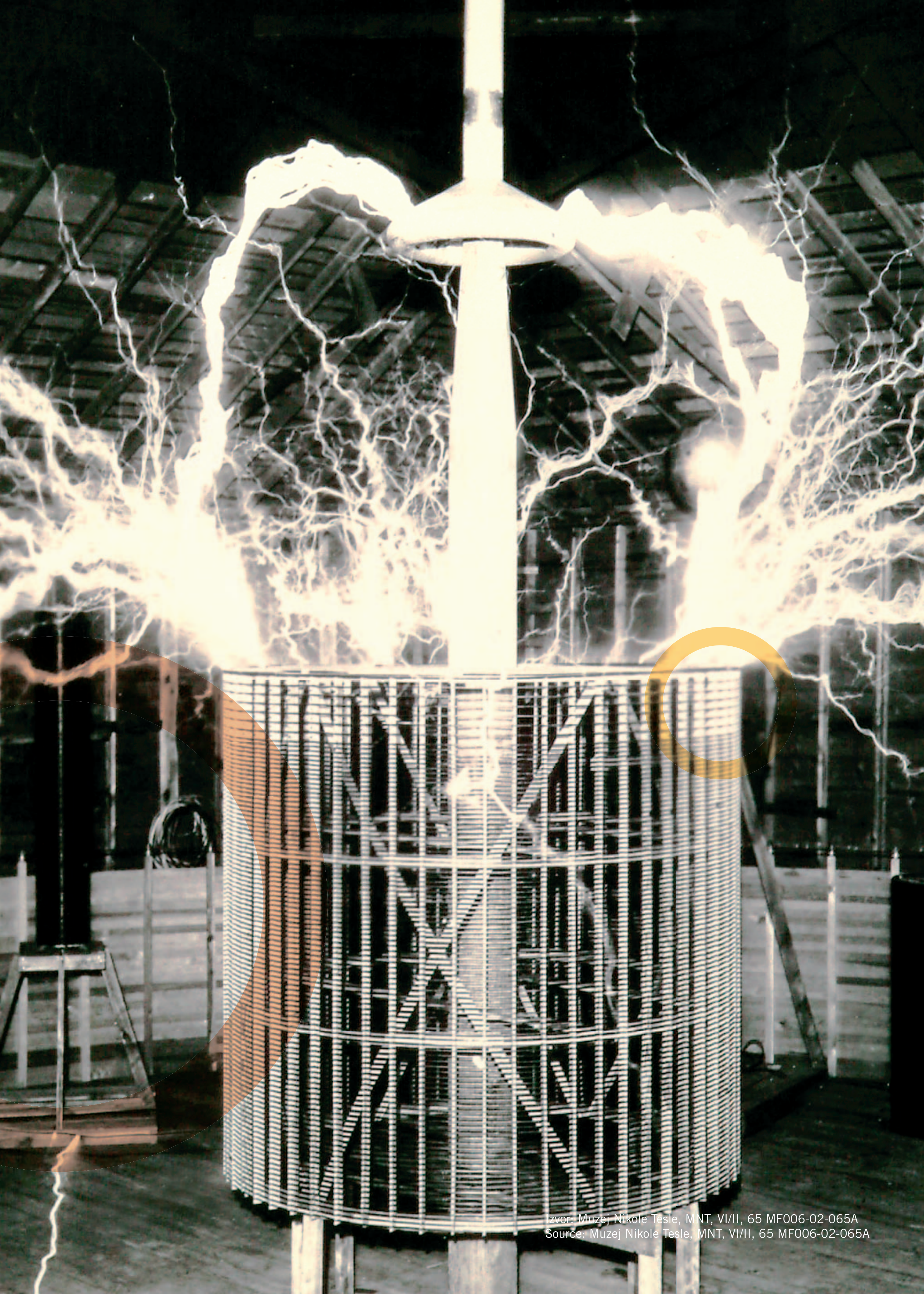
TESLA'S INVENTIONS IN PHYSICS AND HIS ENGINEERING SPIRIT

Prof. dr. sc. Tomislav Petković, Sveučilište u Zagrebu, Fakultet elektrotehnike i računarstva, Unska 3, 10000 Zagreb, Hrvatska
Prof Tomislav Petković, PhD, University of Zagreb, Faculty of Electrical Engineering and Computing, Unska 3, 10000 Zagreb, Croatia

U članku se opisuju Teslini izumi u fizici i njegov inženjerski duh, uz usporedbu s otkrivačkim duhom u elektromagnetizmu M. Faradaya i A. A. Michelsona. Promišlja se, povijesno-znanstvenom metodom, Teslin nedovršeni istraživački put od velikih pokusa u elektrotehnici i radiotehnici do fizikalne teorije koja bi se na njima zasnivala. Opisana su neka otkrića i pojedini pokusi koji su važni za kasniji razvoj akceleratorske tehnologije te Teslina unipol-antena elektromagnetskih valova velikih snaga i dosega u kojima se koristi princip Teslinog transformatora. U okviru klasične elektromagnetske teorije izvedeni su proračuni i moderna analiza sklopa za istraživanja Teslinog modela bežičnog prijenosa elektromagnetske energije ili informacije na daljinu, dokazujući znanstvenu utemeljenost tih Teslinih zamisli. Dan je osvrt i na zastupljenost Tesle i njegovih izuma i doprinosa u nastavi fizike i elektrotehnike na Sveučilištu u Zagrebu, napose u udžbenicima i radovima Ivana Supeka, Vatroslava Lopašića i Tome Bosanca. Na kraju se protumačio Teslin interes za Goetheovom poezijom, što je stalno poticalo Teslinu težnju za izumima i spoznajom.

The article describes Tesla's inventions in physics. Tesla's engineering spirit is compared to M. Faraday's and A. A. Michelson's spirit of discovery in electromagnetism. Tesla's unfinished investigative journey, from great experiments in electrical technology and radio technology to the physical theories he derived from them, are examined historically and scientifically. Several discoveries and individual experiments are described that were significant in the subsequent development of accelerator technology, as well as Tesla's monopole antenna for high power and long-range electromagnetic waves, in which the principle of Tesla's transformer is applied. Within the framework of classical electromagnetic theory, calculations and modern analysis of the system for the study of Tesla's model of the long-distance wireless transmission of electromagnetic energy or information are presented, demonstrating the scientific basis for Tesla's ideas. The coverage of Tesla's inventions and contributions in the physics and electrical engineering curricula at the University of Zagreb is reviewed, especially in textbooks and other works by Ivan Supek, Vatroslav Lopašić and Tomo Bosanac. An interpretation is offered of Tesla's interest in Goethe's poetry, which provided an impetus for his inventions and desire for knowledge.

Ključne riječi: akceleratorska tehnologija, nastava fizike i Tesla, Teslina intuicija, Teslin inženjerski duh, Teslin model bežičnog prijenosa, Teslin transformator, unipol-antena
Key words: accelerator technology, monopole antenna, physics instruction and Tesla, Tesla's engineering spirit, Tesla's intuition, Tesla's model of wireless transmission, Tesla's transformer



Izvor: Muzej Nikole Tesle, MNT, VI/II, 65 MF006-02-065A
Source: Muzej Nikole Tesle, MNT, VI/II, 65 MF006-02-065A

1 UVOD

U Hrvatskoj je godina 2006. proglašena Godinom Nikole Tesle, s ciljevima suvremenog reafirmiranja Teslinih izuma u fizici i genijalnih istraživanja u elektrotehnici te potpunog osvjetljenja mjesta i uloge sveukupnoga Teslinog djela u svjetskoj znanosti i kulturi modernoga doba. Hrvatska politika zajedno s hrvatskom znanošću i umjetnošću napose želi sabrati sve činjenice i one vjerodostojne izvore koji upućuju na hrvatske korijene u zanimljivoj i višeslojnoj Teslinoj osobi i njegovu istraživačkom radu. Formalno uporište za proslavu Tesline godine u Hrvatskoj jest 150. obljetnica njegova rođenja koja pada u 2006. godinu. I UNESCO je 2006. proglasio Godinom Nikole Tesle, u čast 150. obljetnice rođenja toga genija moderne elektrotehnike i fizike.

Spomenutu odgovornu znanstvenu orijentaciju u proslavi Tesline godine u Hrvatskoj moralno podupire i jedan sićušni podatak: u izdanju Encyclopaedije Britannice (2004.) u natuknici Tesla, Nikola, u prvoj rečenici se navodi da je Tesla srpsko-američki izumitelj i istraživač (Serbian-American inventor and researcher), premda za mjesto rođenja stoji Smiljan, Hrvatska. S druge pak strane, u tablici parametara lunarnih kratera na webu NASA, uz Teslin krater navodi se Tesla kao hrvatsko-američki izumitelj (Croatian-American inventor).

Autor toga članka nije se posebno bavio Teslom i njegovim djelom i ne smatra se novopečenim teslologom. Imao je, međutim, prigodu kroz rad u svjetskim akceleratorskim središtima izravno uvidjeti i doživjeti poštovanje suvremenih fizičara i inženjera prema važnosti Teslinih istraživanja u razvoju moderne akceleratorske tehnologije. To je jedan od motiva za ovaj članak o Teslinim izumima i njegovoj inženjerskoj intuiciji. Drugi, ali ne manje važan motiv izvire iz želje da člankom o Tesli nastavi istraživati niz domaćih i svjetskih znanstvenika i/ili filozofa i umjetnika koje je povijesno-znanstveno i filozofski obrađivao u posljednjih desetak godina. U niz u kojemu su Albert Einstein, Enrico Fermi, Frane Petrić, Werner Heisenberg, Nikola Šop, Mirko Dražen Grmek i Hrvoje Požar [1] do [6] prirodno je dodati i Nikolu Teslu.

Nikola Tesla (Smiljan, 10. srpnja 1856.-New York, 7. siječnja 1943.) je svojim izumima i širokim spektrom svojih istraživačkih interesa, napose svojim osebujnim stilom života, još za života priskrbio brojne epitete: od sanjara, ludog znanstvenika, znanstvenog fantasta, inicijatora svjetskog bežičnog sustava i svjetske komunikacije do istraživača koji je primao signale od izvan-

1 INTRODUCTION

In Croatia, the year 2006 has been proclaimed Nikola Tesla Year, a contemporary reaffirmation of Tesla's inventions in physics and brilliant research in electrical engineering, and an opportunity to reassess and illuminate Tesla's overall contribution to world science and the culture of the modern age. Croatian politics, science and art want to collect all the facts and reliable sources that pertain to the Croatian roots of Tesla's complex personality and research endeavors. The formal occasion for the celebration of Nikola Tesla Year in Croatia is that the 150^{th} anniversary of his birth occurs in 2006. UNESCO has also proclaimed 2006 as Nikola Tesla Year, in honor of the 150^{th} anniversary of the birth of this genius of modern electrical engineering and physics.

Moral support for the scientific orientation of the celebration of Nikola Tesla Year in Croatia is provided by the small fact that although the first sentence of the entry Tesla, Nikola in the 2004 edition of the Encylopaedia Britannica states that Tesla is a Serbian-American inventor and researcher, his place of birth is given as Smiljan, Croatia. Furthermore, in a table of the parameters of lunar craters on the NASA website, next to Tesla's Crater it is stated that Tesla was a Croatian-American inventor.

The author of this article has not been particularly involved with Tesla and his work and does not consider himself to be a newly minted expert on the subject. However, while working at world accelerator centers he has had the occasion to witness the high esteem that contemporary physicists and engineers have for Tesla's research in the development of modern accelerator technology. This is one of the motives for this article on Tesla's inventions and his engineering intuition. A second but no less important motive stems from the desire to continue a series written during the past decade on domestic and world scientists, philosophers and artists from the historical/scientific and philosophical points of view, including Albert Einstein, Enrico Fermi, Frane Petrić, Werner Heisenberg, Nikola Šop, Mirko Dražen Grmek and Hrvoje Požar [1] to [6], to which Nikola Tesla is a natural addition.

Nikola Tesla (Smiljan, July 10, 1856-New York, January 7, 1943), owing to his exceptional and broad spectrum of investigative interests and particular lifestyle, received many epithets during his life, including dreamer, crazy scientist, scientific visionary, the initiator of the world wireless system and world communication, the researcher who received signals from extraterrestrial civilizations, a man who could split the earth into two like an zemaljskih civilizacija, čovjeka koji bi mogao raspoloviti Zemlju poput jabuke, tvorca razornih smrtonosnih zraka koje djeluju na daljinu...itd.

Tesla je u životu bio samac, genijalni izumitelj i osoba vrhunskih etičkih principa. U životu je najviše cijenio i poštivao svoje roditelje (otac Milutin, paroh), napose inteligentnu i priprostu majku (Đuka, rođ. Mandić) od koje je, prema vlastitim riječima, naslijedio izumiteljski dar. Tesla je imao tek nekoliko bliskih prijatelja pisaca, među kojima je bio i Mark Twain. Treba, međutim, naglasiti da su Teslu, uz briljantne izumiteljske sposobnosti, intuiciju i fotografsko pamćenje, resili perfekcionizam u poslu (pripremi i izvođenju eksperimenata) i samodisciplina u svakodnevnom životu (fizičke aktivnosti i zdrava prehrana).

Tesla je u Americi 1917. primio Edisonovu medalju, što je najveća počast koju dodjeljuje Američki institut inženjera elektrotehnike (AIEE). O 100. obljetnici Teslinog rođenja mjerna jedinica za gustoću magnetskog toka ili magnetsku indukciju u počast Tesli nazvana je tesla (simbol ili kratica T). Na XI. sastanku CGPM (Conférence Générale des Poids et Mésures), listopada 1960. u Parizu, mjerna jedinica tesla službeno je prihvaćena i ugrađena u korpus mjernih jedinica SI (Sistème International D'Unités) kao izvedena jedinica u elektromagnetizmu. Jedan od kratera na nevidljivoj strani Mjeseca, položaja 38,5N (širina) i 124,7E (dužina) te promjera 43 km, nazvan je po Tesli, što se drži velikim znanstveno-kulturnim priznanjem.

U povodu smrti Nikole Tesle od brojnih prigodnih brzojava izdvajamo onaj gospođe Eleanore Roosevelt u njezino i predsjednikovo ime te brzojave trojice nobelovaca: Roberta A. Millikana, Arthura H. Comptona i Jamesa Francka. Sva trojica nobelovaca, kao slavni eksperimentalni fizičari, jezgrovito su Teslu opisali kao jednog od najistaknutijih umova svijeta koji je zacrtao putove brojnim tehnološkim razvojima modernog doba.

Tesla je američko državljanstvo dobio 1891. godine, koja mu je bila napose plodonosna u smislu njegovih temeljnih izuma u polju visokofrekvencijskih Teslinih struja (Teslin svitak, predavanje s demonstracijom visokofrekvencijskog transformatora na Sveučilištu Columbia, New York), čime se ovaj članak posebno bavi. Tesla je održavao veze s rodnim krajem i narodom iz kojeg je poniknuo. Slavna i trajna jest njegova izjava: Ponosim se srpskim rodom i hrvatskom domovinom.

apple, the creator of deadly penetrating long-distance rays etc.

Tesla was a loner, a brilliant inventor and a man of the highest ethical principles. He had the greatest respect and admiration for his parents. His father, Milutin, was the rector of a Serbian Orthodox parish. It was to his intelligent and unpretentious mother, Đuka née Mandić, that he attributed her gift for invention. Tesla had a few close friends who were writers, including Mark Twain. However, it should be emphasized that Tesla, besides his brilliant inventive abilities, intuition and photographic memory, was a perfectionist in his work (preparing and conducting experiments) and highly disciplined in his daily life (physical activities and healthful diet).

In 1917, Tesla received the Edison Medal, the highest honor awarded by the American Institute of Electrical Engineers (AIEE). On the hundredth anniversary of Tesla's birth, the unit of magnetic flux density or magnetic induction was named tesla (abbreviated as T) in his honor. In October 1960 in Paris, at the eleventh session of the General Conference on Weights and Measures (CGPM - Conférence Générale des Poids et Mésures), the unit tesla was officially accepted and included within the International System of Units (SI - Sistème International D'Unités) as the SI derived unit of magnetic flux density (or magnetic induction). One of the craters on the far side of the moon (latitude 38.5N, longitude 124.7E and 43 km in diameter) was named after Tesla, which is considered to be a high scientific and cultural honor.

On the occasion of Nikola Tesla's death, among the numerous telegrams we single out those from Mrs. Eleanor Roosevelt on behalf of herself and President Franklin Delano Roosevelt, and three Nobel Prize winners: Robert A. Millikan, Arthur H. Compton and James Franck. All three, as celebrated experimental physicists, described Tesla as one of the most distinguished minds of the world, who had outlined the paths for numerous technological developments of the modern age.

Tesla received American citizenship in 1891, a year that was otherwise particularly fruitful regarding his fundamental discoveries in the field of high frequency Tesla currents (the Tesla coil, and a lecture with a demonstration of a high frequency transformer at Columbia University, New York), which will be separately discussed in this article. Tesla maintained ties with his ethnic roots and birthplace, saying: I am proud of my Serbian lineage and Croatian homeland.

2 TESLIN INŽENJERSKI DUH – USPOREDBA S M. FARADAYEM I A. A. MICHELSONOM

Mnogi odgovorni povjesničari fizike u svijetu Teslu uspoređuju s Faradayem, a uporište usporedbi jest izostanak Teslinog formalnog matematičko-fizičkog obrazovanja, što je još jače naglašeno u slučaja s Faradayem. Teslin inženjerski duh dokazan je, poput Faradayevog, u jedinstvenom eksperimentalnom zanosu tijekom cijelog Teslinog života, s dominantnom orijentacijom na izume u fizici i elektrotehnici koje bi nakon pouzdanog otkrića trebalo teorijski obrađivati. Faraday i Tesla imali su gotovo podudarna filozofska gledišta o ulozi eksperimenata u razvitku znanosti. Eksperimenti su ključni za razvoj znanstvenih teorija i važan su izvor novih spoznaja, a ne tek alat za potvrđivanje ili opovrgavanje teorijskih formulacija.

U znanstvenoj javnosti, ponajviše u poljima eksperimentalne fizike čestica i akceleratorske tehnologije, veličanstveno se 1991. obilježila 200. obljetnica rođenja Michaela Faradaya (22. rujna 1791.-25. kolovoza 1867.). Povjesničari znanosti tada su nam ponovno približili Faradayevu akribičnost i pokazali njegovu istraživačku sustavnost kakva se rijetko susreće u čitavoj povijesti prirodnih i tehničkih znanosti. Faraday je u razdoblju između 1831. i 1862. katalogizirao u svoju laboratorijsku knjigu 16 041 zapis (Entries) svojih pokusa. Rezultat svih tih zapisa moguće je sažeti u fundamentalno otkriće elektromagnetizma, odnosno fizike u cjelini, da su sile svojstva polja. M. Faraday je izvornim inženjerskim pokusima, ali bez velikog znanja matematičke fizike svoga doba, omogućio fiziku polja koju je briljantno formulirao J. C. Maxwell 1864. godine. Govorimo o Faraday-Maxwellovom utemeljenju elektromagnetske teorije i klasične elektrodinamike koje su bile uzorom Einsteinovoj teoriji relativnosti te modernim teorijama polja u fizici čestica. Slavni Faradayev Dnevnik (Faraday's Diary, 7 svezaka, pokriva razdoblje od 1820. do 1862.) i njegova dopisivanja (Faraday's correspondence, više od 4 000 pisama koje je napisao Faraday ili koja su napisana njemu) ne svjedoče samo o eksperimentalnome stilu istraživanja polovicom 19. stoljeća nego su i putokazi za stvaralačko mišljenje u modernim tehnologijama. Tesline Zabilješke u Colorado Springsu (Colorado Springs-Notes) [7] i njegov opis vlastitih otkrića (My Inventions) [8] dragocjeni su izvori i primjeri za kreativno mišljenje u modernim tehnologijama, napose u informacijsko-komunikacijskoj tehnologiji. Teslin i Faradayev Dnevnik podjednako su zanimljivi i suvremenim kognitivnim znanostima.

2 TESLA'S ENGINEERING SPIRIT - A COMPARISON WITH M. FARADAY AND A. A. MICHELSON

Many reputable historians of physics in the world compare Tesla to Faraday. The reason for this comparison is Tesla's lack of formal training in physics and mathematics, which was even more evident in Faraday's case. Tesla's engineering spirit, like that of Faraday, manifested itself throughout his life as a passion for experimentation, predominantly oriented toward innovations in physics and electrical engineering that required theoretical analysis following their discovery. Faraday and Tesla had nearly identical philosophical attitudes regarding the role of experiments in science. Experiments are crucial for the development of scientific theories and important sources of new knowledge, not merely tools for the confirmation or refutation of theoretical formulations.

Among the scientific community, particularly in the fields of experimental particle physics and accelerator technology, the two hundredth anniversary of the birth of Michael Faraday (September 22, 1791-August 25, 1867) was celebrated magnificently during the year 1991. Scientific historians took the occasion to examine his scholarly, meticulous and systematic approach to research, the like of which has rarely been encountered throughout the entire history of the natural and technical sciences. During the period between 1831 and 1862, Faraday catalogued 16 041 scientific entries on his experiments in his laboratory log. The result of all these entries can be summarized in the fundamental discovery of electromagnetism, i.e. physics as a whole, that magnetic fields are characterized by lines of force. Through original engineering experiments but without extensive knowledge of the mathematics and physics of his day, M. Faraday made the development of the physics of the electromagnetic field possible, which was brilliantly formulated by J. C. Maxwell in the year 1864. We speak of Faraday-Maxwell's fundamental electromagnetic theories and classical electrodynamics that served as the model for Einstein's theory of relativity, and modern theories in the field of particle physics. Faraday's celebrated diary, consisting of seven volumes, covers the period from 1820 to 1862. His correspondence, consisting of over 4 000 letters he either wrote or received, testifies not only to the experimental style of research in the mid 19th century but also provides orientation for creative thinking in modern technologies. Tesla's notes in Colorado Springs (Colorado Springs — Notes) [7] and his description of his inventions (My Inventions) [8] are valuable sources and examples of creative thinking in modern technologies, particularly

Faraday je vjerovao da su prirodne pojave povezane i to je bila glavna nit njegovih istraživanja. Njegovi radovi i doprinosi protežu se po raznim područjima: od kemije i elektrokemije, elektrostatike i elektromagnetizma (inducirani napon, 1831.), eksperimentalne podloge teoriji polja do optike (zakret ravnine polarizacije polarizirane svjetlosti u jakom magnetskom polju, 1845.). Slika o Faradayu kao znanstveniku koji predano radi u podrumskome laboratoriju Kraljevskog instituta nije potpuni i pravi njegov portret. Faraday eksperimentalac bio je i Faraday filozof, što se nepravedno zanemaruje u tumačenjima njegova života i djela. Njegova izvorna predodžba elektromagnetskog polja međusobno zatvarajućim silnicama (linijama) električnog i magnetskog polja pridaje mu ulogu fizičara koji je prvi znanstveno započeo dematerijalizaciju materije. Isto tako, mnogi istraživači Faradayevog života i djela drže da su Faradayeva kršćanska vjerovanja bila važna za njegovo znanstveno istraživanje. Faraday je bio članom male Sandemanističke sekte (Sandemanian sect), a uporište sekte je u doslovnom poimanju i tumačenju Biblije te moralnome vladanju u skladu s njom. Faradayevo zajedničko putovanje s H. Davyjem po europskim zemljama od studenoga 1813. do travnja 1815. drži se važnim elementom u formiranju njegove filozofije istraživanja. Sve ovo rečeno o Faradayu i njegovoj filozofiji istraživanja vrijedi manje ili više i za Nikolu Teslu.

Teslu možemo opravdano uspoređivati i s američkim eksperimentalnim fizičarom A. A. Michelsonom (Strzelno, Poljska, 19. prosinca 1852.-Pasadena, Kalifornija, SAD, 9. svibnja 1931.) kojemu je točno mjerenje brzine svjetlosti interferometrijskim pokusima bilo znanstvena preokupacija, kao što je Tesli bio bežični prijenos energije i informacije (Tesla World System). Godine 1878. Michelson je započeo s radom na problemu točnog mjerenja brzine svjetlosti, što mu je bila znanstvena strast do kraja života. Zbog usavršavanja u optičkim metodama 1880. putuje u Europu gdje provodi dvije godine u laboratorijima u Berlinu, Heidelbergu i Parizu. Godine 1884. Tesla putuje u suprotnom smjeru, ostajući u Americi do kraja života. Godine 1883. Michelson postaje profesorom fizike u Case školi primijenjene znanosti u Clevelandu, potpuno se posvetivši razvoju interferometra za mjerenje eterskog pomaka. Najvažniji Michelsonovi znanstveni doprinosi bili su prvo (1881., Berlin) i drugo (1887., Cleveland) mjerenje eterskog pomaka s nultim rezultatom (Michelson-Morleyev pokus), zatim dobivanje najtočnijeg podatka toga vremena za brzinu svjetlosti usavršenom metodom L. Foucaultovog rotirajućeg zrcala (1879.) te definicija i mjerenje etalona metra brojem valnih

information-communications technology. Tesla's and Faraday's diaries are equally interesting from the viewpoint of the contemporary cognitive sciences.

Faraday believed that natural phenomena are linked and this was the main thread of his investigations. His work and contributions cover various areas, including chemistry and electrochemistry, electrostatics and electromagnetism (induced voltage, 1831), the experimental basis for the electromagnetic field theory, optics (the rotation of the plane of polarization of a polarized light beam by a strong magnetic field, 1845). The picture of Faraday as a scientist who worked with dedication in the basement laboratory of the Royal Institute is not a complete and accurate portrait. The experimenter Faraday was also Faraday the philosopher, an aspect of his personality that is unjustly neglected in the explanation of his life and work. In light of Faraday's original concept of the electromagnetic field, with closed lines of force in the electric and magnetic fields, he should also be remembered as the first physicist to begin the scientific dematerialization of matter. Similarly, many scholars of Faraday's life and work maintain that Faraday's Christian faith was important in his scientific investigations. Faraday was a member of the Sandemanian sect, whose beliefs are characterized by a literal understanding and interpretation of the Bible as the basis for moral values and behavior. Faraday's travels with H. Davy through European countries from November 1813 to April 1815 are considered to be an important element in the formation of his philosophy of research. Everything that we have said about Faraday and his philosophy of research is also more or less applicable to Nikola Tesla.

We can also justifiably compare Tesla to the American experimental physicist A. A. Michelson (Strzelno, Poland, December 19, 1852- Pasadena, California, USA, May 9, 1931), for whom the precise measurement of the speed of light through interferometric experiments were his scientific preoccupation, as the wireless transmission of energy and information (the Tesla World System) was for Nikola Tesla. In the year 1878, Michelson began work on the problem of the precise measurement of the speed of light, which was to be his scientific passion until the end of his life. In order to pursue advanced studies in optical methods, in 1880 Michelson traveled to Europe and spent two years at laboratories in Berlin, Heidelberg and Paris. In the year 1884, Tesla traveled in the opposite direction, i.e. from Europe to the United States, where he remained until the end of his life. In the year 1883, Michelson became a professor of physics at the Case Institute of Technology in Cleveland, Ohio, and completely devoted himself to the development of interferometry for the measurement of aether drift.

duljina crvene svjetlosti iz pobuđenih atoma kadmija (1893.). Michelson je bio predsjednikom Nacionalne akademije znanosti SAD-a (1923.-1927.), a primio je i zlatnu medalju Kraljevskog astronomskog društva 1923. Krater na Mjesecu nosi Michelsonovo ime, a takva je čast dodijeljena i Tesli. Međutim, za konstrukciju interferometra koja nosi njegovo ime te za niz spektroskopskih i metroloških otkrića Micheslon je 1907. dobio Nobelovu nagradu iz fizike, kao prvi Amerikanac u povijesti te nagrade. Tesla takvu čast nije dočekao za svog života, niti posmrtno osim eulogijskih komentara nobelovaca o vrijednosti njegovog djela na Teslinu pogrebu u New Yorku.

U Teslinu inženjerskom duhu intuicija je bila odlučujuća. Ostavimo li po strani skolastičku tradiciju koja razlučuje intuitivnu od diskurzivne spoznaje, s obzirom na Tesline snažne vizije ili percepcije njegovih izuma (npr. trofazni sustav i rotirajuće magnetsko polje) i matematičku preciznost koja je u njima postojala, možemo reći da je Tesla imao dar kartezijanske intuicije. Tesline intuicije njegovih izuma, prema lat. intueri (pomno motriti, gledati, upirati oči u što) doista su bile očevidne, tim više što su mnoge vrlo uspješno primijenjene u tehnici i industriji. Teslino djelo broji oko 700 izuma (patenata), od kojih više od stotinu u području elektrotehnike i radiotehnike čine njegov najveći doprinos ne samo u tim područjima nego i u brojnim suvremenim tehnologijama (visokofrekvencijska rasvjeta, tele-vizija, internet, mobitel).

3 TESLIN TRANSFORMATOR - IZVOR RF-POLJA VELIKE SNAGE I TEMELJNI UREĐAJ ZA BEŽIČNI PRIJENOS ENERGIJE ILI PORUKE

Nikola Tesla je 20. svibnja 1891. na Sveučilištu Columbia, na konferenciji Američkog instituta inženjera elektrotehnike (AIEE), održao glasovito predavanje popraćeno briljantnim pokusima, pod naslovom: Eksperimenti s izmjeničnim strujama vrlo visoke frekvencije i njihova primjena u metodama umjetnog osvjetljivanja / Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination. Povijest fizike i elektrotehnike priz-naje Tesli pionirsku ulogu u prepoznavanju važnosti visokih frekvencija u istraživanjima električnih i magnetskih pojava (u teoriji polja), a napose u prijenosu energije i informacije te u metodama električne rasvjete. U predavanju Tesla vidovito stavlja naglasak na nove metode glede dobivanja

Michelson's most significant scientific contributions were the measurement of aether drift with the null result (the Michelson-Morley experiment, first performed in Berlin, 1881, and later in Cleveland, 1887), the obtaining of the most precise data of his time on the speed of light by perfecting the method of L. Foucault's rotating mirror (1879), and the defining and measuring of the archive meter according to the number of wavelengths of red light emitted from excited cadmium atoms (1893). Michelson was the president of the U.S. National Academy of Sciences (1923-1927), and also received the gold medal of the Royal Astronomical Society in 1923. A crater on the moon bears Michelson's name, an honor also given to Tesla. However, for the construction of the interferometer that bears Michelson's name, and for a series of spectroscopic and metrological discoveries, he was awarded the Nobel Prize in Physics in 1907, the first American in history to receive this prize. Tesla did not live to see such an honor during his lifetime, nor was there any such an honor after his death, although there were eulogies by Nobel Prize winners on the importance of Tesla's work at his funeral in New York.

In Tesla's engineering spirit, intuition was decisive. Leaving aside the scholastic tradition that distinguishes intuition from discursive cognition, considering Tesla's powerful vision or the perceptions of his inventions (for example, the three-phase system and the rotating magnetic field), and their mathematical precision, we may say that Tesla had the gift of Cartesian intuitions. Tesla's intuitions of his inventions, according to the Latin intueri, were more than evident, and many have been very successfully applied in technology and industry. Tesla's opus includes approximately 700 patents, of which over 100 are in the area of electrical engineering and radio technology, constituting his greatest contribution, not only in these areas but in numerous contemporary technologies (high frequency illumination, television, Internet and cell phone).

3 TESLA'S TRANSFORMER - THE SOURCE OF HIGH POWER RF-FIELDS AND THE BASIC DEVICE FOR THE WIRELESS TRANSMISSION OF ENERGY OR MESSAGES

On May 20, 1891, at a conference of the American Institute of Electrical Engineers (AIEE) held at Columbia University, Nikola Tesla presented a famous lecture, Experiments with Alternate Currents of Very High Frequency and Their Application to Methods of Artificial Illumination, i prijenosa energije, osobito u proizvodnji svjetla jer stari teški strojevi za to više neće biti potrebni. U predavanju se dotiče i fundamentalnog pitanja o naravi elektriciteta u kontekstu teorije etera, 15 godina prije Einsteinove Specijalne teorije relativnosti, ali s izrazito fenomenološkim pristupom.

Tesla je predložio naziv vezani eter za elektricitet koji se javlja u molekulama, a koji je važan za nastajanje svjetlosti. Takvo gledište i naziv J. J. Thomson je smatrao pogrešnim. Međutim, valja naglasiti da je Tesla 1891. ispravno uočio da je nastajanje svjetlosti povezano s poremećajima statičkog električnog naboja u molekulama. Tesli nedvojbeno pripadaju povijesne zasluge da je prvi eksperimentalno pokazao, četiri godine nakon otkrića elektromagnetskih valova H. Hertza 1887. koji su bili predviđeni Maxwellovim jednadžbama 23 godine prije toga, da su visoke frekvencije i potencijali važni za nastajanje svjetlosti i topline (elektromagnetskih valova) bez dodatnih kemijskih procesa u toj tvorbi. Zadivljuje i Teslina intuicija o sveprisutnoj energiji i potrebi da se ona iskoristi za dobrobit čovječanstva.

Na Sveučilištu Columbia Tesla je imao još jedno važno predavanje 16. svibnja 1888. o novome sustavu motora i transformatora s izmjeničnim strujama. Koliko su Teslina predavanja bila važna za razvoj fizike i elektrotehnike toga vremena, najbolje potvrđuje činjenica da je Sveučilište Columbia dodijelilo počasni doktorat (doctor in legibus) Nikoli Tesli 13. lipnja 1894. To je bio prvi počasni doktorat koji je Tesla dobio za svoje izume, najveći dokaz prepoznavanja važnosti njegovih otkrića u elektromagnetizmu. Nakon toga Tesla je primio više od deset počasnih doktorata na sveučilištima u Europi i SAD-u.

Teslin visokofrekvencijski transformator (*RF*-transformator) uistinu je bio prekretnica u razvoju moderne radiofrekvencijske tehnologije. Prisjetimo se Lodgeovih pokusa (Sir Oliver J. Lodge, 12. lipnja 1851. - 22. kolovoza 1940.) s elektromagnetskim titrajnim krugovima. Lodge je engleski fizičar, pionir radija i izumitelj koherera za otkrivanje širenja elektromagnetskih valova. Lodgeovi pokusi temeljili su se na dva razmaknuta titrajna kruga koji su bili sastavljeni od kondenzatora (Leydenska boca) i zavojnice od metalnog okvira. U prvome Lodgeovom titrajnom krugu Leydenska boca bi se nabijala pomoću induktora, a izbijala preko iskrišta kroz bakreni okvir koji je imao ulogu zavojnice. U drugome Lodgeovom titrajnom krugu, udaljenom od prvog, unutarnji i vanjski oblog Leydenske boce bili su spojeni okvirom od žice, ali tako da vertikalni pomični okvir može kliziti po vodoravnim žicama.

accompanied by brilliant experiments. The history of physics and electrical engineering recognizes Tesla's pioneering role in discerning the importance of high frequencies in the investigation of electrical and magnetic phenomena (in the electromagnetic field theory), especially in the transmission of energy and information, and in the methods of electrical illumination. In the lecture, Tesla prophetically placed emphasis upon new methods for obtaining and transmitting energy, especially in the production of light, because the old heavy machinery for this would not be necessary. In the lecture, a fundamental question is touched upon regarding the nature of electricity in the context of the Theory of Aether, fifteen years before Einstein's Theory of Relativity, but with a marked phenomenological approach.

Tesla proposed the name bound aether for the electricity that occurs in molecules, and which is important for the phenomenon of light. J. J. Thomson considers such a view and name to be in error. However, it should be emphasized that in 1891 Tesla correctly noted that the occurrence of light is connected with disturbances in the electrostatic charge of molecules. Tesla should undoubtedly be entitled to historical recognition that he was the first to demonstrate experimentally, four years after H. Hertz's discovery of electromagnetic waves in 1887 which was anticipated by Maxwell's equations twenty-three years earlier, that high frequencies and voltages are important for the occurrence of light and heat (electromagnetic waves) without additional chemical processes. Tesla's intuition regarding omnipresent energy and the need to harness it for the welfare of humankind is amazing.

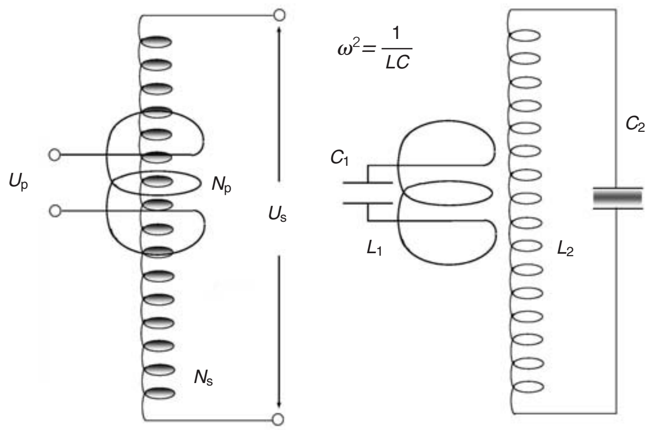
At Columbia University, Tesla delivered another important lecture on May 16, 1888, on a new system for a motor and transformer using alternating current. The importance of Tesla's lectures in the development of the physics and electrical engineering of the time is best confirmed by the fact that Columbia University awarded an honorary doctorate (doctor in legibus) to Nikola Tesla on June 13, 1894. This was the first honorary doctorate that Tesla received for his inventions, the highest proof of the recognition of the importance of his discoveries in electromagnetism. Subsequently, Tesla received more than ten honorary doctorates at universities in Europe and the United States.

Tesla's high frequency transformer (*RF* transformer) was truly a breakthrough in the development of modern radio frequency technology. We recall the experiments by Sir Oliver J. Lodge (June 12, 1851 - August 22, 1940) using electromagnetic oscillating circuits. Lodge was an English physicist, Time se induktivitet okvira i čitavog titrajnog kruga mogao mijenjati (namještati). Drugi titrajni krug imao je i malo pomoćno iskrište za detekciju titraja u drugome krugu. Kad je drugi titrajni krug bio blizu prvome i ako je pomični okvir bio na pogodnom (rezonantnom) mjestu, malo pomoćno iskrište bi probijalo pokazujući da naboj u drugome krugu titra jednakim titrajnim vremenom kao i u prvom. Kažemo da su Lodgeovi titrajni krugovi u rezonanciji jer silnice elektromagnetskih valova zahvaćaju i drugi okvir, što izaziva titranje naboja u drugom krugu. U kontekstu Lodgeovih pionirskih pokusa zrcali se Teslin domet. On je drugi titrajni krug premjestio u središte primarne zavojnice, otkrivši Teslin transformator. Bila je to Teslina revolucija u polju visokofrekvencijske tehnologije.

Teslin visokofrekvencijski transformator, bez karakterističnog željeznog jarma, jest rezonantni transformator sa sekundarnom zavojnicom pod visokim potencijalom. Primarna zavojnica s nekoliko zavoja dio je primarnog titrajnog kruga koje ima Teslino iskrište, a duga sekundarna zavojnica s mnogo zavoja s parazitskom kapacitivnošću između vlastitih zavoja ekvivalentna je visokofrekvencijskom rezonantnom krugu. Najveća transformacija napona i najbolje prilagođenje dobiva se kad je primarna zavojnica dio rezonantnog kruga i kad je ugođena rezonantnoj frekvenciji sekundarne zavojnice. Matematički to odgovara uvjetu: $L_1C_1 = L_2C_2$, koji se dobiva primjenom Thomsonove formule za rezonantno ugođene (povezane) titrajne krugove. Teslin transformator izvor je visokofrekvencijskih polja velikih snaga. Njegova nadomjesna shema s posebno označenom raspodijeljenom parazitskom kapacitivnošću sekundarne zavojnice (C_2) prikazana je na slici 1. Na slici 2 je prikazana školska izvedba Teslinog *RF*-transformatora koji se rabi u pokusima na predavanjima iz kolegija Fizike na Fakultetu elektrotehnike i računarstva (FER) te u nastavi fizike koja se na FER-u izvodi i za druge inženjerske fakultete Sveučilišta u Zagrebu.

radio pioneer and the inventor of the coherer electromagnetic wave detector. Lodge's experiments are based upon two oscillating circuits that are spaced apart, consisting of capacitors (Leyden jars) and rectangular loops. A high-voltage DC generator charges up the capacitor in the first oscillating circuit. At some point, the capacitor discharges via a spark gap into the rectangular loop that has the role of an inductor. In Lodge's second oscillating circuit, separated by a space from the first one, the inside and the outside surfaces of the Leyden jar were connected to the rectangular loop and a movable loop that could slide across the rectangular loop. In this manner, the inductance changes and the frequency of the oscillating circuit is tuned. The second oscillating circuit has an auxiliary spark gap to detect oscillation in the second circuit. When the second oscillating circuit is close to the first one, and if the movable loop is in the resonance position, sparks in the auxiliary spark gap are generated, indicating that the charge in the second loop is oscillating at the same frequency as in the first loop. We can say that Lodge's oscillating circuits are in resonance because the electromagnetic lines of force in the first and second loop are coupled, which generates the oscillation of the charge in the second circuit. Within the context of Lodge's pioneering experiments, Tesla's achievements can be appreciated. He moved the second oscillating circuit into the center of the primary coil, thus discovering the Tesla transformer. This was Tesla's revolution in the field of high frequency technology.

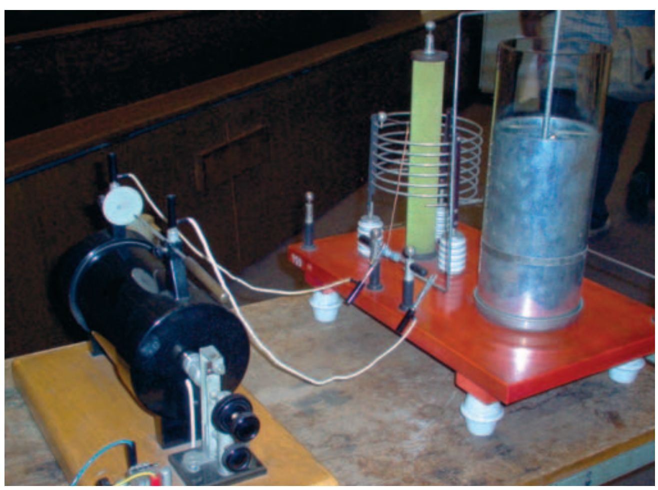
Tesla's high frequency transformer, without the characteristic iron core, is a resonant transformer with a high voltage secondary coil. A primary coil with several turns is part of the primary oscillating circuit together with the Tesla spark gap. The long secondary coil with many turns and stray capacitance between its turns is equivalent to a high frequency resonant circuit. The highest voltage and the best tuning is achieved when the primary coil is a part of the resonant circuit and when it is tuned to the resonant frequency of the secondary coil. This can be expressed as follows: $L_1C_1 = L_2C_2$, obtained by applying the Thomson equation for the resonant tuning (linkage) of the oscillating circuits. Tesla's transformer is a source of high-frequency high-power electromagnetic fields. An equivalent scheme of the transformer, with the distributed stray capacitance of the secondary coil (C_2) indicated, is presented in Figure 1. Figure 2 is a version of Tesla's *RF* transformer that is used in experiments during physics lectures at the Faculty of Electrical Engineering and Computing in Zagreb and in the physics instruction that the Faculty conducts for other engineering faculties of the University of Zagreb.



Slika 1
Nadomjesna shema Teslinog *RF*-transformatora
Figure 1
Equivalent scheme of Tesla's *RF* transformer

Na krajevima duge sekundarne zavojnice dobiva se napon: $U_s = U_P \cdot N_s / N_P$, uz uvjet $N_s >> N_P$ (brojevi zavoja sekundarne i primarne zavojnice). U svojim originalnim proračunima, prema Dnevniku istraživanja u Colorado Springsu [7], Tesla je određivao dužinu žice sekundarne zavojnice transformatora tako da odgovara četvrtini valne duljine elektromagnetskih valova u slobodnome prostoru.

The voltage at the end of the long secondary coil is as follows: $U_s = U_P \cdot N_s / N_P$ under the following condition: $N_s >> N_P$ (the numbers of the turns of the secondary and primary coils). In Tesla's original calculations, according to his records in Colorado Springs [7], he determined the length of the wire of the secondary coil of the transformer so that it corresponded to a quarter of the wavelength of the electromagnetic waves in free space.



Slika 2
Školska izvedba Teslinog *RF*-transformatora
Figure 2
Version of Tesla's *RF* transformer used in schools

Na slici 2 se vidi induktor s ulaznim iskrištem koji ima ulogu da s oko 20 prekida u sekundi ($T \approx$ 0,05 sekundi) stvara kratkotrajne pozitivne naponske impulse visine povrh 50 kV. Naponski impulsi nabijaju Leydensku bocu u primarnom titrajnom krugu (velika staklena boca na slici, s kuglom na kraju aksijalne šipke). Leydenska boca se preko iskrišta izbija kroz primarnu zavojnicu od sedam svitaka (Teslin oscilator s iskrištem). Uzduž osi primarne zavojnice suosno je smještena sekundarna zavojnica (žuti valjak na slici) čiji je

In Figure 2, there is an inductor with a spark gap at the entrance which creates short positive voltage impulses higher than 50 kV with approximately 20 interruptions per second ($T \approx$ 0,05 seconds). The voltage impulses charge the Leyden jar in the primary oscillating circuit (the large glass bottle in the figure, with a sphere at the end of the axial rod. The Leyden jar discharges via the spark gap into the primary coil with 7 turns (Tesla's oscillator with a spark gap). The secondary coil is placed along the axis of the primary coil (the yellow cylinder in the donji kraj uzemljen, a gornji završava kuglom za prilagođeno isijavanje elektromagnetske energije u slobodni prostor. Sekundarna zavojnica (Teslin *RF*-transformator) rezonantno je prilagođena frekvenciji primarnog titrajnog kruga.

Autor ovog članka je u svrhu točnih pokusa s demonstracijom Teslinog transformatora i njegovih primjena u bežičnom prijenosu energije i rasvjete na daljinu izvršio proračun rezonantne frekvencije transformatora i probojnog napona na kugli na slobodnom kraju transformatora (za opažanje Teslinih iskri). Iz geometrije primarnog svitka, zanemarujući rasipanja, izračunao se njegov induktivitet (L = 0,188 H) koji s kapacitetom Leydenske boce ($C \cong$ 1 nF) po Thomsonovoj formuli daje rezonantnu frekvenciju titranja: $\omega_{rez} = 1/\sqrt{LC}$ = 72,93 kHz.

Transformator isijava *EM* valove frekvencije $f = \omega_{rez}/2\pi$ =11,6 kHz, tako da se iskre s kugle transformatora bezopasno primaju metalnim elektrodama, a udaljene neonske cijevi pobuđuju na svijetljenje. Prema Teslinoj izvornoj relaciji (istraživanja u Colorado Springsu), za probojni napon kugle transformatora $V = 75\ 400 \cdot r$, gdje je r polumjer kugle u centimetrima, izračunao se probojni napon: $V = 75\ 400 \cdot 0,75$ V = 56,55 kV. Polumjer kugle školskog transformatora jest r = 0,75 cm. Tesla je u Colorado Springsu 1899. kuglom od 40 cm dobivao napone od $3,016 \cdot 10^6$ V = 3,016 MV i pomoću njih iskre koje se približavaju nebeskim munjama. Premda po dimenzijama i snazi školski, transformator sa slike 2 omogućuje zanimljive pokuse koji izazivaju veliki interes i oduševljenje studenata.

Fundamentalni Teslin izum za istraživanja elektromagnetskih pojava bio je i Teslin svitak (Tesla Coil). Riječ je o prstenastome zavoju (jedan ili nekoliko zavoja) napravljenom od bakra ili nekog drugog vodiča. Kao sklop, to je, zapravo, oscilacijski transformator koji ima primarni i sekundarni transformator i strujni upravljač (iskrište). Kad svitkom teče visokofrekventna struja, magnetsko polje u svitku se vrlo brzo mijenja. Te promjene magnetskog toka obuhvaćene su zatvorenim silnicama električnog polja. Ako se svitak nalazi u razrijeđenom plinu (npr. zrak) i ako je jakost električnog polja dovoljno visoka, dolazi do izboja u plinu, pa se oko Teslinog svitka vidi svijetli ružičasti prsten koji oponaša oblik svitka, odnosno predočava zatvorene električne silnice. Tesla je svitak otkrio 1891., a on se i danas upotrebljava u radijskim i televizijskim uređajima te u mnogim elektroničkim uređajima.

photograph), the bottom end of which is grounded and the upper end terminates with a sphere for the adjusted radiation of the electromagnetic energy into the free space. The secondary coil (Tesla's *RF* transformer) is resonantly tuned to the frequency of the primary oscillating circuit.

For the purpose of precise experiments with a demonstration of Tesla's transformer and its application in the wireless long-distance transmission of energy and light, the author of this article has calculated the resonant frequencies of the transformer and breakedown voltage of the sphere at the free end of transformer (to observe Tesla's sparks). From the geometry of the primary coil, ignoring leakage, its inductivity is calculated (L = 0,188 H) which together with the capacitance of the Leyden jar ($C \cong$ 1 nF) according to Thompson's formula yields the resonant frequency: $\omega_{rez} = 1/\sqrt{LC}$ = 72,93 kHz.

The transformer radiates *EM* waves of $f = \omega_{rez}/2\pi$ =11,6 kHz, so that sparks from the transformer sphere are harmlessly received by the metal electrodes, and the neon tubes at a distance light up. According to Tesla's original formula (research in Colorado Springs) for the breakdown voltage of the transformer sphere: $V = 75\ 400 \cdot r$, where r is the radius of the sphere in centimeters, the breakdown voltage is calculated: $V = 75\ 400 \cdot 0,75$ V = 56,55 kV. The radius of the sphere of the school transformer is r = 0,75 cm. In 1899 in Colorado Springs, Tesla obtained voltage of $3,016 \cdot 10^6$ V = 3,016 MV with a 40 cm sphere, thereby obtaining sparks that approached flashes of lightning. Although of much smaller dimensions, the school transformer in Figure 2 permits interesting experiments that excite great interest and excitement among students.

Tesla's fundamental invention for the investigation of electromagnetic phenomena was the Tesla coil. It is a cylindrical coil (one or several turns), made of copper or some other conductor. It is actually an oscillating transformer with primary and secondary transformers and a current switch (spark gap). When high frequency current passes through the coil, the magnetic fields in the coil change very rapidly. These changes in the magnetic flux are coupled with the closed lines of force of the electrical field. If the coil is located in a rarified gas (for example, air) and if the intensity of the electrical field is sufficiently high, discharge into the gas occurs and a pink ring is seen around the Tesla coil that mimics the form of the coil or the closed electrical lines of force. Tesla discovered the coil in the year 1891 and it is used today in radio, television and many electronic devices.

3.1 Teslin transformator u razvoju akceleratorske tehnologije

U prikazu razvoja akceleratorske fizike čestica, napose tehnologije linearnih ubrzivača čestica, nitko nije tako sažeto i odgovorno prikazao ulogu Teslinog visokofrekvencijskog transformatora u tome razvoju poput prof. dr. Helmuta Wiedemanna iz Odjela za primijenjenu fiziku Sveučilišta Stanford i istraživača u stanfordskom laboratoriju sinkrotronskog zračenja [9]. U tome razvoju važnu ulogu i danas imaju izvori *RF*-polja odgovarajuće snage. Prekretničku ulogu odigrao je baš Teslin *RF*-transformator bez željezne jezgre, prije svega visoki naponi koji se mogu dobiti s kraja njegove sekundarne zavojnice. Tijekom jedne polovice perioda oscilacija napona na sekundarnoj zavojnici napon se rabi za ubrzavanje pulsa (snopa) čestica u kanalu akceleratora. Ta se metoda, dakako, u vrhunskoj tehnologiji upotrebljava danas, napose u supravodičkim akceleratorima elektronskih snopova.

Opisat ćemo je ukratko na primjeru Thomas Jefferson Accelerator Facility, jednog od najpoznatijih supravodičkih elektronskih akceleratora u svijetu. U njemu se izvode temeljna istraživanja u fizici čestica i nuklearnoj fizici na kvarkovskoj osnovici supravodljivosti, fizici materijala i površina, fizici lasera, pa do primijenjenih istraživanja u medicini i biotehnologijama sve do raznih industrijskih primjena. U glavnome kanalu u obliku izdužene elipse, dužine oko 1 milje (oko 1,6 km), nalaze se dva linearna ubrzivača elektrona (tzv. sjeverni i južni linac) koja zajedno imaju 320 radiofrekvencijskih rezonatora (rezonantne šupljine, tzv. *RF* Cavities) u supravodičkoj tehnologiji (materijal niobij Nb, kritična ili prijelazna temperatura u supravodljivo stanje T_k= 9,3 K). U svakom ubrzivaču povećava se energija elektronskog snopa za 400 MeV. Milijardu puta (10^9) u sekundi ubacuje se (fokusira) milijun (10^6) elektrona tako da se dobije elektronski snop debljine ljudske kose (promjer oko 200 μm). Ubrzavanje elektrona u rezonatorima se izvodi pomoću *RF*-polja. Elektronski snop se linearno ubrzava kroz kanal tako da sinkronizirano nailazi svaki put na padajuću stranu pozitivnog poluvala *RF*-signala uzduž aksijalne osi rezonatora.

U znanstvenoj i tehnološkoj grani primjene radiofrekvencija u linearnim ubrzivačima događa se, u naše vrijeme, vrlo zanimljiv tehnološki razvoj i otkriće. Razvoj se zbiva oko glavnog problema: ostvarenje što većeg gradijenta ubrzavanja čestica u linearnim ubrzivačima, iskazano u jedinicama MV/m (megavolt/metar). Cilj je predati što veću energiju čestici (snopu) po jedinici duljine rezonatora u kojemu se ubrzavanje događa. U supravodičkim linearnim ubrzivačima

3.1 Tesla's transformer in the development of accelerator technology

In the presentation of the development of accelerator particle physics, especially the technology of linear particle acceleration, no one has so concisely and responsibly presented the role of Tesla's high frequency transformer as Prof Helmut Wiedemann, PhD, from the Department of Applied Physics, Stanford University, at the Stanford Synchrotron Radiation Laboratory [9]. In such development, sources of *RF* fields of suitable power also have an important role today. Tesla's *RF* transformer without an iron core was a breakthrough, especially due to the high voltages that can be obtained from the end of its secondary coil. During a half-period of voltage oscillation on the secondary coil, the voltage is used for accelerating the pulses of the particles (beam) in the accelerator channel. This method is particularly used in high technology today, especially in superconductor accelerators of electronic beams.

We shall describe it briefly, using the example of the Thomas Jefferson National Accelerator Facility, one of the most famous superconductor electronic accelerators in the world, where basic research in particle physics and nuclear physics is being conducted based upon quark models, superconductivity, the physics of materials and surfaces, the physics of lasers, applied research in medicine and biotechnologies, and various industrial applications. In the main channels in the form of an elongated ellipse, approximately 1 mile in length (approximately 1,6 km), there are two linear electron accelerators (so-called north and south linac) that together have 320 *RF* cavities in superconducting technology (material niobium Nb, critical or transition temperature to the superconducting state T_k= 9,3 K). In each accelerator, the energy of the electronic beam is increased by 400 MeV. A billion (10^9) times per second it focuses a million (10^6) electrons in order to obtain an electronic beam of the thickness of a human hair (a diameter of approximately 200 μm). The acceleration of the electrons in the resonators is achieved using an *RF* field. The electronic beam is accelerated linearly and synchronously arrives at the descending positive half-wave of the *RF* signal along the axial axis of the resonator each time.

In branches of science and technology, very interesting technological developments and discoveries are occurring in our times involving the applications of radio frequencies in linear accelerators. There have been developments concerning the central problem, achieving the maximum possible gradient of particle acceleration in linear accelerators, expressed in units of MV/m (megavolt/meter). The goal is to deliver the

(Superconducting Linear Collider) koji danas operiraju na -271° C (2,15 K) gradijent ubrzavanja tipično iznosi 28 MV/m. Najnovijim tehnološkim razvojem u Jeffersonovu laboratoriju u 2006. godini omogućen je gradijent od 35 MV/m, dok je svjetski rekord poznat kao Cornellov rezultat od 46 MV/m ostvaren potkraj 2004. (objavljen 2005.). U laboratoriju za fiziku elementarnih čestica Sveučilišta Cornell (Cornell University, Ithaca, NY 14853, USA) ostvaren je najveći gradijent ubrzavanja od 46 MV/m u supravodičkom niobijevu *RF*-rezonatoru, na temperaturi od 1,9 K [10].

Korijeni spomenutih dostignuća u razvoju suvremene akceleratorske tehnologije su u Teslinom transformatoru i naponima visokih frekvencija koji se njime dobivaju. Spomenimo još da se prva radionica o radiofrekvencijskim tehnologijama u supravodičkim linearnim ubrzivačima s Teslinim imenom (The 1st TESLA Workshop) održala na Sveučilištu Cornell 1990. godine [11].

3.2 Moderna analiza Tesline unipol-antene za prijenos energije ili poruke na daljinu

U naše doba Tesla je jedan od najzastupljenijih znanstvenika na internetu, gdje se na raznim web adresama opisuje i komentira njegov život i djelo, prije svega njegovi patenti i izumi. Zanimljivo je da su natuknice o Tesli ili članci potaknuti njegovim istraživanjima često napisani na francuskom jeziku, uz uobičajene na engleskom jeziku. Od brojnih web adresa vrijednom i znanstveno aktualnom čini nam se ova: http://www.teslascience.org. Učestali su, napose, web prilozi o Teslinom pristupu i njegovoj ideji tehničkog ostvarenja svjetskog bežičnog sustava (prijenos energije ili poruka na daljinu). U tim znanstvenim, a često i pseudoznanstvenim osvrtima analiziraju se stvarni Teslini tornjevi-stanice s *RF*-oscilatorima i transformatorima za emisiju i bežični prijenos elektromagnetske energije, polazeći od Teslinih istraživačkih zapisa [7]) i nastavljanja tih istraživanja kroz gradnju velebnog tornja-stanice za svjetsku telegrafiju na Long Islandu 1900.-1902., što je ostao Teslin nezavršen projekt.

Teslin laboratorij i toranj na Long Islandu bili su posvećeni fundamentalnim pokusima čiji bi pozitivni rezultati potvrdili novi Teslin model širenja *RF*-valova i prijenosa energije u to doba, nasuprot standardnom Hertzovom modelu usmjerenog zračenja slobodnim prostorom. Teslina znanstveno-tehnološka motivacija bila je fundamentalno razgranata: pravi dokazi za Zemljine stacionarne valove (opažene još u istraživanjima u Colorado Springsu) koji bi mogli poslužiti za ekonomičan prijenos energije na velikoj industrijskoj skali, a

maximum energy to a particle (beam) per unit length of the cavity in which the acceleration occurs. In the superconducting linear colliders operating today at -271° C (2,15 K), the gradient acceleration typically amounts to 28 MV/m. The most recent technological development at the Jefferson laboratories in the year 2006 makes a gradient of 35 MV/m possible, while the world record known as the Cornell result of 46 MV/m was achieved in late 2004 (published in the year 2005). In the elementary particle physics laboratory at Cornell University (Ithaca, NY 14853, USA), the highest gradient acceleration of 46 MV/m in a superconducting niobium *RF* resonator at a temperature of 1,9 K has been achieved [10].

The roots of the cited achievements in the development of modern accelerator technology are in Tesla's transformer and the high frequency voltage obtained with it. We also mention the workshop on radio frequency technology in superconducting linear accelerators, named after Tesla (the 1st TESLA Workshop), held at Cornell University in the year 1990 [11].

3.2 Modern analysis of Tesla's monopole-antenna for the long-distance transmission of energy or messages

In our times, Tesla is one of the most frequently mentioned scientists on the Internet. Various websites describe and comment on his life and work, especially his patents and inventions. It is interesting that entries or articles about Tesla that emphasize his investigations are frequently written in the French language, in addition to the customary English language. Among the numerous websites, the following seems worthwhile and current to us: http://www.teslascience.org. There are frequent web articles on Tesla's idea for the technical realization of a world wireless system (the long-distance transmission of energy or messages). These scientific, and frequently pseudoscientific, articles contain analyses of actual Tesla towers with *RF*-oscillators and transformers for the emission and wireless transmission of electromagnetic energy, based upon Tesla's research notes [7]), including the construction of a massive tower for world telegraphy on Long Island in 1900-1902, which remained Tesla's unfinished project.

Tesla's laboratory and tower on Long Island were devoted to fundamental experiments for the purpose of attempting to confirm his new model for the propagation of *RF*-waves and the transmission of energy, unlike the standard Hertz model of directed radiation through free space. Tesla's scientific-technological areas of interest were fundamentally diverse: authentic proofs of u sustavu Zemlja-ionosfera za transkontinentalnu (globalnu) komunikaciju; dokaz modela Zemlje kao vodiča i rezonantnog sustava s niskim svojstvenim frekvencijama (6, 18, 30 Hz, Teslini brojevi); eksperimentalna potraga za optimalnim predajnikom (λ/4 unipol antena) u sustavu antena-zemlja, glede optimalnog tehničkog omjera u elektromagnetskom prijenosu između širenja energije *EM* valovima i strujom energije koja prolazi zemljom.

Istraživanja i pokusi na Long Islandu pomoću radiotornja za bežični prijenos (wireless transmission tower) trebali su biti krunski Teslini prilozi elektromagnetskoj teoriji i tehnici, s revolucionarnim primjenama u bežičnoj komunikaciji i energetici. To je bio slavni Teslin Wardenclyffe projekt (The Tesla Wardenclyffe Project) u mjestu Wardenclyffe, danas Shoreham, Long Island, New York. Veliki znanstveni toranj visine 187 stopa (57 m), koji je u dogovoru s Teslom projektirao poznati američki arhitekt Stanford White, bio je podignut 1901. Projekt je, ipak, zamro 1905. kada je glavni podupiratelj J. P. Morgan odustao od daljnjeg financiranja.

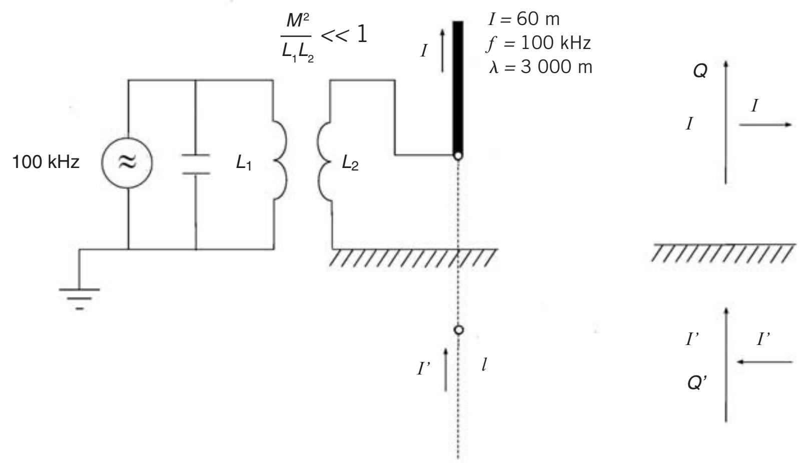
Teorijski doprinos u ovome članku odnosi se na analizu Tesline unipol-antene, na tragu fundamentalnih Teslinih istraživanja u Colorado Springsu i na Long Islandu u kojima je ovakva antena imala ključnu ulogu u aparaturi za prijenos električne energije na daljinu (Teslin patent u 1900. godini: U.S. Patent No. 1 119 732 Apparatus for Transmitting Electrical Energy). Širenjem valova u bežičnoj telegrafiji teorijski se 1909. bavio i A. N. Sommerfeld [12], jedan od najpoznatijih njemačkih fizičara, što je Tesla smatrao velikom intelektualnom podrškom za svoje projekte, posebice u fazama kad mu je iščezavala novčana podrška. Iz razvoja elektromagnetske teorije poznato je da se bežična komunikacija može zasnivati na Zenneck-Sommerfeldovu rješenju Maxwellovih jednadžbi koje specijalno opisuje širenje valova Zemljom (njezinom površinom). Jedna od glavnih Teslinih eksperimentalnih spoznaja iz mjerenja u Colorado Springsu bila je da se kroz zemlju šire stojni valovi.

the earth's stationary waves (already noted in the research in Colorado Springs) that could serve for the economical transmission of energy on a large industrial scale, the system of the earth-ionosphere for transcontinental (global) communication; the evidence of the model of the earth as a conductor and resonant system with low characteristic frequencies (6, 18, 30 Hz, Tesla's numbers); the experimental search for the optimal transmitter (λ/4 monopole antenna) in the antenna-ground system, in view of the optimal technical ratio in electromagnetic transmission between the propagation of energy by *EM*-waves and the energy current that travels the earth.

The research and experiments on Long Island using the wireless transmission tower were supposed to be Tesla's crowning contributions to electromagnetic theory and technology, with revolutionary applications in wireless communication and energetics. This was the famous Tesla Wardenclyffe Project in the locality of Wardenclyffe, now Shoreham, Long Island, New York. The huge scientific tower of 187 feet (57 m), designed according to Tesla's specifications by the famous American architect Stanford White, was erected in the year 1901. The project was terminated, however, in 1905 when its main backer, J. P. Morgan, refused to finance it further.

The theoretical contribution in this article concerns analysis of Tesla's monopole-antenna, based upon Tesla's fundamental research in Colorado Springs and Long Island in which such an antenna had a crucial role in the equipment for the long-distance transmission of electrical energy (Tesla's U.S. Patent No. 1 119 732, Apparatus for Transmitting Electrical Energy, dated 1901). A. N. Sommerfeld, one of the most famous German physicists, was also engaged in the theoretical propagation of waves in wireless telegraphy during 1909 [12], which Tesla considered to be great intellectual support for his projects, especially during the phases when financial support dried up. From electromagnetic theory, it is known that wireless communication can be based upon the Zenneck-Sommerfeld solution to Maxwell's equations that particularly describe the propagation of waves by the earth's surface. One of Tesla's chief experimental discoveries from the measurements at Colorado Springs was that stationary waves are propagated through the earth.

Slika 3
Teslin sklop za sustav antena-zemlja, namijenjen eksperimentalnom istraživanju Teslinog modela bežičnog prijenosa elektromagnetske snage ili poruke
Figure 3
Tesla's device for the antenna-ground system, intended for the experimental investigation of Tesla's model of the wireless transmission of electromagnetic power or messages



U nastavku članka provest će se izvorni izračun jakosti valova (*RF*-polje) i protok snage na velikim udaljenostima od antene, za karakterističan tip Teslinog *RF*-predajnika za sustav antena - zemlja. Znanstveni motiv je dokazivanje ili opovrgavanje fundamentalnih Teslinih zamisli u elektromagnetskoj teoriji i primjeni na *RF*-frekvencijama.

Unipol-antena ili monopol-antena jest jedan pol (polovica) poluvalne antene čija se tehnička upotrebljivost zasniva na pojavi da tlo dobro vodi struje nižih frekvencija (od 10 kHz pa do otprilike 30 MHz). Analizirat će se unipol čija je polarizacija linearna (polarizacija električnog polja vala koji unipol zrači), dok se s obzirom na zemlju antena postavlja vertikalno. Naboj (struja) raspodijeljen po anteni ima svoju pridruženu sliku, čiji iznos i predznak ovise o odnosu dielektričnih konstanti. Neka je u sredstvu ε_1 naboj Q_1, koji se u sredstvu ε_2 odslikava kao Q_2. Odslikani naboji su Q_2 i Q'_1, već prema tome gleda li se u jednom ili drugom sredstvu. Naboji iznose: $Q_2 = [(\varepsilon_1 - \varepsilon_2) / (\varepsilon_1 + \varepsilon_2)] \cdot Q_1$ i $Q'_1 = [2\varepsilon_2 / (\varepsilon_1 + \varepsilon_2)] \cdot Q_1$. Pri vertikalnoj polarizaciji odslikana struja ima takav iznos i smjer da potpomaže zračenje koje realni unipol zrači (slika 3). Za horizontalnu polarizaciju to nije slučaj: struja i njezina slika međusobno se kompenziraju. Zato se vertikalna polarizacija i primjenjuje jer je tada u gornjem poluprostoru polje unipola po jakosti isto kao i kod dipola.

Ova analiza i proračun baš su tomu i upravljeni: da se to detaljno izračuna i matematički pokaže, osobito na velikim udaljenostima od unipola (izvora) što zrači.

Ovakvi proračuni pretpostavljaju zadovoljenje određenih uvjeta. Prvi je da je tlo idealno ili barem u tolikoj mjeri idealno vodljivo da se cjelokupni

In the next section of the article, original calculations will be performed of the wave intensity (*RF*-field) and power flux at significant distances from the antenna for a characteristic type of Tesla's *RF*-transmitter for the antenna-ground system. The scientific motive is to confirm or refute Tesla's fundamental ideas in electromagnetic theory and applications at *RF*-frequencies.

A monopole antenna is a single pole (half) half-wave antenna, the technical usefulness of which is based upon the phenomenon that the soil is a good conductor of low frequency currents (from 10 kHz to approximately 30 MHz). A monopole will be analyzed with a linear polarization (polarization of the electrical wave field radiated from the monopole), while the antenna is erected vertically to the ground. The charge (current) distributed across the antenna has its own associated image, the amount and sign of which depend upon the ratio of the dielectric constants. Let Q_1 be the charge in the medium ε_1, which in the medium ε_2 is reflected as Q_2. The reflected charges are Q_2 and Q'_1, according to whether they are viewed in one or the other medium. The charges are as follows: $Q_2 = [(\varepsilon_1 - \varepsilon_2) / (\varepsilon_1 + \varepsilon_2)] \cdot Q_1$ i $Q'_1 = [2\varepsilon_2 / (\varepsilon_1 + \varepsilon_2)] \cdot Q_1$. At vertical polarization, the imaged current has a value and direction that supports the radiation emitted by the real monopole (Figure 3). This is not the case for horizontal polarization: the current and its associated image compensate mutually. Therefore, vertical polarization is used because in the upper half of the space, the field of the monopole has the same intensity as in the case of a dipole.

The purpose of such analysis is to provide detailed calculation and a mathematical demonstration, particularly at great distances from the radiating monopole (source).

Such calculations assume that certain prerequisites have been met. The first is that the soil is ideally naboj induciran u tlu od antenskog naboja, koji se matematički može opisati, pojavljuje kao plošni naboj na granici tla i slobodnog prostora. Pretpostavljajući da je takav naboj iznosom jednak antenskom (za idealnu vodljivost i za dielektričnu konstantu tla mnogo veću od one slobodnog prostora - to je ispunjeno) te ako se iz teorije elektrostatske slike zna da odslikani naboj ne ovisi o koordinati, već o prije spomenutom odnosu dielektričnih konstanti, može se raspodjela odslikanog naboja prikazati istom funkcijom kao i raspodjela struje na samome unipolu.

Za samu analizu, neka je zadan karakterističan Teslin sklop prikazan na slici 3. Oscilator radi na frekvenciji 100 kHz. Teslin transformator ima slabu spregu, a u sklopu ima ulogu prilagođenja. Unipol-antena ima kapacitivnu reaktanciju koju treba poništiti induktivnom, što se postiže serijski dodanom zavojnicom (transformator): prijenos snage na antenu u tome je slučaju najveći. Antena je duga 60 m, štapna je i unipolna. Praktični kriterij unipolnosti koji polazi od raspodjele struje na anteni određuje unipolom antenu čija je dužina manja od $\lambda/8$. U ovom slučaju to je ispunjeno: $l < \lambda/8$, (60 < 375). Da bi se moglo proračunati elektromagnetsko polje unipola te snaga koju unipol zrači, treba poći od izraza za polje elementarnog električnog dipola. Dipol u mirovanju ima stalan dipolni moment i u okolici stvara samo električno polje (elektrostatički slučaj). Oscilirajući dipol, gdje se naboj giba, stvara elektromagnetsko polje: gibanje naboja je predočeno dipolnim momentom koji je vremenski ovisan, primjerice: $p = p_0 \sin \omega t$ ili $p = p_0 \cos \omega t$, odnosno u kompleksnome zapisu $p = p_0 e^{j\omega t}$.

Takav harmonički dipol predstavlja elektron u atomu, ili elementarna antena duljine dz s konstantnom strujom u svakoj svojoj točki i gdje u svakoj točki takve antene struja ima vremensku promjenu $e^{\omega t}$. Dakle, antenom teče (oscilira) struja $I = I_0 e^{\omega t}$. Takav dipol (antena) rješava se pomoću magnetskog vektor-potencijala u smjeru *z*-osi s faktorom retardacije, što uračunava fizikalnu činjenicu da strujanjem naboja u anteni nastaje polje koje se potom rasprostire konačnom brzinom. Proračun polja za ovaj slučaj može se pronaći u svakoj boljoj knjizi iz teorijske fizike, odnosno elektrotehnike. Uzimaju se, stoga, samo rezultati: postoje samo radijalna komponenta električnog polja (E_r) i tangencijalna (E_θ) te azimutalna komponenta magnetskog polja ($H_\varnothing$). Elementarna antena s komponentama polja što ih zrači prikazana je na slici 4.

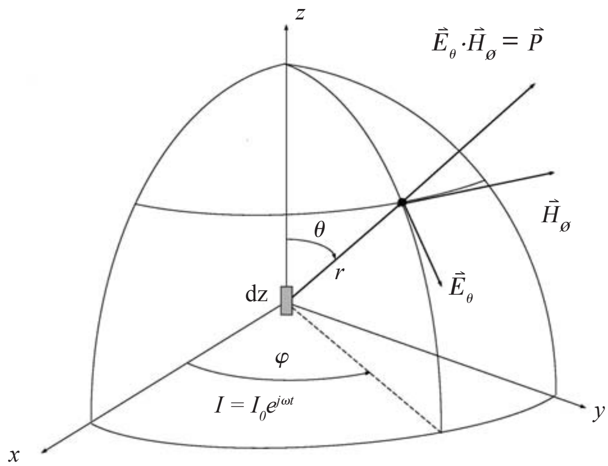
conductive or at least somewhat ideally conductive, that the entire induced charge in the soil from the antenna charge, which can be mathematically described, appears as a surface charge at the interface between the soil and free space. It is assumed that such a charge is equal to that of the antenna (for ideal conductivity and for the dielectric constant of the soil that is far greater than that of the free space, these conditions are met), and if it is known from the electrostatic image theory that the imaged charge does not depend on the coordinates, but rather upon the previously mentioned ratio of the dielectric constants, it is possible to present the distribution of the imaged charge using the same function as for the distribution of the current on the monopole.

For the purpose of analysis, let us use Tesla's characteristic device, as shown in Figure 3. The oscillator operates at a frequency of 100 kHz. Tesla's transformer has a weak coupling, and is used for adjusting the device. The monopole antenna has capacitive reactance that must be cancelled by inductive reactance, which is achieved via an additional serial coil (transformer), in which case the transmission of power to the antenna is the greatest. The antenna is 60 m in length, rod-like and monopolar. The practical criteria of monopolarity according to the distribution of current on the antenna determine that the antenna is monopole and less than d $\lambda/8$ in length. In this case, the criteria are met: $l < \lambda/8$, (60 < 375). In order to calculate the electromagnetic field of the monopole, and the power that the monopole radiates, it is necessary to begin from the expression for the field of an elementary electrical dipole. A dipole at rest has a constant dipolar moment, and creates only an electrical field (electrostatic case) in its surroundings. An oscillating dipole, where the charge moves, creates an electromagnetic field: the charge motion is expressed by dipolar momentum that is time dependent, for example: $p = p_0 \sin \omega t$ or $p = p_0 \cos \omega t$, or $p = p_0 e^{j\omega t}$.

Such a harmonic dipole represents an electron in an atom, or an elementary antenna that is dz in length with constant current in each of its points and where in each point of such an antenna the current has a temporal change of $e^{\omega t}$. Therefore, the (oscillating) current flows through the antenna, $I = I_0 e^{\omega t}$. Such a dipole (antenna) is solved using a magnetic vector potential in the direction of *z*-axis with a retardation factor, which takes into account the physical fact that through the charge flow in the antenna a field is created that is subsequently propagated by the final speed. The calculation of the field for this case can be found in every better book on theoretical physics or electrical engineering. The only results taken into account: the radial component of the electrical field (E_r), tangential (E_θ), and the azimuth component of the magnetic field ($H_\varnothing$) exist. An elementary antenna with the radiated field components is shown in Figure 4.

Slika 4
Komponente električnog ($\vec{E}$) i magnetskog ($\vec{H}$) polja iz elementarne antene dz

Figure 4
Components of the electrical ($\vec{E}$) and magnetic ($\vec{H}$) fields from the elementary antenna dz



Tok snage predočen je Poyntingovim vektorom $\vec{P}$.

Odgovarajući izrazi su:

The power flow is presented according to the Poynting vector $\vec{P}$.

The corresponding expressions are as follows:

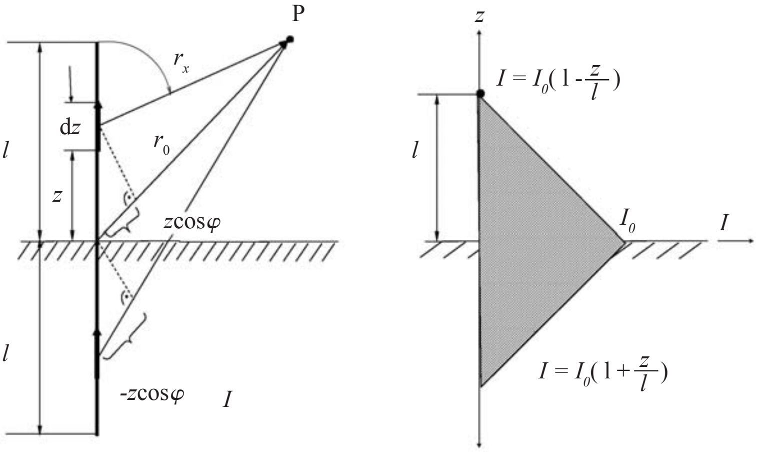
$$E_\theta = \frac{p''}{4\pi\varepsilon r c^2} \cdot \sin\theta \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr)} \qquad H_\phi = \frac{p''}{4\pi r c} \cdot \sin\theta \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr)}$$

ili / or (1)

$$E_\theta = \frac{\mathrm{j} Z_0 I \,\mathrm{d}z}{2\lambda r} \cdot \sin\theta \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr)} \qquad H_\phi = \frac{\mathrm{j} I \,\mathrm{d}z}{2\lambda r} \cdot \sin\theta \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr)}$$

Vektorski produkt od $\vec{E}$ i $\vec{H}$ daje protok energije kroz jedinicu površine (Poyntingov vektor). Iz slike 4 se vidi da $\vec{E}_r$ i $\vec{H}_\varnothing$ daju Poyntingov vektor koji je tangencijalan (kruženje energije oko dipola), dok $\vec{E}_\theta$ i $\vec{H}_\varnothing$ daju radijalnu komponentu Poyntingova vektora koja predstavlja isijavanje energije u prostor. Izrazi za električno i magnetsko polje daleko od dipola, prema relaciji (1), ukazuju na ovisnost polja o raspodjeli struje ($I\mathrm{d}z$ u brojniku). Problem raspodjele struje na anteni rješava se uzimajući u obzir rubne uvjete prijelaza vodič-vakuum na cijeloj anteni. Poznato je iz teorije antena da je raspodjela struje na poluvalnoj anteni (cilindrična poluvalna antena duljine l i polumjera presjeka a) sinusna. Za unipol, koji je mnogo kraći od poluvalne antene, u dobroj aproksimaciji možemo primijeniti trokutnu raspodjelu struje. Uz to, unipol koji je na kraju neopterećen, raspodjela struje na krajevima unipola jest nula. Vidimo da u slučaju unipola, od njegove virtualne poluvalne antene dolazi u obzir tek onaj dio koji duljinom odgovara unipolu. Uzimajući u obzir pojavu električne slike u sustavu antena-zemlja i prije navedene pretpostavke, raspodjela struje na unipolu izgleda kao na slici 5.

The vector product from $\vec{E}$ and $\vec{H}$ yields a flow of energy through a surface unit (Poynting vector). It is seen from Figure 4 that $\vec{E}_r$ and $\vec{H}_\varnothing$ yield a Poynting vector that is tangential (rotating energy around the dipole), while $\vec{E}_\theta$ and $\vec{H}_\varnothing$ yield a radial component of the Poynting vector that represents the radiation of energy in a space. The expressions for the electrical and magnetic fields at a distance from the dipole, according to expression (1), show the dependence of the field upon current distribution ($I\mathrm{d}z$ in the numerator). The problem of current distribution on the antenna is solved by taking into account the marginal conditions of the conductor-vacuum transition on the entire antenna. It is known from antenna theory that current distribution on a half-wave antenna (cylindrical half-wave antenna length l and the cross-section radius a) is sinusoidal. For a monopole, that is much shorter than a half-wave antenna, with a good approximation we can apply a triangular distribution of current. Moreover, for a monopole without a load at the end, the distribution of current at the ends of the monopole is zero. We see that in the case of the monopole, from its virtual half-wave antenna only the part that is of a length corresponding to that of the monopole can be considered. Taking into account the phenomenon of the electrical image in the antenna-ground system and the aforementioned prerequisites, current distribution on the monopole is shown in Figure 5.



Slika 5
Aproksimacija trokutnom raspodjelom struje u Teslinoj unipol-anteni
Figure 5
Approximation of the triangular current distribution in Tesla's monopole antenna

Izračunajmo polje E_θ u točki P, udaljenoj za r_0 od unipola.

U elementu dz neka je naboj Q koji struji brzinom v. Jakost struje tada iznosi:

Let us calculate field E_θ at point P, at a distance r_0 from the monopole.

In element dz, let charge Q flow at the speed of v. The current strength is then as follows:

$$i = Q\frac{v}{\mathrm{d}z}, \qquad Qv = p' = i\,\mathrm{d}z, \qquad v = \frac{\mathrm{d}z}{\mathrm{d}t} \tag{2}$$

Struju kroz unipol opisujemo funkcijom $i = f(z)\cdot\cos(\omega t)$, što uračunavanjem retardacije daje:

We describe the current through the monopole with the function $i = f(z)\cdot\cos(\omega t)$, which, taking retardation into consideration, yields:

$$i = f(z)\cdot\cos(\omega t - kr_x)$$

Nadalje, imamo p' i p'':

Furthermore, we have p' and p'':

$$p' = i\,\mathrm{d}z = f(z)\cdot \mathrm{e}^{\mathrm{j}(\omega t - kr_x)} \text{ i } p'' = \mathrm{j}\omega p' \tag{3}$$

Iz relacija u (1) imamo izraz za E_θ, zanemarivši vremensku zavisnost $e^{j\omega t}$ jer smo je već uzeli u retardaciji struje. Element dz u točki r_x ima polje:

From the relation in (1) we have an expression for E_θ, ignoring temporal dependence $e^{j\omega t}$ because we have already taken it in current retardation. Element dz point r_x has the following field:

$$\mathrm{d}E_\theta = \frac{p''}{4\pi\varepsilon r_x c^2}\cdot\sin\theta\cdot \mathrm{e}^{\mathrm{j}(\omega t - kr_x)}\cdot \mathrm{e}^{-\mathrm{j}kr_x} \tag{4}$$

Iz slike 5 se vidi da je za daleku točku r_x približno jednako r_0, ali se fazna razlika mora uzeti u obzir, što daje:

From Figure 5, it is evident that for the distant point, r_x is nearly equal to r_0, but the phase difference must be taken into account, which yields:

$$r_x = r_0 - z\cos\theta$$

Polje u dalekoj točki P je suma elementarnih polja s uračunatom faznom razlikom između njih:

The field in distant point P is the sum of the elementary fields with a calculated phase difference among them:

$$E_\theta = \frac{\mathrm{j}\omega \sin\theta}{4\pi\varepsilon r_0 c^2} \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr_0)} \int_{-l}^{+l} \mathrm{e}^{-\mathrm{j}kr_0} \cdot \mathrm{e}^{\mathrm{j}kz\cos\theta} f(z)\,\mathrm{d}z \tag{5}$$

Ako je $l << \lambda$, onda je $kz = (2\pi/\lambda)z$ vrlo mala veličina, što uz izostavljanje e^{-jkro}, jer je već uračunat u retardaciji, daje:

If $l << \lambda$, then $kz = (2\pi/\lambda)z$ is very small, which with the omission of e^{-jkro} because it has previous been calculated in retardation, yields:

$$E_\theta = \frac{\mathrm{j}\omega \sin\theta}{4\pi\varepsilon r_0 c^2} \cdot \mathrm{e}^{\mathrm{j}(\omega t - kr_0)} \int_{-l}^{+l} f(z)\,\mathrm{d}z \tag{6}$$

Budući da je:

Since:

$$\int_{-l}^{+l} f(z)\,\mathrm{d}z = I_0 l \tag{7}$$

dobivamo E_θ da u nekoj dalekoj točki za r udaljenoj od unipola iznosi:

we obtain that E_θ at a distant point, r, from the monopole is

$$E_\theta = \frac{\mathrm{j}\omega \sin\theta}{4\pi\varepsilon r c^2} \mathrm{e}^{\mathrm{j}(\omega t - kr)} I_0 l \tag{8}$$

Za prosječan tok snage kroz jedinicu površine u jedinici vremena potreban je kvadrat polja. Dakle, E_θ iz relacije (8) množimo s njegovom konjugirano-kompleksnom vrijednošću:

For the average flux power per square unit per time, the square of the field is needed. Therefore, E_θ from expression (8) is multiplied by its conjugated-complex value:

$$E_\theta^2 = E_\theta E_\theta^* = \frac{\omega^2 \sin^2\theta}{16\pi^2 \varepsilon^2 c^4 r^2} I_0^2 l^2 \tag{9}$$

Pitanje je, međutim, je li ovakvo računanje primjenom aproksimacija pravi put u analizi unipol-antene? Sigurno jest da ono ne daje uvid u veličine pogrešaka koje se njime čine!

Stoga se obavlja detaljna analiza polazeći od same fizikalne situacije, pa se onda napravi aproksimacija, ako je moguća. Polje E_θ jest suma dvaju integrala koji u integrandu imaju suprotna fazna zaostajanja ($\mathrm{e}^{jkz\cos\theta}$ i $\mathrm{e}^{-jkz\cos\theta}$, vidi sliku 5):

It is a question, however, whether such calculation through applied approximations is the appropriate path for monopole-antenna analysis. It certainly does not provide insight into the magnitude of the errors that are thereby incurred!

Therefore, detailed analysis is performed, starting from the physical situation, followed by approximation to the extent possible. Field E_θ is the sum of two integrals which have opposite phase lags in the integrand ($\mathrm{e}^{jkz\cos\theta}$ and $\mathrm{e}^{-jkz\cos\theta}$, see Figure 5):

$$E_\theta = I_0 \alpha \sin\theta \left\{ \int_0^l \left(1 - \frac{z}{l}\right) \mathrm{e}^{\mathrm{j}kz\cos\theta} \mathrm{d}z + \int_0^l \left(1 - \frac{z}{l}\right) \mathrm{e}^{-\mathrm{j}kz\cos\theta} \mathrm{d}z \right\} \tag{10}$$

Konstanta α uključuje valni otpor zraka i neke druge veličine te vremensku ovisnost u retardiranoj formi (uzimanjem kvadrata ona pridonosi jedinicom). Vrijednost prvog integrala u zagradi u relaciji (10) jest E_1, a drugog E_2:

Constant α includes free-space wave impedance, some other values and the time retardation term (taking a second power yields unity). The value of the first integral in parentheses in expression (10) is E_1, and the second is E_2:

$$E_1 = \frac{-\mathrm{j}}{k\cos\theta} - \frac{\left(\mathrm{e}^{\mathrm{j}kl\cos\theta}-1\right)}{lk^2\cos^2\theta}, \qquad E_2 = \frac{\mathrm{j}}{k\cos\theta} - \frac{\left(\mathrm{e}^{-\mathrm{j}kl\cos\theta}-1\right)}{lk^2\cos^2\theta} \tag{11}$$

E_θ jest suma od E_1 i E_2:

E_θ is the sum of E_1 and E_2:

$$E_\theta = \frac{2I_0\alpha\sin\theta}{lk^2\cos^2\theta}\{1-\cos(kl\cos\theta)\} \tag{12}$$

Budući da se u računanju zračenja u cijeli prostor (u 4π) prosječno zračenje po jedinici površine u jedinici vremena množi s diferencijalnim elementom površine zamišljene kugle, poželjno je izraz (12) nadomjestiti odgovarajućom aproksimacijom. Unipol isijava u gornji poluprostor, pa karakteristične točke iznose $\theta = 0$ i $\pi/2$. Član [1-cos(kl cosθ)] iz izraza (12), razvijanjem u red za $\theta = 0$, postaje:

Since in the calculation of radiation to the full space (in 4π) the average radiation per square unit per time is multiplied by the differential surface element of the imaginary sphere, it is desirable to replace expression (12) with the corresponding approximation. The monopole radiates in the upper half of the space, so the characteristic points are $\theta = 0$ i $\pi/2$. Term [1-cos(kl cosθ)] from expression (12), expressed in terms of $\theta = 0$, becomes:

$$1-\cos(kl\cos\theta) = 1-1+\frac{(kl)^2}{2}-\frac{(kl)^4}{4!}+\frac{(kl)^6}{6!}-\ldots\ldots \tag{13}$$

Aproksimaciju sada možemo učiniti tako da zanemarimo sve članove počevši od člana s četvrtim faktorijelom koji je za kl = 0,125 vrlo mali. Dakle, cijeli ovaj član može se nadomjestiti s $(kl)^2/2$. Za $\theta = \pi/2$ ovaj član daje nulu. Drugi karakteristični član za $\theta = \pi/2$ predstavlja neodređeni oblik 0/0. Dvostrukom primjenom L´Hospital-Bernoullijevog pravila član postaje:

We may now make an approximation by ignoring all the terms starting with those of the fourth order, which is very low for kl = 0,125. Therefore, this entire term can be replaced with $(kl)^2/2$. For $\theta = \pi/2$, this term yields zero. Another characteristic term for $\theta = \pi/2$ represents the indeterminate form 0/0. Through the two-fold application of the L´Hospital-Bernoulli Rule, the term becomes:

$$\frac{1-\cos(kl\cos\theta)}{\cos^2\theta} = \lim_{\theta\to\pi/2}\left[\frac{\cos(kl\cos\theta)\cdot(-\sin\theta)}{-\sin\theta}\cdot\frac{(kl)^2}{2}\right] = \frac{(kl)^2}{2} \tag{14}$$

Dakle, polje E_θ u dalekoj točki od unipola, uz opasku da smo ga prije svega izveli pomoću izraza za računanje cjelokupne emisije, ima vrijednost:

Therefore, field E_θ at a distant point from the monopole, which we have obtained, using the expression for the calculation of the total emission, has the following value:

$$E_\theta = \frac{2I_0\alpha\sin\theta}{lk^2}\cdot\frac{(kl)^2}{2} = lI_0\alpha\sin\theta \qquad \alpha = \frac{\mathrm{j}Z_0}{2\lambda r}\mathrm{e}^{\mathrm{j}(\omega t-kr)} \tag{15}$$

Ukupna emisija unipola u gornji poluprostor iznosi:

The total emission of the monopole in the upper half space is as follows:

$$P_{uk} = \int_0^{\pi/2} P_{pr} r^2 2\pi \sin\theta \, d\theta \qquad P_{pr} = \frac{E_\theta^2}{2z_0} \qquad E_0^2 = E_\theta E_\theta^* \qquad (16)$$

Integriranjem, ukupna emisija jest:

Through integration, the total emission is:

$$P_{uk} = \frac{Z_0 L^2 I_0^2 \cdot \pi}{6\lambda^2} \qquad (17)$$

S druge strane, ako ukupno zračenje izrazimo preko otpora isijavanja i efektivne vrijednosti struje napajanja unipola, dobivamo:

From the other aspect, if we express the total radiation through the emission impedance and the effective value of the supply current to the monopole, we obtain:

$$P_{uk} = I_{ef}^2 \cdot R_{is} \qquad I_0^2 = 2I_{ef}^2 \qquad (18)$$

Uspoređivanjem izraza (17) i (18) dobivamo da je otpor isijavanja asimetrično napajanog unipola jednak polovici otpora isijavanja dipola (uvjetno: poluvalne antene):

By comparing expressions (17) and (18), we obtain that the radiation resistance of the asymmetrically supplied monopole is equal to half the resistance value of the dipole (conditionally: half-wave antenna):

$$R_{is} = \frac{Z_0 \pi}{3}\left(\frac{l}{\lambda}\right)^2, \qquad (19)$$

Z_0 je valni otpor slobodnog prostora (impedancija).

Ovo je pravi dokaz da je proračun valjan i da su primijenjene aproksimacije također valjane, kao i fizikalna slika od koje se krenulo. Moglo se i prije proračuna pretpostaviti da unipol zrači polovicu snage ekvivalentne poluvalne antene, uz istu struju napajanja. Prema tomu i otpor isijavanja unipola treba biti polovica otpora poluvalentne antene ili dipola (poluvalna antena je identična dipolu ako ima konstantnu raspodjelu struje jer su izrazi za polje dipola izvedeni za konstantnu raspodjelu). Ovi su, pak, rezultati dobiveni polazeći izravno od samog unipola i proračunom njegovog polja i snage, što verificira izračun kao takav, a napose fizikalnu sliku i čitavu analizu koja je primijenjena.

Čitav proračun izveden je za idealni unipol: unipol čija je duljina mnogo veća od polumjera presjeka, tako da je utjecaj otpora gubitka u tom slučaju zanemariv. Osim toga, tlo nikada nije idealno vodljivo, stoga su i gubici zbog toga jako veliki. Veliki gubici su i u antenskoj zavojnici. Stanovito poboljšanje postiže se ukapanjem metalnih traka

Z_0 is the wave resistance of the free space (impedance).

This is genuine proof that the calculation is valid and that the applied approximations are also valid, as is the physical image we started from. Prior to the calculation, it could have been assumed that the monopole radiates half the power of an equivalent half-wave antenna, with the same supply current. Accordingly, the radiation resistance of the monopole should be half the resistance of the half-wave antenna or dipole (a half-wave antenna is identical to a dipole if it has constant current distribution, because the expressions for the dipole field are calculated for constant distribution). These results were, nonetheless, obtained by starting directly from the monopole itself and calculating its field and power, which are verified by the calculation as such, particularly the physical image and entire analysis applied.

The entire calculation was performed for an ideal monopole: a monopole with a length far longer than that of the radius of the cross section, so that the influence of resistance loss is negligible in this case. Moreover, soil is never ideally conductive and, therefore, the consequent losses are very great.

u tlu ispod unipola ili se sam unipol modificira. Unipol se, naime, savije na vrhu u obliku slova L ili T, ili se na vrhu optereti kuglom. Kugla prima određeni iznos naboja i tako površinu raspodjele struje čini većom. Istu ulogu ima L ili T završetak unipola. Time je emisija snažnija za takve realno modificirane unipole. Odnos realnog i idealnog unipola može se, dakako, ustanoviti usporedbom izmjerenih i računom dobivenih podataka.

Primjer: Pokazuje se red veličine parametara kad unipol zrači. Izračuna se struja potrebna za zračenje od 200 kW i električno polje unipola na udaljenosti 30 km od unipola.

Za zračenje snage od 200 kW u gornji poluprostor, za unipol na slici 3, potrebna efektivna vrijednost struje napajanja unipola iznosi 1,126 · 10^3A. Jakost električnog polja elektromagnetskog vala na udaljenosti 30 km od unipola na tlu prema relaciji (15) ili (8) iznosi:

There are also great losses in the antenna coil. Some improvement is achieved by burying a metal strip in the soil under the monopole or by modifying the monopole itself. The monopole is bent at the tip in the form of the letter L or T, or has a sphere at the tip. The sphere receives a certain amount of charge and thereby increases the current distribution surface. The L or T tip of the monopole performs the same role. Thereby, emission for such real modified monopoles is intensified. The ratio between the real and ideal monopole can be established through a comparison of the measured and calculated data obtained.

Example: The order of the value of the parameters when the monopole radiates is presented. The current necessary for 200 kW radiation and the electric field of the monopole at a distance of 30 km from the monopole are calculated.

For 200 kW of radiation in the upper half space of the monopole in Figure 3, the necessary effective value of the supply current is 1,126 · 10^3A. The intensity of the electric field of the electromagnetic wave at a distance of 30 km from the monopole on the ground according to expression (15) or (8) is as follows:

$$E_\theta = \mathrm{j}0{,}1415\,\mathrm{e}^{\mathrm{j}62{,}8\left(10^4 t-1\right)}\ \mathrm{V/m},$$

Iz električnog se polja može izračunati magnetsko ($E_\theta/H_\varnothing = Z_0$, ili iz Maxwelovih jednadžbi za slobodni prostor pomoću kojih se dobiva $H = E/\mu_0 c$). Za naš primjer H iznosi:

The magnetic field can be calculated from the electric field ($E_\theta/H_\varnothing = Z_0$, or from Maxwell's equation for free space, according to which $H = E/\mu_0 c$ is obtained). For our example, H is:

$$H_\phi = 3{,}75\cdot 10^{-4}\ \mathrm{A/m}.$$

Poyntingov vektor, 30 km od unipola, na tlu iznosi:

The Poynting vector, 30 km from the monopole, on the ground is:

$$P = P_{\mathrm{pr}} = \frac{E_\theta^2}{2Z_0} = 2{,}656\cdot 10^{-5}\ \mathrm{W/m^2}$$

Tesla je zamišljao da njegov model prijenosa sustavom antena-zemlja može omogućiti gotovo 90 posto prijenosa energije površinom Zemlje, a preostalih 10 % elektromagnetskim Hertzovim valovima kroz atmosferu. On je nastojao konstruirati snažni predajnik za takav prijenos i pouzdano eksperimentalno utvrditi valne duljine, radi određivanja fenomenoloških zakona rasprostiranja kroz zemlju i zrak. Teslina antena (predajnik, toranj) trebala je imati slabo prilagođenje impedancije na slobodni prostor, da bi se potisnulo širenje energije valovima. U

Tesla believed that his transmission model using the antenna-ground system could transmit nearly 90 % of the energy via the earth's surface and the remaining 10 % via electromagnetic Hertz waves through the atmosphere. He attempted to construct a powerful transmitter for such transmission and determine wavelengths reliably through experiments, with the goal of defining the phenomenological laws of propagation through the earth and air. Tesla's antenna (transmitter, tower) was supposed to have weak impedance matching for the free space, in order to decrease energy

Hertzovu modu prijenosa cilj je imati što bolje prilagođenje antene onoj slobodnog prostora (377 Ω).

Bežično širenje valova kroz zrak-zemlju, kao dva sredstva, računali su Arnold Sommerfeld i Jonathan Zenneck. Uz Zenneckove i/ili Sommerfeldove površinske valove bilo je kasnije mnogo korisnih rješenja na toj crti istraživanja. Tesla je takva rješenja smatrao najvećom podrškom svome modelu. Analitički izračuni Teslinog sklopa za sustav antena-zemlja, koji su izvedeni u ovome članku s primjerom na kraju, pokazuju da je polje malo, a snaga zaista slaba na velikim udaljenostima od unipola. Prijenos kroz površinu Zemlje (Teslin mod) čini se prirodnim i tehnički opravdanim, što dokazuje ovaj proračun. Nažalost, ostao je to samo san jer Tesla nije dovršio istraživanja i ponudio svoja tehnička rješenja, premda su mu ideje bile znanstveno utemeljene.

4 IZUMI I DOPRINOSI NIKOLE TESLE U NASTAVI FIZIKE I ELEKTROTEHNIKE NA SVEUČILIŠTU U ZAGREBU

Percepcija Teslinih izuma u fizici i elektrotehnici u hrvatskoj znanosti i kulturi bila je vrlo efikasna. Nisu posrijedi bile samo simpatije prema istraživaču iz našeg kraja nego stvaralačka zainteresiranost hrvatskih sveučilišnih nastavnika fizike i elektrotehnike za ugradnjom Teslinih spoznaja u nastavne programe. Takav odnos prema Tesli dokazuju i najveće počasti koje je primio u hrvatskom znanstveno-kulturnom krugu. Nikoli Tesli dodijeljen je počasni doktorat (doctor honoris causa) 29. lipnja 1926. na Elektrotehničkom odsjeku Tehničkog fakulteta na Sveučilištu Kraljevine SHS u Zagrebu koja mu je bila uručena u New Yorku. Zanimljiva je formulacija u odluci da Tesla počasni doktorat tehničkih znanosti prima u povodu 70. obljetnice rođenja, ali kao prvi počasni doktor prirodoznanstvenik na Sveučilištu. Nikola Tesla izabran je za počasnog člana JAZU (današnjeg HAZU) već 1896. godine. Zastupljenost Teslinih znanstvenih dostignuća u nastavi fizike i elektrotehnike na Sveučilištu u Zagrebu obradit će se selektivno na primjerima trojice uglednih hrvatskih znanstvenika: Ivana Supeka, Vatroslava Lopašića i Tome Bosanca. Dakako da ima i ostalih koji su se ozbiljno bavili Teslom i njegovim djelom. Međutim, presuđuju ovdje dva razloga: glede Ivana Supeka, autor je bio recenzent dopunjenog izdanja njegove Povijesti fizike [13], a glede Vatroslava Lopašića, jedan od nastavljača na katedri fizike na FER-u, odnosno prije zvanom Elektrotehničkom fakultetu, gdje je

propagation by the waves. In Hertz's transmission mode, the goal was to have the optimal matching of the antenna to the free space (377 Ω).

The wireless propagation of waves via air-ground, as two media, was calculated by Arnold Sommerfeld and Jonathan Zenneck. In addition to Zenneck's and/or Sommerfeld's surface waves, there were many useful solutions later along this line of research. Tesla felt that such solutions provided great support for his model. The analytical calculations of Tesla's device for the antenna-ground system that are presented in this article, with an example at the end, show that the field is small and the power is quite weak at great distances from the monopole. Transmission via the earth's surface (Tesla's mode) seems naturally and technically justified, as demonstrated by these calculations. Unfortunately, such transmission has remained a mere dream because Tesla did not complete his research or provide a technical solution, although his ideas were well founded scientifically.

4 THE INCLUSION OF NIKOLA TESLA'S INVENTIONS AND CONTRIBUTIONS IN THE PHYSICS AND ELECTRICAL ENGINEERING CURRICULA AT THE UNIVERSITY OF ZAGREB

There has been considerable recognition afforded to Tesla's inventions in physics and electrical engineering in Croatia. This is not merely due to an affinity toward a researcher from our homeland but the creative interest by Croatian university instructors of physics and electrical engineering to incorporate Tesla's ideas into the curricula. Such an attitude toward Tesla has also been expressed through the high honors that have been awarded by the Croatian scientific and cultural milieu. Nikola Tesla received an honorary doctorate (doctor honoris causa) on June 29, 1926, from the Department of Electrical Engineering, Faculty of Technology; University of the Kingdom of the Serbs, Croats and Slovenes, in Zagreb, which was presented to him in New York. Tesla received an honorary doctorate of technical sciences on the occasion of his 70th birthday, the first honorary doctorate of natural sciences at the university. Nikola Tesla was chosen as an honorary member of the Yugoslav Academy of Arts and Sciences (today the Croatian Academy of Arts and Sciences) in 1896. It will be selectively discussed the inclusion of Tesla's scientific achievements in physics and electrical engineering instruction at the University of Zagreb, through the examples of three distinguished Croatian scientists: Ivan Supek, Vatroslav Lopašić and Tomo Bosanac. Certainly there are also others who on dulji niz godina bio predavačem. Tomo Bosanac je 1976. dao poticaj za proračun Tesline unipol-antene koji je izveden u ovome članku.

4.1 Zastupljenost Nikole Tesle u Supekovoj Povijesti fizike

U svojoj poznatoj knjizi Povijest fizike [13], jednoj od najpoznatijih knjiga u hrvatskoj povijesti znanosti, Ivan Supek iznosi na više mjesta jezgrovite komentare o Teslinoj ulozi i značenju njegovih izuma u razvitku elektrotehnike (strojevi i motori) i radiotehnike. U poglavlju knjige Elektrodinamika, na crti razvoja elektrotehnike i elektromagnetskih strojeva i aparata koji se zasnivaju na jakim električnim strujama, Supek uz Oersteda, Gaussa, Ampèrea, Faradya i Jacobija smješta i Teslu. Nikola Tesla je bio jedan od protagonista tog razvoja. Malo dalje u istom poglavlju spominje se Teslin motor konstruiran 1886. za dobivanje jakih izmjeničnih struja, na principu elektromagnetske indukcije. Dodajmo da je Tesla ideju za takav motor imao još tri godine prije toga, dok je u Parizu radio za Edisonovu kompaniju za Europu, a tada je konstruirao i prvu verziju takvog motora. U odjeljku o elektromagnetskim valovima, njihovu stvaranju i korisnim primjenama, Supek posebno naglašava velikog izumitelja Nikolu Teslu. Tesla je, nezavisno od ruskog fizičara Aleksandra Popova, konstruirao radijsku antenu i prvi slao elekromagnetsku energiju na velike udaljenosti. On je primao valove od radiostanica udaljenih i do 1 000 km te ga po tome treba smatrati pionirom radiotehnike. Zanimljiv je i točan Supekov komentar o Teslinu karakteru i inženjerskom duhu, što je Teslu, zapravo, lišilo i Nobelove nagrade za izum bežične telegrafije. Potkraj 19. stoljeća Tesla je oklijevao u praktičnoj primjeni i upotrebi svojih izuma o prijenosu elektromagnetskih valova (*EM*-valova) na daljinu jer je bio zaokupljen rješavanjem svoga veličanstveno zamišljenog svjetskog sustava bežičnog prijenosa energije. Dotle je Guglielmo Marconi, potaknut Hertzovim pokusima iz 1887. u Karlsruheu, započeo 1894. svoje pokuse o elektromagnetskim valovima i bežičnoj telegrafiji (wireless telegraphy). Već 1895. poslao je prvi telegrafski signal kroz slobodni prostor (zrak). Marconi je 1901. poslao *EM*-valove iz Velike Britanije u SAD. Bila je to svjetska senzacija, prva transatlantska bežična komunikacija, zametak suvremene elektromagnetske komunikacije. Za takve pokuse i uređaje prikladne za komercijalnu primjenu G. Marconi je primio Nobelovu nagradu iz fizike 1909. za bežičnu telegrafiju. Marconijevi uspjesi su na neki način osujetili Teslin projekt svjetskog telegrafskog sustava na Long Islandu.

have been seriously engaged with Tesla and his work. However, the author of this article was the editor of the revised edition of Ivan Supek's Povijest fizike (History of Physics) [13] and Vatroslav Lopašić was an instructor for many years at the Physics Department of the Faculty of Electrical Engineering and Computing (formerly the Faculty of Electrical Engineering). In 1976, Tomo Bosanac provided the initiative for the calculation of Tesla's monopole antenna, which is presented in this article.

4.1 Nikola Tesla's inclusion in Supek's History of Physics

In Ivan Supek's well known Povijest fizike (History of Physics) [13], one of the best known books in the history of Croatian science, in several places the author presents succinct commentary on Tesla's role and the significance of his inventions in the development of electrical engineering (machines and motors) and radio technology. In the chapter of the book on electrodynamics, where there is an account of the development of electrical engineering, electromagnetic machinery and devices based upon high power electrical currents, in addition to Oersted, Gauss, Ampère, Faraday and Jacobi, there is also Tesla. Nikola Tesla was one of the protagonists of this development. A little further on in the chapter, there is mention of Tesla's motor, constructed in 1886 for obtaining high power alternating currents, on the principle of electromagnetic induction. We add that Tesla had the idea for such a motor three years earlier, while he was working at Edison's company for Europe in Paris, when he constructed the first version. In the section on electromagnetic waves, their generation and useful application, Supek specifically refers to Nikola Tesla as a great inventor. Tesla, independently of the Russian physicist Aleksander Popov, constructed a radio antenna and was the first to send electromagnetic energy over a long distance. He received waves from radio stations up to 1 000 km distant, and should be considered as a pioneer of radio technology. Supek provides an interesting and accurate commentary on Tesla's character and engineering spirit, which actually deprived Tesla of the Nobel Prize for the invention of the wireless telegraph. At the end of the 19th century, Tesla hesitated regarding the practical application and use of his inventions for the long-distance transmission of electromagnetic waves (*EM*-waves) because he was occupied with the solution for his magnificent concept of a world system for the wireless transmission of energy. Meanwhile, Guglielmo Marconi, inspired by H. Hertz's experiments of 1887 in Karlsruhe, began his experiments on electromagnetic waves and wireless telegraphy in 1894. In 1895, he already sent his first telegraph signal through the air. In 1901, Marconi sent *EM*-waves from Great Britain to the United States. It was a world sensation, the first transatlantic wireless communication, the beginning of modern

Koliko su Supekovi komentari o Tesli i njegovu uključivanju u povijest razvoja fizike dragocjeni, svjedoči i podatak da npr. svjetski poznati povjesničar fizike Abraham Pais, u svom kapitalnom djelu: Inward Bound, Of matter and Forces in the Physical World (1986) spominje Marconija, ali ne i Teslu.

4.2 Zastupljenost Nikole Tesle u Lopašićevim Predavanjima o elektromagnetskom polju i radovima Tome Bosanca

Autor ovog članka već je više puta referirao i napisao da se Vatroslav Lopašić (Pakrac, 9. prosinca 1911.-Zagreb, 17. prosinca 2003.) može smatrati klasikom nastave fizike na Elektrotehničkom i drugim tehničkim fakultetima Sveučilišta u Zagrebu.

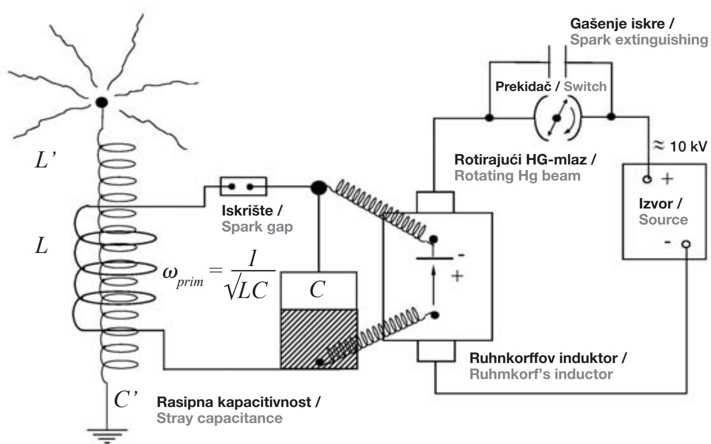
electromagnetic communication. For such experiments and devices suitable for commercial application, G. Marconi received the Nobel Prize in Physics in 1909 for wireless telegraphy. Marconi's successes in a sense were instrumental in the defeat of Tesla's project on Long Island for a world telegraphic system.

The value of Supek's commentaries and his inclusion of Tesla in the history of the development of physics becomes more apparent when one considers, for example, that Abraham Pais, the world famous historian of physics, mentions Marconi but not Tesla in his capital work entitled: Inward Bound, Of Matter and Forces in the Physical World (1986).

4.2 The coverage of Nikola Tesla in Lopašić's lectures on the electromagnetic field and the work of Tomo Bosanac

The author of this article has already referred several times to Vatroslav Lopašić (Pakrac, December 9, 1911 - Zagreb, December 17, 2003) whose lectures in physics at the Faculty of Electrical Engineering and other technical faculties of the University of Zagreb can be considered classics.

Slika 6
Izvedba (replika) Teslinog transformatora u Lopašićevim predavanjima iz fizike
Figure 6
Replica of Tesla's transformer in Lopašić's physics lectures



Uz izvorne doprinose u pristupu klasičnoj fizici i metodi nastave utemeljenoj na pokusima tijekom predavanja, posebno treba naglasiti Lopašićevu knjigu Predavanja iz fizike: Elektromagnetsko polje [14]. To je jedan od najboljih uvoda u elektromagnetsku teoriju na hrvatskome jeziku. Knjiga se izdvaja originalnim fenomenološkim pokusima kojima se pokazuju i izvode glavni zakoni električnog i magnetskog polja, pa i slavne Maxwellove jednadžbe. U toj su knjizi znatno zastupljeni Nikola Tesla i preslike slavnih Teslinih pokusa, što ih je Lopašić zajedno sa svojim suradnicima složio i osobno izvodio. Može se reći da su za sintagmu klasik nastave fizike uvelike

In addition to original contributions in the approach to classical physics and the method of instruction based upon experiments during lectures, it is particularly important to point out Lopašić's book Predavanja iz fizike: Elektromagnetsko polje (Lectures on Physics: Electromagnetic Field) [14]. This is one of the best introductions to electromagnetic theory in the Croatian language. The book is distinguished by original phenomenological experiments that demonstrate the main laws of electrical and magnetic fields, and the famous Maxwell equations. In this book there is significant space devoted to Nikola Tesla and copies of Tesla's famous experiments, which zaslužni baš pokusi s Teslinim transformatorom i Teslinim strujama, što ih je Lopašić izvodio na predavanjima.

Opisat će se replika Teslinog visokofrekvencijskog transformatora, u Lopašićevoj izvedbi [14]. Shema Teslinog *RF*-transformatora prikazana je na slici 6. Veliki induktor napaja se iz istosmjernog generatora snage od oko 10 kW. Prekidač je izvorne Tesline konstrukcije motorni, a spoj i prekid postižu se rotirajućim živinim mlazom. Induktor nabija bateriju Leydenskih boca s debelim staklom. Boce se izbijaju kroz iskrište i zavojnicu primarnog kruga od desetak zavoja. U toj zavojnici koaksijalno je smještena sekundarna, visoka i s mnogo zavoja. Donji je kraj te sekundarne zavojnice uzemljen, a gornji završava nekom elektrodom. Sekundarna zavojnica treba biti rezonantno ugođena na titranje naboja u primarnoj (princip Teslinog transformatora).

Lopašić zanimljivo opisuje električne pojave koje se dobivaju pomoću Teslinog transformatora. Kad uređaj radi, iz gornjeg kraja sekundarne zavojnice izbijaju u zrak električne iskre duge više od pola metra. U blizini Teslina transformatora fluorescentne cijevi svijetle, a da nisu spojene s transformatorom. Električna iskra iz transformatora može zapaliti drvo, a može je se primiti na metalnu elektrodu koja se drži golom rukom. Neće se osjetiti električni udar. Da bi se dobili vrlo visoki naponi, u pokusima s Teslinim transformatorom, Lopašić je rabio Ruhmkorffov induktor. Posebno zorno Lopašić opisuje princip rada induktora, da bi studenti razumjeli bit i primjenu zakona elektromagnetske indukcije.

Profesor Tomo Bosanac (Stare Plavnice kraj Bjelovara, 15. svibnja 1918. - Zagreb, 12. kolovoza 2003.), ugledni nastavnik FER-a na katedri Teorijske elektrotehnike, također ističe važnost primjene Ruhmkorffova induktora u Teslinim istraživanjima *VF*-struja [15] i [16]. Prema Bosancu, Ruhmkorffov induktor se do Tesle rabio za dobivanje visokih frekvencija, ali ga Tesla prvi upotrebljava kao pravi transformator kojemu dodaje specijalno usavršeno iskrište da bi energijski gubici u iskrištu bili najmanji. Tesla je tako dobio snažne izvore *VF*-struja od nekoliko milijuna perioda u sekundi i brojne neviđene učinke koji su ga učinili slavnim. Nikola Tesla je bio prvi eksperimentalni fizičar koji je tehnički primijenio prijenosni vod kao oscilacijski sustav na visokim frekvencijama, prije slavnih fizičara Hermanna von Helmholtza i J. J. Thomsona. Tomo Bosanac je bio jedan od glavnih pokretača svečanog obilježavanja 120. obljetnice rođenja Nikole Tesle 1976. godine u Zagrebu. U spomen tog događaja tiskan je u izdanju JAZU zbornik

Lopašić together with his associates set up and personally conducted. It can be said that the experiments with Tesla's transformer and Tesla's currents that Lopašić performed during his lectures are largely responsible for the syntagma of classical physics instruction

Lopašić's replica of Tesla's high frequency transformer will be described [14]. A diagram of Tesla's *RF* transformer is shown in Figure 6. The large coil is supplied from an approximately 10 kW DC power generator. The switch is Tesla's original construction, and switching is achieved using a rotating mercury beam. The coil charges a battery composed of Leyden jars with thick glass. The jars are discharged through the spark gap and a primary coil of approximately ten turns. A tall secondary coil with many turns is placed coaxially in the primary coil. The bottom end of the secondary coil is grounded and the top is connected to an electrode. The secondary coil should be resonantly tuned to the oscillation of the charge in the primary coil (the principle of Tesla's transformer).

Lopašić describes the electrical phenomena obtained using Tesla's transformer in an interesting manner. When the device is working, from the top of the secondary coil there is electrical discharge with sparks in the air that are over a half a meter in length. Near the Tesla transformer, fluorescent tubes that are not connected to the transformer are lit. An electrical spark from the transformer can set wood on fire. When such a spark is received with a metal electrode held in a bare hand, no electrical shock is felt. In order to obtain very high voltage, Lopašić used a Ruhmkorff inductor in experiments with Tesla's transformer. Lopašić describes the principle of the operation of the inductor especially vividly, in order for students to understand the essence and application of the law of electromagnetic induction.

Prof. Tomo Bosanac (Stare Plavnice near Bjelovar, May 15, 1918 - Zagreb, August 12, 2003), a distinguished instructor at the Faculty of Electrical Engineering and Computing in the department of theoretical electrical engineering, also emphasized the importance of the use of the Ruhmkorff inductor in Tesla's investigation of HF currents [15] and [16]. According to Bosanac, the Ruhmkorff inductor was used before Tesla for obtaining high frequencies, but Tesla was the first to use it as a true transformer to which he added an improved spark gap so that energy losses in the spark gap would be minimal. In this manner, Tesla obtained powerful sources of *HF* currents of several million periods per second and numerous effects not seen before that made him famous. Nikola Tesla was the first experimental physicist to apply a transmission line as an oscillating system at high frequencies, Simpozij 'Nikola Tesla' koji je uredio Tomo Bosanac [16]. U kontekstu 120. godišnjice Teslinog rođenja Školska knjiga u Zagrebu tiskala je lijepo dvojezično englesko-hrvatsko izdanje Moji pronalasci / My Inventions Nikole Tesle, u čijem je prevođenju sudjelovao Tomo Bosanac i za koju je napisao pogovor [8].

Profesor Tomo Bosanac je autoru ovog rada dao i poticaj za proračun Tesline unipol-antene za sustav antena-zemlja, daleke 1976. na tragu i odjecima uspješnog međunarodnog simpozija o 120. obljetnici Teslinog rođenja u Zagrebu u organizaciji JAZU [17]. Teslin model bežičnog prijenosa elektromagnetske snage ili poruke na daljinu na fundamentalnoj Teslinoj intuiciji o svjetskom bežičnom sustavu postao je iznova zanimljiv 2006. povodom 150. obljetnice rođenja i Tesline godine. Proračuni su ponovno izvedeni i dotjerani na razdjelnici između Teslinog načina prijenosa koji koristi zemlju te Hertzovog za slobodni prostor, a rezultati su pokazani u poglavlju 3.2 u ovome članku.

Teslin najvažniji izum u elektrotehnici jesu višefazne izmjenične struje, osobito trofazne. Trofazni sustav najobičniji je i najrašireniji način proizvodnje i prijenosa električne energije. U svibnju 1885. George Westinghouse, šef istoimene električne kompanije u Pittsburghu, otkupio je u dogovoru s Teslom patentna prava na Teslin višefazni sustav izmjeničnih struja, uključujući generator višefaznog napona, transformator te asinkroni Teslin elektromotor na principu rotirajućeg magnetskog polja. Te je godine započela divovska bitka između Edisonovog sustava zasnovanog na istosmjernoj struji i Tesla-Westinghouse izmjeničnog sustava. Pobijedio je Teslin sustav, uvodeći čovječanstvo divovskim koracima u modernu civilizaciju elektroenergetike i elektroindustrije.

Prema Lopašiću, otkriće višefaznih električnih izmjeničnih struja ostaje Tesli kao njegov trajni spomenik i doprinos čovječanstvu. Pomoću trofaznih struja koje se šalju kroz prostorno zgodno raspoređene zavojnice može se kao rezultirajuće magnetsko polje dobiti takvo u kojemu jakost polja uvijek ima isti iznos, ali mu se smjer u prostoru vrti. Ako su zavojnice raspoređene tako da im osi leže u istoj ravnini i čine kutove po 120°, pa kroz te zavojnice tjeramo izmjenične struje pomoću napona redom iz faza $R, S, T,$ onda rezultirajuće polje $\vec{H}$ u sjecištu osi zavojnica ne mijenja svoju jakost, ali se vrti u smislu slijeda faza kutnom brzinom ω. Međutim, metalni vodič na tom mjestu počne pratiti vrtnju polja jer se u njemu induciraju struje na koje magnetsko polje zavojnica djeluje silama. To odgovara pojavi tzv. rotacijskog

earlier than the celebrated physicists Hermann von Helmholtz and J. J. Thomson. Tomo Bosanac was one of the principal initiators of the formal commemoration of the 120th anniversary of the birth of Nikola Tesla that was held in Zagreb in the year 1976. For this event, the proceedings of the Nikola Tesla Symposium organized by Tomo Bosanac were published by the Yugoslav (now Croatian) Academy of Arts and Sciences [16]. In the context of the 120th anniversary of Tesla's birth, the publisher Školska knjiga in Zagreb printed an attractive English-Croatian edition of My Inventions/Moji pronalasci by Nikola Tesla, for which Tomo Bosanac was one of the translators and the author of the epilogue [8].

In 1976, Prof. Tomo Bosanac also gave the author of this article the impetus for the calculation of Tesla's monopole antenna for the antenna ground system, during the aftermath of the previously mentioned symposium [17]. Tesla's model of the long-distance wireless transmission of electromagnetic power or messages based on Tesla's fundamental intuition about the world wireless system is attracting renewed attention in 2006, on the occasion of the 150th anniversary of Tesla's birth and the Nikola Tesla Year. Calculations have once again been performed and revised for Tesla's approach based on energy transmission by the earth and Hertz's approach using free space. The results are presented in Chapter 3.2 of this article.

Tesla's most important inventions in electrical engineering are multiphase alternating currents, especially three-phase. The three-phase system is the most common and most widespread manner of producing and transmitting electrical energy. In May 1885, George Westinghouse, head of the company of the same name in Pittsburgh, purchased the patent rights to Tesla's multi-phase system of alternating current, including a multi-phase voltage generator, transformer and Tesla's asynchronous electrical motor on the principle of the rotating magnetic field. That year, a tremendous battle was waged between Edison's system based on direct current and the Tesla-Westinghouse alternating system. Tesla's system won, bringing humankind into the modern era of electrical energy and industry.

According to Lopašić, the discovery of multi-phase alternating currents remains Tesla's lasting monument and contribution to humankind. Using three-phase currents that are sent through coils that are appropriately positioned in space, it is possible to obtain a magnetic field in which the magnetic field strength always has a constant value but is rotating in space. If the coils are spaced at 120° from one another, and three-phase AC voltage (R, S, T) is applied to the coils, the resulting magnetic field strength $\vec{H}$ at the intersection point of the coil axes does not change its strength but rotates following the phase sequence at an angular velocity magnetizma u pokusu koji je Dominique F. Arago (2. listopada 1786.-26. veljače 1853.) izveo 1825., samo se ovdje vrti polje, a ondje se vrtio vodič. Rotirajuće magnetsko polje osnova je rada Teslina asinkronog elektromotora.

5 UMJESTO ZAKLJUČKA - TESLINI IZUMI I NJEGOV INTERES ZA GOETHEOVOM POEZIJOM

Poznato je da je Tesla najdulje i najbolje studirao na Technische Hochschule u Grazu (1875.-1878.), da bi obrazovanje potom nastavio u Pragu. Studij filozofije prirode upisao je 1880. na Sveučilištu u Pragu, ali je već 1881. prešao u Budimpeštu gdje se zapošljava u Središnjem telegrafskom uredu. U Budimpešti u veljači 1882. dobiva najvažniju intuiciju u svom životu o rotirajućem magnetskom polju. Šetajući gradskim parkom s prijateljem Antonyjem Szigetyjem, recitirajući ulomak iz Fausta, Tesli je u njegovu umu poput bljeska munje sinula ideja o rotirajućem magnetskom polju. On je istog trenutka štapom u pijesku nacrtao dijagram takvog polja, a Szigety je odmah shvatio o čemu je riječ. Ponovila se, dakle, starogrčka platonovska situacija kad je Sokrat robu crtanjem na pijesku uspješno objasnio Pitagorin poučak (Menon, dijalog iz prijelaznog razdoblja Platonova stvaralaštva). Fizikalnu sliku i objašnjenje rotirajućeg magnetskog polja $\vec{H}$ upravo smo opisali u prethodnom odjeljku 4.2.

Navodimo ulomak iz Goetheova Fausta [18] [19] koji je Tesli, prema njegovu vlastitom tumačenju, pomogao u otkriću najveće tajne koju je uspio iščupati iz prirode:

PRED GRADSKIM VRATIMA

FAUST

Već tone sunce, zamire već dan,
Al ono drugdje novi život stvara.
O, imat krila –moj je davni san,
O, letjet za ljepotom toga žara!
...
Da, divna sna! al sunce zapada.
Ah, čovjek ima krila duhovna,
Al tjelesna mu bozi nisu dali.

of ω. However, the metal conductor at that position starts to follow the rotating magnetic field because of the currents induced in it that are affected by the forces of the coils' magnetic field. This corresponds to the phenomenon of so-called rotating magnetism in an experiment performed by Dominique F. Arago (October 2, 1786-February 26, 1853) in 1825, only here it is the field that turns and there the conductor turned. A rotating magnetic field is the basis of the operation of Tesla's asynchronous electric motor.

5 IN LIEU OF A CONCLUSION - TESLA'S INVENTIONS AND INTEREST IN GOETHE'S POETRY

It is known that Tesla studied the longest and best at the Technische Hochschule in Graz (1875-1878), and continued his education in Prague. He enrolled in the study of natural philosophy in 1880 at the University of Prague but already in 1881 went to Budapest where he was employed at the Central Telegraphic Office. While in Budapest in February 1882, he experienced the most significant intuition of his life regarding the rotating magnetic field. Walking in the city park with his friend Antal Szigety, reciting an excerpt from Faust, the idea of the rotating magnetic field struck Tesla like a bolt of lightning. He immediately drew a diagram of such a field in the sand with a stick, which Szigety immediately understood. Thus, the ancient Greek Platonic situation was repeated when Socrates successfully explained the Pythagorean Theorem to a slave by making a drawing in the sand (Meno, dialogue from the transitional period of Plato's works). We have presented the physical picture and explanation of the rotating magnetic field $\vec{H}$ in the previous Chapter, 4.2.

We present the passage from Goethe's Faust [18] [19] which helped Tesla, according to his own account, to discover the greatest secret that he successfully wrested from nature.

BEFORE THE CITY GATES

FAUST

The sun retreats – the day, outlived, is o'er,
It hastens hence and lo! a new world is alive!
Oh, that from earth no wing can lift me up to soar
And after, ever after it to strive!
...
A lovely dream, the while the glory fades from sight.
Alas! To wings that lift the spirit light
No earthly wing will ever be a fellow.

VOR DEM TOR

FAUST

Sie rückt und weicht, der Tag ist überlebt,
Dort eilt sie hin und fördert neues Leben.
O daß kein Flügel mich vom Boden hebt,
Ihr nach und immer nach zu streben!
...
Ein schöner Traum, indessen sie entweicht.
Ach! zu des Geistes Flügeln wird so leicht
Kein körperlicher Flügel sich gesellen.

U Faustu Goethe pjeva o borbi dobra i zla, duha i tijela, života i nihilizma, na najvećoj kozmičkoj skali. Pokretač i glavni protagonist te borbe na jednoj strani jest novovjekovni znanstvenik Faust, razočaran i uznemiren u svojim znanstvenim težnjama, a na drugoj đavolska spodoba u liku Mefistofelesa, kao partnera i protivnika na Faustovu istraživačkom putu (putovanju). Takva filozofska i pjesničko-mistička slika dojmila je Teslu i silno ga privlačila tijekom cijelog života. Osobito Faustov filozofski izbor koji ovozemaljske radosti koje nudi Mefistofeles podređuje fundamentalnom opredjeljenju za ljudsku kreativnost, rad i slobodu, koje na povijesnoj i kozmičkoj skali znače napredak čovječanstva.

Tesla je svoje izume u fizici i elektrotehnici otkrivao ili uviđao onakvom intuicijom kakvu je René Descartes propisao i komentirao u 3. pravilu o jasnoj i očitoj intuiciji, u svom prvom važnom filozofskom djelu metodičke naravi: Pravila za usmjeravanje naše urođene inteligencije (lat. izvornik: Regulae ad directionem ingenii). Descartes je najvjerojatnije ovo kratko djelo napisao oko 1628. ili koju godinu prije. U komentaru 3. pravila, kad govori o intuiciji, Descartes je stvorio zanimljiv pojam urođene svjetlosti: poimanja (lat. ratione luce), u francuskom jeziku: lumière innée (lumière naturelle), odnosno: light of reason na engleskom jeziku. Tomu Descartesovu idealu najbolje se približava Nikola Tesla svojim fundamentalnim otkrićima u elektromagnetizmu i pripadajućim tehnologijama. Pozadinu modernog procesa globalizacije i globalnog umrežavanja čini informacijsko-komunikacijska tehnologija (u filozofskome jeziku elektromagnetska kultura) gdje se protoci informacija događaju najvećim mogućim brzinama koje odgovaraju Descartesovu idealu. Teslino je djelo u temeljima takve suvremene kulture. Teslino ime, djelo i njegov kozmopolitizam, napose Teslina strast za znanstvenim pomaganjem čovječanstvu, ostaju trajnim uzorom u ljudskoj znanosti i kulturi.

VOR DEM TOR

FAUST

Sie rückt und weicht, der Tag ist überlebt,
Dort eilt sie hin und fördert neues Leben.
O daß kein Flügel mich vom Boden hebt,
Ihr nach und immer nach zu streben!
...
Ein schöner Traum, indessen sie entweicht.
Ach! zu des Geistes Flügeln wird so leicht
Kein körperlicher Flügel sich gesellen.

In Faust, Goethe tells of the struggle between good and evil, the spirit and body, life and nihilism, on the highest cosmic scale. The moving force and main protagonist in this struggle on the one side is the scientist Faust, disappointed and restless in his scientific aspirations, and on the other side the satanic figure of Mephistopheles, as a partner and opponent on Faust's investigative journey. Such a philosophical and poetic-mystical image made a profound impression on Tesla and greatly attracted him throughout his life. It was particularly Faust's philosophical choice, the rejection of the joys of this world as offered by Mephistopheles in favor of a fundamental commitment to human creativity, work and freedom, which signifies the advancement of humankind on the historical and cosmic scale.

Tesla discovered or obtained insight into his inventions in physics and electrical engineering with the same intuition that René Descartes commented upon in his first important philosophical work of a methodological nature, Regulae ad directionem ingenii (The Rules for the Direction of the Mind). Descartes probably wrote this brief work around the year 1628 or some years earlier. In the commentary on the third rule that speaks of intuition, Descartes created an interesting concept of the light of reason (Latin: ratione luce, in the French language: lumière innée, lumière naturelle). Nikola Tesla approaches Descartes' ideal with his fundamental discoveries in electromagnetism and the corresponding technologies. The background of the modern process of globalization and global networking is the information/communication technologies (in the philosophical language, the electromagnetic culture), where the flow of information occurs at the greatest possible speeds that correspond to Descartes' ideal. Tesla's work has been incorporated into the foundations of our contemporary culture. Tesla's name, work and cosmopolitism, particularly his passion for helping mankind through science, remain a lasting model in human science and culture.

LITERATURA / REFERENCE

[1] PETKOVIĆ, T., Znanstveni izvori bioetike, Primjer Enrica Fermija, posljednjeg univerzalnog fizičara, Filozofska istraživanja 83, God. 21, Sv. 4, pp. 633-645, 2001.
[2] PETKOVIĆ, P., Franciscus Patricius' model of thinking and modern cosmology, poglavlje u knjizi: Francesco Patrizi filosofo platonico nel crepuscolo del Rinascimento, P. Castelli, ed., Florence: Leo S. Olschki, 2002, pp. 197-215.
[3] PETKOVIĆ, T., Werner Heisenberg - čovjek i djelo. Povodom 100. obljetnice rođenja, Matematičko-fizički list 208 (2001.-2002.), God. LII, Zagreb, 2002., str. 226-228.
[4] PETKOVIĆ, T., O znanstveno-inženjerskom duhu i enciklopedijskome djelu akademika Hrvoja Požara, Hrvatski identitet, 3. program Hrvatskog radija, tekst 8 stranica, emisija 29. srpnja 2003.
[5] PETKOVIĆ, T., L'universo poetico di Nikola Šop fra le forme noetiche di Platone e lo spazio-tempo einsteiniano, poglavlje u knjizi: La poesia di Nikola Šop (1904.-1982.), Tra filosofia e cosmologia, ur. F. Ferluga-Petronio, Marsilio Editori, Venezia, 2004, str. 125-134
[6] PETKOVIĆ, T., Mirko Dražen Grmek i njegov model povijesti znanosti, Hrvatsko zagorje, Časopis za kulturu, Br. 2, Krapina, prosinac 2001., God. VII., str. 117-122
[7] NIKOLA TESLA, Colorado Springs - Notes, Nolit, Beograd, 1978.
[8] NIKOLA TESLA, Moji pronalasci / My Inventions, preveli: prof. dr. Tomo Bosanac i Vanja Aljinović, Školska knjiga, Zagreb, 1984.
[9] WIEDEMANN, H., Particle Accelerator Physics, Basic Principles and Linear Beam Dynamics, Springer-Verlag, Berlin Heidelberg, 1993.
[10] GENG, R. L., PADAMSEE, H., SEAMAN, A., SHEMELIN, V. D., World Record Accelerating Gradient Achieved in a Superconducting Niobium RF Cavity, Proceedings of the Particle Accelerator Conference, PAC 2005, 16-20 May 2005, pp. 653-655.
[11] Proceedings of the 1st TESLA Workshop, Cornell University, Ithaca, NY, CLNS 90 –1029 (1990).
[12] SOMMERFELD, A. N., Über die Ausbreitung der Wellen in der drahtlosen Telegraphie, Annalen der Physik, Bd. 28 (1909), S. 665-736
[13] SUPEK, I., Povijest fizike, II. dop. izd., Školska knjiga, Zagreb, 1990.
[14] LOPAŠIĆ, V., Predavanja iz fizike: Elektromagnetsko polje, Školska knjiga, Zagreb, 1979.
[15] BOSANAC, T., Teoretska elektrotehnika, I. dio, Tehnička knjiga, Zagreb, 1973.
[16] Simpozij "Nikola Tesla", u okviru programa proslave 120. obljetnice rođenja Nikole Tesle, Zagreb - Smiljan/Gospić, 7.-10. srpnja 1976., urednik: BOSANAC, T., JAZU, Zagreb, 1978.
[17] PETKOVIĆ, T., Fizikalna analiza linearne unipol-antene i njezin proračun, neobjavljeni rad, Zavod za fiziku, ETF, Zagreb, 1976.
[18] GOETHE, J. W., Faust I i II dio, Tragedija, preveo Tito Strozzi, Zora i Matica hrvatska, Zagreb, 1970.
[19] GOETHE, J. W., Faust I und Faust II, Eine Tragödie, Werke Sechster Band, Insel Verlag, Frankfurt am Main, 1981.

Uredništvo primilo rukopis:
2006-05-15

Prihvaćeno:
2006-06-14

Manuscript received on:
2006-05-15

Accepted on:
2006-06-14

Zahvala

Članak o Tesli napisan je u stvaralačkom valu, brzo, na nagovor kompetentnih znanstvenika, stručnjaka i filozofa u ozračju 150. obljetnice Teslinog rođenja i Tesline godine 2006. U brzome nastajanju članka u računalnome oblikovanju slika mnogo je pomogao mr. sc. K. Gergeta, znanstveni novak/asistent u Zavodu za primijenjenu fiziku FER-a. Napose se zahvaljujem T. Petkoviću ml., dipl. ing., znanstvenome novaku/asistentu u Zavodu za elektroničke sustave i obradu informacija FER-a, za čitanje i matematičke korekcije u engleskoj inačici članka.

Acknowledgments

This article on Tesla was written in a creative heat, quickly, at the behest of competent scientists, experts and philosophers in commemoration of the 150th anniversary of Tesla's birth and the Nikola Tesla Year 2006. K. Gergeta, MSc, scientific novice/assistant at the Department of Applied Physics, Faculty of Electrical Engineering and Computing, provided significant assistance in preparing the figures in computer format. I am very grateful to T. Petković jr., dipl. ing., scientific novice/assistant at the Department of Electronic Systems and Information Processing, Faculty of Electrical engineering and Computing, for his careful mathematical correcting the English version of the paper.